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A Comparison of Catches and Bycatches from Three Non-trawl Penaeid-Fishing Gears Used in an Australian Estuary

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Abstract

The catches and bycatches from stow and trap nets and seines used by commercial fishers in Lake Illawarra, southeastern Australia, were assessed via an observer-based sampling program during the 1999/2000 fishing season. Observed retained catches included *Penaeus plebejus*, *Metapenaeus macleayi* and *M. bennettae*, while bycatches comprised a total of 48 species of teleosts and 9 species of invertebrate. Average daily catches and bycatches were greatest in stow nets and least in trap nets. Bycatch composition varied greatly among gear types and for trap nets, between the 1st and 2nd half of the fishing season. *Gerres subfasciatus*, *Acanthopagrus australis, Portunus pelagicus* and *Sillago maculata* were numerically most abundant in seines, *Centropogon australis, Pomatomus saltatrix and Loligo sp*. in stow nets and *G. subfasciatus, Loligo sp*., *Hyporhamphus regularis* and *C. australis* in trap nets. Trap and stow nets accounted for greatest (80%) and least (2%) reported fishing effort, respectively. Trap nets accounted for 82% of the estimated total penaeid catch and 69% of estimated total bycatch during the fishing season. The results are discussed in terms of differences in the selection mechanisms and spatial and temporal operations of the 3 gears and consequences for sustainable and environmentally-responsible fishing.

Introduction

Penaeid prawns form the basis of important commercial fisheries in temperate and tropical regions throughout the world. A common problem in many of these fisheries is the incidental capture and subsequent discarding of unwanted species, collectively termed ‘bycatch’ (for reviews, see Saila 1983; Andrew and Pepperell 1992; Alverson et al. 1994). In recent years, considerable research has been done to identify, quantify, and where required, reduce problematic bycatches in several penaeid-trawl fisheries (see Broadhurst 2000 for review). Less work has been directed towards the issue of bycatch from other penaeid-catching gears like seines, and cast, stow and trap nets, even though they are used in many

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small-scale artisanal fisheries world-wide (Venderville 1990; Changchen 1992; Chavez 1992; Andrew et al. 1995; Gray 2001; Gray et al. 2003).

In addition to trawls, three other types of fishing gear, including towed seines and static stow and trap nets, are used to commercially target penaeids in several estuaries in New South Wales (NSW), Australia (Andrew et al. 1995; Gray 2001; Gray et al. 2003; Broadhurst et al. 2004; Macbeth et al. 2005a,b). One of the most contentious issues facing the management of fisheries using these gears concerns the impacts of discarding bycatches. Of specific concern is the mortality of large numbers of juveniles of species important in other commercial and recreational fisheries (Liggins et al. 1996; Gray 2001). Secondary issues include the impacts of fishing gears on benthic habitats, and the conflict between different industry sectors over the quantities and sizes of penaeids harvested in estuaries. In particular, fishers using trawls in oceanic areas claim that it is wasteful to catch small penaeids during the estuary phase of their life cycle. An important first step in dealing with such issues is to quantify what is captured, retained and discarded and compare the efficiencies and selectivities of the different fishing gears to assess their relative merits. Whilst there have been some isolated quantitative assessments of bycatches from the estuarine penaeid-trawl (Gray et al. 1990; Liggins and Kennelly 1996; Liggins et al. 1996; Kennelly et al. 1998), stow-net (Andrew et al. 1995) and seine (Gray 2001; Gray et al. 2003) fisheries in NSW, there are few comparative data on the species and size compositions of penaeids and bycatches caught in different gears across similar temporal and spatial scales. Such comparisons can be useful for determining the most sustainable gears to harvest the target species, and to help identify mechanisms to reduce bycatches (Broadhurst et al. in press).

In this study, we placed observers with commercial seiners and stow and trap netters working in Lake Illawarra, NSW during the 1999/2000 fishing season. We were therefore able to directly compare catches and bycatches across gear types within the one estuary and fishing season. An observer-based survey was chosen because this is generally acknowledged to be the most reliable and accurate way to quantify catches and bycatches in commercial fisheries; compared to other methods such as logbooks and fishery-independent studies (Alverson et al. 1994; Andrew and Pepperell 1992; Kennelly 1995).

Materials and Methods

Study area

Lake Illawarra (33°16'S; 151° 30'E) (Fig. 1) is a shallow (mean depth 1.9 m, maximum depth 3.7 m) elongate barrier estuary with a surface area of approximately 34 km^2 and a constricted entrance to the sea that intermittently opens and closes (Roy et al. 2001). The shallow foreshores of the lake are lined with aquatic vegetation, particularly *Zostera capricorni*, *Ruppia* sp., and *Halophila* spp. (West et al. 1985). Lake Illawarra supports significant commercial and recreational finfish, penaeid prawn and portunid crab fisheries (Gray 2004; Reid and Montgomery 2005).

Commercial penaeid fisheries

Approximately 18 commercial fishers use trap and stow nets and seines to harvest penaeids in Lake Illawarra between Monday and Friday throughout the fishing season, which usually occurs between October and February, but with peak reported effort in January and

February. Fishers are permitted to only retain penaeids; all other organisms (i.e. bycatch) must be discarded.

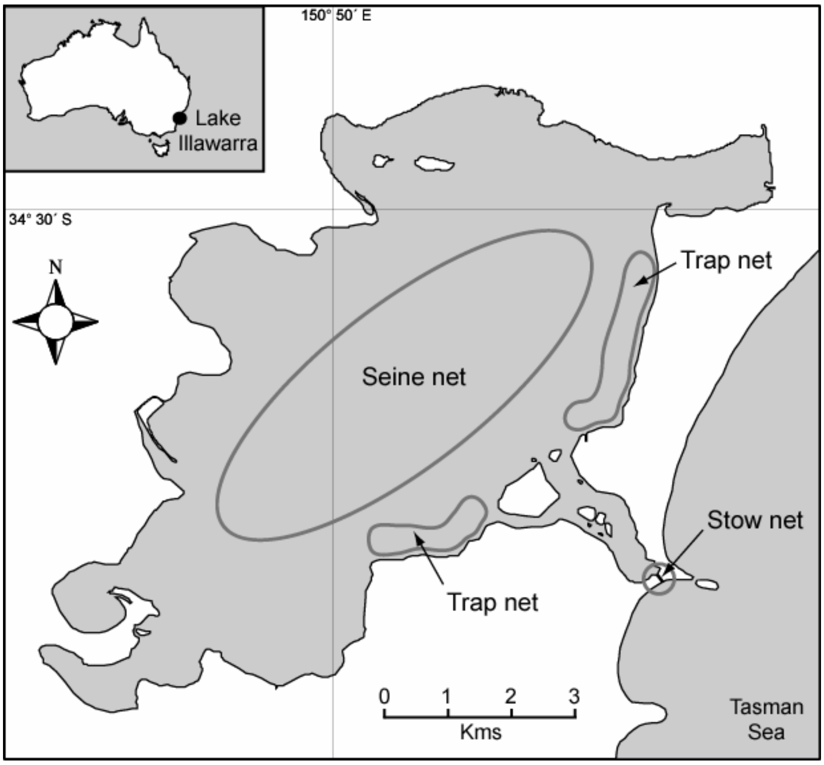

Fig. 1. Map of Lake Illawarra showing the areas where stow and trap nets and seines were observed to be used during the study.

Trap nets are predominately used along the eastern shoreline north and south of the entrance channel (Fig. 1), and are set on the ebb tide at night between the last and first quarter phases of the moon. Each trap net consists of a wall of netting up to 140 m in length and between 2 and 3 m in depth, made from polyethylene (PE) or polyamide (PA) twine with a hanging ratio of 50%. Legal mesh sizes are between 25 and 36 mm, but as with the other gears, all fishers use the minimum legal mesh size. Trap nets are set by anchoring one end near the shore and attaching the other end to the horizontal gunwale of a small dory anchored offshore (Fig. 2a). Wind-generated currents cause the netting to distend and assume a parabolic shape, effectively trapping migrating penaeids and other organisms. A trap net can be set for a maximum of 1 hour, after which fishers use a second dory to retrieve the net from the shore to the stationary boat, where the catch is lifted onboard and sorted (Fig. 2b). Fishers can only set and lift the net once, after which they must move to another site. Effectively, competing fishers take turns at setting and retrieving trap nets at each particular location.

Stow nets are used at 3 identified locations in the entrance channel (Fig. 1). Like trap nets, they are secured using anchors and/or poles driven into the substratum and primarily fished during the ebb tide at night between the last and first quarters of the moon (Fig. 2c). Stow nets have legal mesh sizes between 30 and 36 mm (stretched) and a maximum headline length of 20 m. During deployment, tidal currents maintain the funnel shape of the net and also wash penaeids and other organisms through to the codend (Fig. 2c). Periodically, the codend is lifted aboard an anchored dory and the catch sorted. The codend soak time depends on tidal flow, catch rates, quantities of jellyfish and detached weed, but typically varies between 10 and 60 minutes.

Seines are fished throughout the entire lake (except at the entrance channel) mostly during the day between the first and last quarters of the moon (Fig. 1). Seines have the same mesh sizes as stow nets and a maximum headline length of 140 m, with additional 140-m hauling rope (bridles) attached to each wing end. Each deployment usually takes about 15 minutes, and involves the fisher securing a buoy to the end of one hauling rope and deploying it along with the seine and second hauling rope from a small dory (< 6 m) around the area to be fished (Fig. 2e). The dory then returns to the buoy and tows the entire configuration at approx. 0.5 ms^{-1} until the two wings of the seine come together (Fig. 2e). The seine is then hauled (usually by hand) onboard where the catch is sorted.

Observer survey

Scientific observers accompanied commercial fishers using each gear type on daily or nightly fishing trips between October 1999 and February 2000 (the duration of the fishing season). During each trip, the commercial fisher and the observer sorted the catch from each individual deployment into retained penaeids and discarded bycatch. Data were collected on the total weights of penaeids and bycatch; the weights and numbers of individual species comprising bycatch; and the total or fork lengths (TL or FL - to the nearest 0.5 cm) of key bycatch species. A 1kg subsample of penaeids was purchased and used to determine the species and size compositions (to the nearest 1 mm carapace length – CL). Operational data were also collected for each trip and included the date, times of fishing, weather conditions, locations and gear configurations.

Data analyses

The average catches of penaeids and bycatches per fishing trip (± 1se) were calculated for each gear type. Data for trap nets were separated into 2 fishing periods: time 1 - between November and December (1^{st} half of fishing season), and time 2 - between January and February (2^{nd} half of fishing season). One-factor analyses of variance (ANOVA) were used to test for statistically significant differences in the quantities of catches and bycatches between gear types and trap nets in times 1 and 2. Data were ln(x+1) transformed to minimise heterogeneity of variances (tested by Cochran's test). Where an ANOVA detected significant differences in the average catch rates, Student-Newman-Keuls (SNK) tests were used to separate significantly different means. A ratio of weight of penaeids to bycatch (and associated standard error) was determined for each gear type following the procedures outlined in Cochran (1963).

Non-parametric multivariate analyses were used to delineate spatial and temporal patterns in bycatch compositions among gear types. All analyses were done using PRIMER (www.primer.com), following the general procedures outlined in Clarke (1993). Matrices based on the Bray-Curtis similarity measure were generated using non-transformed bycatch data and the inter-relationships among samples were displayed graphically in a 2-dimensional multidimensional scaling (MDS) ordination plot. One-way analyses of similarity (ANOSIM) were used to test for differences in bycatches caught using the different gear types and for trap nets between time periods. Similarity percentage analysis (SIMPER) was used to identify those species most responsible for determining the similarity matrix among sample groupings. The ratio of similarity/standard deviation is a measure of how consistently each species contributed to the similarity measure within each gear type. Species displaying a high ratio and a high contribution can be considered good discriminating species (Clarke and Warwick 2001).

Estimates of total catches and bycatches (± 1 se) taken by all fishers using each gear type in Lake Illawarra throughout the 1999/2000 season were also derived. This was done by multiplying the average catch rates per fishing trip by the reported number of trips fished by all fishers using each gear type throughout the season and using the standard method for estimating a total and standard error across multiple randomly-sampled strata as described in Cochran (1963). The total reported fishing trips for each gear type were obtained from the forms that commercial fishers are legally required to submit to the NSW Department of Primary Industries and from interviews with individual fishers at the end of the fishing season.

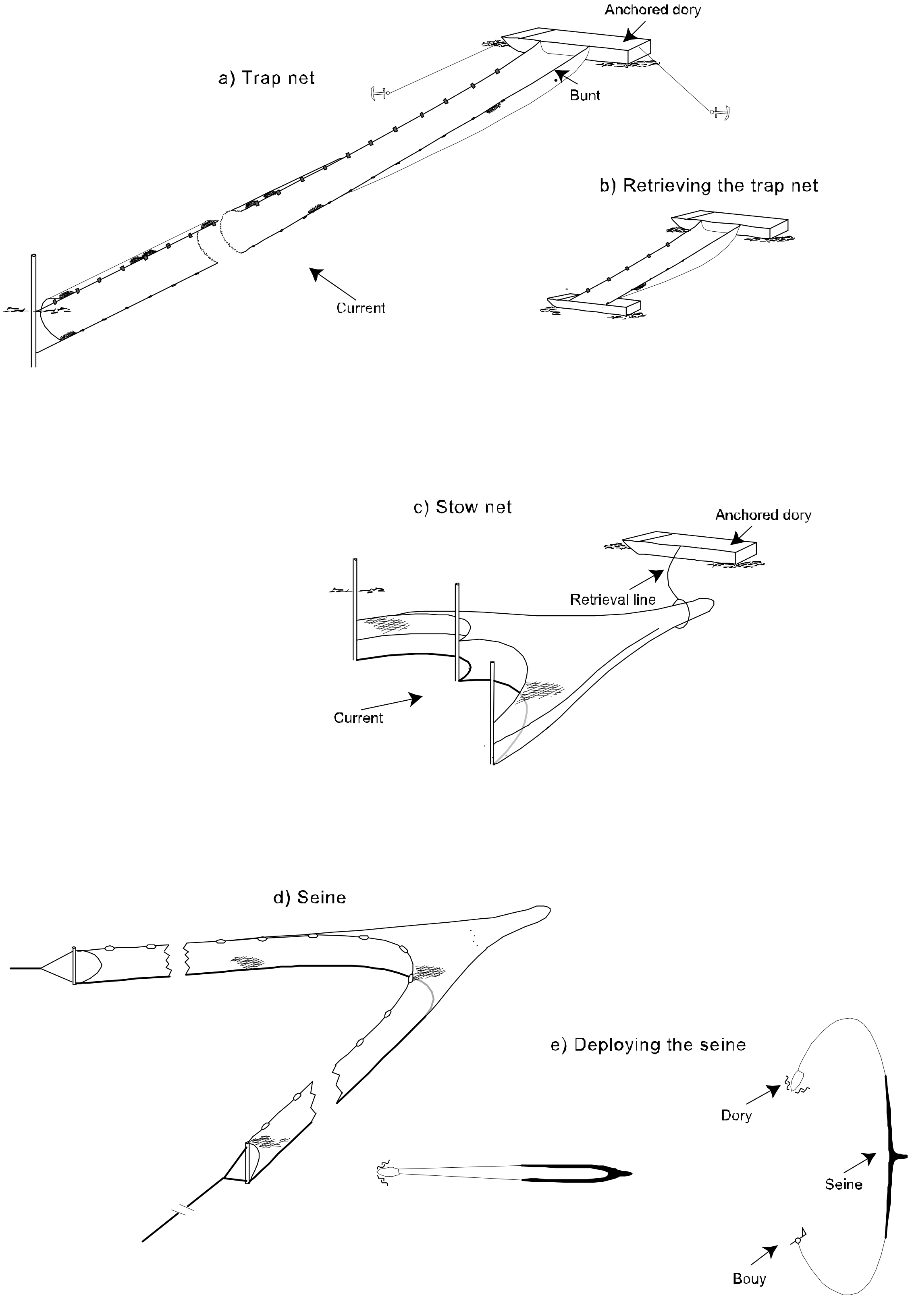

Fig. 2. Diagrammatic representation of a) trap net and b) method of retrieval, c) stow net and d) seine and e) method of deployment.

Results

Fishing effort and observer coverage

A total of 16 fishers reported using the 3 gears to target penaeids in Lake Illawarra during the 1999/2000 season. The reported total fishing effort in numbers of fishing trips by all fishers in Lake Illawarra between October 1999 and February 2000 was 421 nights for trap nets (108 in time 1 and 313 in time 2), 96 days for seines and 11 nights for stow nets. Trap nets were used in all months between October and February, whereas stow nets and seines were only used during January and February. We observed a total of 21 fishing trips for trap nets (9 in time 1 and 12 in time 2), 6 for seine nets and 4 for stow nets.

Penaeid catch composition

Retained penaeid catches comprised 3 species: *Penaeus plebejus*, *Metapenaeus macleayi* and *M. bennettae*. *M. bennettae* were caught in very low numbers (< 1% of total samples) and were therefore excluded from the main analyses concerning penaeid composition and sizes, but were included in the comparisons of total penaeid catches vs. total bycatches. *P. plebejus* were more prevalent (> 60%) than *M. macleayi* in catches by trap and stow nets, while the opposite pattern was evident in catches by seines (Fig. 3). The average CL of *P. plebejus* caught was significantly smaller in stow nets compared to trap nets and seines, whereas the average CL of *M. macleayi* was significantly smaller in seines compared to the other gears (Table 1, Fig. 3).

Table 1. Summary of results of ANOVA and SNK tests comparing catches across trap nets in times 1 and 2, stow nets and seines.

	Mean Square (df = 3, 27)	F-ratio	Significance	SNK ranking
Total penaeid weight	7.528	5.528	**	T1<Se<T2<St
Penaeus plebejus weight	5.925	3.098	*	Se<T2=St=T1
Metapenaeus macleayi weight	2.912	2.190	ns	-
Penaeus plebejus length	0.019	4.160	*	St<Se=T2=T1
Metapenaeus macleayi length	0.110	17.948	***	Se<T1<St=T2
Bycatch number	4.609	11.179	***	T1<T2<Se=St
Bycatch weight	0.966	2.248	ns	-
Gerres subfasciatus	5.755	4.377	*	St<T1=T2<Se
Acanthopagrus australis	11.870	26.591	***	St=T1=T2<Se
Rhabdosargus sarba	5.425	8.412	***	St=T1=T2<Se
Sillago maculata	10.565	21.680	***	St=T1=T2<Se
Pagrus auratus	5.427	14.866	***	T1=T2=St<Se
Pelates sexlineatus	5.805	8.490	***	St=T1=T2<Se
Arenigobius bifrenatus	3.052	5.590	**	St=T1=T2<Se
Portunus pelagicus	10.527	11.793	***	T1<T2<St=Se
Dicotylichthys punctulatus	2.740	3.221	*	T1<T2=Se=St
Centropogon australis	18.553	40.995	***	Se=T1<T2<St
Achoerodus viridis	6.868	64.587	***	T1=T2=Se<St
Pomatomus saltatrix	11.597	13.916	***	T1<T2=Se<St
Loligo sp.	11.785	9.767	***	T1=T2<Se<St
Herklotsichthys castelnaui	2.135	3.674	*	St=Se<T1=T2
Hyporhamphus regularis	6.102	5.982	**	Se=St<T2=T1
Synaptura nigra	1.666	6.150	**	St=T2=Se=T1

Numbers are shown except where noted. Degrees of freedom = 3, 27; ns = $P > 0.05$, *, **, *** = $P < 0.05$, < 0.01, < 0.001 respectively. T1 = trap net time 1, T2 = trap net time 2, St = stow net, Se = seine.

Penaeid – bycatch relationships

The average observed catch rates of penaeids throughout the survey was greatest in stow nets (142 kg per fishing trip) and least in trap nets in time 1 (14 kg per fishing trip) (Fig. 4). The average penaeid catch in trap nets was significantly greater in time 2 (76 kg) than in time 1 (14 kg) (Table 1). The average observed bycatch rates by weight did not differ significantly among gear types (Table 1), ranging from 5 to 13 kg per fishing trip (Fig. 4). The ratio of the total weight of penaeids to bycatch (± 1se) was 1:2.08 (1.22) and 1:0.16 (0.05) for trap nets in times 1 and 2, respectively and 1:0.30 (0.04) and 1:0.11 (0.02) for stow nets and seines, respectively. There was a significant correlation between the weight of penaeids and bycatch per fishing trip for stow nets ($r_{(4)} = 0.975$, $P < 0.05$), but not for seines ($r_{(6)} = -0.511$, $P > 0.05$) or trap nets during time 1 ($r_{(9)} = 0.484$, $P > 0.05$) and time 2 ($r_{(12)} = 0.311$, $P > 0.05$).

Bycatch composition

A total of 48 teleost and 9 invertebrate species were observed in bycatches throughout the survey; 44, 36 and 33 species in trap and stow nets and seines, respectively. Bycatch composition varied between gear types (ANOSIM, R = 0.686, $P < 0.001$, Fig. 5) with all pairwise comparisons significant. Bycatches in seines and stow nets were more similar to bycatches taken in trap nets during time 2 than during time 1. The ten predominant species caught in each gear type accounted for more than 90% of the similarity among samples (Table 2). Although all 3 gears caught most bycatch species, there were significant differences in the average catch rates between gear types and between times for trap nets (Table 2). Trap net catches were dominated numerically by *Gerres subfasciatus* (Gerreidae) and *Hyporhamphus regularis* (Hemiramphidae) in time 1, but *Centropogon australis* (Scorpaenidae), *Portunus pelagicus* (Portunidae) and *Loligo* sp. (Loliginidae) in time 2 (Table 2). Stow net catches were dominated numerically by *C. australis*, *Pomatomus saltatrix* (Pomatomidae), *P. pelagicus* and *Loligo* sp., whereas seine catches were dominated numerically by *G. subfasciatus*, *P. pelagicus*, *Acanthopagrus australis* (Sparidae) and *Sillago maculata* (Sillaginidae). Catch rates of *C. australis* and *P. saltatrix* were greatest in stow nets, *G. subfasciatus*, *A. australis* and *S. maculata* in seines and *H. regularis* in trap nets (Table 2). Bycatch species not listed in Table 2 were generally caught at abundances averaging less than 1 individual per fishing trip.

The majority of fish and invertebrates comprising bycatches were small (< 25 cm TL or FL). Specifically, lengths of *G. subfasciatus*, *Rhabdosargus sarba* (Sparidae), *A. australis*, *Girella tricuspidata* (Girellidae) and *P. saltatrix* were mostly < 15 cm FL, whereas *S. maculata* and *H. regularis* ranged between 6 and 24 cm FL.

Estimated total penaeid catches and bycatches

An estimated 30,000 kg of penaeids and 3,600 kg of bycatch (approximately 65,000 individuals) were caught in Lake Illawarra throughout the 1999/2000 fishing season (Table 3). Trap net catches during time 2 accounted for 77 and 53% of the estimated total penaeid catch and bycatch, respectively during the season. *G. subfasciatus* dominated bycatches, contributing 22% towards the estimated total.

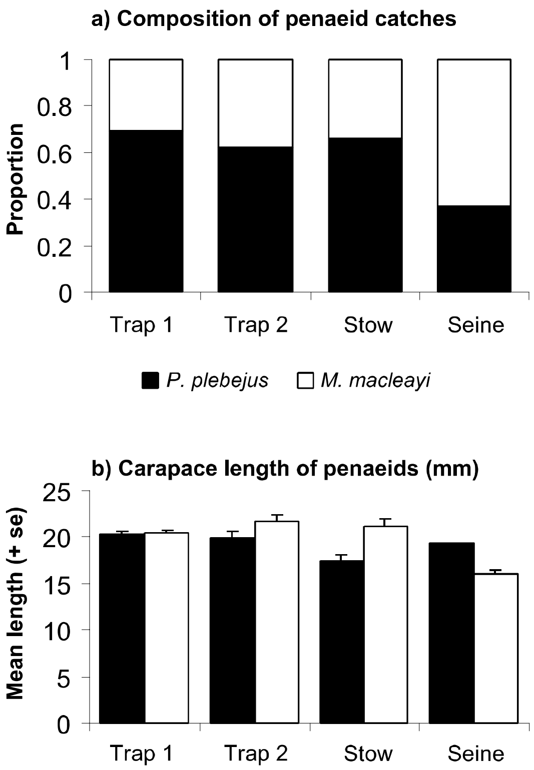

Fig. 3. Comparisons of the a) composition and b) carapace lengths of penaeids caught by each gear type.

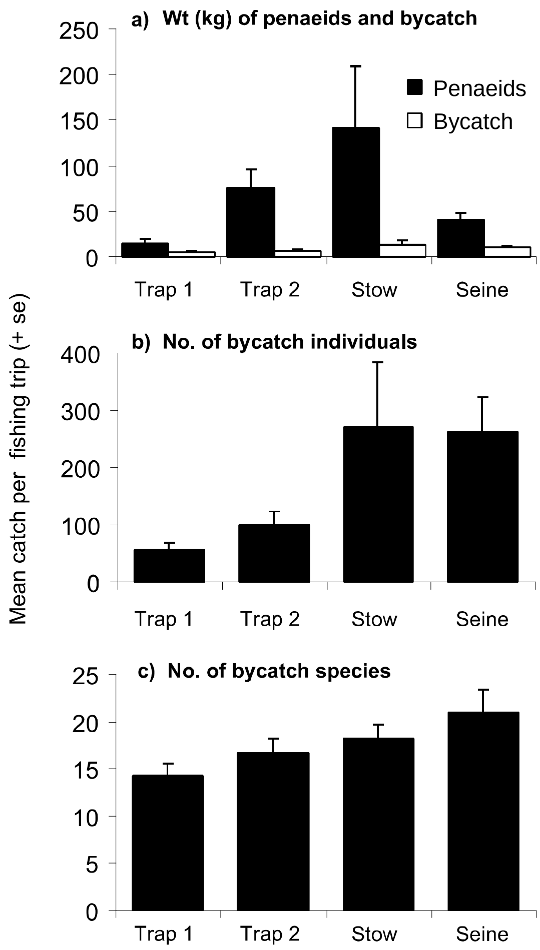

Fig. 4. Weights of a) total penaeids and bycatches and numbers of b) bycatch individuals and c) species caught by each gear type.

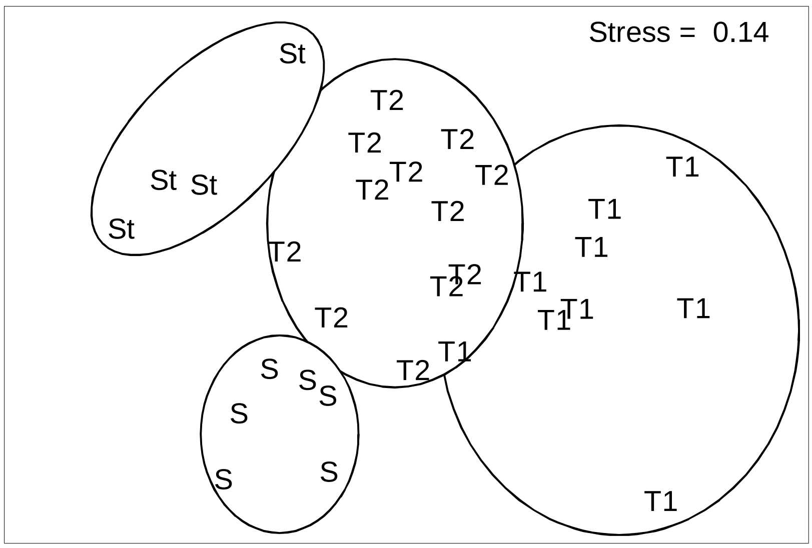

Fig. 5. MDS ordination plot showing dissimilarity of bycatches taken in trap (T1 = time 1; T2 = time 2) and stow nets (St) and seines (S) in Lake Illawarra.

Table 2. Results of SIMPER analysis showing the top 10 bycatch species that contributed greatest to the similarity matrix among samples for each gear type. The mean abundance, average similarity, ratio of similarity/standard deviation and percent contribution to the similarity measure is given.

Species	Common name	Mean abundance	Average similarity	ratio sim/stdev	Percent contribution	Cumulative contribution
Trap net - time 1: average similarity 36.71						
Hyporhamphus regularis	River garfish	10.89	11.32	1.04	30.84	30.84
Gerres subfasciatus	Silver biddy	15.33	7.72	1.02	21.01	51.86
Dicotylichthys punctulatus	Porcupinefish	6.00	3.90	0.92	10.62	62.48
Synaptura nigra	Balck sole	3.00	3.52	1.87	9.60	72.08
Rhabdosargus sarba	Tarwhine	2.22	1.44	0.88	3.93	76.01
Sillago ciliata	Sand Whiting	1.33	1.39	0.90	3.79	79.80
Arothron hispidus	Toad	2.22	1.31	0.53	3.57	83.37
Centropogon australis	Fortescue	1.78	1.28	0.71	3.48	86.85
Platycephalus fuscus	Dusky flathead	1.11	1.01	0.68	2.76	89.61
Herklotsichthys castelnaui	Southern Herring	2.11	0.78	0.34	2.12	91.73
Trap net - time 2: average similarity 39.51						
Centropogon australis	Fortescue	12.25	11.27	1.6	28.54	28.54
Gerres subfasciatus	Silver biddy	17.67	6.77	1.82	17.13	45.67
Portunus pelagicus	Blue swimmer crab	9.33	4.96	1.02	12.54	58.21
Loligo sp.	Squid	12.42	2.81	0.71	7.12	65.33
Hyporhamphus regularis	River garfish	9.17	2.58	0.75	6.53	71.86
Pomatomus saltatrix	Tailor	7.08	2.49	0.76	6.31	78.16
Pelates sexlineatus	Six-lined trumpeter	4.42	2.39	1.56	6.06	84.22
Sillago ciliata	Sand whiting	3.92	1.20	0.65	3.05	87.27
Herklotsichthys castelnaui	Southern herring	3.50	1.13	0.88	2.87	90.14
Dicotylichthys punctulatus	Porcupine fish	3.58	1.05	0.56	2.65	92.79
Stow net: average similarity 46.72						
Centropogon australis	Fortescue	83.00	22.66	3.29	48.49	48.49
Pomatomus saltatrix	Tailor	57.75	7.12	1.18	15.24	63.73
Portunus pelagicus	Blue swimmer crab	26.25	5.03	0.96	10.76	74.49
Loligo sp.	Squid	36.75	4.92	1.46	10.53	85.02
Achoerodus viridis	Blue groper	15.75	2.21	2.52	4.74	89.76
Hyperlophus vittatus	Sandy sprat	4.75	0.66	0.81	1.41	91.17
Anguilla sp.	River eel	7.25	0.51	0.41	1.10	92.26
Gerres subfasciatus	Silver biddy	5.75	0.45	0.82	0.96	93.22
Ambassis marianus	Perchlet	2.00	0.43	2.34	0.92	94.14
Atypichthys strigatus	Mado	1.75	0.40	0.79	0.86	95.00
Seine net: average similarity 45.53						
Gerres subfasciatus	Silver biddy	77.67	11.41	1.27	25.07	25.07
Portunus pelagicus	Blue swimmer crab	27.67	7.98	2.28	17.53	42.60
Acanthopagrus australis	Bream	30.33	6.01	1.54	13.21	55.81
Sillago maculata	Trumpeter whiting	26.83	3.84	1.19	8.44	64.25
Pomatomus saltatrix	Tailor	10.50	3.45	1.67	7.59	71.83
Rhabdosargus sarba	Tarwhine	13.83	3.35	1.16	7.35	79.18
Loligo sp.	Squid	19.17	3.13	1.16	6.87	86.05
Pagrus auratus	Snapper	11.50	2.36	1.45	5.19	91.24
Pelates sexlineatus	Six-lined trumpeter	15.00	2.28	0.91	5.01	96.25
Arenigobius bifrenatus	Bridled goby	11.33	0.51	0.40	1.13	97.38

Table 3. Estimated total penaeid catches and bycatches taken by all fishers using each gear type throughout the 1999/2000 fishing season and the percentage contribution of the ten most numerous bycatch species to the estimated total bycatch of all gears combined. Number is given except where noted.

	Trap net time 1		Trap net time 2		Stow net		Seine net		Total	% total bycatch
	Total	SE	Total	SE	Total	SE	Total	SE		
Penaeid weight (kg)	1551	(579)	23891	(6087)	1562	(741)	3872	(823)	30876	
Bycatch weight (kg)	588	(146)	1922	(528)	148	(59)	979	(170)	3636	
Gerres subfasciatus	1656	(848)	5530	(2081)	63	(39)	7456	(3061)	14705	22.4
Loligo spp.	12	(12)	3886	(2498)	404	(214)	1840	(720)	6143	9.4
Portunus pelagicus	132	(69)	2921	(650)	289	(98)	2656	(486)	5998	9.2
Centropogon australis	192	(62)	3834	(516)	913	(204)	16	(16)	4955	7.6
Hyporhamphus regularis	1176	(260)	2869	(1090)	25	(12)	0	(0)	4070	6.2
Pomatomus saltatrix	72	(60)	2217	(892)	635	(315)	1008	(160)	3932	6.0
Acanthopagrus australis	72	(36)	496	(229)	0	(0)	2912	(1059)	3480	5.3
Sillago maculata	84	(35)	261	(184)	0	(0)	2576	(1087)	2921	4.5
Pelates quadrilineatus	72	(40)	1382	(460)	3	(3)	1440	(513)	2897	4.4
Rhabdosargus sarba	240	(100)	991	(353)	0	(0)	1328	(356)	2559	3.9
Dicotylichthys punctulatus	648	(223)	1122	(506)	0	(0)	128	(110)	1898	2.9
Sillago ciliata	144	(40)	1226	(460)	0	(0)	336	(243)	1706	2.6
Pagrus auratus	36	(25)	339	(136)	14	(5)	1104	(481)	1493	2.3
Herklotsichthys castelnaui	228	(107)	1096	(519)	0	(0)	0	(0)	1324	2.0
Arenigobius bifrenatus	12	(12)	0	(0)	0	(0)	1088	(720)	1100	1.7
Total remaining 42 species	1236		3087		638		1392		6344	9.7
Total all species	6012	(1488)	31248	(6855)	2984	(1087)	25280	(5903)	65524	

Discussion

This study has demonstrated considerable variability in the compositions and quantities of catches by stow and trap nets and seines used to target penaeids in the Lake Illawarra fishery. The observed differences were most likely due to a combination of several factors that included (1) variations in the behaviors, life histories and temporal and spatial abundances of the key species (Ruello 1973a,b; Young and Carpenter 1977; Coles and Greenwood 1983; Gray et al. 1990; Montgomery 1990; Wassenberg and Hill 1994; Gray 2001) and (2) gear-specific selection mechanisms (Broadhurst et al. 2004, Macbeth et al. 2005a,b,c).

Each of the three gears used in Lake Illawarra are designed to exploit key behavioral characteristics of the targeted penaeids. Specifically, trap and stow nets are primarily used to target juvenile *P. plebejus*, which generally remain buried in the substratum during the day and then become active at night, especially between the last and first quarter phases of the moon; either moving around the shallow vegetated edges of the lake or migrating to sea (Ruello 1975; Montgomery 1990). In contrast, seines are used in Lake Illawarra to mostly target *M. macleayi*, which also undertake estuarine-oceanic migrations, but tend to occur across deeper, non-vegetated habitats and are generally more active during the day (Ruello 1973a,b). Unlike static trap and stow nets, which are used in shallow near-shore areas and rely on strategic tide- and wind-generated currents to passively direct catches into the bunt or codend, seines are actively towed and considerably less restrictive in terms of where they are fished.

The different spatial and temporal deployment of the three gears largely explains the observed biases in the compositions of *P. plebejus* by trap and stow nets (> 60%) and *M. macleayi* by seines (> 65%), but not the variations in the retained sizes of these individuals. Despite having a considerably smaller mesh size (i.e. 25 vs. 30 mm), trap nets retained a significantly larger mean size of *P. plebejus* and *M. macleayi* than stow nets and seines, respectively. Broadhurst et al. (2004) discussed similar gear-specific differences in size selection between trap nets and larger-meshed seines and trawls and attributed their superior size selection to operational characteristics and associated mechanisms. In particular, the method of retrieving the trap net by hauling the headline and foot rope into a dory effectively spreads large (> 2m) transverse sections of the netting and so maximizes lateral mesh openings at a point where the catch is dispersed and being rolled towards the bunt (see also Broadhurst et al. 2004). This process ensures that all organisms repeatedly encounter openings and have numerous opportunities to be selected. In contrast, selection in funnel-shaped gears like seines and stow nets often occurs in the posterior body and/or codend, where mesh openings are mostly orientated parallel to the movement of catch and frequently narrow in proportion to the mesh size (Broadhurst et al. 2004; Macbeth et al. 2005a,b,c). These characteristics can limit the probability of small organisms escaping from such gears.

Differences in the selection mechanisms and temporal and spatial deployment of the 3 gears would have also contributed towards their significantly divergent assemblages of bycatch. For example, many of the discriminating species caught in relatively large abundances in seines, including *G. subfasciatus*, *S. maculata*, *A. australis* and *P. auratus*, are capable swimmers, often occurring in schools and were probably easily herded into the codend of the towed seine by the long hauling ropes (140 m) and wings (70 m). Further, because seines were used during the day, the hauling ropes and wings would have been quite visible and this probably contributed towards the capture of schooling fish (Wardle 1983). In contrast, many fast-swimming fish would have been able to actively avoid the static trap and stow nets; the catches of which included relatively greater abundances of slower-swimming benthic species such as *C. australis*, *Dicotylichthys punctulatus* (Diodontidae), and *Synaptura nigra* (Soleidae). While selection mechanisms may explain some of the variations in catch structures, it is likely that differences in the preferred habitats of many species, including *H. regularis* and *Loligo* sp., contributed towards the observed variations in their abundances. Previous studies have established that the compositions and quantities of bycatches taken in penaeid fisheries can vary considerably over a range of short- and long-term spatial and temporal scales (Gray et al. 1990; Ramm et al. 1990; Liggins et al. 1996; Kennelly et al. 1998; Gray et al. 2003). As one example, Gray et al. (1990) and Gray (2001) observed that simple differences in habitat type and distance from the estuary mouth considerably influenced the bycatch composition of similar penaeid-catching gears.

The overall penaeid-to-bycatch ratios observed here were less than 1:1, except for the trap net during time 1 when very few penaeids were caught. In general, these ratios are considerably less than those reported for penaeid-trawl fisheries overseas (typically between 1:5-10; Andrew and Pepperell 1992) and in other NSW estuaries (1:0.45-3.5; Liggins et al. 1996). Further, the observed ratios for stow nets and seines were comparable or less than those recorded for similar gears fished in the Clarence River (1:0.38; Andrew et al. 1995) and Tuggerah Lake (<1:1, Gray 2001; Gray et al. 2003), respectively. All gears were characterized by considerable variation in penaeid-to-bycatch ratios, but especially trap nets which varied by an order of 10 between the two periods sampled. Moreover, considerable variation was observed between individual trips and deployments within trips. Other studies have demonstrated substantial temporal and spatial variations in targeted catch-to-bycatch ratios (Rothschild and Brunenmeister 1984; Liggins et al. 1996; Chavez 1992; Ye 2002) and such variability needs to be considered when comparing ratios between fisheries that are based on studies done at different places and times.

Although the survival rates of bycatch were not quantified here, many individuals from the trap and stow nets appeared to be in relatively good condition after sorting, which is in general agreement with observations made by Andrew et al. (1996) for stow nets used in the Clarence River and most likely a consequence of the passive fishing method and relatively short deployment periods. This observation, combined with the relatively low total bycatches by these gears (i.e. total of 2,658 kg), suggests that discarding of non-target individuals probably had minimal impact on their population levels. Conversely, most of the bycatch from seining (a total of 979 kg) appeared to be in a relatively poorer condition after sorting, and a large proportion was consumed by birds that followed the fishing dories during the day. Additional data on the survival rates of bycatches taken in the different gears, and according to different sorting techniques, are required to ascertain the actual impacts of discarding from these fishing gears (Andrew and Pepperell 1992; Jennings and Kaiser 1998).

Bycatch reduction is a common goal of many fisheries and conservation agencies. Various bycatch reduction devices (BRD's) inserted in the codends of penaeid-trawl nets have proven to be very effective in reducing the types and quantities of unwanted catches (see review by Broadhurst 2000). More recently, simple modifications to the configurations and sizes of mesh in codends have been demonstrated to significantly improve species and size selection in some seines and stow nets (Macbeth et al. 2005a,b,c). For example, compared to conventional codends made from 30-mm diamond-shaped mesh, designs constructed entirely of square-shaped mesh (between 20 to 30 mm hung on the bar) have reduced the bycatches of small fishes from some of NSW's estuarine seines and stow nets by up to 95% (Macbeth et al. 2005a,b,c). Assuming the majority of organisms escaping from such designs actually survive the process (Broadhurst et al.1997), their wide scale introduction should positively benefit stocks of these species (Chopin and Arimoto 1995).

On-going research is needed to determine the potential for simple modifications like BRDs to conventional penaeid-catching gears to reduce the fishing mortality of non-target organisms. Some assessment of the relative impacts of these different gears on the substratum and non-retained fauna and flora is also required. This information, combined with quantitative estimates of catches and bycatches across similar spatial and temporal scales like those presented here, will facilitate assessment of the most ecologically-appropriate fishing methods for the continued harvesting of penaeids in estuaries.

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