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Management implications of discarding in an estuarine multi-species gill net fishery

Charles A. Gray*

Fisheries Research Institute, NSW Fisheries, P.O. Box 21, Cronulla 2230, NSW, Australia

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Abstract

Commercial fishers are permitted to set gill nets overnight in New South Wales (NSW) estuaries during the winter months of June, July and August. Scientific observers sampled the retained and discarded catches from 55 fishing trips sampled across six estuaries throughout the 1999 winter fishing season. A total of 69 fish and 3 invertebrate species was identified in catches, with 38 species being retained by fishers and 64 species being discarded. Discards included the juveniles of fish species of commercial and recreational importance, as well as some species of little commercial value. Discards accounted for 19% of total catches by weight and 33% by number, and were mostly alive (>82%) when nets were retrieved from the water. Subsequent mortality after release was not assessed. The mesh size of the nets observed ranged between 80 and 250 mm and the size compositions of catches generally portrayed the relative selectivity of the different mesh sizes. The data are discussed in terms of their consequences for managing the estuarine fisheries resources of NSW.

Keywords: Gill net fishery; Selectivity; By-catch; Discard survival; Discard management; Australia

1. Introduction

Discarding is one of the most important issues facing the management of fisheries world-wide (Alverson et al., 1994; Hall, 1999). Considerable research over the past decade has shown that discarding can impact on the yields of fisheries and the functioning of ecosystems (Fennessy, 1994; Jennings and Kaiser, 1998; Hall, 1999; Kaiser and de Groot, 2000). Consequently, much emphasis is being placed on reducing discarding in all types of fisheries. Further, unquantified discarding can have important implications when undertaking stock assessments (Alverson et al., 1994; Hall, 1999). In developing strategies to manage discarding and to assess fish stocks, 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 behaviour and selectivity of fishing gears and the species captured can help ascertain ways to mitigate discarding (Hall, 1999; Millar and Fryer, 1999; Broadhurst, 2000). Such information has been used to successfully reduce discarding and wastage in some fisheries (see Hall, 1999; Broadhurst, 2000; Kaiser and de Groot, 2000).

As in many coastal fisheries throughout the world, one of the most contentious issues surrounding the management of the multi-species commercial

* Tel.: +61-2-9527-8411; fax: +61-2-9527-8576.
E-mail address: grayc@fisheries.nsw.gov.au (C.A. Gray).

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estuarine fisheries in New South Wales (NSW), Australia, concerns by-catch and discarding. In particular, various resource interest groups have expressed concerns that many commonly used commercial fishing gears incur high levels of discarding, including species important in other recreational and commercial fisheries. Most initial concerns involved gears used to capture prawns. Thus, there has been several quantitative assessments of by-catch and discarding from the estuarine prawn trawl (Gray et al., 1990; Liggins and Kennelly, 1996; Liggins et al., 1996), prawn stow net (Andrew et al., 1995) and prawn seine net (Gray, 2001) the fisheries. More recently, however, the focus on discarding in the estuarine fisheries has shifted to gears used to capture finfish. Whilst assessments of discarding in the estuarine beach-seine (Gray et al., 2001) fisheries have been made, no such data were available for the multi-species gill net fishery.

Gill nets form the basis of many commercial fisheries throughout the world (Petrakis and Stergiou, 1996; Hickford et al., 1997; Lamberth et al., 1997; Madsen et al., 1999) and are the most common gear used by commercial fishers in NSW estuaries (Pease, 1999). A wide variety of fish taxa, including sparids, platycephalids, mugilids and monocanthids, are targeted using gill nets of varying mesh size. Although the regulations governing the use, mesh size and length of gill nets in NSW vary between estuaries and months of the year, there are three basic methods of operation: (1) set, splash and retrieve; (2) 3 h set; (3) overnight set. Gill nets can be set overnight only throughout the winter months of June, July and August due to the belief that, during this period of cold water, there is minimal mortality to unwanted fish and thus the majority of discards are alive when released. The condition of the retained fish is good for marketing, as opposed to summer, when warmer water causes the condition of fish to deteriorate quickly, leading to greater mortalities of discards and poorer quality of retained fish. At present, commercial fishers are issued annual permits to set gill nets overnight, but as part of the developing management of this fishery and to address public concerns over discarding, information on the catch composition, magnitude of discarding and selectivity of nets is required.

Several methods have been used to quantify the compositions and magnitudes of by-catch and discards, including: (1) logbooks and/or interviews with fishers; (2) independent research surveys using the same fishing gears and done at the same places and times as commercial fishers; (3) observer-based surveys, where scientific observers are placed on board commercial vessels to record data during normal fishing operations (see Saila, 1983; Andrew and Pepperell, 1992). Although such observer surveys must assume fishers do not alter their fishing operations and discarding practices in the presence of an observer, they form the most accurate and reliable way of quantifying the discarding practices of commercial fishing fleets (Saila, 1983; Howell and Langan, 1987; Alverson et al., 1994; Kennelly, 1995).

The aims of the current study were to use an observer-based survey of commercial gill nets set overnight in several NSW estuaries to assess the: (1) composition and magnitude of the retained and discarded catches; (2) rates of capture of retained and discarded species; (3) size-compositions of retained and discarded fishes in nets of different mesh size and, hence, the relative selectivity of nets; (4) condition of discards upon retrieval of nets. This information was subsequently used to assess options to manage discarding in this fishery.

2. Materials and methods

2.1. Overnight setting of gill nets

Between June and August, commercial fishers are permitted to set gill nets between sunset (approx. 6 p.m.) and sunrise (approx. 7 a.m.) in most NSW estuaries. The mesh size of the nets must not be <80 mm (stretched), while the length of any individual net or combination of nets must not exceed 725 m (except for Lake Wooloweyah and the Broadwater in the Clarence River where nets can be 1250 m long). A range of mesh sizes from 80 to 250 mm are used in the fishery, with nets made of a variety of materials, the most common being multi-monofilament and nylon, generally red, green or black, 25–50 meshes deep of 4–8 ply. Typically, nets are staked or anchored at each end and are bottom set, but where they are used in shallow water they may fish the entire water column. Fishers usually deploy and retrieve nets from small boats (<5 m).

2.2. Sampling catches

Commercial gill net catches were sampled from six NSW estuaries spanning 1000 km of coast between June and August 1999 (Fig. 1, Table 1). Scientific observers accompanied commercial fishers during the early mornings when they retrieved gill nets that had been set overnight. In each estuary, it was initially envisaged that 12 trips would be sampled throughout the study, but complete coverage was not possible in all estuaries (Table 1). 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 (to the nearest centimetre) of several species were also measured. Discarded organisms (except crabs) were classified by the

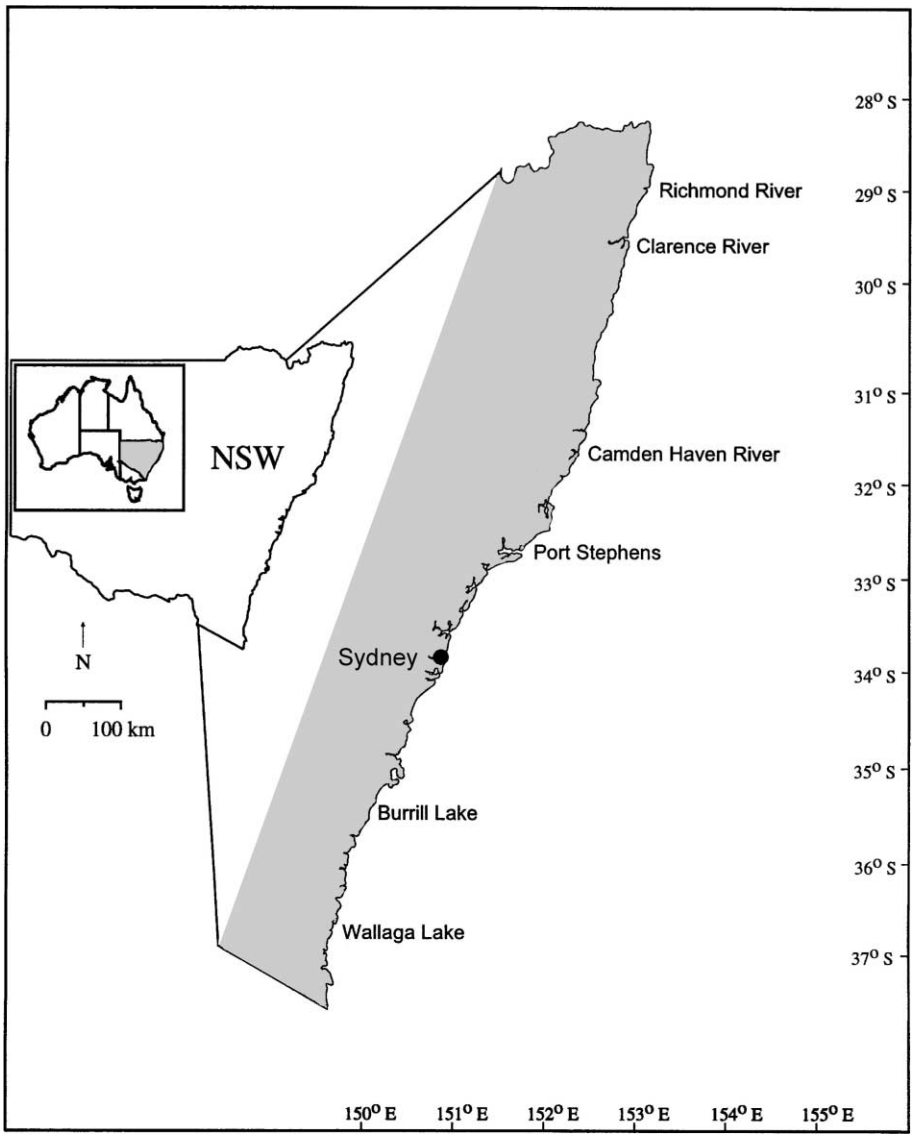

Fig. 1. Map of NSW showing the six study estuaries. In this study, the Clarence River included Lake Wooloweyah and the Broadwater, while the Camden Haven River refers to Queens and Watson Taylors Lakes, and Port Stephens excluded the Myall Lakes.

Table 1
The number of days fished sampled and the total reported fishing effort in number of days that fishers set gill nets overnight (fisher-days) in each of the six study estuaries throughout the survey

Estuary	Catches observed	Total fisher-days	Mesh sizes observed (mm)
Richmond River	4	57	150, 163, 175, 200, 213
Clarence River	12	1018	80, 83, 95, 100
Camden Haven River	12	568	80, 83, 100
Port Stephens	11	315	80, 100, 120
Burrill Lake	4	42	80
Wallaga Lake	12	142	80, 100

observer as dead or alive when they were removed from each net. This assessment was made prior to the fish being processed by the observer, to eliminate the effects of any handling by observer on the condition of fish. Discarded fish were generally processed immediately, so that they could be released quickly to minimise further stress and mortality, whereas much of the retained dead catch was processed after the entire net was retrieved. The observers also recorded operational data, including mesh size and length of nets, fishing time and location.

2.3. Data analysis

2.3.1. Variations in rates of retained and discarded catches

Mean observed retained and discarded catch rates per fisher-day (± 1 S.E.) were calculated for each estuary. One-way analysis of variance (ANOVA) on data transformed to $\log(x+1)$ was used to test for differences between estuaries in the mean weights and numbers of species and individuals of retained and discarded catches. Student–Newman–Keuls (SNK) tests were used to identify significant differences among means.

2.3.2. Estimates of total retained and discarded catches by entire fleets

Estimates of the retained and discarded catches (± 1 S.E.) from all overnight set gill nets in each study estuary throughout the 3-month survey were derived by multiplying the observed mean catch rates per fisher-day (CPUE) by the reported number of days fished by all fishers using overnight set gill nets in each estuary between June and August 1999. The total fishing effort (fisher-days) for each estuary was obtained from the monthly returns that commercial fishers are required to submit to NSW Fisheries, combined with post-survey interviews with commercial fishers in the relevant estuaries. Fishers were questioned on: (1) whether they set nets overnight throughout the survey period; (2) the number of days they set nets overnight; (3) the mesh sizes of nets set.

2.3.3. Size compositions of retained and discarded catches

Observed size compositions of the retained and discarded catches of each commercial species 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. Kolmogorov–Smirnov tests were used to assess differences in the size compositions of fishes captured in different mesh sizes.

3. Results

3.1. Observer coverage

A total of 55 gill net catches was observed in the study. The number of days sampled, the range of mesh sizes fished and the total fishing effort by all fishers who set gill nets overnight in each study estuary are shown in Table 1. Fewer catches were observed in the Richmond River and Burrill Lake due to lower total fishing effort. The most common mesh sizes observed were 80 mm (25 nets) and 100 mm (21 nets). The post-survey interviews confirmed these mesh sizes were most commonly used by fishers. In the Richmond River, mesh sizes >150 mm were used to target estuary sharks and large sciaenids.

3.2. Catch composition

A total of 69 finfish and 3 invertebrate species was identified in commercial catches throughout the study. Fishers retained 38 species, while 64 species were discarded, with 34 of these latter species always discarded. Overall, *Girella tricuspidata*, *Platycephalus fuscus*, *Acanthopagrus australis* and *Mugil cephalus* accounted for 74% of the total individuals captured (Table 2). A total of 33.3% by number and 19.3% by weight of total catches was discarded.

Discards included the smaller (undersized) individuals of the target species, including *A. australis*, *G. tricuspidata*, *P. fuscus*, *M. cephalus*, other species of recreational and commercial value, *Pomatomus saltatrix*, *Pseudocaranx dentex*, *Portunus pelagicus*, as well as several species of little commercial value, including *Cnidoglanis macrocephalus*, *Dasyatis* sp. and *Dicotylichthys punctulatus* (Table 2).

Discards made a significant contribution to the total catch of some target species, including *A. australis* and *G. tricuspidata* (Table 2), which accounted for 54% of all discards observed in the study.

3.3. Variations in mean daily catch rates of retained and discarded species

A greater mean number of species was discarded than retained in the Clarence River and Port Stephens, but there were no such trends in the other estuaries (Fig. 2). In contrast, a greater mean total weight and total number of individuals was retained than discarded in each estuary (Fig. 2). The observed mean weight of retained catches varied between 60 and 80 kg per fisher-day in each estuary except in Wallaga Lake, where the observed mean daily catch rate was 32 kg. Observed mean daily weights of discards ranged from 1 kg in the Richmond River to 36 kg in Burrill Lake. ANOVAS and SNK tests showed that significantly ($p < 0.001$) fewer species and total individuals were retained in the Richmond River than elsewhere, and that the number of total individuals and

Table 2
The 20 most numerous species observed in the survey showing the total number caught, their contribution to the total catch, the proportion discarded, the contribution of discards of each species to the numbers of total discards and the percentage of discards that were alive upon retrieval from nets. (na: not assessed)

Species	No. caught	Total catch (%)	Discarded (%)	Total discards (%)	Discards alive (%)
Girella tricuspidata	2071	23.6	41.4	29.3	98.1
Platycephalus fuscus	1534	17.5	9.7	5.1	72.5
Acanthopagrus australis	1476	16.8	49.2	24.8	91.9
Mugil cephalus	1386	15.8	2.5	1.2	82.6
Portunus pelagicus	344	3.9	80.8	9.5	na
Sillago ciliata	284	3.2	7.7	0.8	72.7
Liza argentea	282	3.2	23.8	2.3	76.1
Arius graeffei	237	2.7	5.1	0.4	100
Cnidoglanis macrocephalus	165	1.9	37.0	2.1	70.5
Dasyatis sp.	112	1.3	99.1	3.8	92.8
Pseudocaranx dentex	75	0.9	41.3	1.1	96.8
Meuschenia trachylepis	74	0.8	64.9	1.6	97.9
Dicotylichthys punctulatus	69	0.8	100.0	2.4	100
Pomatomus saltatrix	65	0.7	40.0	0.9	26.9
Argyrosomus japonicas	60	0.7	75.0	1.5	57.8
Gerres subfasciatus	52	0.6	100.0	1.8	73.0
Carcharhinus obscurus	51	0.6	0.0	0.0	–
Monocanthus chinensis	42	0.5	33.3	0.5	78.6
Aptychotrema rostrata	36	0.4	94.4	1.2	100
Scatophagus argus	33	0.4	78.8	0.9	96.9
All other species	335	3.8	79.4	9.1	–
Total	8783		33.3		

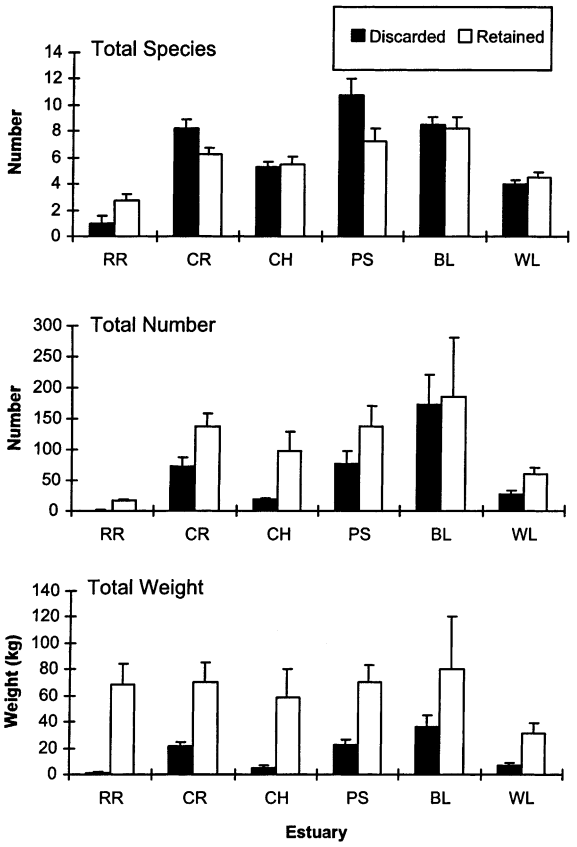

Fig. 2. Mean daily (±1 S.E.) weight and number of total retained and discarded catches in each study estuary during the survey. RR: Richmond River, CR: Clarence River, CH: Camden Haven River, PS: Port Stephens, BL: Burrill Lake, WL: Wallaga Lake.

the weight of discards was greatest in Burrill Lake (Table 3). Few discards occurred in the Richmond River because of the large mesh sizes used.

Ratios (+1 S.E.) of the total weights of retained to discarded catches ranged from 1:0.014 (0.005) in the Richmond River to 1:0.603 (0.069) in Burrill Lake, while the ratios for total number of individuals caught ranged from 1:0.058 (0.021) to 1:1.269 (0.164) in the same locations.

Variations between estuaries in mean daily rates of retained and discarded catches for the major species are shown in Fig. 3. Fewer *P. fuscus*, *M. cephalus* and *Sillago ciliata* were discarded than retained in all estuaries, except in the Richmond River where few of these species were observed in catches. Patterns of discarding of the other major species were not the same across all estuaries, where more of a particular species (e.g. *A. australis* and *P. saltatrix*) was discarded in one estuary, but retained in another estuary. For example, in the Clarence River and Wallaga Lake a greater number of *A. australis* were retained than discarded, but in Port Stephens and Burrill Lake the opposite pattern was evident (Fig. 3).

ANOVAS revealed significant ($p < 0.01$) differences between estuaries in the mean daily rates of retained and discarded catches for most species (Table 3). Rankings of retained and discarded catches between estuaries were species-specific. In general, however, retained and discarded catch rates of most species were low in the Richmond River where large mesh sizes were used. Discards of several target species, including *G. tricuspidata*, *P. saltatrix* and *P. dentex*, were greatest in Burrill Lake, whereas discards of *P. fuscus* and *M. cephalus* were greatest in the Clarence River.

3.4. Size composition and relative selectivity of nets

Figs. 4–6 provide summaries of the sizes of the main fish species retained and discarded per each major mesh size. *A. australis*, *G. tricuspidata*, *M. cephalus*, *S. ciliata* and *P. fuscus* were both retained and discarded, with fish below the minimum legal length (MLL) mostly being discarded. It was noted that some fish of these species with lengths greater than the MLL were also discarded due to the occurrence of a cutaneous ulcerative disease (red spot). Although there is no MLL on *Liza argentea*, the smallest individuals were mostly discarded, but because of their low market value, this varied between fishers. The proportion of total individuals by number ($r^2 = 0.32, p < 0.001$) and weight ($r^2 = 0.76$, $p < 0.001$) that were discarded significantly decreased with increasing mesh size (Table 4). It is noted, however, that the low proportion of discards in nets with mesh >120 mm greatly influenced these results.

The majority (83%) of *A. australis* and (54%) of *G. tricuspidata* captured in the 80 and 83 mm mesh nets were discarded, whereas the opposite pattern was evident for the 95 and 100 mm mesh (Fig. 4). Although few *M. cephalus* (Fig. 5) and *P. fuscus* (Fig. 6) less than the MLL were caught, the mean sizes of these species tended to increase with increasing mesh size

Table 3
Summaries of mean squares and *F*-ratios of one-way analyses of variance and SNK tests of retained and discarded catches for the dominant species from the observer survey. Data transformed to log $(x+1)$. For the SNK ranking, mean catch of each variable for each estuary are ranked from least to greatest. Significant differences between ranked means are shown by less than symbol (<). RR: Richmond River, CR: Clarence River, CH: Camden Haven River, PS: Port Stephens, BL: Burrill Lake, WL: Wallaga Lake ($^{**}p < 0.01$; $^{***}p < 0.001$; ns $p > 0.05$)

	Estuary MS (d.f. = 5)	Residual MS (d.f. = 49)	*F*-ratio	Significance	SNK ranking
Retained					
No. of species	0.101	0.017	6.031	***	RR < WL,CH,CR,PS,BL
Total individuals	0.652	0.098	6.681	***	RR < WL,CH,PS,CR,BL
Weight (kg)	0.254	0.106	2.400	ns[a]	
A. australis	2.735	0.148	18.499	***	RR,CH,BL,PS,WL < CR
G. tricuspidata	2.502	0.341	7.343	***	RR,CR,CH < PS,WL,BL
L. argentea	0.646	0.164	3.933	**	PS,RR,WL,CR,BL,CH
Monocanthidae	0.362	0.057	6.361	***	CR,RR,WL,CH < PS,BL
M. cephalus	1.008	0.453	2.226	ns	
P. fuscus	1.385	0.154	8.990	***	RR < WL,BL,PS,CR,CH
P. saltatrix	0.137	0.060	2.279	ns	
P. dentex	0.207	0.057	3.653	**	CH,CR,RR,PS < WL,BL
S. ciliata	1.099	0.135	8.163	***	RR,WL < CH,PS,CR,BL
P. pelagicus	0.529	0.062	8.566	***	CH,CR,RR,WL < PS < BL
Discarded					
No. of species	0.474	0.020	23.724	***	RR < WL,CH < CR,BL,PS
Total individuals	2.280	0.120	19.034	***	RR,CH,WL < PS,CR < BL
Weight (kg)	1.429	1.429	15.261	***	RR,CH,WL,CR,PS,BL
A. australis	1.560	0.209	7.471	***	RR < WL,CH,PS < CR,BL
G. tricuspidata	2.657	0.256	10.394	***	RR,CR < CH,PS,WL < BL
L. argentea	0.143	0.086	1.673	ns	
Monocanthidae	0.650	0.044	14.890	***	CR,RR,CH,PS,WL < BL
M. cephalus	0.236	0.039	6.034	***	BL,RR,WL,CH,PS < CR
P. fuscus	0.999	0.092	10.849	***	RR,PS,WL,BL,CH < CR
P. saltatrix	0.166	0.028	6.017	***	RR,CR,PS,CH,WL < BL
P. dentex	0.226	0.033	6.846	***	CH,CR,RR,PS,WL < BL
S. ciliata	0.053	0.033	1.614	ns	
P. pelagicus	1.070	0.144	7.455	***	CH,CR,RR,WL,BL < PS

[a] $p > 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Table 4
The percentage of fish by number and weight that were discarded in each observed mesh size. Data pooled across all species and estuaries

Mesh size (mm)	Number (%)	Weight (%)
80	37.5	20.7
83	31.9	19.5
95	25.5	30.2
100	26.9	20.7
120	15.6	9.4
>150	5.8	1.8
All mesh sizes	33.3	19.3

even though a greater proportion of undersized fish were captured in the 100 mm mesh net. *S. ciliata* and *L. argentea* were predominantly caught in the 80 and 83 mm mesh nets.

3.5. Condition of discards

Excluding the Richmond River, where only four discarded fish were observed in catches, greater than 82% of total discards (excluding portunid crabs) were alive when they were removed from nets (Table 5). ANOVA revealed that there were no significant differences (F-ratio = 2.43; d.f. = 4.46; $p > 0.05$)

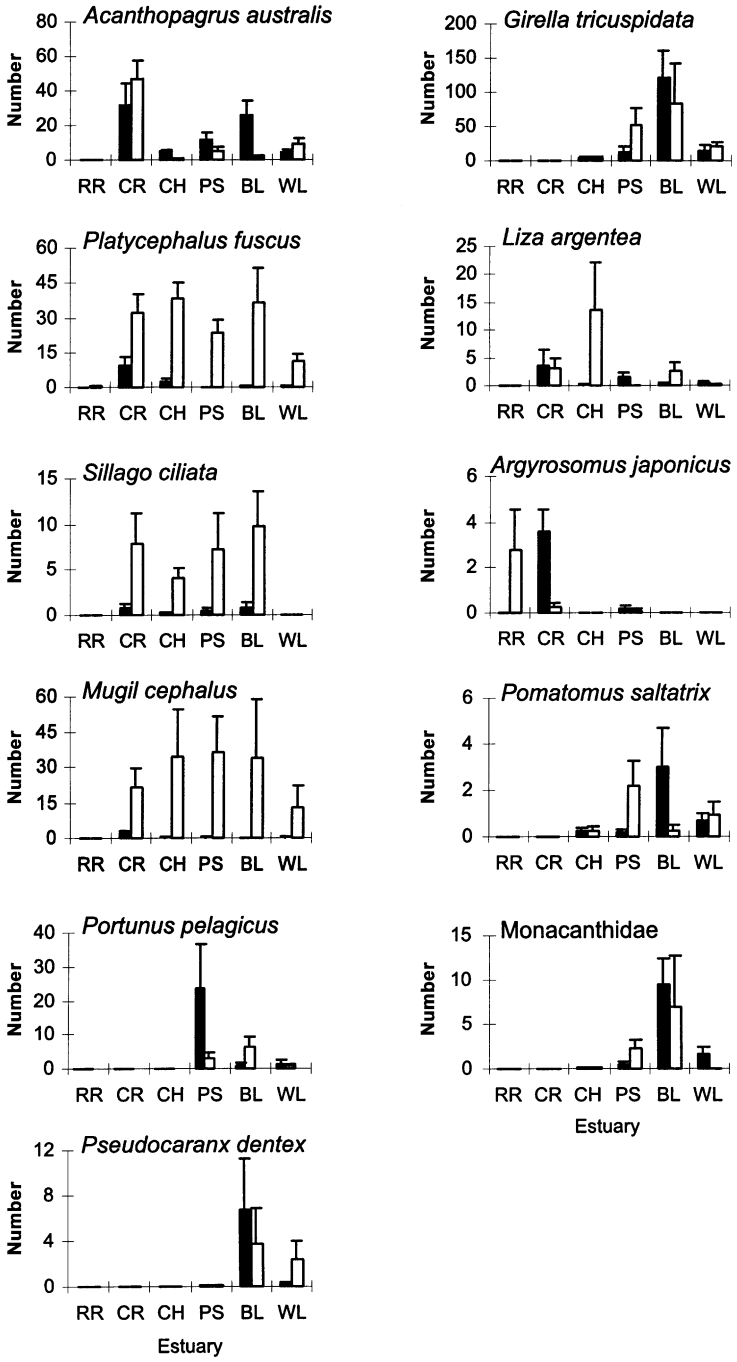

Fig. 3. Mean daily (±1 S.E.) number of retained and discarded catches of major species in each study estuary during the survey. Shading as per Fig. 2.

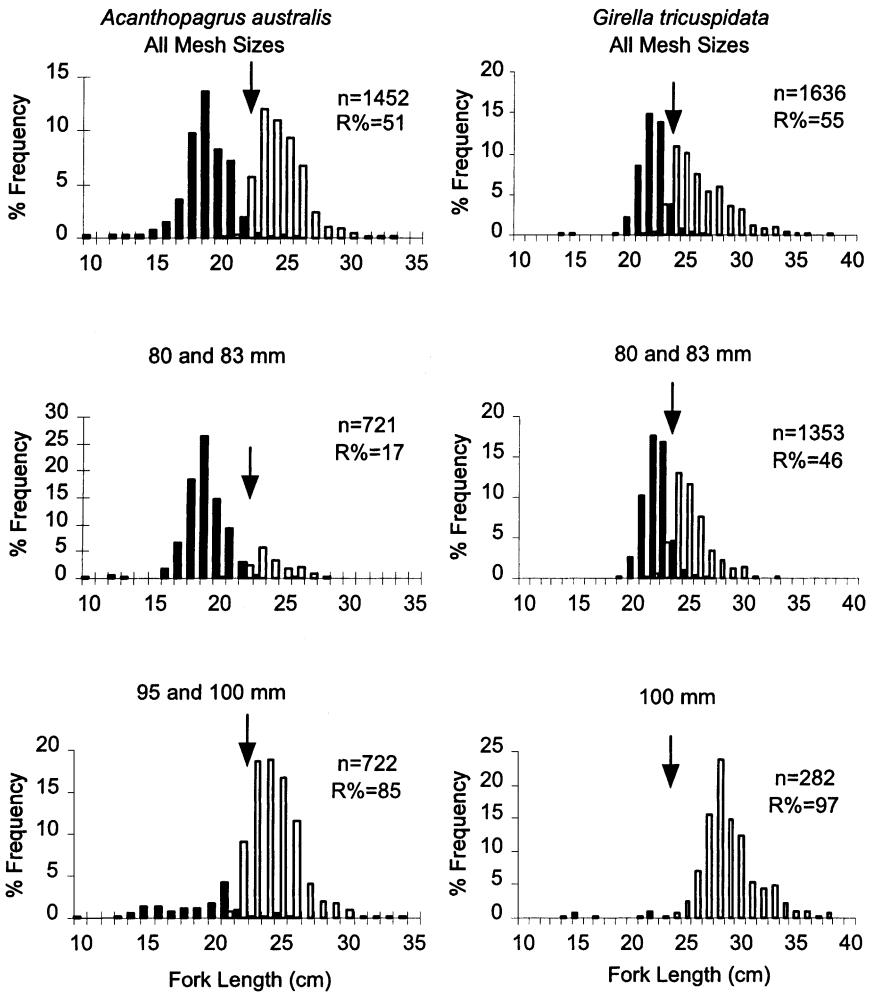

Fig. 4. Length–frequency distributions of retained and discarded catches of *A. australis* and *G. tricuspidata* in each mesh size. Note the data pooled for some mesh sizes due to low sample sizes. *n* denotes the number of fish measured and *R%* the percentage of fish retained. The arrows denote the MLL of the species. Shading as per Fig. 2.

Table 5
Average (±1 S.E.) percent of discarded fishes that were alive when enmeshed from nets in each estuary throughout the survey

Estuary	Alive (%)	S.E.
Richmond River	25.0	25.0
Clarence River	82.7	2.9
Camden Haven River	93.3	2.9
Port Stephens	89.6	3.0
Burrill Lake	97.5	1.0
Wallaga Lake	91.7	3.6

between estuaries in the percent of fishes alive when retrieved from nets. The proportion of discarded fish that were alive upon removal from nets varied between species (Table 3). For example, 98% of discarded *G. tricuspidata*, but only 27% of discarded *P. saltatrix*, were alive when nets were retrieved.

3.6. Estimates of total retained and discarded catches in each estuary

Table 1 lists the total number of days fished in each estuary throughout the study. Estimates of total

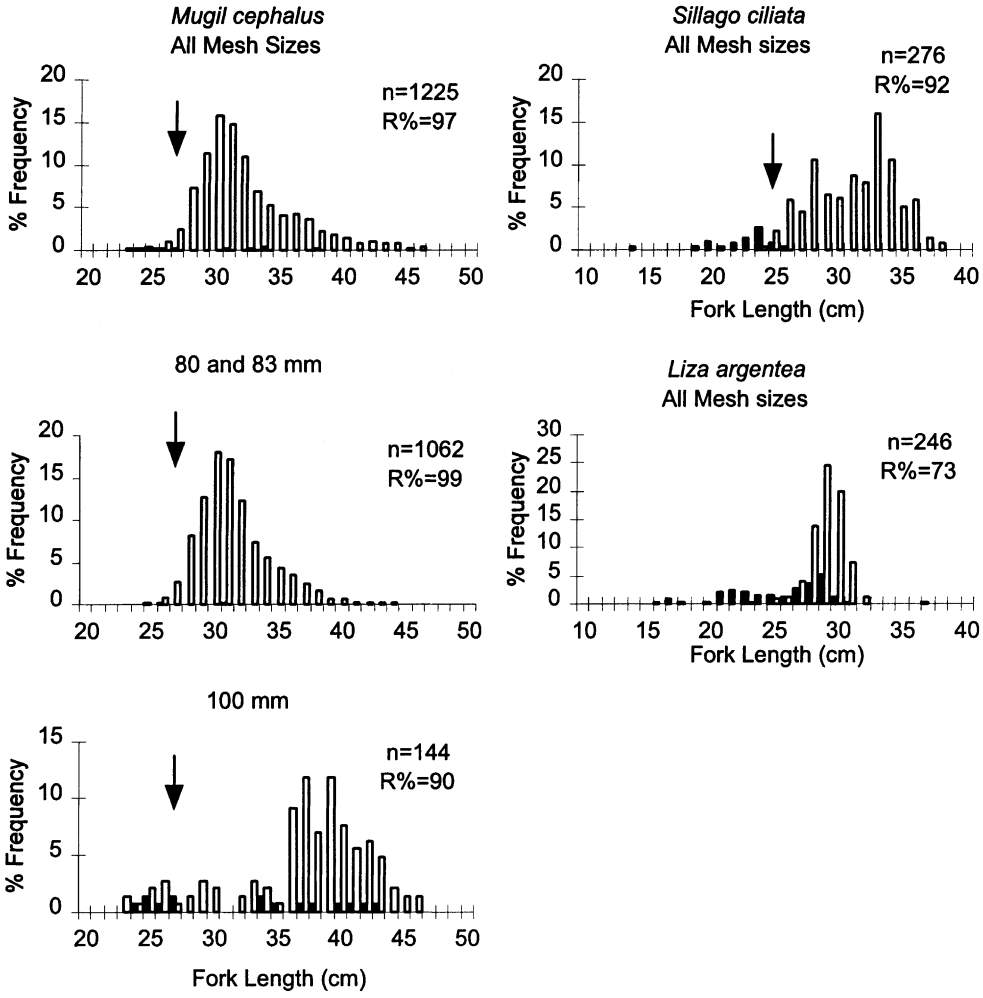

Fig. 5. Length–frequency distributions of retained and discarded catches of *M. cephalus*, *S. ciliata* and *L. argentea* in each mesh size. Note the data pooled for some mesh sizes due to low sample sizes. *n* denotes the number of fish measured and *R%* the percentage of fish retained. The arrows denote the MLL of the species. Shading as per Fig. 2.

retained and discarded catches (±1 S.E.) for the major species by all fishers in each study estuary are presented in Table 6. Note, however, that the precision of these estimates varies between species and estuaries. The estimated total retained catch in the 3-month winter period ranged between 3300 ± 1700 kg in Burrill Lake to 71400 ± 15100 kg in the Clarence River. Similarly, the estimated total discarded catch for this period ranged between 71 ± 54 kg in the Richmond River to 21500 ± 3700 kg in the Clarence River.

4. Discussion

4.1. Composition and magnitude of retained and discarded catches

Recreational fishers and other commercial fishers in estuarine and coastal waters in NSW target many species caught in this estuarine gill net fishery (e.g. *A. australis*, *P. fuscus*). This has lead to allocation disputes between resource user groups similar to that observed in other coastal fisheries (e.g. Lamberth et al.,

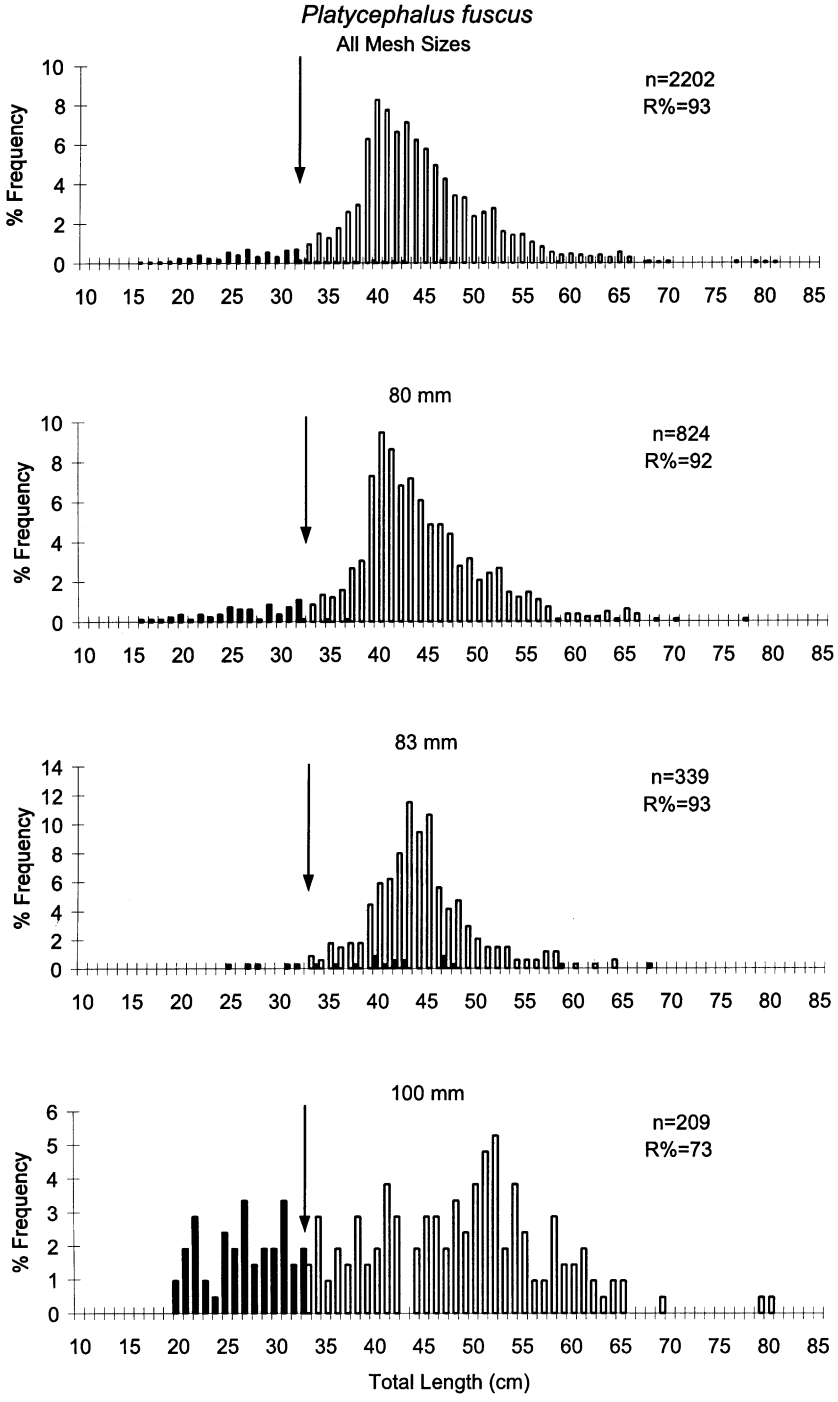

Fig. 6. Length–frequency distributions of retained and discarded catches of *P. fuscus* in each mesh size. *n* denotes the number of fish measured and *R%* the percentage of fish retained. The arrows denote the MLL of the species. Shading as per Fig. 2.

Table 6
Estimated total (±1 S.E.) retained and discarded catches (number except where noted) for the major species in gill nets set overnight in each study estuary between June and August 1999 (r: retained, d: discarded)

	Richmond River	Clarence River	Camden Haven River	Port Stephens	Burrill Lake	Wallaga Lake
Total weight (kg)						
r	3893 (934)	71387 (15106)	33635 (11877)	22220 (3935)	3374 (1674)	4497 (1043)
d	71 (54)	21534 (3755)	3040 (622)	7070 (1285)	1513 (385)	920 (328)
Total number						
r	926 (197)	140145 (20760)	55664 (17680)	43212 (10528)	7749 (4052)	8449 (1750)
d	57 (33)	73296 (15748)	10413 (2011)	24026 (6645)	7245 (2063)	3704 (1124)
A. australis						
r	0	47846 (10557)	521 (130)	1690 (669)	74 (32)	1290 (495)
d	14 (14)	32661 (11891)	2651 (704)	3665 (1383)	1092 (337)	615 (250)
P. fuscus						
r	29 (29)	32491 (8678)	21631 (3914)	7474 (1610)	1523 (645)	1621 (381)
d	0	9501 (3733)	1420 (808)	29 (29)	21 (12)	59 (48)
L. argentea						
r	0	3224 (1871)	7763 (4726)	0	105 (70)	24 (16)
d	0	3563 (2945)	47 (47)	515 (205)	11 (11)	59 (41)
G. tricuspidata						
r	0	679 (229)	2509 (1537)	16208 (7833)	3465 (2448)	3041 (921)
d	0	85 (85)	2698 (1211)	3809 (2978)	5040 (1697)	2201 (1034)
S. ciliata						
r	0	7974 (3371)	2319 (627)	2291 (1217)	410 (162)	0
d	0	848 (431)	142 (74)	172 (89)	32 (32)	0
M. cephalus						
r	14 (14)	21548 (8527)	19549 (11467)	11311 (4800)	1407 (1071)	1811 (1345)
d	0	2206 (673)	142 (102)	86 (61)	0	36 (36)
P. saltatrix						
r	0	0	142 (102)	687 (342)	11 (11)	130 (81)
d	0	85 (85)	142 (74)	57 (38)	126 (71)	95 (50)
P. pelagicus						
r	0	0	0	888 (513)	273 (124)	107 (94)
d	0	0	0	7417 (4114)	32 (32)	189 (177)
Monocanthidae						
r	0	0	47 (47)	716 (291)	294 (241)	0
d	0	0	47 (47)	200 (88)	399 (125)	237 (118)

1997). As in other multi-species finfish fisheries (Howell and Langan, 1987; Gray et al., 2001), the discarded catches were dominated by juveniles of some of the main target species (e.g. *A. australis*, *G. tricuspidata*), juveniles of other species of recreational and commercial significance (e.g. *P. dentex*, *P. pelagicus*, *P. saltatrix*), as well as several species of little commercial or recreational value (e.g. *D. punctulatus*, *C. macrocephalus* and *Dasyatis* sp.). The enforcement of an MLL was the principal reason for the discarding of many species, as it is illegal to retain and sell individuals below the MLL. The

discarding of commercial species with no MLL (e.g. *L. argentea* and *P. dentex*) was also size-based (and probably market driven), with only the larger individuals being retained for sale.

Although retained and discarded catch rates were species-specific, varied among estuaries and were often dependent on a combination of location and mesh size, the data presented provide some evidence of geographical variation in catches. Several species, including *P. saltatrix*, *P. dentex*, *P. pelagicus* and monocanthids, were predominantly caught in the three southern estuaries (Port Stephens, Burrill and Wallaga Lakes) and were rare or absent in the three northern estuaries. Conversely, *Argyrosomus japonicus* was predominantly captured in the Richmond and Clarence Rivers. These differences probably reflect the different mesh sizes and the targeting practices of fishers between these regions. It should be noted, however, that latitudinal changes in catch compositions have been used to zone the estuarine commercial fisheries in NSW (Pease, 1999). Species-specific latitudinal gradients in the by-catches of the NSW coastal prawn trawl fishery have also been reported (Kennelly et al., 1998).

Estimated retained to discarded catch ratios (by weight) in the gill net fishery were less than 1:0.7 in all estuaries. Discard ratios ranging from 1:0.24 to 1:2.48 have been reported for the estuarine commercial beach-seine fishery in Botany Bay, NSW (Gray et al., 2001). Discard ratios similar to those reported here have been reported for other multi-species fisheries, including demersal fish trawling and Danish seining (see Alverson et al., 1994), but there are few reports for commercial gill net fisheries. Low discard ratios have been reported for pelagic gill net fisheries (see Alverson et al., 1994).

The total estimated retained and discarded catches for each estuary generally reflected differences in total reported fishing effort, along with the predominant mesh sizes used in each estuary during the 3-month period. Reported fishing effort was greatest in the Clarence River, as were the estimates of total retained and discarded catches. Likewise, estimated total catches were least in the Richmond River because of a combination of low fishing effort and the large mesh sizes used to target sharks in this estuary. Hence, there were negligible discards in the Richmond River. Although there was also low fishing effort in Burrill Lake, the greater overall mean daily catch rates of discards in this estuary lead to higher estimated total discarded catches than nearby Wallaga Lake, where fishing effort was approximately 3 times higher. Because the overnight setting of gill nets occurs for only 3 months, it is hard to compare estimates of total discards with those for other estuarine and coastal fisheries in southeastern Australia, which generally operate all year round.

Factors affecting the accuracy of the estimated total retained and discarded catches in each estuary need to be considered. In making these estimates, it was assumed that: (1) the observer days were unbiased and represented the catches of all fishers; (2) there were no systematic measurement errors made by the observers; (3) the presence of an observer did not influence normal fishing operations and sorting practices; (4) the reported fishing effort in terms of the number of days fished by each fisher were accurate; (5) the estimates of total discarded catches assumed that individuals were not captured more than once. Assumptions 1, 2 and 3 were considered valid because the fishers observed and days fished were done haphazardly and observers often approached fishers after they had set their nets for permission to accompany them when they retrieved their nets. Thus, they could not affect where the netting took place. Observers also reported that netting generally took place around other commercial fishers. It is acknowledged, however, that the presence of an observer may have affected some sorting practices. In regard to assumption 4, it is not known whether, on average, fishers over- or underestimated monthly fishing effort, and it was impractical to monitor effort by all fishers in each estuary during the survey. It is noted, however, that fishers were interviewed following the field survey to help ascertain the true level of fishing effort in each port. Assumption 5 was not quantified during this 3-month study.

It is possible to scale the estuary-wide estimates of retained and discarded catches for the 3-month period given in Table 6 to state-wide estimates by dividing the reported state-wide fishing effort of 6461 days by the total reported fishing effort of 2142 days in the study estuaries. This gives the appropriate scaling factor of 3.02. Therefore, estimated state-wide totals of retained and discarded catches may be obtained by tripling the total of all six estuaries in Table 6. Alternatively, it is

possible to stratify the state into three zones (see Pease, 1999), and the two study estuaries in each of these zones could be used as described above to produce total zone estimates that could then be summed to produce state-wide estimates. Whilst these manipulations are mathematically easy to do, some assumptions need to be considered, including: (1) the study estuaries were representative of all 56 estuaries fished throughout the state during this period; (2) similar gears were used in all estuaries. In regard to assumption 2, it is known that nets of 70 mm mesh are allowed to be used in five estuaries during this period and catches from these nets have not been assessed. Nonetheless, these state-wide estimates provide approximate totals for assessing the relative magnitude and impacts of discarding from this fishery.

4.2. Relative net selectivity

Knowledge of mesh selectivity can be important in assessing solutions to mitigate and manage discarding in fisheries (Hall, 1999; Broadhurst, 2000). It is generally assumed that gill nets are highly size-selective (Hamley, 1975; Gulland, 1983; Millar and Fryer, 1999) and the data presented here show the relative selectivity of the different mesh sizes of gill nets used in the fishery for the major species. In general, the mean size of the fish captured increased with increasing mesh size, as generally found for gill nets elsewhere (Marais, 1985; Petrakis and Stergiou, 1996; Santos et al., 1998). It should be noted, however, that net selectivity is not only a function of mesh size and fish shape, but also dependent on a combination of biotic (e.g. fish behaviour) and abiotic (e.g. net colour and hanging ratio, water currents, habitat characteristics) factors (Hamley, 1975; Marais, 1985; Acosta, 1994; Acosta and Appeldoorn, 1995; Hickford et al., 1997; Reis and Pawson, 1999).

Discard rates were relatively low in all mesh sizes for some important species, notably *P. fuscus*, *M. cephalus* and *S. ciliata*, suggesting that these nets were relatively effective in catching these species with minimal wastage. In contrast, other important species including *A. australis*, *G. tricuspidata* and *P. saltatrix* displayed high discard rates, particularly in the smaller (80–83 mm) mesh sizes, indicating that harvesting of these species with these mesh sizes was relatively inefficient. The data presented show how the proportion of discards in total catches varied with mesh size; fewer discards were observed in the larger mesh sizes. For example, discards accounted for 37% of the catch of 80 mm mesh, but only 27% of the 100 mm mesh (see Table 4). More dramatic trends were evident for individual species, notably *A. australis* and *G. tricuspidata* (see Fig. 4), and it is therefore evident that an increase in the minimum mesh size in this fishery from the current 80 to 95 or 100 mm would result in fewer discards. Because of the multi-species nature of the fishery, such an increase in minimum mesh size could, however, have an adverse impact on the retained catches for some species, including *M. cephalus* and *S. ciliata*. A change in mesh size would have little effect in reducing the discarding of portunid crabs, which become entangled in nets of all mesh sizes.

4.3. Survival of discards

Overall, most discards (>82%) were alive when removed from nets, which is generally greater than that observed in other net-based fisheries, including gill nets (Chopin and Arimoto, 1995; Gallinat et al., 1997). Survival rates were, however, species-specific, indicating the different susceptibility of each species to capture by this type of gillnetting. Although *A. australis* and *G. tricuspidata* made up approximately 54% of all discards, greater than 90% of these fish were alive when released from nets. In contrast, only a small proportion of *P. saltatrix*, *Argyrosomus japonicas* and *S. ciliata* were alive upon net retrieval (Table 3). Andrew et al. (1995) reported similar survival patterns for *A. australis* and *P. saltatrix* discarded from an estuarine prawn stow (pocket) net fishery in NSW. It is generally regarded that survival of discards following capture by commercial fishing gears is highly variable, as it depends on a range of factors, including length of time retained in the gear, size of fish, water temperature and handling by fishers (see Chopin and Arimoto, 1995). Although longer-term survival was not assessed here, other studies show that post-capture mortality generally increases after initial release (see Chopin and Arimoto, 1995; Kaiser and Spencer, 1995) and, thus, the survival rates reported here should be used as maximal estimates. These estimates, therefore, provide some indication of

minimal mortality rates of discards for stock assessment purposes.

4.4. Management considerations

Discarding, as described here, may have a range of impacts on fish stocks and ecological interactions among species (see Pitcher and Chuenpagdee, 1994; Jennings and Kaiser, 1998; Hall, 1999). The direct effects of discarding from this fishery are not known, however, as they depend on several interacting factors for which data are currently lacking. These data include the proportion of the stock that the discards represent and the natural mortality that individuals would have experienced had they not been captured (see Andrew and Pepperell, 1992; Pitcher and Chuenpagdee, 1994; Kennelly, 1995). Despite this, given the species composition and quantities of discards involved in this fishery, the low survival rates observed for some species and growing public concerns over discarding, it would be advisable for industry, managers and scientists to seek ways to reduce any negative effects of discarding from this fishery.

Regulations governing allowable mesh and fish sizes are used in most net-based fisheries throughout the world to minimise the capture and subsequent mortality of certain-sized (generally immature) fish (Petrakis and Stergiou, 1996; Lamberth et al., 1997; Santos et al., 1998). To minimise the impacts of discarding in gill net fisheries, it is important that mesh size regulations are set large enough to allow undersize fish to escape without being entangled, but still allow the retention of legal-sized fish. In assessing the most appropriate mesh size to use in multi-species fisheries, managers and industry need to set priorities in terms of the importance of minimising the discarding of each species as opposed to maximising the retained catches of those and other species. It is clear in the fishery under study that no current mesh size is best suited to harvesting all species whilst overall minimising the quantity of discards.

The simplest solution to ameliorate discarding in this multi-species gill net fishery would be to increase the permitted minimal mesh size from the current 80 to 95 or 100 mm. This would have a significant effect in reducing the discarding of *A. australis* and *G. tricuspidata*, but would most likely have an impact on the retention rates of *S. ciliata* and *M. cephalus*, which are primarily taken in 80 and 83 mm mesh nets. Commercial fishers could still use 80 and 83 mm mesh to target these latter species, however, using the alternative methods of gill net operation; i.e. set, splash and retrieve and 3 h setting. Discard levels and subsequent mortalities of fish in these operations may be lower because of the reduced soak times. This hypothesis, however, needs testing.

Solutions to discarding problems in multi-species fisheries elsewhere include the development of more selective nets and fishing practices that minimise the capture and mortality of non-target species and undersized individuals of the target species. Current net configurations used in this gill net fishery largely depend on the personal preferences of individual fishers, with nets made of a variety of materials, including multi-monofilament and nylon of assorted colours, twine and ply size and of different hanging ratios and depths. Elsewhere, the selectivity of gill nets has been shown to vary according to factors including the material, colour, twine and ply thickness and elasticity, hanging ratio and depth of net (Hamley, 1975; Acosta and Appeldoorn, 1995; Millar and Fryer, 1999). To further assist the management of discarding in this multi-species fishery, it may be profitable for industry and scientists to develop and test gill nets of more appropriate configurations.

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References

Acosta, A.R., 1994. Soak time and net length effects on catch rates of entangling nets in coral reef areas. Fish. Res. 19, 105–119.

Acosta, A.R., Appeldoorn, R.S., 1995. Catching efficiency and selectivity of gillnets and trammel nets in coral reefs from southwestern Puerto Rico. Fish. Res. 22, 175–196.

Alverson, D.L., Freeberg, M.H., Murawski, S.A., Pope, J.G., 1994. A global assessment of fisheries bycatch and discards. FAO Fish. Tech. Paper 339, 233 pp.

Andrew, N.L., Pepperell, J.G., 1992. The by-catch of shrimp trawl fisheries. Oceanogr. Mar. Biol. Ann. Rev. 30, 527–565.

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

Broadhurst, M.K., 2000. Modifications to reduce bycatch in prawn trawl fisheries: a review and framework for development. Rev. Fish Biol. Fish. 10, 27–60.

Chopin, F.S., Arimoto, T., 1995. The condition of fish escaping from fishing gears: a review. Fish. Res. 21, 315–327.

Fennessy, F.T., 1994. The impact of commercial prawn trawlers on linefish off the north coast of Natal, South Africa. S. Afr. J. Mar. Sci. 14, 263–279.

Gallinat, M.P., Ngu, H.H., Shivley, J.D., 1997. Short-term survival of lake trout released from commercial gill nets in Lake Superior. N. Am. J. Fish. Mgmt. 17, 136–140.

Gray, C.A., 2001. Spatial variation in by-catch from a prawn seine net fishery in a south-east Australian coastal lagoon, Mar. Freshwat. Res. 52, 987–993.

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. Aust. J. Mar. Freshwat. Res. 41, 13–26.

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. Fish. Res. 50, 205–219.

Gulland, J.A., 1983. Fish Stock Assessment: A Manual of Basic Methods. FAO/Wiley, Rome/New York.

Hall, S.J., 1999. The effects of fishing on marine ecosystems and communities. Fish Biology and Aquatic Resources Series 1. Blackwell Science, Oxford.

Hamley, J.M., 1975. Review of gillnet selectivity. J. Fish. Res. Board. Can. 32, 1943–1969.

Hickford, M.J.H., Schiel, D.R., Jones, J.B., 1997. Catch characteristics of commercial gill-nets in a nearshore fishery in central New Zealand. NZ J. Mar. Freshwat. Res. 31, 249–259.

Howell, W.H., Langan, R., 1987. Commercial trawler discards of four flounder species in the Gulf of Maine. N. Am. J. Fish. Mgmt. 7, 6–17.

Jennings, S., Kaiser, M.J., 1998. The effects of fishing on marine ecosystems. Adv. Mar. Biol. 34, 201–352.

Kaiser, M.J., de Groot, S.J., 2000. Effects of Fishing on Non-target Species and Habitats. Blackwell Science, Oxford.

Kaiser, M.J., Spencer, B.E., 1995. Survival of bycatch from a beam trawl. Mar. Ecol. Prog. Ser. 126, 31–38.

Kennelly, S.J., 1995. The issue of bycatch in Australia's demersal trawl fisheries. Rev. Fish Biol. Fish. 5, 213–234.

Kennelly, S.J., Liggins, G.W., Broadhurst, M.K., 1998. Retained and discarded by-catch from oceanic prawn trawling in New South Wales, Australia. Fish. Res. 36, 217–236.

Lamberth, S.J., Sauer, W.H.H., Mann, B.Q., Brouwer, S.L., Clark, B.M., Erasmus, C., 1997. The status of the South African beach-seine and gill-net fisheries. S. Afr. J. Mar. Sci. 18, 195–202.

Liggins, G.W., Kennelly, S.J., 1996. By-catch from prawn trawling in the Clarence River estuary, New South Wales, Australia. Fish. Res. 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. Mar. Freshwat. Res. 47, 877–888.

Madsen, N., Holst, R., Wileman, D., Moth-Poulsen, T., 1999. Size selectivity of sole gill nets fished in the North Sea. Fish. Res. 44, 59–73.

Marais, J.F.K., 1985. Some factors influencing the size of fishes caught in gillnets in eastern cape estuaries. Fish. Res. 3, 251–261.

Millar, R.B., Fryer, R.J., 1999. Estimating the size-selection curves of towed gears, traps, nets and hooks. Rev. Fish Biol. Fish. 9, 89–116.

Pease, B.C., 1999. A spatially orientated analysis of estuaries and their associated commercial fisheries in New South Wales, Australia. Fish. Res. 42, 67–86.

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

Pitcher, T.J., Chuenpagdee, R. (Eds.), 1994. By-catches in fisheries and their impact on the ecosystem. Fisheries Centre Research Reports, Vol. 2, No. 1. University of British Columbia, Canada. ISSN 1198-6727.

Reis, E.G., Pawson, M.G., 1999. Fish morphology and estimating selectivity by gillnets. Fish. Res. 39, 263–273.

Saila, S.B., 1983. Importance and assessment of discards in commercial fisheries. FAO Fish. Circ. 765, 62 pp.

Santos, M.N., Monteiro, C.C., Erzini, K., Lasserre, G., 1998. Maturation and gill-net selectivity of two small sea breams (genus *Diplodus*) from the Algarve coast (south Portugal). Fish. Res. 36, 185–194.