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Influences of hanging ratio, fishing height, twine diameter and material of bottom-set gillnets on catches of dusky flathead *Platycephalus fuscus* and non-target species in New South Wales, Australia

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ABSTRACT: Three experiments were done to test for the influences of different (i) hanging ratios (E = 0.5, 0.65 and 0.8); (ii) fishing heights (25 and 12 meshes); and (iii) twine diameters (0.41, 0.56 and 0.62 mm) and materials (multifilament nylon and multimonofilament nylon polyamide) on catches and by-catches in the estuarine gillnet fishery for *Platycephalus fuscus* in New South Wales, Australia. In each experiment, the various 100-m treatment panels comprising 80-mm (nominal) mesh rigged according to the different configurations being examined were configured in a single gang between 1090 and 1310 m in length, and fished according to commercial practices. The results showed no significant differences between different hanging ratios or twine diameters for the numbers, weights and size compositions of catches and by-catches. Twine material had an effect on only one key by-catch species (*Acanthopagrus australis*), with fewer caught in panels made from multifilament nylon compared with multimonofilament nylon. In contrast to the above modifications, lowering the fishing height of the floatline significantly reduced total by-catch by up to 46% and the individuals of key by-catch species (*Mugil cephalus*, *A. australis* and *Girella tricuspidata*) by between 60 and 85% with no effect on catches of targeted *P. fuscus*, or legally retained byproduct, *Portunus pelagicus*. The results are used to provide directions for the future management of this fishery and have relevance to other similar bottom-set gillnet fisheries.

KEY WORDS: **by-catch reduction, commercial fishery, discard, gillnet, Platycephalidae.**

INTRODUCTION

During the past two decades, considerable research has been done to reduce non-target catches (by-catch[1,2]) in many of the world's fisheries. Most of this work has concentrated on towed gears such as demersal trawls, dredges and seines, and involved the testing of alternate mesh arrangements and physical modifications comprising various types of sorting grids and escape panels. These by-catch reduction devices are designed to exclude by-catch while maintaining target catches at existing levels.[3,4] Less attention has been directed towards reducing by-catch in fisheries that use static gears, such as gillnets. Further, of the relevant studies that have been done, most have concentrated on the incidental capture of marine mammals and seabirds.[5–7] However, as with towed gears, the discarding of small fish and particularly juveniles of important species is also considered problematic in many fisheries that use gillnets.[8–14] Specifically, concern over the potential for large fishing mortalities of important species has led to significant pressure on management agencies and commercial fishing industries to mitigate against discard and wastage in such fisheries.

Gillnets are used to harvest many species of fish in coastal areas throughout the world.[9,15–21] It is well-established that these gears are selective for particular sizes and species, although this depends on several biotic factors,[22–28] including the morphology, behavior and vertical and horizontal distribution of fish, and abiotic factors[22,26–33] that include twine diameter and material, and size and hanging ratio of meshes. The development of more selective fishing gears requires an understanding of the effects of such technical factors on catchabil-

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ity of target and non-target species.[1,4,22,26] Most research concerning the effects of these factors on selectivity has been done to maximize catches of the targeted species. Few studies have investigated simple changes to the technical aspects of gillnets (other than mesh size) as a tool for mitigating against by-catch.[34]

In this study, the influence of some of these technical factors on bottom-set gillnets used to target dusky flathead, *Platycephalus fuscus* (Pisces: Platycephalidae) in New South Wales (NSW), Australia, are examined. At present, commercial *P. fuscus* gillnetters are permitted to fish in four marine-dominated barrier estuaries (also termed coastal lagoons) (Wallis, Smiths, Tuggerah and Illawarra Lakes) in NSW.[11,35] This fishery accounts for approximately 40% of reported commercial landings of *P. fuscus* in NSW (200 t valued at AUD$0.7 million/year). Current regulations specify that *P. fuscus* gillnets must have a mesh size of 70–80 mm (diagonal stretched mesh opening), a maximum depth of 25 meshes and constructed so that the floatline is positioned less than 0.5 m above the bottom. The length of any individual gillnet or combination of gillnets set by a fisher at any one time must not exceed 1450 m. Typically, the nominal twine thickness and material of nets is either 0.62 mm diameter multifilament nylon polyamide (PA) or 0.41 mm diameter multimonofilament (8 strand) nylon PA netting. Gillnets can be set overnight between February and November in Wallis and Tuggerah Lakes and between May and August in Smiths and Illawarra Lakes. Fishers are not permitted to retain any other species, except legal-sized blue swimmer (*Portunus pelagicus*) and mud crabs (*Scylla serrata*).

An observer-based survey identified that the discarding of undersized *P. fuscus* and *P. pelagicus* and several species (e.g. *Mugil cephalus*, *Acanthopagrus australis* and *Girella tricuspidate*) important in other fisheries had the potential to decrease stocks.[11] Because of specific concerns over the stock status of *P. fuscus*,[35] management and industry recently agreed to increase the minimum legal length of the target species from 33 to 36 cm total length (TL), and concomitantly increase the minimum mesh size of gillnets from 70 to 80 mm. The larger mesh should alleviate some of the fishing mortality of conspecifics and some small individuals comprising by-catch, but because nearly all of the key unwanted species are represented by wide ranges of sizes across the same areas as *P. fuscus*, their absolute numbers in by-catches will remain similar.[10,36] Alterations to other technical aspects of the gears are a simple option that might facilitate a reduction in their fishing mortality on stocks. Therefore, in this study, the effects of altering the hanging ratio, fishing height and twine material on catches and by-catches in this fishery were tested.

MATERIALS AND METHODS

Three experiments were done between September 2001 and June 2003 in Wallis Lake, Tuggerah Lake and Lake Illawarra (Fig. 1) to test the effects of (i) hanging ratio; (ii) fishing height of net; and (iii) mesh material and twine diameter on the catches of bottom-set gillnets. All gillnets (Table 1) were configured from 100-m treatment panels of light colored 80-mm (nominal) mesh made of nylon PA (Double Diamond Nets, Sydney, Australia) arranged in a single gang between 1090 m and 1310 m long (Fig. 2a). Mesh size was determined by measuring the inside distance between opposing knots of 20 randomly selected openings using calipers and light manual force to stretch the mesh (Table 1). Each replicate panel was randomly positioned throughout the gang on a set-by-set basis

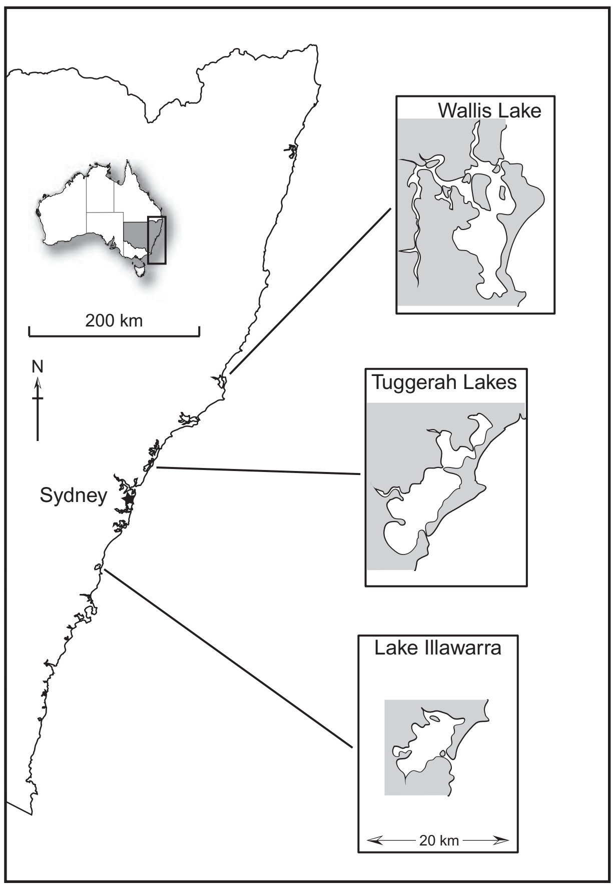

Fig. 1 Map of the coastline of New South Wales showing the location of the 3 estuaries where sampling occurred.

Table 1 Technical specifications of the experimental gillnets used in the three experiments

Experiment	Mesh opening (mm; mean ± SD)	Hanging ratio	Height of net	Mesh material & thickness	No of experimental treatments	No of replicate experimental panels	Experimental panel length	Space between panels	Total net length
Exp 1 – hanging ratio	81.00 ± 0.21 mm	E = 0.5, 0.65, 0.8	20 meshes	multimonofilament nylon (0.5 × 8 strand), 0.41 mm ø	3	4	100 m	10 m	1310 m
Exp 2 – net height	81.00 ± 0.21 mm	E = 0.5	12, 25 meshes	multimonofilament nylon (0.5 × 8 strand), 0.41 mm ø	2	5	100 m	10 m	1090 m
Exp 3 – twine diameter & material	a, 81.00 ± 0.21 mm	E = 0.5	12 meshes	a. multimonofilament nylon (8 strand), 0.41 mm ø	3	4	100 m	10 m	1310 m
	b, 80.75 ± 0.14 mm			b. multifilament nylon (210/4), 0.56 mm ø					
	c, 79.85 ± 0.21 mm			c. multifilament nylon (210/6), 0.62 mm ø					

to minimize (i) potential experimental artifacts caused by panel placement; (ii) edge effects from potential variation in catch efficiency and selectivity due to changes in net geometry adjacent to anchors; and (iii) the effects of variable distributions of fish. To maintain independence among treatment panels, each panel was separated by 10-m lines (Fig. 2a). Each panel was attached to a 6 mm diameter polyethylene floatline and leadline rigged with 31 (60 × 33.5 mm cylinder) floats and 45 (50 g cylinder) weights, respectively.

This general gillnet configuration was set from chartered commercial vessels (or from a 5.5 m research vessel of similar dimensions to those operated by commercial fishers) in a straight line along the bottom at commercial fishing locations in each estuary 1 h prior to sunset and left to fish overnight before being retrieved at sunrise, as per current commercial fishing regulations. Soak times varied between experiments according to the month when each experiment took place. The direction of set and retrieval depended on the prevailing wind direction, with setting always completed within 20 mins, but retrieval taking up to 2 h.

Experiment 1: comparison of three hanging ratios

Hanging ratio (E) is defined as the length of a rope on which a net panel is mounted divided by the actual length of stretched netting on the rope.[37] The hanging ratio of a gillnet is one of the most important factors affecting catches.[22,26,27] At low hanging ratios, meshes have narrow openings that can easily entangle fish across a wide range of sizes. In contrast, at large hanging ratios the mesh height is lowered and the lateral opening increased, effectively increasing the probability of fish being gilled across a defined size range. Because *P. fuscus* has a flattened anterior morphology with numerous discontinuities, increasing the hanging ratio from 0.5 (that normally used by commercial fishers) to 0.65 and 0.8 was not expected to affect their catches, but reduce the entangling of those more fusiform and laterally compressed species comprising by-catch (e.g. *M. cephalus*, *A. australis* and *G. tricuspidata*).

Four replicate 100-m panels of each of three hanging ratios (E = 0.50, 0.65, and 0.8) were fished simultaneously in a 1310-m gang (Fig. 2a). All panels were constructed according to conventional practices and comprised 0.41 mm diameter multi-monofilament (8 strand) nylon PA mesh, 20 meshes in depth. The number of transversal meshes per 100-m panel were 50 000 (E = 0.5),

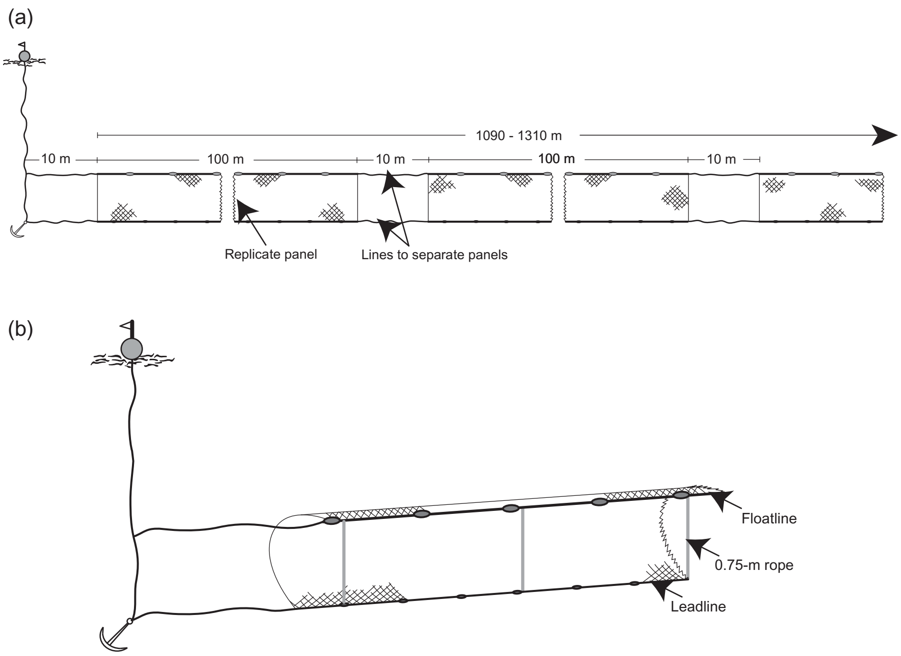

Fig. 2 Diagrammatic representation of (a) the fleet of gillnets and experimental panels, and (b) method for securing the floatline to the footrope in the experiment comparing different hanging ratios.

38 400 (E = 0.65) and 31 200 (E = 0.8). To eliminate potential confounding of treatment panels due to differences in the fishing heights of nets with the same mesh depth as conventional nets, but different hanging ratios, a 0.75 m length of twine (0.72 mm diameter nylon PA) was secured between the floatline and leadline at each cork and the end of each panel to ensure a maximum fishing height of 0.75 m (Fig. 2b). Underwater observations revealed that this was the maximum fishing height of 20 meshes of 80-mm mesh hung at E = 0.8. Differences in the slackness of nets of each treatment were not observed. Eleven replicate nights of fishing were done at Tuggerah Lake during February 2001. Nets were set on sunset (20:00 h) and retrieved at sunrise (06:00 h), thus having a soak time of 10 h.

Experiment 2: comparison of two fishing heights

In a previous study,[36] significant species-specific differences in the vertical distributions of catches in bottom-set gillnets were observed, with *P. fuscus* mainly caught in the lower section. Reducing the fishing height of conventional nets (hung at E = 0.5) by 50% from the maximum 25 meshes (approximately 1.7 m) currently permitted in the fishery to 12 meshes (approximately 0.8 m) was not expected to affect catches of *P. fuscus*, but reduce the by-catch of species that orient higher in the water column.

Five replicate 100-m panels of each of these two different mesh heights were fished simultaneously in a 1090-m gang. The total number of meshes per panel was 30 000 (12 meshes) and 62 500 (25 meshes). All nets were made from 0.41 mm diameter (ø) multimonofilament (8 strand) nylon PA mesh. A total of 16 replicate nightly sets of the experimental gillnet was completed in three estuaries (seven nights in Wallis Lake during October 2001 and four and four nights in Tuggerah Lake and Lake Illawarra, respectively, during September 2001). Nets were set on sunset (19:00 h) and retrieved at sunrise (06:00 h), thus having a soak time of 11 h.

Experiment 3: comparison of twine diameter and material

The diameter and material of twine can influence visibility, elasticity and flexibility, and therefore the efficiency of gillnets.[33] Because multifilament nylon panels are more visible, it was expected they would catch less fish than multimonofilament nylon PA panels, and that 0.62 mm ø multifilament (210 D/6) would catch less than 0.56 mm ø multifilament (210 D/4) nylon PA netting.

This experiment involved a comparison of three gears constructed from 0.56 mm and 0.62 mm ø multifilament nylon PA and 0.41 mm ø multimonofilament (8 strand) nylon PA netting, respectively. Four replicate panels of each treatment were set in a gang that totaled 1310 m in length. The 0.62 mm multifilament nylon PA and the 0.41 mm multimonofilament (8 strand) netting are the same materials as those currently primarily used in the commercial fishery, as determined by interviews with industry. All experimental panels had a height of 12 meshes (based on results from experiment 2), and a hanging ratio E = 0.5. This experiment was done over 8 days in Tuggerah Lake and 3 days in Wallis Lake during May and June 2003. Nets were set on sunset (18:00 h) and retrieved at sunrise (07:00 h), thus having a soak time of 13 h.

Data collection and analysis

Data collected from each treatment panel in each experiment included: (i) the total number and weight of catch; (ii) the total number of species; (iii) the retained and discarded numbers and weights of individual species; and (iv) the TL (± 0.5 cm) of key species (except *Portunus pelagicus*, which was not measured). Analyses of variance (ANOVA) were used to test for differences in variables among treatments in each experiment. Data were standardized to catch per 100 m panel (CPUE). Days fished, and estuary (where applicable), were included in each analysis to test for consistency of treatment effects across space and time.[38] Prior to analysis, data were transformed by $\ln(x+1)$ to account for multiplicative treatment effects[32] and tested for heteroscedascity using Cochran's test. Data sets showing heteroscedascity were analyzed at significance levels of $P = 0.01$ in the ANOVA to counteract the increased probability of Type 1 error.[38] Comparison of the length compositions of key fish species caught in the different treatment nets was used to assess the relative selectivity of nets within each experiment. Owing to lack of replication across different spatial and temporal scales, relative selectivity of nets was not compared between experiments.

RESULTS

Experiment 1: comparison of three hanging ratios

The mean numbers and weights of key fish species CPUE for each experimental hanging ratio are summarized in Table 2. While there was general

Table 2 Mean numbers and weights of key species (*Platycephalus fuscus*, *Portunus pelagicus*, *Mugil cephalus*, *Acanthopagrus australis*, *Girella tricuspidata*, *Synaptura nigra*, *Pseudorhombus jenynsii*) caught per 100-m experimental treatment panel of gillnets with 3 different hanging ratios

	Hanging ratio		
	E = 0.5	E = 0.65	E = 0.8
Number per 100 m			
P. fuscus (legal)	4.64 (0.50)	3.43 (0.42)	3.14 (0.31)
P. fuscus (undersize)	0.14 (0.05)	0.20 (0.07)	0.07 (0.04)
Po. pelagicus (legal)	6.11 (1.15)	3.91 (0.67)	3.00 (0.53)
Po. pelagicus (undersize)	3.66 (0.93)	2.77 (0.66)	2.02 (0.62)
M. cephalus	5.50 (1.43)	6.57 (1.60)	5.70 (1.35)
A. australis	2.50 (0.39)	2.68 (0.54)	2.57 (0.53)
G. tricuspidata	8.93 (2.46)	7.52 (1.82)	9.05 (2.46)
S. nigra	2.00 (0.41)	1.05 (0.30)	1.14 (0.31)
P. jenynsii	1.55 (0.29)	0.70 (0.17)	0.89 (0.24)
Total individuals	38.52 (3.47)	32.18 (2.78)	30.05 (2.98)
Number of species	6.61 (0.34)	6.57 (0.33)	6.00 (0.25)
Weight per 100 m			
P. fuscus (legal)	3.52 (0.39)	2.85 (0.37)	2.41 (0.25)
P. fuscus (undersize)	0.02 (0.01)	0.04 (0.01)	0.01 (0.01)
Po. pelagicus (legal)	1.35 (0.26)	0.92 (0.15)	0.70 (0.12)
Po. pelagicus (undersize)	0.57 (0.16)	0.34 (0.07)	0.27 (0.08)
M. cephalus	3.54 (1.11)	4.12 (1.17)	3.44 (0.91)
A. australis	0.49 (0.08)	0.56 (0.12)	0.51 (0.10)
G. tricuspidata	3.62 (1.03)	2.96 (0.73)	3.44 (0.95)
S. nigra	0.35 (0.07)	0.22 (0.08)	0.19 (0.06)
P. jenynsii	0.18 (0.04)	0.07 (0.02)	0.10 (0.03)
Total weight	14.97 (1.66)	13.26 (1.53)	11.95 (1.37)

Standard error in parentheses.

Table 3 *F*-values and significance from ANOVA comparing catches of key species (*Platycephalus fuscus, Portunus pelagicus, Mugil cephalus, Acanthopagrus australis, Girella tricuspidata, Pseudorhombus jenynsii, Synaptura nigra*) in each of the 3 treatments of hanging ratio across the 11 sampling days

Factor	Day	HR	Day*HR	Error
Degrees of freedom	10	2	20	99
P. fuscus (legal)[a]	0.78*	0.82	0.50	0.37
P. fuscus (undersize)[a]	0.09*	0.09	0.04	0.06
Po. pelagicus (legal)[a]	4.30**	2.12*	0.50	0.74
Po. pelagicus (undersize)[a]	7.51	0.88	0.47	0.44
A. australis[a]	3.88**	0.17	0.61	0.39
M. cephalus[a]	4.47**	0.24	0.68	0.95
G. tricuspidata[a]	13.94**	0.48	0.51	0.90
P. jenynsii[a]	0.98**	1.06	0.38	0.34
S. nigra[a]	1.28**	1.15	0.46	0.42
Total number[a]	2.99**	0.76	0.23	0.19
Total species[a]	0.33**	0.06	0.05	0.06
Weight				
P. fuscus (legal)[a]	0.58	0.53	0.44	0.33
P. fuscus (undersize)[a]	0.01	0.00	0.00	0.00
Po. pelagicus (legal)[a]	1.33**	0.63*	0.16	0.17
Po. pelagicus (undersize)[a]	0.93**	0.20	0.08	0.07
A. australis[a]	0.68**	0.00	0.14*	0.08
M. cephalus[a]	3.39**	0.18	0.47	0.72
G. tricuspidata[a]	8.68**	0.10	0.00	0.44
P. jenynsii[a]	0.03	0.09	0.16	0.02
S. nigra[a]	0.12	0.18	0.09	0.07
Total weight[a]	3.15**	0.29	0.26	0.22

HR denotes hanging ratio; data transformed to $\ln(x + 1)$ prior to analysis; a denotes variances homogeneous after transformation ($P > 0.05$). Significant at $^*P < 0.05$, $^{**}P < 0.01$.

reduction in mean total catch associated with increasing hanging ratio, this was not significant. The only variable to show a significant effect of hanging ratio was legal-sized *P. pelagicus*, which were caught in greater quantities in panels with E = 0.5 (Tables 2,3). Catches of most species were significantly different among days (Table 3). There were no significant interactions between days and hanging ratio, indicating that the effect of the latter was consistent across the sampling period. The length compositions of *P. fuscus*, *A. australis*, *M. cephalus*, *G. tricuspidata* were similar among the panels with different hanging ratios, indicating that there was no difference in the relative size selectivity of the different configured nets on these species (Fig. 3). The data show that the 80 mm mesh predominantly caught legal-sized (>36 cm TL) *P. fuscus*.

Experiment 2: comparison of two fishing heights

There was no significant effect of fishing height on catches of the target species, but there were significant reductions in total catch (42–46% by weight and 38–43% by number), the numbers of total species and *M. cephalus*, *A. australis* and *G. tricuspidata* and the weight of *M. cephalus* and *A. australis* in panels that were 12 meshes high (Tables 4,5). Several variables were significantly different among days and estuaries (Table 5). While significant interactions were detected between fishing height and estuary for the number of *A. australis* and catches of *M. cephalus* and between fishing height and days for the weight of *G. tricuspidata*, the means of these interactions followed a similar trend of lower catches in the panels made from 12 meshes (Table 4). The observed mean reductions in *G. tricuspidata* and *A. australis* were not due to particular length classes, with similar size compositions of catches recorded in panels of both height in Tuggerah Lake and Lake Illawarra (Fig. 4). Similarly, both treatment panels caught the same cohort of *P. fuscus* (Fig. 4). Catches were generally low in Wallis Lake and are not presented.

Experiment 3: comparison of twine diameter and material

There were no significant differences in catches between the multifilament nylon panels made from 0.56 mm and 0.62 mm ø netting (Tables 6,7)

Table 4 Mean numbers and weights of catches per 100 m in gillnets of 12 and 25 meshes deep in each of three study estuaries

Estuary	Tuggerah		Illawarra		Wallis	
Net height (no. meshes)	12	25	12	25	12	25
Number per 100 m						
P. fuscus (legal)	0.52 (0.14)	0.28 (0.11)	0.45 (0.15)	1.70 (0.74)	1.00 (0.23)	1.66 (0.21)
P. fuscus (undersize)	0.04 (0.04)	0.24 (0.13)	0.10 (.07)	0.00 (0.0)	0.09 (0.05)	0.09 (0.05)
P. pelagicus (legal)	1.48 (0.37)	0.84 (0.27)	1.50 (0.63)	3.20 (1.67)	1.94 (0.44)	2.80 (0.54)
P. pelagicus (undersize)	1.28 (0.47)	0.88 (0.33)	1.85 (0.94)	2.05 (1.31)	2.00 (0.53)	2.37 (0.59)
M. cephalus	4.28 (1.16)	13.12 (3.07)	0.95 (0.34)	2.70 (0.80)	0.00 (0.00)	0.00 (0.00)
A. australis	9.80 (2.00)	12.6 (2.95)	4.15 (0.80)	4.40 (0.82)	0.46 (0.12)	3.25 (0.53)
G. tricuspidata	7.92 (1.52)	12.44 (2.32)	17.15 (6.99)	27.75 (8.42)	0.43 (0.15)	1.03 (0.24)
Total number	27.36 (2.87)	44.48 (4.37)	28.75 (8.11)	46.20 (11.43)	7.47 (0.91)	13.11 (1.15)
Number of species	5.36 (0.32)	5.92 (0.49)	4.45 (0.37)	5.90 (0.32)	3.03 (0.23)	4.63 (0.21)
Weight per 100 m						
P. fuscus (legal)	0.33 (0.10)	0.15 (0.06)	0.32 (0.14)	0.925 (0.45)	0.60 (0.15)	0.96 (0.12)
P. fuscus (undersize)	0.01 (0.01)	0.06 (0.03)	0.02 (0.01)	0.00 (0.00)	0.02 (0.01)	0.02 (0.01)
P. pelagicus (legal)	0.34 (0.14)	0.19 (0.06)	0.34 (0.14)	0.62 (0.33)	0.49 (0.11)	0.76 (0.14)
P. pelagicus (undersize)	0.18 (0.06)	0.12 (0.05)	0.18 (0.08)	0.22 (0.14)	0.27 (0.07)	0.35 (0.09)
M. cephalus	2.03 (0.55)	5.98 (1.37)	0.43 (0.15)	1.29 (0.38)	0.00 (0.00)	0.00 (0.00)
A. australis	1.86 (0.37)	2.35 (0.55)	0.77 (0.15)	0.84 (0.15)	0.10 (0.03)	0.76 (0.14)
G. tricuspidata	2.36 (0.46)	4.09 (0.83)	5.09 (2.06)	8.77 (2.83)	0.15 (0.05)	0.34 (0.08)
Total weight	7.83 (0.85)	14.53 (1.66)	7.64 (2.24)	13.65 (3.54)	2.38 (0.26)	4.18 (0.35)

Standard error in parentheses. Species: *Platycephalus fuscus, Portunus pelagicus, Mugil cephalus, Acanthopagrus australis, Girella tricuspidata.*

Table 5 *F*-values and significance from ANOVA comparing catches in gillnets 12 and 25 meshes deep across three estuaries and four sampling days in each estuary

Factor	Estuary	Day	Height	E*H	D*H	Error
Degrees of freedom	2	3	1	2	3	96
Number per 100 m						
P. fuscus (legal)[a]	2.43**	0.17	0.97	0.53	0.22	0.30
P. fuscus (undersize)[b]	0.03	0.05	0.04	0.08	0.07	0.05
P. pelagicus (legal)[a]	0.80	3.64**	0.00	0.08	0.25	0.22
P. pelagicus (undersize)[b]	1.41	2.62**	0.00	0.03	0.17	0.26
A. australis[a]	15.13	4.31**	2.64*	2.46*	0.39	0.62
M. cephalus[b]	20.86**	1.31**	8.44**	2.85**	0.35	0.26
G. tricuspidata[a]	46.18*	9.69**	5.36**	0.42	0.29	0.29
Total number[a]	18.51*	4.05**	8.26**	0.18	0.21	0.28
Total species[a]	1.25*	0.29**	1.80**	0.21	0.14	0.10
Weight per 100 m						
P. fuscus (legal)[b]	1.33**	0.14	0.26	0.21	0.14	0.18
P. fuscus (undersize)[b]	0.00	0.01	0.01	0.01	0.01	0.00
P. pelagicus (legal)[a]	0.80	3.64**	0.27	0.23	0.15	0.22
P. pelagicus (undersize)[a]	1.41	2.62**	0.00	0.37	0.17	0.25
A. australis[a]	4.56	1.57**	0.67*	0.33	0.10	0.16
M. cephalus[b]	9.96**	0.51**	4.67**	1.68**	0.17	0.15
G. tricuspidata[b]	18.13	6.33**	2.87*	0.28	0.29*	0.13
Total weight[a]	10.23	3.75**	7.77**	0.10	0.28	0.26

E, estuary; H, height; data transformed to ln(x + 1); a, variances homogeneous following transformation ($P > 0.05$); b, variance heterogeneous following transformation ($P < 0.05$). Significant at $*P < 0.05$, $**P < 0.01$. Key species: *Platycephalus fuscus, Portunus pelagicus, Mugil cephalus, Acanthopagrus australis, Girella tricuspidata.*

tering a net.[27] It is possible that such patchy (day-to-day and estuary-to-estuary) distributions of fish may have contributed to the general lack of significant differences in some experiments, particularly where changes in variables between treatments were subtle. In contrast to most related studies, which have simply compared the collective differences (i.e. total catches) between particular treat-

Table 6 Mean number and weight of catches in multifilament nylon gillnets with different twine diameters and multimonofilament nylon gillnet in Tuggerah and Wallis Lakes

	0.56 mm multifilament nylon	0.62 mm multifilament nylon	0.41 mm multi-monofilament (8 strand) nylon
(a) Tuggerah Lake ($n = 8$ days)			
Number per 100 m (se)			
P. fuscus (legal)	3.00 (0.51)	4.09 (0.63)	3.09 (0.62)
P. pelagicus (legal)	2.19 (0.38)	2.09 (0.29)	1.47 (0.32)
P. pelagicus (undersize)	0.75 (0.20)	1.34 (0.29)	0.81 (0.20)
A. australis	2.19 (0.52)	2.63 (0.88)	4.97 (0.83)
G. tricuspidata	4.97 (1.48)	3.38 (0.63)	5.75 (1.22)
M. cephalus	1.63 (0.31)	1.13 (0.18)	1.44 (0.32)
Total number	17.38 (2.15)	16.97 (1.56)	19.78 (1.66)
Total species	5.41 (0.36)	4.97 (0.33)	5.41 (0.33)
Weight per 100 m			
P. fuscus (legal)	1.70 (0.30)	2.26 (0.33)	1.74 (0.38)
P. pelagicus (legal)	0.56 (0.11)	0.52 (0.11)	0.32 (0.07)
P. pelagicus (undersize)	0.07 (0.02)	0.15 (0.03)	0.08 (0.02)
A. australis	0.46 (0.11)	0.56 (0.17)	1.05 (0.19)
G. tricuspidata	1.77 (0.56)	0.90 (0.17)	1.91 (0.40)
M. cephalus	0.83 (0.16)	0.58 (0.11)	0.72 (0.17)
Total weight	6.10 (0.81)	5.70 (0.54)	6.58 (0.65)
(b) Wallis Lake ($n = 3$ days)			
Number per 100 m			
P. pelagicus (legal)	19.22 (5.84)	23.67 (4.92)	25.33 (5.42)
P. pelagicus (undersize)	4.78 (0.84)	6.00 (1.57)	7.00 (1.04)
Weight per 100 m			
P. pelagicus (legal)	4.27 (1.57)	5.61 (1.19)	5.70 (1.52)
P. pelagicus (undersize)	0.59 (0.15)	0.68 (0.22)	1.00 (0.16)

ments over an entire study, or have not included replicates of each treatment tested, our experimental designs tested for the amount of variation within each treatment compared to the amount of difference between treatments. While the former approach probably would result in more significant differences among the various treatments examined here, it is essential that gear-related experimental studies, including those dealing with the power and selectivity of fishing and sampling gears, take account of within and among treatment variation.[4,27,32]

Factors such as hanging ratio and twine thickness affect gillnet catches and selectivity once fish have encountered a net.[26,27] Most previous studies have reported significant negative correlations between catches and mean size of fish and hanging ratio.[22,30,31] However, other researchers have tested for the effects of reducing conventional hanging ratios on catches, compared to our study that tested for the effects of increasing hanging ratios beyond that normally used in a fishery. Although an overall reduction in mean total catch associated with increasing hanging ratio was observed, (e.g. 38.52, 32.18 and 30.05 individuals per panel at $E = 0.5$, 0.65 and 0.8, respectively, Table 2), this result was not significant and therefore does not warrant the raising of hanging ratio of nets in this fishery. One possible explanation for the lack of significant correlation may have been the effect of the twine used to standardize the fishing height of the various treatment panels (Fig. 2b). Rigging the panels in this configuration would have removed all force on the netting and allowed the bulk of meshes in the various panels to assume a similar geometry, irrespective of their different hanging ratio at the floatline and footrope. Using different mesh depths, instead of rope, to regulate the fishing heights of panels with different hanging ratios would address this issue.

Our observations concerning the thickness and material of twine also conflicted with the results of several studies.[22,33,42,43] Therefore, there was no evidence to support the hypothesis that fishing power and the relative size selectivity of gillnets (i.e. size composition of fish caught) is generally correlated with the twine thickness of netting.[33,43] Previous studies reported that the greatest catches and the widest size selection of individual species occurred in gillnets made from the thinnest twine and attrib-

Table 7 *F*-values and significance from ANOVA's comparing catches in gillnets with different twine diameters and monofilament and multimonofilament PA nets in Tuggerah Lake

Factor	Day	Ply	Day*Ply	Error
Degrees of freedom	7	1	7	57
0.56 mm vs 0.62 mm multifilament nylon				
Number				
P. fuscus (legal)[a]	2.27**	0.98	0.26	0.31
P. pelagicus (legal)[a]	1.90**	0.18	0.33	0.44
P. pelagicus (undersize)[a]	1.29**	0.81	0.19	0.25
M. cephalus[a]	0.49	0.28	0.20	0.31
A. australis [b]	1.68*	0.03	0.04	0.64
G. tricuspidata[a]	5.27**	0.02	0.39	0.36
Total number[a]	2.80**	0.01	0.15	0.18
Total species[a]	0.70**	0.08	0.04	0.06
Weight				
P. fuscus (legal)[a]	1.44*	0.57	0.13	0.21
P. pelagicus (legal)[a]	0.42**	0.01	0.07	0.11
P. pelagicus (undersize)[a]	0.04	0.06	0.01	0.01
M. cephalus[a]	0.33*	0.20	0.10	0.14
A. australis [b]	0.33*	0.01	0.04	0.14
G. tricuspidata[b]	2.11**	0.20	0.22	0.17
Total weight[a]	1.81**	0.00	0.13	0.13
0.56 mm multifilament nylon vs 0.41 mm multimonofilament (8 strand) nylon				
Number				
P. fuscus (legal)[a]	1.45**	0.00	0.23	0.43
P. pelagicus (legal)[a]	1.64**	1.08	0.67	0.32
P. pelagicus (undersize)[a]	0.67	0.03	0.24	0.23
M. cephalus[a]	1.32**	0.14	0.27	0.29
A. australis [b]	2.2**	5.27**	0.21	0.59
G. tricuspidata[a]	5.63*	1.37	0.35	0.46
Total number[b]	2.41**	0.57	0.07	0.23
Total species[a]	0.56**	0.00	0.08	0.07
Weight				
P. fuscus (legal)[a]	0.89	0.01	0.15	0.29
P. pelagicus (legal)[a]	0.29*	0.31	0.14	0.08
P. pelagicus (undersize)[b]	0.02	0.00	0.01	0.01
M. cephalus[a]	0.72**	0.10	0.17	0.13
A. australis [b]	0.49**	1.37**	0.08	0.14
G. tricuspidata[b]	2.67*	0.59	0.2	0.25
Total weight[b]	1.57*	0.18	0.08	0.19

Data transformed to $\ln(x + 1)$; a, variances homogeneous following transformation ($P > 0.05$); b, variance heterogeneous following transformation ($P < 0.05$). Significant at $*P < 0.05$, $**P < 0.01$.

uted this correlation to a combination of factors, including lower visibility, improved elasticity and a greater probability of fish encountering the meshes. Although the difference in twine thickness examined here was comparable to that in previous studies,[33] similar differences in efficiency and relative size selectivity were not observed in the species examined in this study. The exception was *G. tricuspidata*, which were on average smaller in the 0.62 mm ø multifilament netting: all other species displayed similar size distribution across all nets. Water clarity was generally low during our experiment and this may have confounded our comparisons as it is possible that, owing to low light and turbidity at the bottom, the two twine thickness examined potentially had a similar visibility during our experiment, particularly since most fishing occurred at night. The potential reduced visibility during our experiment also could have contributed to the lack of significant differences in catches and size compositions of species between the multifilament nylon PA and multimonofilament nylon PA netting. Although using thinner twine than examined here may affect catches, commercial fishers in NSW are unwilling to use it as it is easily damaged by entangled crabs.

Lowering the relative fishing height of panels was the only modification that influenced species selectivity; significantly reducing the total by-catch by up to by 46% and the numbers of key unwanted

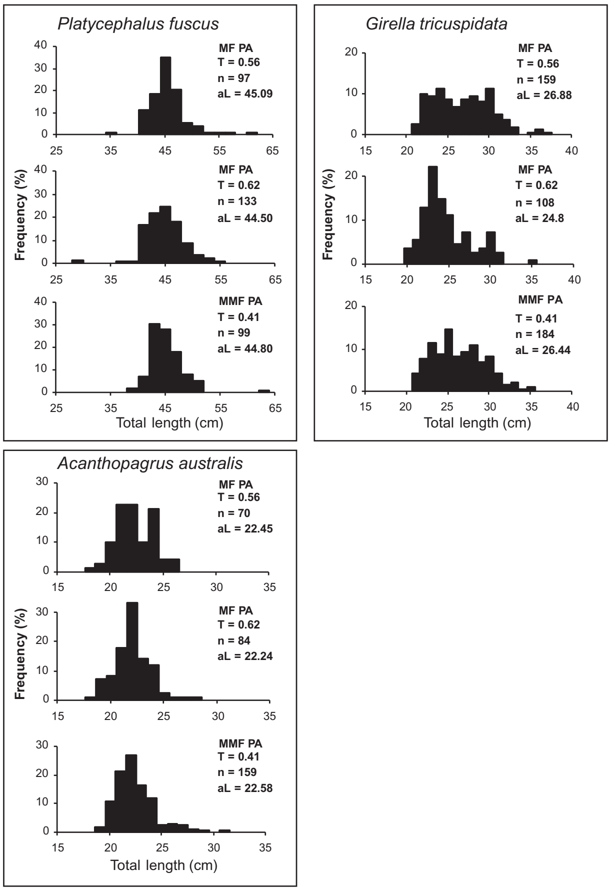

Fig. 5 Length compositions of *P. fuscus*, *A. australis* and *G. tricuspidata* caught in nets of different twine diameter and net material. MF PA, multifilament nylon netting, MMF PA, multimonofilament polyamide netting; T, twine diameter (mm); *n*, number of fish measured; aL, average total length (cm).

individual species (*M. cephalus A. australis* and *G. tricuspidate*) by between 60 and 85%. Equally importantly, this configuration had no effect on the catches of the targeted *P. fuscus* or the legally retained byproduct, *P. pelagicus*, both of which are benthic-dwelling. These observations are similar to those made during an earlier study in the same fishery,[36] and can be attributed to species-specific differences in vertical distributions, and the lower probability of fish encountering the net.[26,27] The fishing depth of pelagic gillnets (drift-net) impact on catches of tunas, with nets set lower in the water column away from surface, catching less fish.[31]

It is likely that a lower fishing height, combined with the recent increase in mesh size from 70 to 80 mm, will significantly alleviate some of the negative effects associated with by-catches in this fishery. It may be possible to further augment species selectivity by other alterations to fishing practices and/or gears that exploit differences in behavior. One option would be to investigate the effects of reducing the permitted maximum setting time (currently up to 12 h) of nets on catches and by-catches. Commercial fishers generally report that catches of *P. fuscus* are greatest around dawn and dusk. Fishers could be restricted to setting nets for shorter periods (e.g. 2 h) across these times. This practice would reduce the amount of incidental species encountering the gear and facilitate improved survival of those that are inadvertently caught.[39,44] An alternative management of by-catch in this fishery would be to allow fishers to retain legal-sized individuals of species that are currently prohibited. This practice may negate potential wastage in the fishery, but could lead fishers using gillnets to target other species, potentially increasing effort. The preferred option is to prescribe the sorts of modifications and practices listed above that minimize the capture of non-target organisms.

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