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Seasonal, spatial and gear-related influences on relationships between retained and discarded catches in a multi-species gillnet fishery

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Abstract

A scientific observer program was used to quantify relationships among the compositions and rates of retained and discarded catches taken in a temperate estuarine commercial gillnet fishery in southeastern Australia. Sampling was stratified across six estuaries and three fishing seasons that corresponded to different permitted setting practices (set and immediate retrieve versus overnight set). A total of 265 fishing trips was sampled throughout 2001, yielding 57 species (52 finfish, 3 invertebrate, 1 bird and 1 tortoise), of which 42 and 45 species were retained and discarded, respectively. More species and a greater mean number and weight of total individuals were retained than discarded during each fishing season. Throughout the entire survey, 6.2% by number and 3.3% by weight of catches were discarded. Average retained catches ranged from 37 to 609 kg fisher-day^{-1} and discarded catches from 1 to 10 kg fisher-day^{-1}. *Mugil cephalus* and *Girella tricuspidata* accounted for 85% by number of total observed catches, with a further 10% being contributed by *Acanthopagrus australis*, *Platycephalus fuscus* and *Portunus pelagicus*. *G. tricuspidata*, *A. australis* and *P. pelagicus* below the minimum legal length collectively accounted for 69% by number and 49% by weight of all discards observed. Discarding was greatest in the smallest mesh sizes and during winter when nets can be set overnight. Increasing the minimum permitted mesh size as well as decreasing the maximum soak time of nets set in winter will further reduce the low levels of discarding in this fishery.

Keywords: Australia; Discarding; Estuary fishery; Gillnet; Observer survey

1. Introduction

Knowledge of the retained and discarded catches in a fishery and how these vary spatially, temporally and among different fishing operations is necessary for identifying the potential impacts of fishing on stocks and ecosystems, as well as assessing potential

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interactions among fisheries competing for the same resources (Alverson et al., 1994; Kennelly, 1995; Hall, 1999). Fishing can directly and indirectly affect the biomasses and harvested yields of stocks, ecological interactions among species and the productivity and functioning of ecosystems (Fennessy, 1994; Jennings and Kaiser, 1998; Hall, 1999; Blaber et al., 2000; Kaiser and deGroot, 2000). Discarding in many fisheries is perceived as wasteful and can lead to significant conflict among different users of the resource and if not quantified, can be a major source of uncertainty in fisheries assessments (Chen and Gordon, 1997; Hall, 1999). Information on retained and discarded catch compositions along with data on the selectivity of the fishing gears used and behaviour of the species captured can greatly assist in determining ways to mitigate bycatches and discarding in fisheries (Chopin and Arimoto, 1995; Hall, 1999; Millar and Fryer, 1999; Broadhurst, 2000). Because of the critical importance of bycatches and discarding issues in many fisheries throughout the world and the need for environmental assessments of fisheries, there has been much research in recent years to identify and resolve discarding and wastage (Alverson et al., 1994; Kennelly, 1995; Hall, 1999; Broadhurst, 2000). This research has mostly been focused on fisheries that use towed fishing gears such as demersal trawls and seines (see Hall, 1999; Broadhurst, 2000; Kaiser and deGroot, 2000). Much less emphasis has been placed on fisheries incorporating static fishing gears, including gillnets and trammel nets (but see Berrow, 1994; Trippel et al., 1996; Akiyama, 1997; Trent et al., 1997; Erzini et al., 2002; Gray, 2002; Hutchings and Lamberth, 2002, 2003; Godoy et al., 2003; Perez and Wahrlich, 2005).

Gillnets are used to harvest many different types and species of fish and form the basis of many commercial fisheries throughout the world (Berrow, 1994; Petrakis and Stergiou, 1996; Hickford et al., 1997; Lamberth et al., 1997; Madsen et al., 1999; Trent et al., 1997; Hutchings and Lamberth, 2002; Stergiou et al., 2002). Significant controversy surrounds many coastal and oceanic gillnet fisheries, particularly those that interact with, and include, marine mammals, turtles and sea birds as bycatches (Quinn, 1988; Trippel et al., 1996; Cox et al., 1998; Julian and Beeson, 1998; D'agrosa et al., 2000; Kinas, 2002; Oesterblom et al., 2002). Consequently, in such fisheries, much research is being done to reduce the bycatch of such organisms (Trippel et al., 1999; Melvin et al., 1999). Controversy in gillnet fisheries is not restricted to high profile and large-scale fisheries. For example, in several small-scale gillnet fisheries, such as those based in coastal and estuarine waters in southern Africa and Australia, there is considerable conflict among different resource interest groups over the use of gillnets and their potential impacts on the sustainability of stocks as well as general concerns among different fishing sectors over access and allocation to the resource (Lamberth et al., 1997; Gray, 2002; Hutchings and Lamberth, 2003). Much of this conflict stems from the fact that the primary species targeted and many of the discards in these gillnet fisheries are important in other regional commercial and recreational fisheries (Bronte and Johnson, 1983; Gray, 2002; Hutchings and Lamberth, 2002; Gray and Kennelly, 2003). Consequently, there is much pressure to mitigate discarding and reduce effort in these fisheries.

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

2. Materials and methods

2.1. NSW estuarine commercial gillnet fishery

In 2001, approximately 770 fishers were endorsed to participate in the estuarine commercial gillnet fishery across 85 estuaries in NSW. The fishery annually lands approximately 2500 tonnes of finfish and crabs valued at around AUD$ 5 million per annum. Gillnets are used year-round and although different regulations govern the use, mesh sizes and lengths of gillnets among estuaries and months of the year, there are two main methods of operation: (i) set and immediate retrieval and (ii) overnight set. Three-hour setting of nets is also permitted but is little used in the fishery. In general, the practice of set and immediate retrieval is permitted year-round and often involves deploying the net around a school of fish or a submerged structure, after which the fishers often disturb the water (e.g. using oars or outboard motor), scare the fish into the meshes and then retrieve the net. Fishers primarily target *Mugil cephalus*, *Girella tricuspidata* and *Acanthopagrus australis* using this practice. The extended overnight (sunset to sunrise) setting of gillnets is permitted during winter (May–August) and generally involves fishers setting nets in areas where fish travel between tides and/or day and night and relies more on the movements of fish compared to the practice of set and immediate retrieval. Fishers using this practice primarily target *Platycephalus fuscus* as well as the species listed above. The overnight setting of nets is permitted only in winter due to the belief that the cold water reduces the mortality of unwanted fish and thus the majority of discards are alive when released (see Gray, 2002). Further, the condition of the retained fish is good for marketing, as opposed to summer, when warmer water causes the fish to deteriorate quickly. There is also a separate, but limited, estuarine gillnet fishery for *P. fuscus* permitted in four estuaries, but this is dealt with elsewhere (Gray et al., 2004).

Mesh sizes from 80 to 250 mm are used in the fishery to target a wide variety of species of different morphologies and sizes (Pease, 1999; Gray, 2002). Nets are generally constructed of either multi-monofilament (8 strand) or multi-filament nylon (210/4–210/6 strand nylon) of 0.41–0.62 mm twine thickness, 20–66 meshes deep, 725 m in length and hung at a ratio of 0.5. Gillnets are generally staked or anchored at each end and are mostly bottom set (except when targeting schools of *M. cephalus*). Nets used in shallow areas may fish the entire water column.

2.2. Observer coverage and sampling of retained and discarded catches

Commercial gillnet catches were sampled between January and December 2001 from six estuaries (Richmond, Clarence, Camden Haven and Shoalhaven Rivers and Wallis and Illawarra Lakes) spanning approximately 1500 km of coast (Fig. 1). In this study, the Clarence River included Lake Woolooweyah and the Broadwater, whilst the Camden Haven River included Queens and Watson Taylors Lakes. Sampling in each estuary was stratified across three fishing seasons to coincide with permitted fishing practice—Season 1 (January–April) and Season 3 (September–December) coincided with the continuous fishing practice of set and immediate retrieval, whereas Season 2 (May–August) corresponded to when nets can be set overnight.

For each sample, scientific observers accompanied commercial fishers during one full-days fishing activity (including night-time). For nets set overnight, observers accompanied fishers during the morning when they retrieved their nets. Industry participation with the sampling program was voluntary and not all fishers agreed to comply with the program. Observer trips in each estuary and fishing season were chosen on a random draw based on fishing day and fisher. For each sampling season and for each estuary, firstly the observer days were selected and secondly a fisher was selected for observation on each particular day. If on any given day the chosen fisher was not going to fish or did not want to participate in sampling, a second or third fisher was chosen for observation. If no fishers fished (or would not participate) on a particular day, then the following day(s) was chosen for logistic purposes.

As each net was retrieved into the boat, each organism was disentangled from the net by the fisher, who then decided whether it would be retained or discarded. The observer identified, counted and determined the total weight of all retained and discarded species. The lengths (fork length (FL)—for fish with forked or emarginate caudal fin; total length (TL)—for fish with truncated or rounded caudal fin) to the nearest 1-cm of key species were also measured. Discarded fish that were alive were generally processed immediately, so that they could be released quickly back into the water to minimise further stress and mortality. In contrast, much of the retained dead catch was processed after the

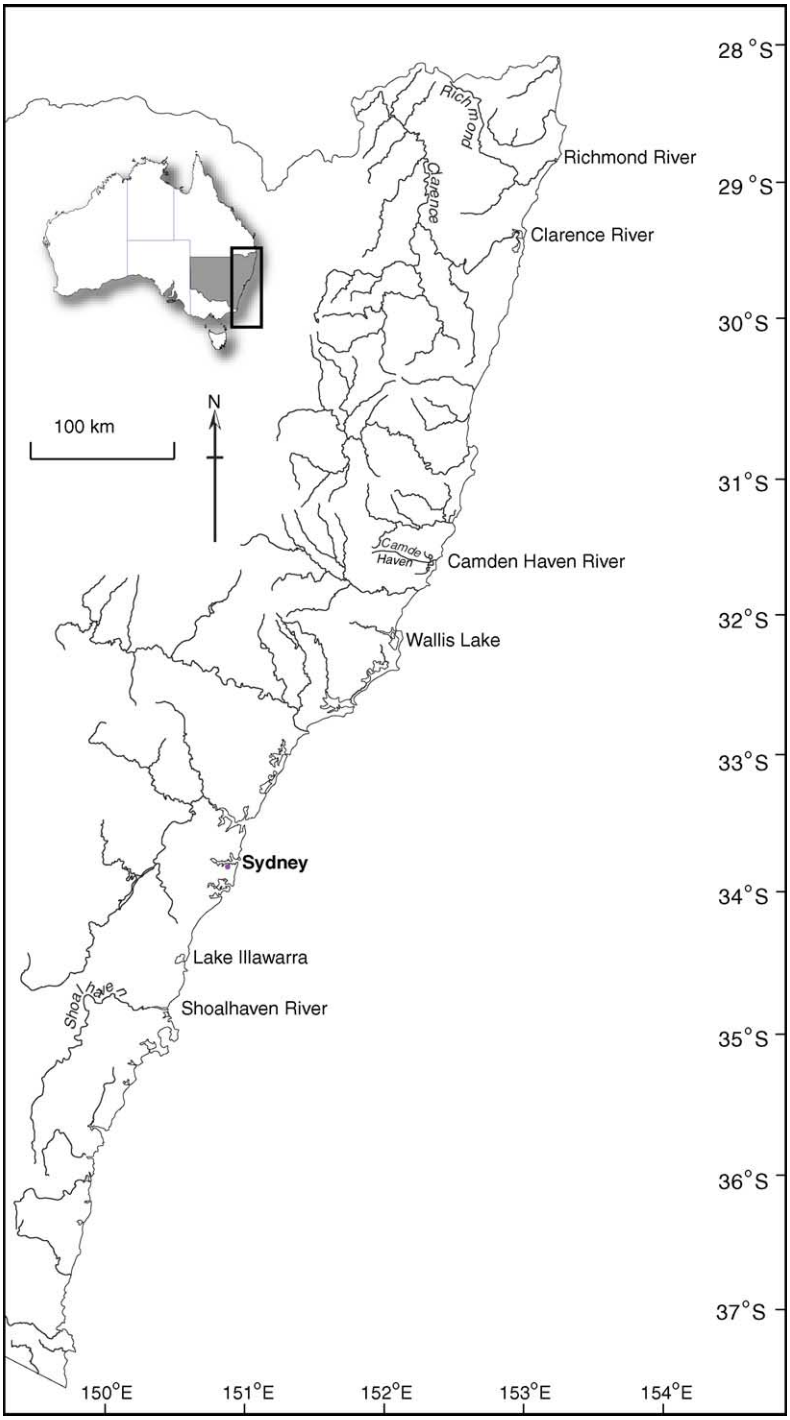

Fig. 1. Map of New South Wales showing the six study estuaries.

entire net was retrieved. The observers also recorded operational data, including mesh and twine thickness, length, depth and hanging ratio of nets, fishing time and location.

A total of 265 gillnet catches were observed throughout the study: 18 in the Richmond River, 60 in the Clarence River, 50 in the Camden Haven River, 53 in Wallis Lake, 41 in Lake Illawarra and 43 in the Shoalhaven River. A total of 195 observations for set and immediate retrieval (99 in Season 1, 11 in Season 2 and 85 in Season 3), 3 for 3-h sets and 67 for overnight sets (all in Season 2) were made during the study. Overnight sets accounted for 82.7% of observed catches in Season 2. The number of catches observed for each mesh size was: 80 mm (131 catches), 100 mm (61 catches), 95 mm (29 catches), 89 mm (22 catches), 83 mm (12 catches), 98 mm (9 catches) and 150 mm (1 catch). The majority of nets observed were constructed of multi-monofilament (429 nets), compared to multi-filament nylon (31 nets). Few catches were observed in Season 1 and none in Season 2 in the Richmond River as this estuary was closed to fishing between February and September 2001 following a large flood event that caused massive fish kills (for details, see Kennelly and McVea, 2002).

2.3. Data analyses

2.3.1. Effects of estuary and fishing season on retained and discarded catches

Non-parametric multivariate analyses were used to delineate estuary and fishing season differences in the structures (composition and relative numbers of each retained and discarded species) of catches. The general procedures used followed those outlined in Clarke (1993) and Clarke and Warwick (2001). Similarity matrices based on the Bray–Curtis similarity measure were generated using non-transformed catch data and the inter-relationships among individual catches were displayed graphically in two-dimensional multidimensional scaling (MDS) ordination plots. Samples that grouped together in each ordination were most similar and the stress coefficient indicated the goodness of fit of the data. A stress coefficient of <0.15 indicates that the ordination is a relatively good representation of underlying data. One-way analyses of similarity (ANOSIM) were used to test for differences in catch structure between fishing seasons. Similarity percentage (SIMPER) analyses were used to identify the species that were most responsible for the similarity of catches within each estuary and fishing season.

Mean ± 1standard error (S.E.) per fishing trip of the retained and discarded catch rates of total species, individuals and weights and numbers of the six most predominant individual species were calculated for each fishing season in each estuary. Analyses of variance (ANOVA) were used to test for differences in the weights and quantities of retained and discarded catches between estuaries, fishing seasons and mesh sizes. Data were transformed to $\log(x + 1)$ to account for multiplicative treatment effects and stabilize variances (Cochran's test). Student–Newman–Keuls (SNK) tests were used to determine differences among means following ANOVA.

The ratio of retained to discarded catch by weight was determined for each estuary in each fishing season. The ratio of weight of the retained catch to weight of discarded catch was calculated for each estuary for each fishing season following the procedures and formulae detailed in Gray et al. (2001).

2.3.2. Effects of mesh size on retained and discarded catches

Observed length compositions of retained and discarded catches of several key species—*M. cephalus*, *G. tricuspidata*, *A. australis* and *P. fuscus*—were plotted for each mesh size used. Data for each mesh size were pooled across all study estuaries and when sample sizes were small, data were also pooled across specific mesh sizes. These data were used to assess the effects of the range of mesh sizes used in the fishery on the sizes of key species caught.

3. Results

3.1. Retained and discarded catch composition

A total of 57 species comprising 52 teleosts, 3 invertebrate, 1 bird and 1 tortoise were identified in observed commercial catches throughout the study. Fishers retained a total of 42 species, whilst 45 species were discarded, with 14 of these latter species always discarded. Eleven species were solely retained, but these were captured in low numbers. Overall, *M.*

Table 1
Summary of the observed top 10 species caught by number and weight in gillnets pooled across all estuaries and fishing seasons and their contribution to total catch, the proportion retained and contribution to the total retained and discarded catch

Species	Total caught	Total catch (%)	Retained (%)	Total retained catch (%)	Total discarded catch (%)
(a) Number					
Mugil cephalus	40415	64.6	99.8	68.8	1.7
Girella tricuspidata	13077	20.9	92.2	20.5	26.5
Acanthopagrus australis	3043	4.9	64.2	3.3	28.1
Portunus pelagicus	1426	2.3	61.2	1.5	14.3
Platycephalus fuscus	1359	2.2	95.1	2.2	1.7
Liza argentea	614	1.0	91.9	1.0	1.3
Sillago ciliata	540	0.9	91.7	0.8	1.2
Myxus petardi	302	0.5	54.0	0.3	3.6
Cnidoglanis macrocephalus	204	0.3	90.2	0.3	0.5
Argyrosomus japonicus	176	0.3	33.0	0.1	3.0
All other 47 species	1367	2.2	48.8	1.1	18.1
Total	62523		93.8	100.0	100.0
(b) Weight (kg)					
Mugil cephalus	22206.6	70.2	99.9	71.4	1.6
Girella tricuspidata	5811.8	18.4	96.1	18.0	21.3
Acanthopagrus australis	1046.8	3.3	78.1	2.6	21.8
Platycephalus fuscus	880.6	2.8	98.6	2.8	1.2
Dasyatis thetidis	282.0	0.9	32.8	0.3	18.0
Arius graeffi	266.6	0.8	99.7	0.9	0.1
Portunus pelagicus	244.6	0.8	74.7	0.6	5.9
Cnidoglanis macrocephalus	202.8	0.6	89.8	0.6	2.0
Myxus petardi	198.1	0.6	59.7	0.4	7.6
Liza argentea	196.4	0.6	93.0	0.6	1.3
All other 47 species	753.0	2.4	73.2	1.9	19.2
Total	31628.1		96.7	100.0	100.0

cephalus and *G. tricuspidata* accounted for 85% by number and 89% by weight of the observed total catch and 89% by number and weight of the total retained catch, pooled across all estuaries and fishing seasons (Table 1). *A. australis*, *Portunus pelagicus* and *P. fuscus* were the next most numerous species caught and collectively contributed 9% by number and 7% by weight towards the observed total catch and 7% by number and weight to the total retained catch. The remaining 52 species attributed <5.5% by number of the total observed catch (Table 1).

Overall, 6.2% by number and 3.3% by weight of the total observed catch was discarded, with undersized (individuals < minimum legal length (MLL)) *G. tricuspidata*, *A. australis* and *P. pelagicus* collectively accounting for 69% by number and 49% by weight of all discards observed (Table 1). The large stingray, *Dasyatis thetidis*, accounted for 18% of the weight of the total observed discarded catch. Discards made a significant contribution to the total catch of some of the predominant species, including *A. australis* (36% by number), *P. pelagicus* (39%) and *Argyrosomus japonicus* (67%) (Table 1). Adherence to MLL's accounted for most of the observed discarding, but discarding of species with no MLL (e.g. *Cnidoglanis macrocephalus* and *Liza argentea*) was also length based with the smallest individuals mostly being discarded, but because of their low market value, this varied among individual fishers and often was dependent on total catch. Several species of little commercial or recreational value, including *Notesthes robusta*, *Selenotoca multifasciata*, *D. thetidis* and *Dicotylichthys punctulatus*, that were generally caught in low numbers were always discarded.

3.2. Effects of estuary and fishing season on retained and discarded catches

MDS and ANOSIM tests showed that the structure of catches differed between estuaries and fishing seasons (Figs. 2 and 3; Tables 2 and 3). The separation of estuaries was due to several species displaying restricted distributions; for example, *Arius graeffei*, *Mugil georgii* and *Myxus petardi* were only caught in the two most northern estuaries and *Macquaria novemaculeata* and *M. colonorum* were caught only in the riverine estuaries (Richmond, Clarence and Shoalhaven Rivers). Retained and discarded catch rates of the six most predominant species also varied between estuaries (Figs. 4 and 5). Retained and discarded catches of *P. pelagicus* were greater in Lake Illawarra than elsewhere, but no clear spatial trends were evident for the other species.

Within each estuary, catch structure varied between fishing seasons (Fig. 3; Table 2), except between Seasons 1 and 3 in Wallis Lake and the Camden Haven and Shoalhaven Rivers, and between Seasons 1 and 2 in the Shoalhaven River (Table 2). The SIMPER analyses identified that retained *M. cephalus* contributed greatest to the similarity of catches in Seasons 1 and 3 in each estuary, except for the Richmond River in Season 3 and the Shoalhaven River in Seasons 1 and 3 where *G. tricuspidata* contributed greatest (Table 3). Although both these species were also important to distinguishing catches in Season 2, retained *P. fuscus* contributed greatest to the similarity of catches in the Camden Haven and Wallis Lake, whilst retained *A. australis* provided the greatest contribution in the Clarence River and *G. tricuspidata* in Lake Illawarra and the Shoalhaven River (Table 3). Retained catches of *M. cephalus* generally tended to be greatest in Seasons 1 and 3, and this was also true for *G. tricuspidata* except in the Shoalhaven River (Fig. 4). Retained and discarded catches of *P. fuscus* were greatest in Season 2, except in the Richmond and Shoalhaven Rivers where they were caught in low numbers (Fig. 5). In Lake Illawarra, retained and discarded *P. pelagicus* were most abundant in Season 2. There were no clear temporal patterns for catches of *A. australis* and *S. ciliatia*.

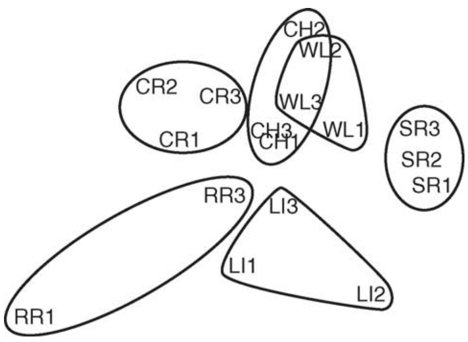

Fig. 2. MDS ordinations showing differences in total catches between estuaries and fishing seasons. RR: Richmond River, CR: Clarence River, CH: Camden Haven, WL: Wallis Lake, LI: Lake Illawarra and SR: Shoalhaven River. Number refers to season.

Except for the Richmond River and Lake Illawarra in Season 1 and the Clarence River in Season 3, a greater mean total number of species was retained than discarded in each estuary and fishing season (Fig. 6). Further, a greater mean total weight and mean total number of individuals was retained than discarded in each estuary in each fishing season (Fig. 6). Observed mean total weight of retained catches varied between 37 kg fisher-day^{-1} (Lake Illawarra in Season 2) and 609 kg fisher-day^{-1} (Richmond River in Season 1), whilst observed mean total weight of discards per fisher-day ranged from 1 kg (Wallis Lake in Season 1) to 10 kg (Richmond River in Season 1). For the six most predominant species, fewer *M. cephalus*, *G. tricuspidata* and *P. fuscus* were discarded than retained in all estuaries (Figs. 4 and 5). This was also true for *S. ciliata*, except in Lake Illawarra in Season 1, but no clear pattern was evident for *A. australis* and *P. pelagicus*. For example, more *A. australis* were retained than discarded in Wallis Lake and the Shoalhaven River, but the opposite was evident in the Camden Haven River (Fig. 4).

Observed ratios (+1S.E.) of the total weights of retained to discarded catches varied significantly according to estuary and season (ANOVA, d.f. = 16, 247, MS = 0.104, $p < 0.01$) but were low in all estuaries and seasons, ranging from 1:0.010 (0.004) in Wallis Lake Season 1 to 1:0.099 (0.006) in Lake Illawarra Season 2. There was no significant correlation between the weight of retained catch to discarded catch per fishing day in any estuary or season (Table 4). Except for the Clarence River, the ratio of catch discarded was greatest in each estuary in Season 2 (Table 4), but this was also dependent on mesh size (see below).

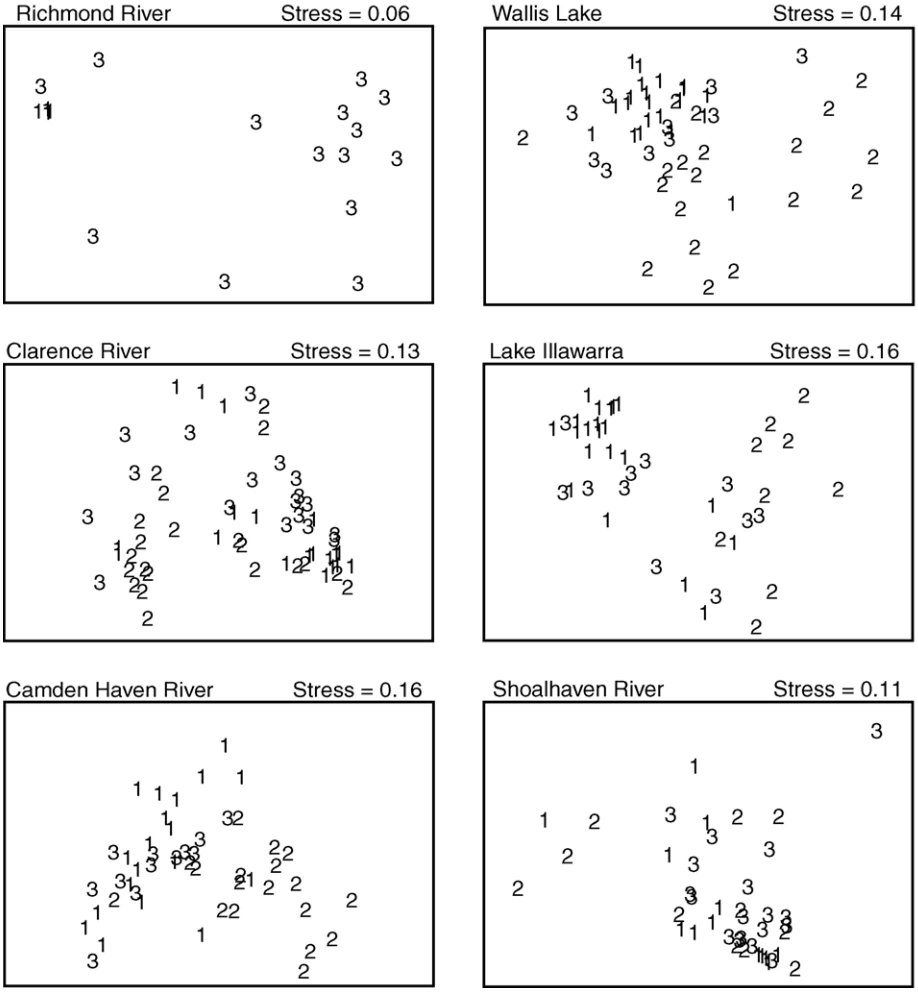

Fig. 3. MDS ordinations showing differences in catches between fishing seasons in each estuary. Number refers to season.

Table 2
Summary of results of one-way analyses of similarity comparing the structure of catches across the three fishing seasons (S) within each estuary

Estuary	*R* significance		
	S1 vs. S2	S1 vs. S3	S2 vs. S3
Richmond River	–	0.475 (0.2%)	–
Clarence River	0.165 (0.6%)	0.080 (2.8%)	0.231 (0.3%)
Camden Haven River	0.398 (0.1%)	−0.075 (96.4%)	0.386 (0.1%)
Wallis Lake	0.372 (0.1%)	0.086 (15.0%)	0.139 (3.4%)
Lake Illawarra	0.648 (0.1%)	0.210 (1.5%)	0.360 (0.3%)
Shoalhaven River	0.021 (25.6%)	0.030 (20.9%)	0.152 (4.3%)

5000 permutations were done for each analysis on non-transformed data.

Table 3
Summary of SIMPER analyses listing the five species that contributed greatest to the percent contribution of similarity measure of total catches in each fishing season in each estuary

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

r and d denote retained and discarded, respectively. No data were collected during Season 2 in the Richmond River. Analyses done on non-transformed data.

3.3. Effects of mesh size on retained and discarded catches

The length compositions of the three predominant fish species caught in each major mesh size observed are shown in Fig. 7. The mean length of catches of these species increased with increasing mesh size. Nets of all mesh sizes were relatively efficient and selective for harvesting legal-sized *M. cephalus* and *P. fuscus*, with more than 99% (by number) of *M. cephalus* and 94% of *P. fuscus* retained in all observed mesh sizes (80–100 mm). In contrast, up to 76% of *A. australis* caught in 80 mm mesh were discarded, but this observation was reversed in nets having 89 mm mesh and greater. Up to 11% of *G. tricuspidata* captured in 80 and 83 mm mesh were dis-

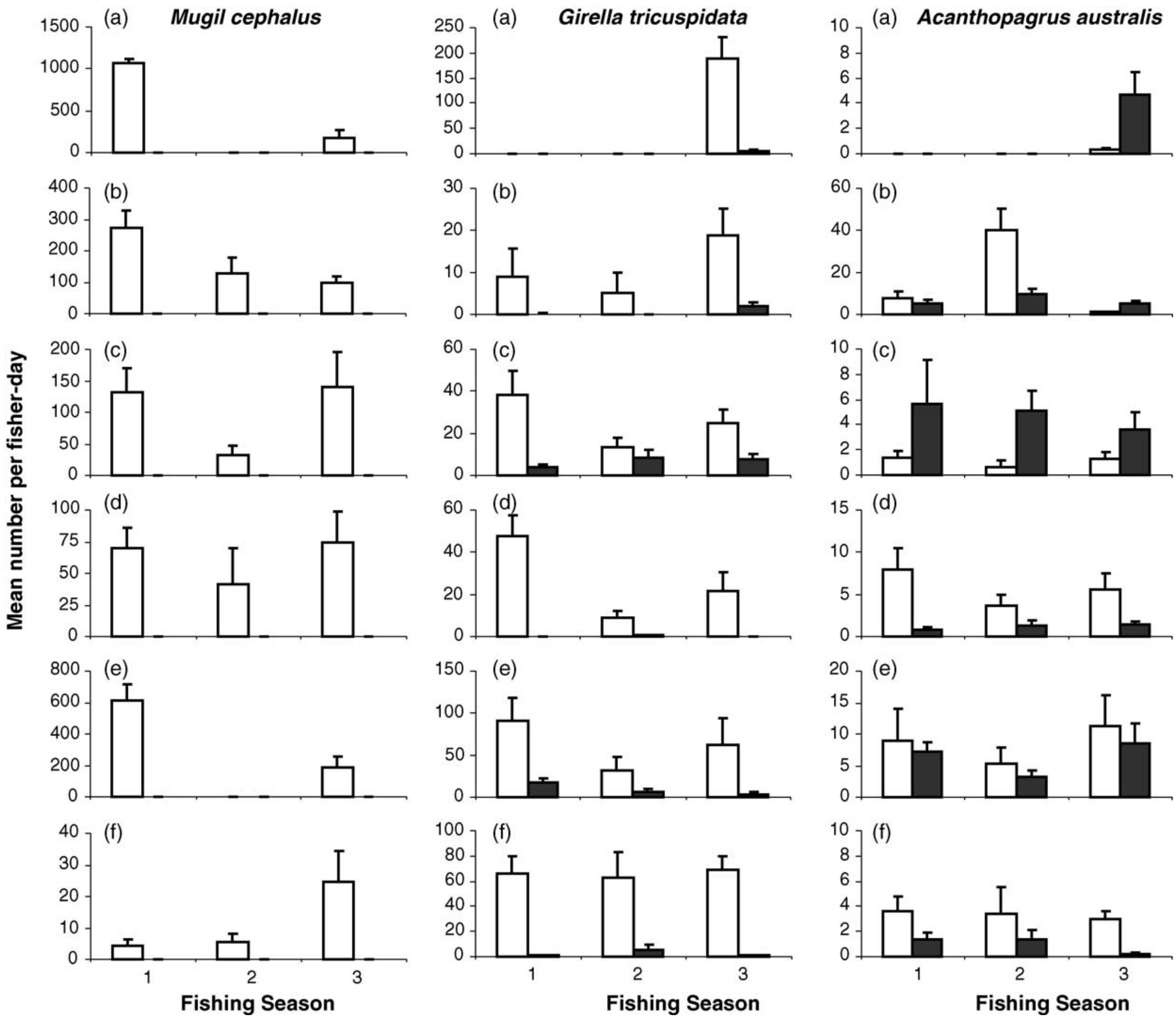

Fig. 4. Mean daily (+1S.E.) number of retained and discarded catches of *Mugil cephalus*, *Girella tricuspidata* and *Acanthopagrus australis* in each studied estuary during the survey: (a) Richmond River, (b) Clarence River, (c) Camden Haven, (d) Wallis Lake, (e) Lake Illawarra and (f) Shoalhaven River. White bar denotes retained catch; black bar denotes discarded catch.

carded, but this decreased to <4% in nets with 89 mm mesh or larger. *S. ciliata* were predominantly caught in gillnets with 80 mm mesh, of which 95% were retained.

Although the proportion of each of the key species retained generally increased with increasing mesh size (Fig. 7), there was no such trend for total numbers and weights of all species combined as the proportions retained varied according to mesh size and season (Table 5). The proportion of retained to discarded catch by weight varied according to mesh size and season (ANOVA, d.f. = 10, 244, MS = 0.150, $p < 0.01$). SNK tests identified that the mean number and weight of both the total retained and discarded catches in each season were greatest in the 80 mm mesh (Table 5). A greater number and weight of discards was caught during Season 2 compared to Seasons 1 and 3 in the 80, 95 and 100 mm mesh. Further, for the 80 and 95 mm mesh, the proportion of catch retained was least during Season 2 compared to Seasons 1 and 3. In 80 mm mesh, fewer fish were retained during Season 2 than in Seasons 1 and 3.

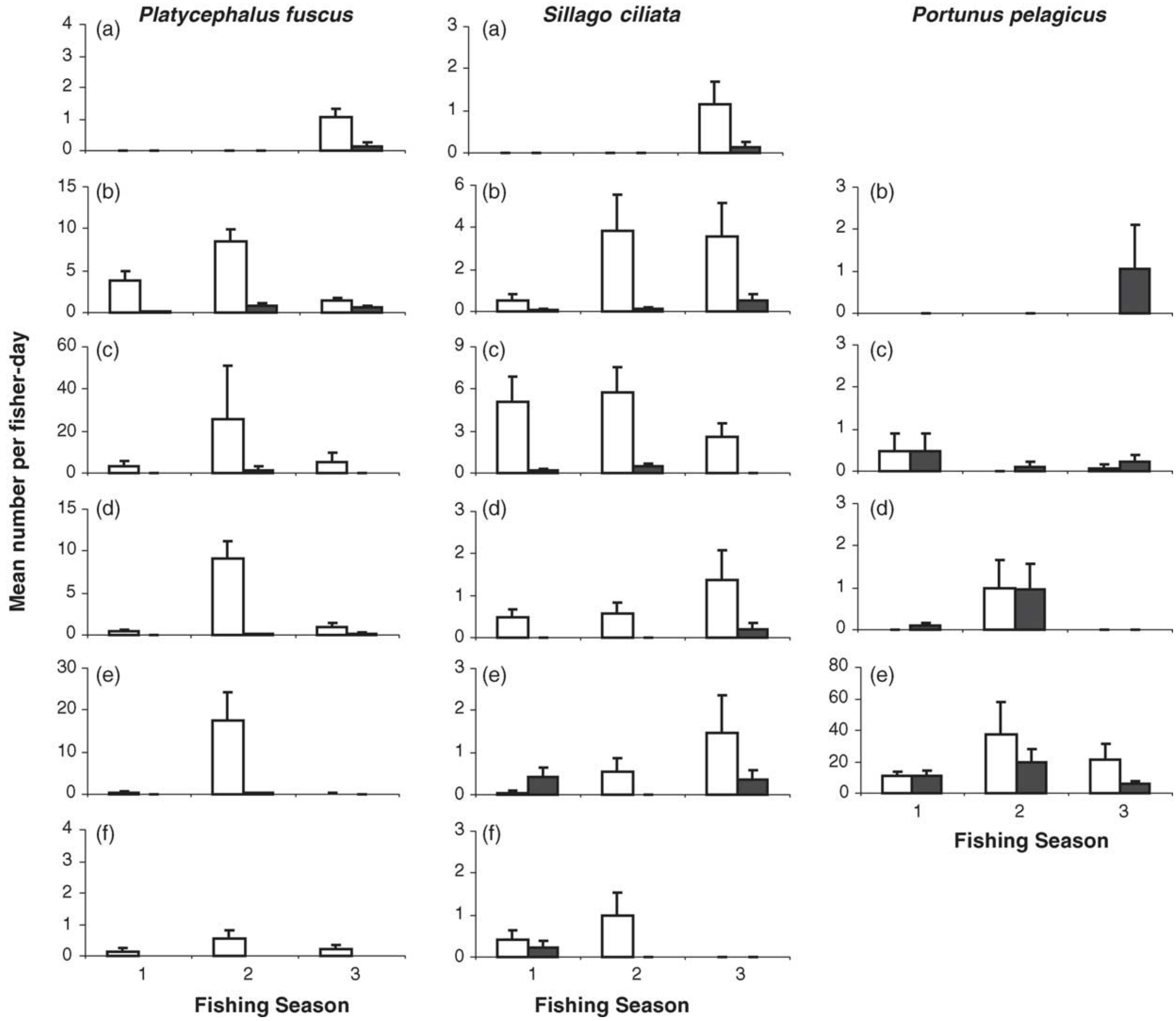

Fig. 5. Mean daily (+1S.E.) number of retained and discarded catches of *Platycephalus fuscus*, *Sillago ciliata* and *Portunus pelagicus* in each studied estuary during the survey: (a) Richmond River, (b) Clarence River, (c) Camden Haven River, (d) Wallis Lake, (e) Lake Illawarra and (f) Shoalhaven River. White bar denotes retained catch; black bar denotes discarded catch.

4. Discussion

The data provided here and in Gray (2002) show that a diverse assemblage of species are retained and discarded in this estuarine gillnet fishery in southeastern Australia. The primary species retained (e.g. *M. cephalus*, *A. australis*, *G. tricuspidata* and *P. fuscus*) in this gillnet fishery are species that are targeted by other commercial fishing sectors (e.g. beach-seine, traps and handlines) and except for *M. cephalus*, by recreational fishers (handline only) in estuarine and inshore waters. Similarly, the discarded catches were dominated numerically by undersize (<MLL) conspecifics of some key retained species (notably *A. australis*, *G. tricuspidata* and *P. pelagicus*), as well as juveniles of other species of recreational and commercial significance (e.g. *M. novaemaculeata*, *Pomatomus saltatrix* and *A. japonicus*). Hence, this gillnet fishery directly interacts with several other regional fisheries, but we cannot ascertain the impacts of this fishery (including discarding) on stocks from the data collected here alone. Our data show, however, that in contrast to other

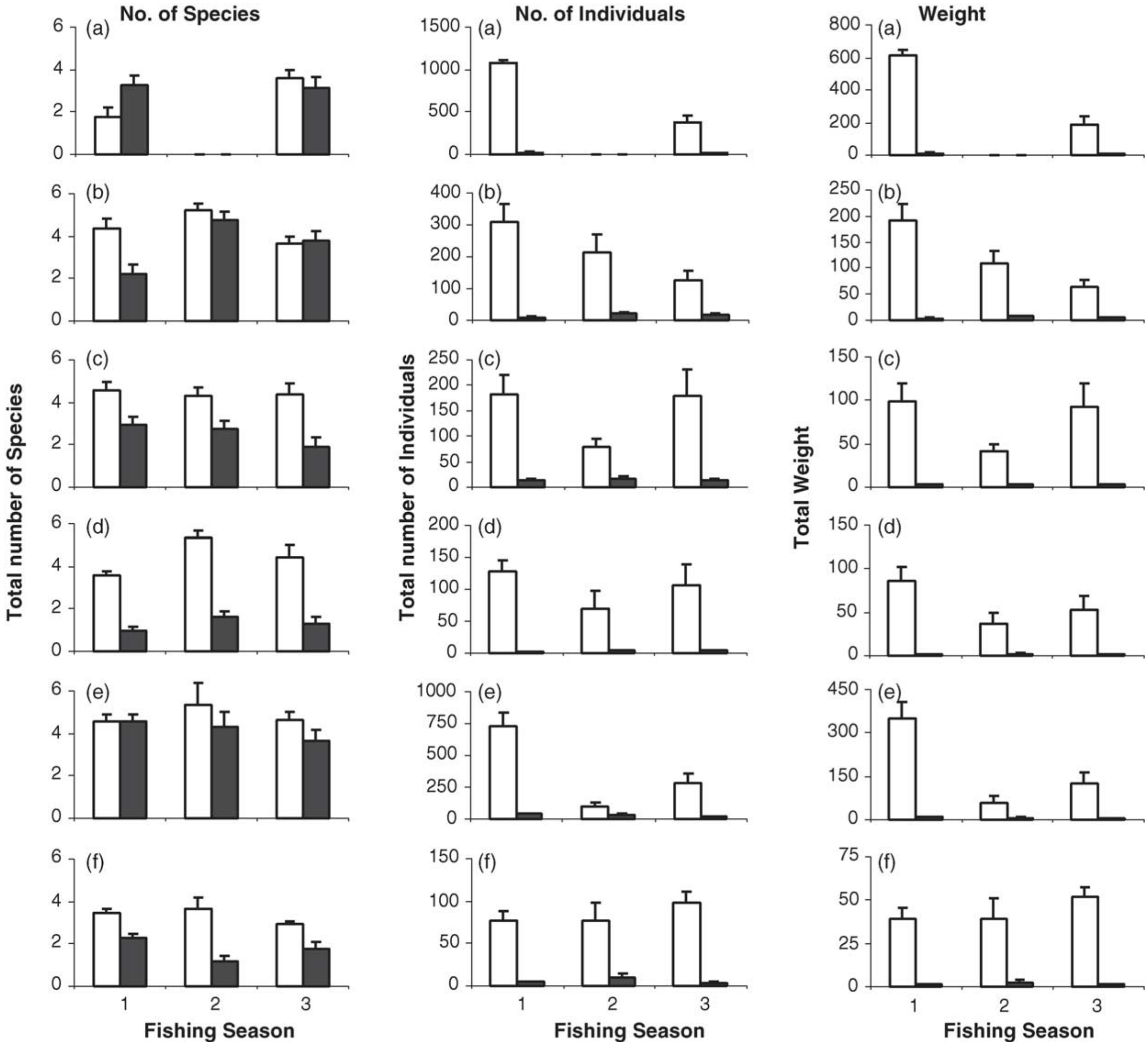

Fig. 6. Mean daily (+1S.E.) weight and number of total retained and discarded catches in each studied estuary during the survey: (a) Richmond River, (b) Clarence River, (c) Camden Haven, (d) Wallis Lake, (e) Lake Illawarra and (f) Shoalhaven River. White bar denotes retained catch; black bar denotes discarded catch.

gillnet fisheries, this fishery does not pose a direct threat to populations of tortoises, seabirds and dolphins. Only one observed bycatch occurrence of a tortoise and seabird occurred throughout the survey and although dolphins do occur, and were observed, in estuaries during the study, no captures were recorded in nets.

The multivariate analyses suggested that catch structures were relatively distinct among estuaries. A similar pattern was reported in Gray (2002), suggesting there may be some latitudinal gradient in the structure of catches taken in the gillnet fishery throughout NSW. Similar species-specific latitudinal gradients in the bycatches from the estuarine prawn seine (Gray et al., 2003) and coastal prawn trawl (Kennelly et al., 1998) fisheries in NSW have been reported. Similarly, Pease (1999) showed that the composition of the reported retained commercial catches from all estuarine commercial fishing methods in NSW varied

Table 4
Summary of mean ratio by weight of retained-to-discarded catch, associated standard error (S.E.) and *r*-value and significance of correlation

	n	Ratio	S.E.	r^2	Significance
Richmond River S1	4	1:0.016	0.007	0.117	ns
Richmond River S3	14	1:0.026	0.012	−0.335	ns
Clarence River S1	20	1:0.017	0.004	0.640	ns
Clarence River S2	21	1:0.069	0.024	−0.052	ns
Clarence River S3	19	1:0.082	0.022	0.030	ns
Camden Haven S1	19	1:0.036	0.011	0.045	ns
Camden Haven S2	18	1:0.093	0.024	0.654	ns
Camden Haven S3	13	1:0.027	0.008	0.424	ns
Wallis Lake S1	23	1:0.010	0.004	0.212	ns
Wallis Lake S2	19	1:0.053	0.031	−0.205	ns
Wallis Lake S3	11	1:0.019	0.004	0.865	ns
Lake Illawarra S1	21	1:0.022	0.004	0.317	ns
Lake Illawarra S2	9	1:0.099	0.058	−0.048	ns
Lake Illawarra S3	11	1:0.031	0.011	0.344	ns
Shoalhaven River S1	14	1:0.038	0.009	−0.248	ns
Shoalhaven River S2	11	1:0.071	0.038	−0.064	ns
Shoalhaven River S3	18	1:0.030	0.008	0.481	ns

according to latitude and estuary type. These latitudinal differences in catches most likely reflect differences in the ichthyofaunal assemblages in the different estuaries throughout NSW. These combined findings suggest that fishing-induced impacts on estuarine ecosystems could vary between different types of estuaries and geographic regions. This does not warrant, however, the introduction of different management regimes for each estuary or region as this would be very complicated, expensive and difficult to enforce.

Seasonal changes in the prevalence and catch rates of specific retained and discarded species were evident and these generally reflected changes in permitted fishing practice (i.e. set and immediate retrieval versus overnight set). Retained *M. cephalus* and *G. tricuspidata* dominated total catches in all estuaries during fishing Seasons 1 and 3 when fishers were only observed to set and immediately retrieve nets. This fishing practice resulted in the least amount of observed discarding (<3% except for Season 3 in the Clarence River). This was particularly evident when fishers were targeting surface schools of *M. cephalus* using nets that had minimal contact with the substratum. Fishers use negatively buoyant nets to target *G. tricuspidata*, which is a benthic species often associated with submerged structures and vegetated (seagrass) habitats. Consequently, more discards were observed when fishers were actively targeting this species compared to *M. cephalus*. Catches of *M. cephalus* and *G. tricuspidata* collectively accounted for 85% by number of the total observed catches throughout the entire survey, with retained catch rates generally greatest during Seasons 1 and 3 when these two species contributed >90% towards the similarity of total catches within each estuary. Although *M. cephalus* and *G. tricuspidata* were also abundant in catches during winter when 82% of observed catches were from nets set overnight, other species, notably retained *P. fuscus* and *S. ciliata* and retained and discarded *A. australis*, were more prevalent and important in distinguishing catches than at other times of the year. This was due to the extended soak times of nets and that this fishing practice mainly involves fishers setting nets in areas where fish travel between tides and/or day and night and relies more on the movements of fish compared to the practice of set and immediate retrieval. Observed rates of discarding were greatest (5–10%) during winter and were comparable to those (up to 6%) reported by Gray (2002) for gillnets set overnight in 1999. These data document how rates of discarding and relationships with retained catches can vary in time and space and between fishing practices within a given fishery (see also Gray et al., 2001; Ye, 2002).

Discard rates were very low (<1%) in all mesh sizes for *M. cephalus* documenting that there was virtually no wastage in the harvesting of this species.

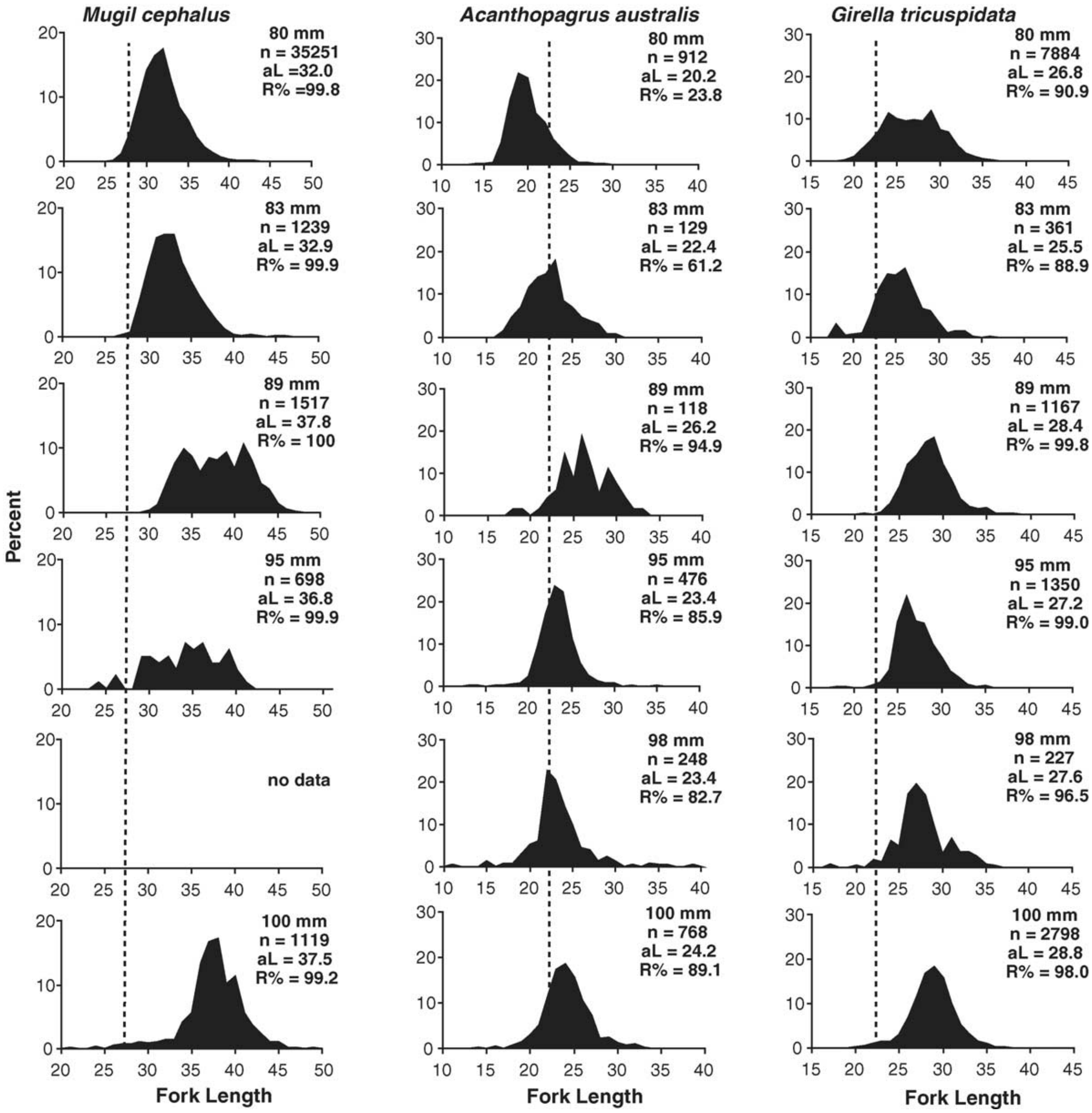

Fig. 7. Length–frequency distributions of total catches of *Mugil cephalus*, *Girella tricuspidata* and *Acanthopagrus australis* in each mesh size. Note data pooled across all estuaries and fishing seasons. *n* denotes number of fish measured, aL: mean length of fish sampled, *R*%: proportion of fish retained. Vertical line denotes the minimum legal length (MLL) of the species.

In contrast, *A. australis* displayed high (up to 76%) discard rates in the smaller (80–83 mm) mesh sizes, indicating that the harvesting of this species with these mesh sizes was relatively inefficient, and depending on rates of mortality, potentially very wasteful. A similar, but less alarming, pattern was evident for *G. tricuspidata* (see also Gray, 2002). Given these data and the fact that the proportion of total discards was negatively correlated with increasing mesh size, it is evident that an increase in the minimum mesh size in this fishery from the current 80 mm to at least 89 mm (but preferably 95 mm; see Gray, 2002) would

Table 5
The average number and weight of retained and discarded catches and the proportion retained in each mesh size in each season where $n \geq 5$ observations

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

Data pooled across all species and estuaries. *n*: number of observations, R: retained catch, D: discarded catch, *R*%: percentage of catch retained.

result in fewer total discards. In particular, this would have a significant effect on reducing the discarding of *A. australis* and *G. tricuspidata*, which collectively accounted for 55% of total discards. A change in mesh size may have little effect in reducing the discarding of portunid crabs (14% of total discards), which probably become entangled in nets of all mesh sizes.

Because of the multi-species nature of the fishery, any increase in minimum mesh size would not be suitable during all fishing seasons and for all fishing practices as it would greatly impact on the retention rates of, and virtually eliminate the fishery for, *M. cephalus*, the most abundant and valuable (as determined by total landings) species taken in the fishery. A solution would be to increase the mesh size in nets set overnight but still allow fishers to use nets of 80 and 83 mm mesh to target this species using the practice of set and immediate retrieval. This would not greatly impact on retained catches of *M. cephalus*, but it would greatly reduce discards of other species. However, because *M. cephalus* is also harvested for its roe in an adjacent coastal beach-seine fishery (Smith and Deguara, 2002), the most appropriate size and life history stage for its sustainable harvest needs to be determined and a suitable mesh size enforced in all fisheries. A further option to ease discarding in this fishery would be to reduce the permitted maximum soak time (e.g. down to 3 h) of nets during winter. Discard levels would be lower and subsequent mortalities of fish may also be reduced because of the reduced soak times (Acosta, 1994; Chopin and Arimoto, 1995), potentially further decreasing any potential negative impacts of this fishery on the shared estuarine fisheries resources of southeastern Australia. Alternatively, more selective and appropriately configured gillnets (e.g. height, material and hanging ratio of nets; see Hamley, 1975; Millar and Fryer, 1999; Broadhurst et al., 2003; Godoy et al., 2003) that minimise the capture and mortality of non-target species and undersized individuals could be developed. This, however, would be more expensive than the simpler options of altering existing mesh sizes and soak times.

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