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

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Abstract

A scientific observer programme was used to estimate the retained and discarded catches taken in two of the largest commercial beach-seine fisheries (Lake Macquarie and St. Georges Basin) in New South Wales, Australia. Catches were sampled in each estuary in each of four seasons throughout 1998/1999 and the data were used to estimate the quantities and length compositions of species caught, retained and discarded in these fisheries and to assess potential interactions with other fisheries. A total of 118 catches were sampled which yielded 72 finfish and 10 invertebrate species. Multivariate analyses showed that the mix of species in catches varied between estuaries, with 70 species (41 of which were retained) captured in Lake Macquarie and 37 species (26 retained) in St. Georges Basin. Despite these differences, the predominant species taken and patterns of discarding were similar in the two fisheries. The sparids *Rhabdosargus sarba*, *Acanthopagrus australis* and the gerreid *Gerres subfasciatus* were three of the four most abundant species caught in each estuary, with 99, 88 and 34% of these species discarded, respectively. Compliance with minimum legal length (MLL) accounted for most discarding practices, but for those species with no MLL, discarding was generally market-driven and size-based. An estimated 65% by number and 57% by weight of the catch in Lake Macquarie, and 77% by number and 59% by weight of the catch in St. Georges Basin, was discarded. We estimated that a total of 468 t (269 t discarded) was caught in Lake Macquarie and 143 t (85 t discarded) was caught in St. Georges Basin throughout the 1 year survey. We discuss our findings in relation to interactions with other fisheries and future management strategies.

Keywords: Discard; Bycatch; Seine net; Estuarine fish assemblages; Australia

1. Introduction

Fishing can directly and indirectly affect the biomasses and harvested yields of stocks, ecological interactions among species and the productivity and functioning of ecosystems (Fennessy, 1994; Jennings and Kaiser, 1998; Hall, 1999; Kaiser and deGroot, 2000). Discarding in many fisheries is perceived as a very wasteful practice and can lead to significant conflict among different users of the resource. Discards are also a major source of uncertainty in many fisheries assessments and it is well recognized that accurate and robust stock assessments need quantitative information concerning both the retained and discarded components of catches (Chen and Gordon, 1997; Hall, 1999). Because of the critical importance of bycatch and discarding issues throughout the world, there has been a great deal of research in recent

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years to identify and resolve bycatch, discarding and wastage in many fisheries (Alverson et al., 1994; Kennelly, 1995; Hall, 1999).

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

In New South Wales (NSW), Australia, commercial beach-seining (known locally as "fish hauling") is permitted in many estuaries, where it forms the basis of a regionally-based fishery that annually lands approximately 2000 t of finfish valued at approximately AUD 5 million. As with coastal beach-seine fisheries in other parts of the world (e.g. South Africa—Lamberth et al., 1997), these fisheries occur in areas adjacent to populated centers and consequently attract significant public scrutiny and conflict. Such conflicts have led to so much controversy in NSW that several resource user groups have recommended the method be banned (see Gray et al., 2001). The reasons for this are threefold: (1) disputes over resource allocation among interacting fisheries; (2) concerns over the sustainability of the shared resource; (3) environmental impacts of beach-seines on benthic habitats and discards. Most concerns stem from the fact that the primary species targeted and many of the discards in these fisheries are often important in other regional commercial and recreational fisheries (Lamberth et al., 1994; Gray et al., 2001).

The aims of the current study were to redress the current lack of knowledge of the composition and quantities of the retained and discarded components of catches for the estuary-based beach-seine fisheries in NSW. We used an observer-based survey to quantify the species, quantities and length distributions of catches taken in two of the largest barrier estuaries in NSW, Lake Macquarie and St. Georges Basin. We present a comparison of the catch characteristics among these estuaries and during four seasons in 1998/1999. The data presented can be used to help develop ways to ameliorate discarding and to aid the development of management plans for these and similar fisheries.

2. Materials and methods

2.1. Study estuaries

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

2.2. Commercial beach-seine fisheries

The estuarine beach-seine fisheries in NSW are managed by input controls, including spatial and temporal closures and gear restrictions including minimum and maximum mesh sizes and lengths of nets. Minimum legal length (MLL) restrictions are enforced for several species of fish. Beach-seine nets used in both estuaries are permitted to have a maximum headline length of 1000 m with a further 1000 m

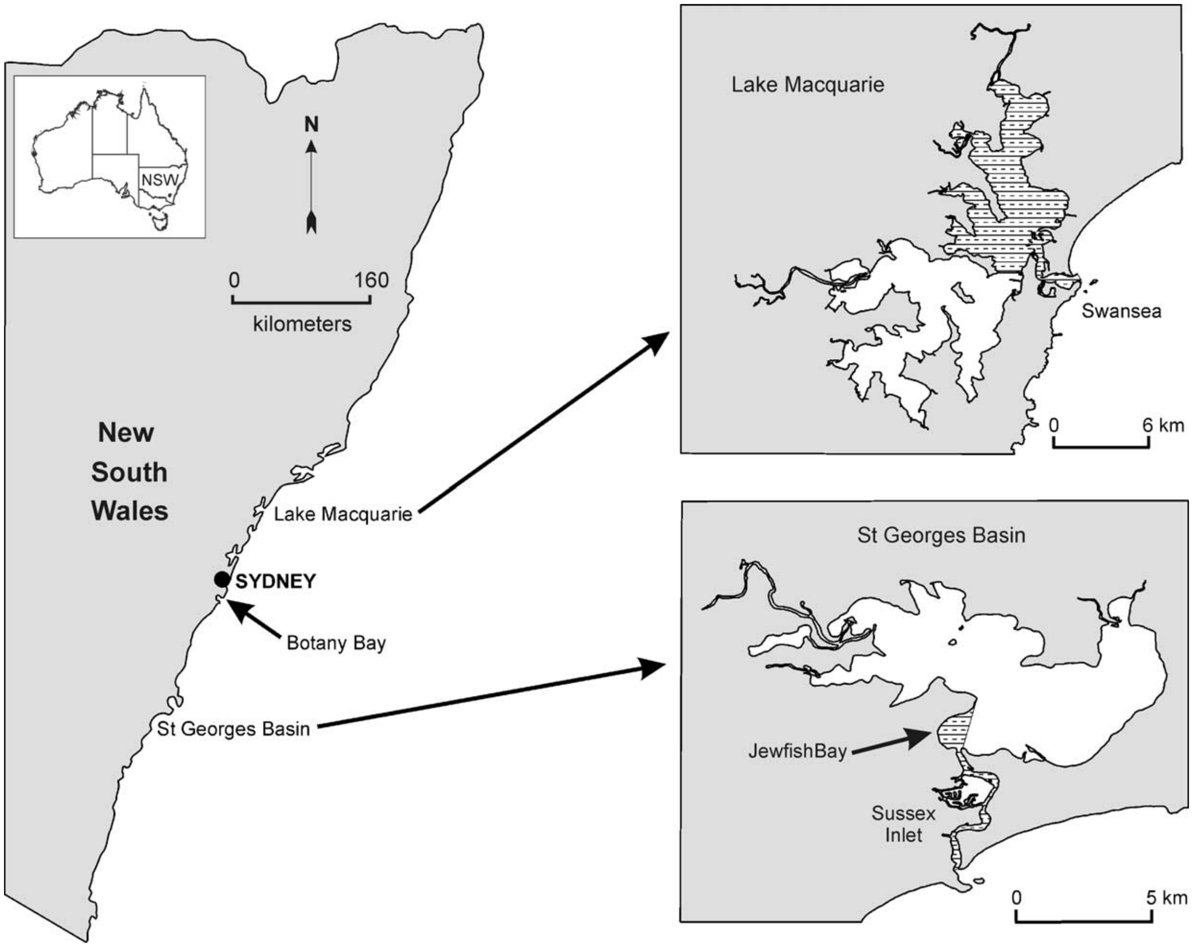

Fig. 1. Map of southeastern Australia showing Lake Macquarie and St. Georges Basin. Hatching denotes areas closed to beach-seining.

of hauling rope on each end which can be increased up to 2000 m of rope during the winter months of June–August. The length of the bunt must not exceed 90 m and it must include a center cod-end. Mesh sizes in the cod-end must be between 30 and 50 mm, whilst the mesh in the rest of the bunt must not be less than 50 mm and the mesh in the wings must not be less than 80 mm (Fig. 2).

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

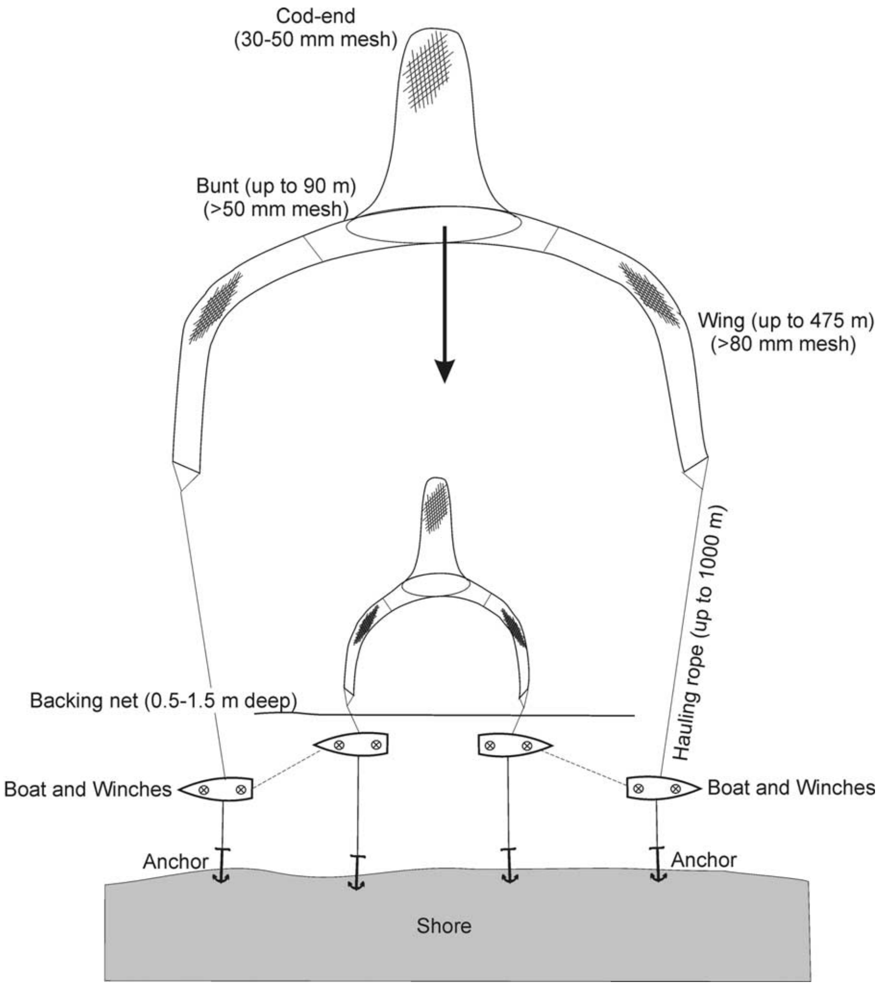

Fig. 2. Diagram of a beach-seine net as used in the NSW estuarine beach-seine fishery.

the net. Depending on catch levels, however, sorting of the catch can often take several hours after the net is landed. Most seine crews consist of three to four persons and generally two or three boats are used in each operation.

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

2.3. Observer survey and sampling procedures

Scientific observers accompanied commercial beach-seine crews on 12–17 randomly selected fishing trips (days) in each season between March 1998 and February 1999 (Table 1). For each observed haul, between three and six random samples of the total catch were obtained prior to it being sorted by the fishers. These samples were sorted into retained and discarded components by a crewmember, and the total numbers and weights of each individual species retained and discarded were recorded by the observer, as were the lengths (fork length (FL) for fish with forked or emarginate caudal fin, total length (TL)

Table 1
The total number of reported fishing days (hauls) and sampled days (hauls) in each season in Lake Macquarie and St. Georges Basin during the study[a]

Season	Months	Lake Macquarie		St. Georges Basin	
		Fishing (days)	Sample (days)	Fishing (days)	Sample (days)
Autumn	March–May 1998	195	17	67	14
Winter	June–August 1998	208	14	54	15
Spring	September–November 1998	131	15	82	16
Summer	December–February 1999	154	12	45	15
Total (% coverage)		688	58 (8.4)	248	60 (24.2)

[a] The percentage of all fisher-days sampled is given for each estuary.

for fish with truncated or rounded caudal fin) to the nearest 1 cm of key species. The total weights of the retained catch and of each individual species retained were obtained when fishers deposited and weighed each catch at the local fishers' cooperative. A ratio of sampled to total retained catch was determined for each sample and this ratio was used in estimating the total weight and number of discarded species. The weights and numbers of discards determined in each sample were multiplied by the appropriate ratio to obtain estimates of the total weight and number of discarded catch in each observed trip.

2.4. Data analyses

2.4.1. Variations in structures of catches

Non-parametric multivariate analyses were used to identify spatial and temporal differences in the assemblage composition (relative number of each species) of catches. The general procedures used followed those outlined in Clarke (1993) and Clarke and Warwick (1994). Data on the number of each individual species in each catch were fourth root transformed to ensure that each taxonomic grouping contributed fairly evenly to each analysis. Similarity matrices based on the Bray–Curtis similarity measure were generated and the inter-relationships among individual catches were displayed graphically in a two-dimensional multidimensional scaling (MDS) ordination plot. Samples that grouped together in the ordination were most similar and the stress coefficient indicated the goodness-of-fit of the data. One-way analyses of similarity (ANOSIM) were used to test for spatial and seasonal differences in the structures of catches. Similarity percentage analyses (SIMPER) were used to identify those species that were most responsible for the similarity of catches within each season, and the overall dissimilarity among catches in Lake Macquarie and St. Georges Basin. The ratio of similarity/standard deviation is a measure of how consistently each species contributed to the similarity measure within a group, or to the dissimilarity measure between groups. Taxa displaying a high ratio and a high contribution can be considered good discriminating species (Clarke and Warwick, 1994).

2.4.2. Variations in rates of retained and discarded catches

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

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

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

2.4.4. Length compositions of retained and discarded catches

Observed length compositions of the retained and discarded catches of each commercial species were scaled to represent the annual catch by all crews in each estuary. Length composition data were weighted according to the ratio of total fishing effort to sampling effort in each season and then summed to provide an annual distribution, from which relative annual length compositions were calculated (see also Liggins and Kennelly, 1996). For five key species with no MLL, the percentage of fish discarded in each length class was determined and logistic curves were used to estimate the length that 50% were discarded/retained.

3. Results

3.1. Fishing and sampling effort

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

3.2. Retained and discarded catch composition

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

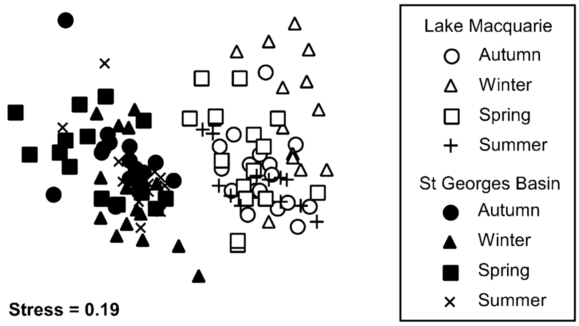

Fig. 3. MDS ordination showing differences in the assemblage composition of catches between estuaries based on numbers of each species captured.

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

A. australis, *R. sarba* and *G. subfasciatus* were among the four most numerically abundant species caught in both estuaries, with significant numbers contributing to both the retained and discarded components of catches (Tables 5 and 6). Up to 99% of *R. sarba*, 88% of *A. australis* and 34% of *G. subfasciatus* were discarded. Other numerically dominant

Table 2
The 25 species that contributed greatest to the dissimilarity between observed beach-seine catches in Lake Macquarie and St. Georges Basin[a]

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

[a] Average catch per haul (number pooled across all samples), the ratio of similarity to the standard deviation and the percentage contribution of each species to the dissimilarity between estuaries are shown.

species observed in catches in both estuaries included *P. sexlineatus*, *Pagrus auratus*, *Girella tricuspidata* and *Pomatomus saltatrix*, with >60% of each species being discarded. Cephalopods, *S. maculata* and *Mugil cephalus* were numerically abundant in catches in Lake Macquarie but not in St. Georges Basin, whereas the opposite was observed for *P. dentex* and *S. ciliata*. In both estuaries, species that were only discarded were dominated numerically by *Dicotylichthys punctulatus*, whilst in Lake Macquarie, *Leiognathus* sp. and *Herklotsichthys castelnaui* were also only discarded in numerically large numbers. The six species that

Table 3
Summary of ANOSIM results comparing the structure of beach-seine catches between seasons in Lake Macquarie and St. Georges Basin[a]

	Lake Macquarie		St. Georges Basin	
	R-statistic	Significance (%)	*R*-statistic	Significance (%)
Global test	0.221	0.00	0.231	0.00
Autumn vs. winter	0.295	0.00	0.243	0.00
Autumn vs. spring	0.163	0.30	0.206	0.10
Autumn vs. summer	0.113	3.50	0.237	0.00
Winter vs. spring	0.238	0.10	0.314	0.00
Winter vs. summer	0.423	0.00	0.3	0.00
Spring vs. summer	0.171	1.00	0.176	0.20

[a] Five thousand permutations were used in each test.

Table 4
The 10 species that contributed greatest to the similarities in beach-seine catches in each season in Lake Macquarie and St. Georges Basin[a]

Species	Lake Macquarie			Species	St. Georges Basin		
	Average catch (number)	Ratio	%		Average catch (number)	Ratio	%
Autumn							
R. sarba	5128.03	3.68	14.92	*A. australis*	614.02	5.93	14.99
S. maculata	3692.70	4.61	13.14	*R. sarba*	603.13	4.22	13.52
A. australis	622.88	3.56	9.47	*S. ciliata*	311.43	3.21	10.37
S. maculata	596.46	4.75	8.39	*M. trachylepis*	76.84	4.63	8.44
P. saltatrix	296.27	3.95	7.05	*P. dentex*	66.06	4.64	8.25
D. punctulatus	154.10	7.27	6.53	*G. tricuspidata*	381.05	1.85	8.21
P. sexlineatus	306.27	2.13	5.95	*G. subfasciatus*	344.80	1.38	7.62
P. auratus	431.15	1.08	4.77	*P. auratus*	142.08	1.19	6
G. tricuspidata	86.79	2.17	4.66	*P. saltatrix*	31.45	1.9	5.95
M. chinensis	54.68	5.26	4.48	*M. chinensis*	46.33	2.02	5.95
Winter							
R. sarba	1114.15	3.63	10.88	*A. australis*	2894.25	4.36	18.27
G. subfasciatus	2720.50	1.64	10.54	*R. sarba*	2132.10	3.75	17.04
D. punctulatus	218.68	2.24	8.67	*G. subfasciatus*	1627.82	3.21	13.04
S. maculata	790.75	1.32	7.92	*P. sexlineatus*	1244.83	1.1	7.72
P. saltatrix	413.41	3.26	7.14	*P. dentex*	93.36	1.71	6.49
A. australis	213.07	2.27	7.06	*P. saltatrix*	76.80	2	5.86
S. australis	274.33	1.17	6.56	*M. chinensis*	71.58	1.65	5.78
L. argentea	323.57	2.49	6.19	*S. ciliata*	810.72	1.06	5.56
P. sexlineatus	323.78	1.34	5.85	*M. trachylepis*	74.82	2.08	5.52
M. chinensis	22.01	4.09	5.14	*P. fuscus*	47.22	1.15	3.33
Spring							
G. subfasciatus	2423.54	5.05	17.02	*A. australis*	382.25	5.77	14.4
R. sarba	1596.43	3.84	13.59	*R. sarba*	601.27	3.42	13.4
A. australis	324.64	6.18	9.36	*G. subfasciatus*	410.23	3.17	11.48
S. australis	164.07	2.24	7.03	*G. tricuspidata*	129.60	4.21	10.9
D. punctulatus	126.04	2.17	6.7	*S. ciliata*	246.15	1.48	8.15
P. auratus	535.80	0.97	5.57	*P. fuscus*	58.33	3.18	6.95
S. maculata	150.26	1.54	5.13	*P. sexlineatus*	195.55	1.11	6.31
P. sexlineatus	326.58	1.44	4.98	*M. trachylepis*	12.41	4	5.94
P. saltatrix	185.50	1.3	4.42	*M. chinensis*	42.19	1.24	5.35
M. chinensis	23.49	1.44	3.48	*P. auratus*	104.99	0.94	4.89
Summer							
R. sarba	2854.45	4.38	12.58	*A. australis*	1006.48	5.51	13.41
A. australis	606.28	5.07	9.53	*R. sarba*	830.82	7.14	12.99
G. subfasciatus	1848.28	1.72	8.83	*G. tricuspidata*	731.39	4.78	11.4
P. saltatrix	534.82	3.37	7.06	*S. ciliata*	498.99	2.8	9.19
S. maculata	346.19	4.34	6.81	*P. sexlineatus*	418.07	2.12	7.71
P. sexlineatus	462.44	1.42	6.22	*G. subfasciatus*	529.90	1.48	7.44
G. tricuspidata	267.30	1.82	5.96	*M. chinensis*	127.08	4.44	7.4
P. auratus	478.39	1.31	5.86	*P. auratus*	677.77	1.76	7.36
D. punctulatus	138.80	2.13	5.34	*P. fuscus*	93.64	3.91	6.96
M. cephalus	229.06	1.84	5.18	*P. saltatrix*	45.69	4.24	5.91

[a] Ratio: ratio of similarity to standard deviation; %: percent contribution of each species to the total similarity in season in each estuary.

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

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

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

Species	Common name	Retained number	S.E.	Discarded number	S.E.	Discarded (%)	Retained weight (kg)	S.E.	Discarded weight (kg)	S.E.	Discarded (%)
Total individuals		283243	35182	955166	135837	77.1	57919	4509	84794	10190	59.4
A. australis	Bream	36527	4581	276242	7239	88.3	13022	12	31382	734	70.7
R. sarba	Tarwhine	15347	3758	241779	4853	94.0	3559	7	13246	233	78.8
G. subfasciatus	Silver biddy	145407	32831	43342	3221	23.0	10583	21	1633	109	13.4
P. sexlineatus	Six-lined trumpeter	2468	2468	121882	4139	98.0	207	2	4543	135	95.6
S. ciliata	Sand whiting	20682	5143	89331	2766	81.2	5928	9	10366	296	63.6
G. tricuspidata	Luderick	27519	5148	50791	2124	64.9	10856	16	8559	403	44.1
P. auratus	Snapper	648	292	69187	2466	99.1	292	1	6619	231	95.8
M. chinensis	Fanbelly leatherjacket	3437	803	13806	302	80.1	892	2	1396	42	61.0
P. dentex	Silver trevally	4866	1459	11764	302	70.7	989	2	850	22	46.2
M. trachylepus	Yellow-finned leatherjacket	4276	913	7001	271	62.1	927	2	765	27	45.2
P. saltatrix	Tailor	3424	645	6180	246	64.3	1525	2	648	27	29.8
P. fuscus	Dusky flathead	6803	1235	2772	61	28.9	5822	9	608	15	9.5
D. punctulatus	Porcupinefish	0	0	9498	415	100.0	0	0	2389	132	100.0
T. novaezelandi	Yellowtail	3610	1926	4638	221	56.2	351	1	378	18	51.8
S. maculata	Trumpeter whiting	1338	663	920	41	40.8	248	1	101	4	29.0
Myxus elongatus	Sand mullet	1421	832	668	80	32.0	472	2	198	25	29.6
L. 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
M. cephalus	Sea mullet	933	613	59	8	6.0	568	3	15	2	2.5
C. 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
H. castelnaui	Southern harring	0	0	637	35	100.0	0	0	40	3	100.0
Cnidoglanis macrocephalus	Estuary catfish	0	0	588	42	100.0	0	0	363	25	100.0
Pseudorhombus arsius	Large-toothed flounder	38	38	344	44	90.0	8	0	53	7	87.4
Remaining 12 species		1293		1615		55.5	365		250		40.7

were solely retained in Lake Macquarie (*Argyrosomus japonicus*, *Sphyrna* sp., *Rachycentron canadum*, *Scylla serrata*, *Octopus* sp., *Chelidonichthys kumu*) were relatively rare and occurred in very low abundances (estimated <100 individuals of each species caught per year).

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

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

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

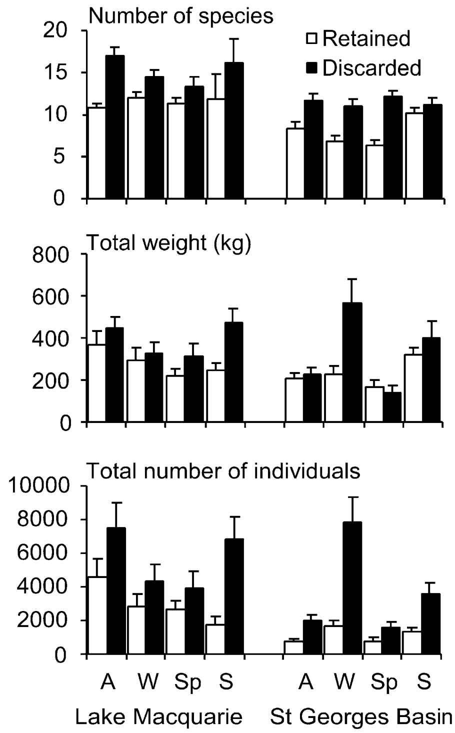

Fig. 4. Mean (±1 S.E.) numbers of retained and discarded species, total weights and total numbers of individuals taken in each season in each estuary.

Table 7
Summary of results of two-factor analyses of variance comparing catches across Lake Macquarie and St. Georges Basin and the four seasons for the common species presented in Fig. 3

	Total catch			Retained catch			Discarded catch		
	Estuary (E)	Season (S)	E × S	Estuary (E)	Season (S)	E × S	Estuary (E)	Season (S)	E × S
No. of species	**	ns[a]	ns	**	**	*	**	ns	ns
No. of individuals	**	**	**	**	ns	**	**	**	**
Weight (kg)	*	**	*	ns	*	*	*	**	*
G. subfasciatus	**	ns	**	*	ns	**	**	**	ns
A. australis	**	**	**	**	**	*	**	**	**
R. sarba	**	**	**	**	**	ns	**	**	**
P. auratus	ns	**	ns	ns	*	ns	ns	**	ns
S. ciliata	**	*	ns	**	*	ns	**	ns	ns
S. maculata	**	ns	*	**	*	*	**	ns	ns
P. sexlineatus	ns	*	**	ns	ns	ns	ns	*	**
P. dentex	**	*	ns	**	ns	ns	**	**	**
G. tricuspidata	**	**	ns	**	**	ns	*	**	ns
M. trachylepis	**	ns	**	*	ns	**	**	ns	ns
M. chinensis	ns	**	ns	ns	*	ns	ns	*	ns
P. saltatrix	**	**	ns	ns	ns	**	**	*	*

[a] ns: $P > 0.05$.
* $P < 0.05$.
** $P < 0.01$.

Macquarie. Overall, discarding (by weight and number) was greatest in autumn and summer in Lake Macquarie, but in winter and summer in St. Georges Basin. Conversely, retained catches (by weight and number) were greatest in autumn in Lake Macquarie, but in summer (weight) and winter (number) in St. Georges Basin.

Spatial and temporal variations in retained and discarded catch rates of several important species are shown in Fig. 5. More *A. australis*, *R. sarba* and *P. auratus* were discarded than retained in each season in both estuaries. This was also evident for *P. saltatrix* in Lake Macquarie and *S. ciliata* and *Monacanthus chinensis* in St. Georges Basin. No clear discarding

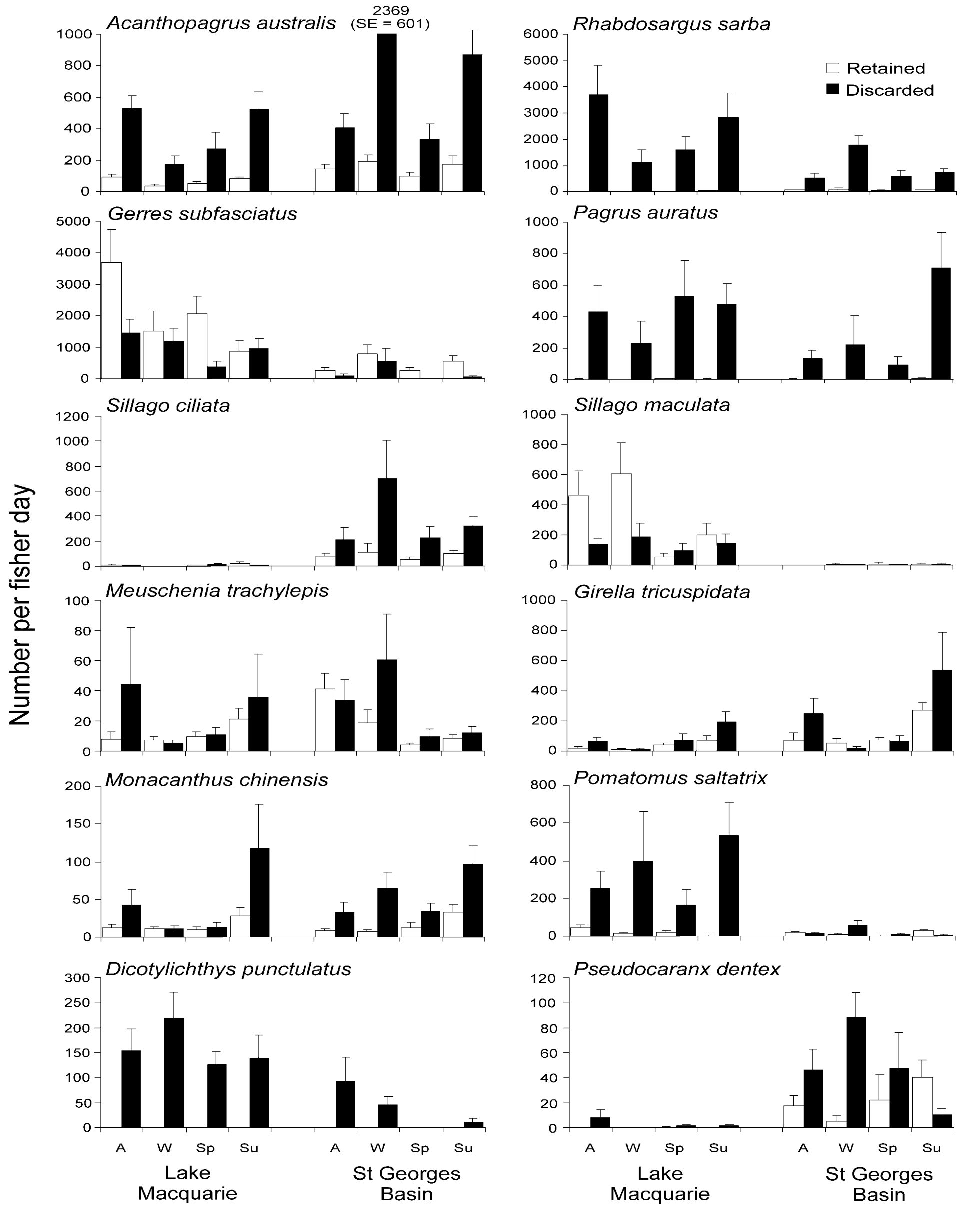

Fig. 5. Mean (±1 S.E.) numbers of retained and discarded catches of individual species.

patterns were evident for the other important species, with more of one species being discarded in a particular season but more retained in another season. For example, in St. Georges Basin, more *P. dentex* were discarded than retained in autumn and winter, whereas the opposite occurred in summer. Relationships between retained and discarded catch rates of most species also varied between seasons and estuaries. For example, rates of discarding of *S. maculata* in Lake Macquarie were similar across seasons, whereas retained catch rates were greater in autumn and winter compared to spring and summer.

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

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

3.4. Estimates of annual retained and discarded catches

Estimates of total annual retained and discarded catches for the predominant species by the entire beach-seine fishery in each estuary are provided in Tables 5 and 6. It was estimated that a total of 468 t (approx. 6,025,000 individuals) was caught in Lake Macquarie, of which 269 t and 3.9 million individuals were discarded and 143 t (approx. 1,234,000 individuals) in St. Georges Basin, of which 85 t and 955,000 individuals were discarded throughout the 1 year survey. The precision of these estimated total retained and discarded was relatively similar for both estuaries (S.E. = 7–15%), even though the observer coverage per reported fishing effort was greater in St. Georges Basin (24.2%) than in Lake Macquarie (8.4%). Estimated total retained catches were greater in Lake Macquarie (by a factor of 4.9 by number and 3.3 by weight) than in St. Georges Basin. A similar trend was also evident for several important species, including *A. australis*, *R. sarba*, *P. auratus*, *S. maculata* and cephalopods which were captured in significantly greater numbers in Lake Macquarie. Estimated total discards in both estuaries were dominated numerically by *G. subfasciatus* and *R. sarba* in Lake Macquarie and *R. sarba* and *A. australis* in St. Georges Basin.

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

3.5. Length compositions of retained and discarded catches

The length compositions of important fish species retained and discarded are shown in Fig. 6. The existence of MLL explained the length-based discarding of most species, including high value species such as *A. australis*, *R. sarba*, *P. auratus* and *S. ciliata*. Although there is no MLL on *G. subfasciatus*, *Meuschenia trachylepis*, *M. chinensis*, *S. maculata* and *P. sexlineatus*, generally only the larger individuals were retained. As determined by the logistic function, the length that 50% of each of these species was retained (pooled across both estuaries) was 10.8, 21.3, 22.0, 17.5 and 17.0 cm, respectively.

4. Discussion

In any study designed to quantify retained and discarded catches, several inherent assumptions are usually made. In this study, the specific assumptions underlying the accuracy of our estimates are: (1) the actual days and hauls randomly selected for sampling were representative of the hauls done by all fishers; (2) there were no systematic measurement errors made by the observers; (3) the presence of an observer did not influence normal fishing operations and sorting practices; (4) the reported fishing effort in terms of the numbers of days fished by each crew was accurate; (5) the estimates of total discarded catches assumed that individual fish were not captured more than once. Our attempts to select the days fished and the fishers at random supports assumptions 1, 2 and 3 but we

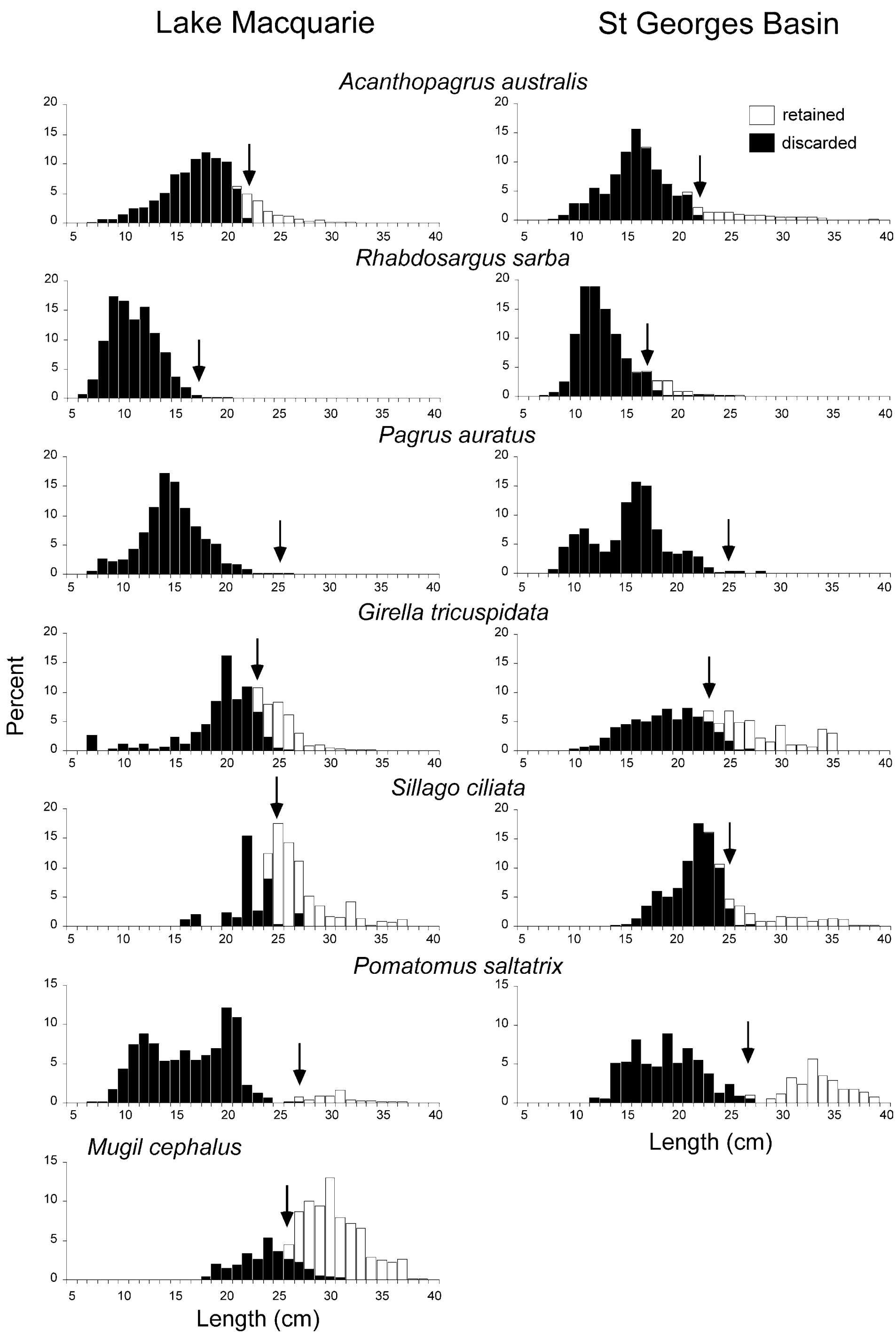

Fig. 6. Size compositions of retained and discarded catches. Arrows denote MLL.

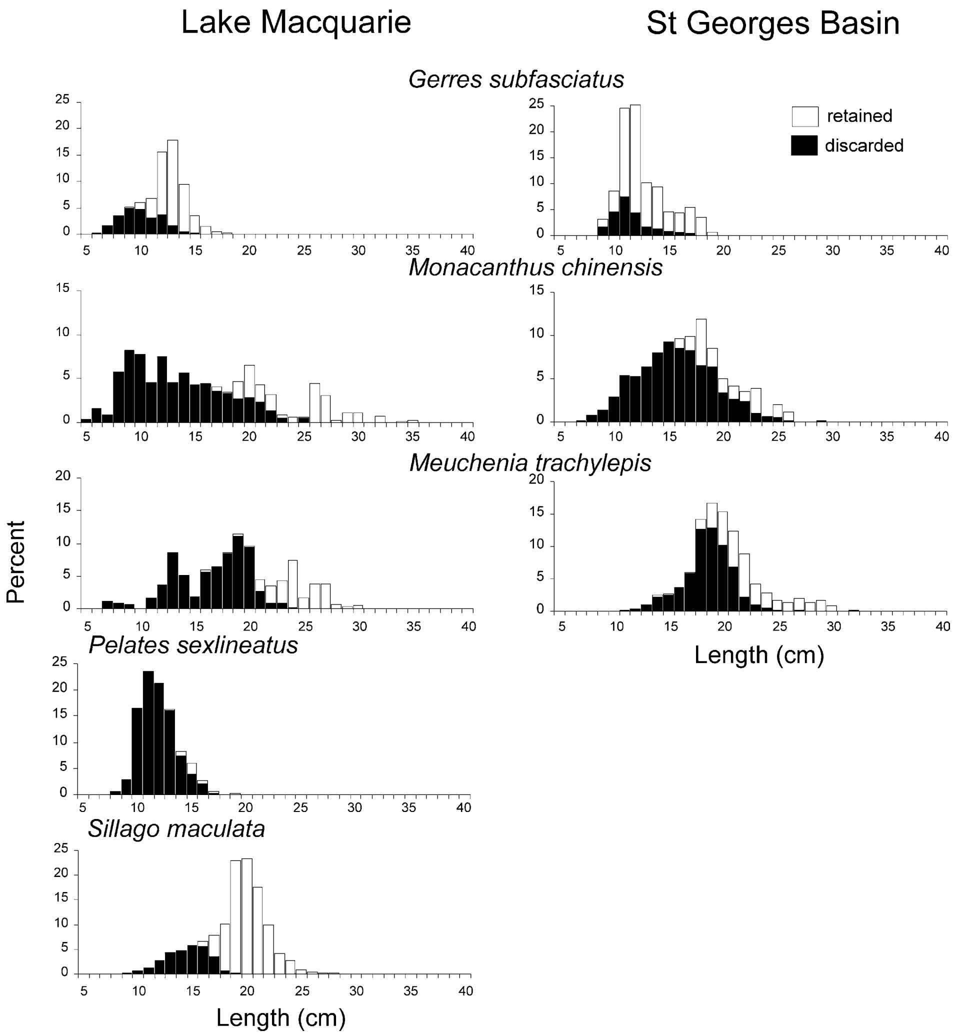

Fig. 6. (*Continued*).

acknowledge that the presence of an observer may have affected some sorting practices and, unfortunately, it was beyond the scope of this study to examine the validity of assumptions 4 and 5. Nevertheless, the data presented here and in Gray et al. (2000, 2001) have revealed several general conclusions concerning the spatial and temporal variabilities in catches and the relative non-selectivity of the fishing gears used in estuarine beach-seine fisheries in NSW.

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

We can infer from these results the somewhat obvious conclusion that the catch characteristics of estuarine beach-seine fisheries probably differ due to basic differences in the faunal assemblages in the estuaries throughout the year. Such differences are, in turn, probably caused by a suite of abiotic and biotic factors such as the effects of estuarine geomorphology on hydrographic conditions (Roy et al., 2001), rates of immigration and emigration of individual species and recruitment fluctuations (Blaber, 2000). An important implication of this conclusion is that fishing-induced impacts on species and the estuarine systems in which they occur will vary substantially between estuaries, forcing any solutions to ameliorate such impacts to be developed on an estuary-specific basis. Spatio-temporal interactions such as these are not uncommon in estuarine and coastal ichthyofaunal assemblages and their associated fisheries (Potter and Hyndes, 1999; Blaber, 2000; West and Walford, 2000), making the management of these types of fisheries (and their very significant discarding problems) among the most complex of any fishery-type in the world.

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

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

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

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

As in other multi-species fisheries, including other beach-seine fisheries in Australia (Gray et al., 2001) and South Africa (Lamberth et al., 1994, 1995a,b), the discards sampled in the present study contained juveniles of most of the primary target species. For some of these, the discarded component exceeded the retained catches. For example, up to 88% of the total catches of *A. australis* and 99% of *R. sarba* and *P. auratus* (a total of more than 10 t) were discarded. These same trends were evident in the Botany Bay fishery (Gray et al., 2001) and highlight how these nets are not effective in catching these targeted species selectively. With the exception of *G. subfasciatus*, most of the primary species captured in these beach-seine fisheries are also targeted in other commercial and recreational fisheries in southeastern Australia (see Gray, 2002), causing the significant conflict with other users and the concerns over wastage mentioned in the introduction. In general, the overarching conclusion from this study is that the beach-seine nets as currently configured and used in the estuarine fisheries of NSW are relatively non-selective in that they catch a wide range of species of differing morphologies and sizes. This is typical of other coastal beach-seine fisheries throughout the world (Jones, 1982; Lamberth et al., 1995a) and is the underlying cause of many debates concerning the potential ecological impacts of these types of fisheries.

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

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

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

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