At-sea testing of a submerged light BRD onboard the *FV Ocean Thief* for approval in Australia's Northern Prawn Fishery

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Executive summary

Light as a bycatch reduction tool has been successfully tested in the East Coast Prawn Trawl Fishery and the Torres Strait Prawn Fishery with significant bycatch reductions (30% and 18% respectively) and increases in prawn catches (32% and 5.5% respectively). This report documents the trialling of submerged lighting as a novel bycatch method in the Northern Prawn Fishery during the 2009 tiger prawn season against the NPF Bycatch Subcommittee's performance requirements.

The aims of this trial were to 1) show light can significantly change the catch rate of bycatch species and 2) use light to reduce bycatch weight by at least 10% as required under the testing protocol.

Small finfish dominated the total weight of bycatch. Four fish families accounted for over 60% of bycatch weight. Three families accounted for more than 60% of bycatch abundance, one of which was non-target prawns. Mean ranking of families identified the following five families as the greatest contributors to bycatch during the trials: 1) ponyfishes (family Leiognathidae), 2) biddies (family Gerridae), 3) sweetlips (family Haemulidae), 4) non-target prawns (family Penaeidae) and 5) goatfishes (family Mullidae).

The inclusion of light in the trawl system significantly changed the catch per unit effort (weight and abundance) of ponyfishes, biddies, non-target prawns, trevallies (family Carangidae), and threadfin salmon (family Polynemidae). The weight of whiting (family Sillaganidae) and abundance of cardinalfish (family Apogonidae) also changed.

The trial was halted after five tows (13.9 trawl hours) due to a commercially unacceptable reduction in the catch rate of the target species. The orientation of the lights (facing downwards, along the headline) caused an overall increase in bycatch weight (51%), mainly attributable to significant increases in ponyfishes. This increase in bycatch weight translated into the reduced target species catch rate.

Lights can be used to manipulate bycatch behaviour. Further work is required on the orientation of the lights to optimise the benefit of the technology to industry, specifically upward facing lights need to be tested. In the future, dedicated vessel time is required to optimise the position and orientation of the lights system prior to testing against NORMACs *TED and BRD testing protocol*. Changes in swept area related to codend loading need to be included in analyses to better understand how changes in bycatch weight affect swept area and hence benthic species catch rates.

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Introduction

The Northern Prawn Fishery (NPF) is a demersal trawl fishery targeting penaeid prawns, one component of a highly diverse fish and invertebrate assemblage (Stobutzki et al 2001 a & b). Tropical prawn trawling is recognised as one of the most unselective industrial fishing methods (Alverson 1994), responsible for 27% of the global fishery discards (estimated 7.3 million tonnes annually; Kelleher 2005). Based on historic fishery data for the NPF the ratio of bycatch to target species weight is in the order of 9:1 (Barratt et al 2001). Gear selectivity has been improved in recent years with the mandatory inclusion of turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) in the trawl system (Brewer et al 2006) as well as the continual development of bycatch action plans in line with national policy (AFMA 2007; DAFF 1999).

The NPF industry works with the Australian Fisheries Management Authority, research bodies and gear suppliers to continually develop and improve the effectiveness of BRDs. The Northern Prawn Fishery Management Advisory Committee (NORMAC) estimate bycatch has been reduced by 50% since 1998, and continue to support research in the area (AFMA n.d.). To aid the development and implementation of suitable devices the NORMAC Bycatch Subcommittee developed the *TED and BRD Testing Protocol* (Appendix 1). This protocol clearly identifies the pathway to approval of new devices for use in the fishery. In short, any new device needs to pass through three phases, with the final phase requiring extensive at-sea testing. A new device may be approved if a minimum of 10% bycatch reduction is achieved.

There are seven BRD/TED designs identified in the Northern Prawn Fishery Operational Information 2009 (AFMA 2009) all of which are located in the codend, requiring the escape of non-target animals after entering the trawl system (Maynard 2008). Broadhurst et al (2006) identified the need to move bycatch reduction efforts from the codend to the anterior sections of the gear to improve selectivity and mitigate unaccounted fishing mortality. The Australian Maritime College has been developing a novel technology based on submerged lighting that influences fish behaviour at the trawl mouth. Under experimental trawl conditions in the East Coast Prawn Trawl Fishery and the Torres Strait Fishery the phototactic response of bycatch species was exploited to reduce bycatch weight by 30 and 18.2% respectively (target species catch weight increased in both experiments; Maynard 2008; Maynard & Gaston 2009).

Based on this work the NORMAC Bycatch Subcommittee and AFMA supported the at-sea testing of lights in the NPF during the 2009 tiger prawn season, with the view to approving the technology for use by industry. This report presents the results of the trial.

Aim

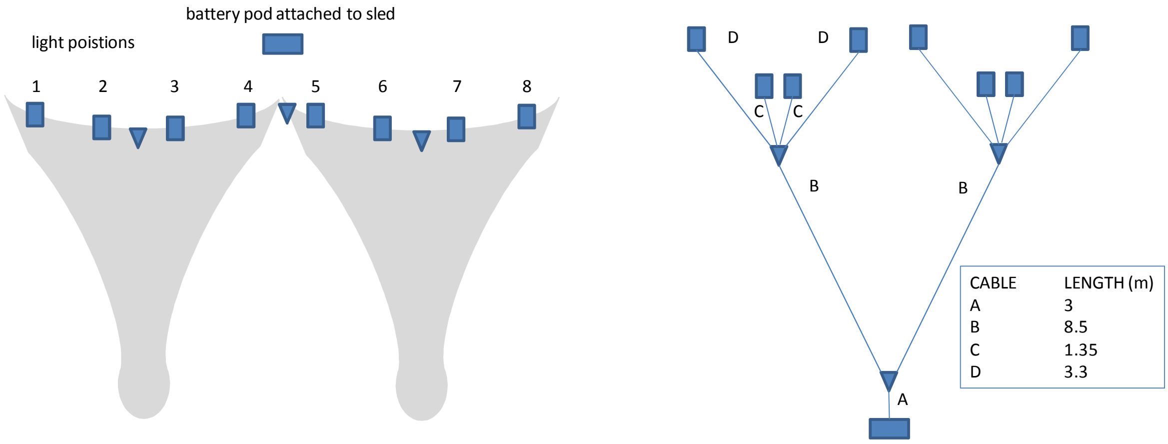
The aims of this trial were to:

1) Show that submerged lighting can significantly change the bycatch composition, and
2) Use submerged lighting to reduce bycatch weight by at least 10%.

Methods

Two identical custom-made underwater light systems were manufactured by the Australian Maritime College Underwater Technology Centre for this experiment. Each light system comprised eight 3 Watt, 98° beam angle LED lights, power cable and battery pod. A representative light system appears in Fig. 1 and schematics of the system developed for this experiment appear in Figure 2.

Figure 1: A representative light system as used in the field trials. The battery pod (right) is cabled to each of the lights. Each light is attached to a mounting bracket, allowing the lights to be uniformly attached and orientated.



CABLE	LENGTH (m)
A	3
B	8.5
C	1.35
D	3.3

Figure 2: *Right:* A schematic of the custom-made lighting system used in the field trials (not to scale). *Left:* The location of lights, cable junctions and battery pod on the trawl system during the trials (not to scale). The lights and cable junctions were attached to the headline. The battery pod was attached to the sled.

The lights were positioned equidistantly along the headline and oriented to face downwards, illuminating the seabed and water column directly below the headline (Figure 3).

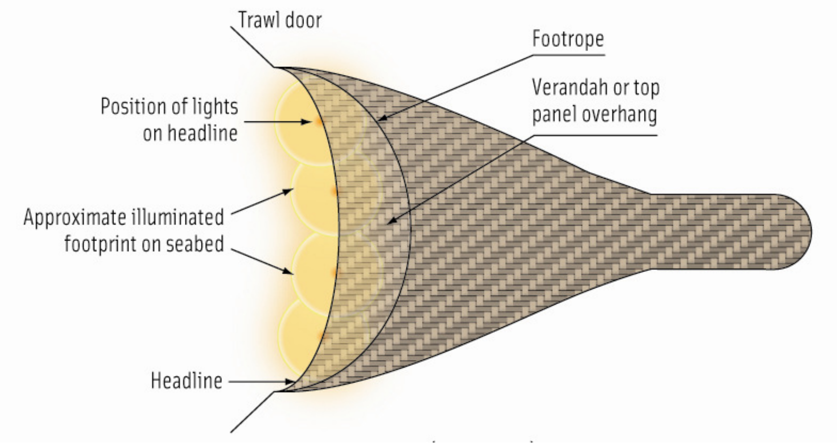


Figure 3: A schematic of a single prawn trawl net in plan-view (not to scale). The diagram shows the relative position of each light and the illuminated 'footprint' on the seabed (image source: FRDC FISH magazine, September 2009).

A light system (as described in Figure 2) was attached to the paired nets on both sides of the vessel (Figure 4). Lights were turned on and off as necessary by breaking the circuit at the battery pod.

Fig 4. The battery pod attached to the sled and a light mounted on the headline *(left).* The illuminated trawl net at the surface (*right*).

The Austral vessel *Ocean Thief* hosted the field trials. This vessel, operating in the Northern Prawn Fishery, uses a quad rig prawn trawl system (Figure 5). The distance between the port and starboard net pairs is estimated to be 10 m.

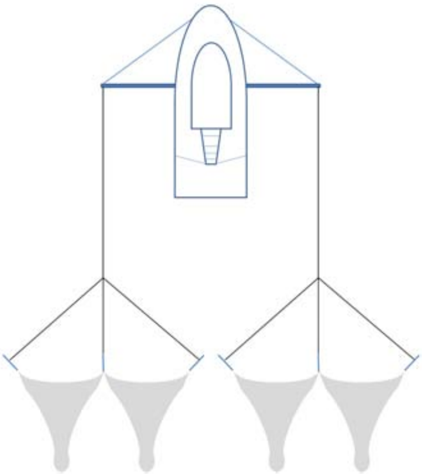


Figure 5: A schematic of a quad rig trawl system (not to scale).

The headline length of each trawl net was 7 ¼ fathoms (~13.3 m). This equals an overall headline length 14.5 fathoms (~26.5 m) on each side of the vessel, fishing at a spread ratio of 80% (estimated). Codends were constructed of 2 ¼ inch (57 mm) diamond mesh (larger than the industry standard 1 ¾ inch (45 mm) mesh) with skirts and 4 inch square mesh panels. Lights were equidistantly attached along the headline (~ 3.3 m) spacing, beginning at half the spacing distance from the end of the headline. The trawl boards used were #7 Bison boards (1750 mm L x 1150 mm H). The board height combined with a light beam angle of 98° produces an illuminated 'footprint' of ~2.65 m diameter on the seabed. The light spacing (~3.3 m) results in 80% coverage of the headline length.

Between August 19 and August 20 2009, 5 trawls were conducted in the NPF (Figure 6). Most trawls were approximately 3 hours duration. Trawl speed ranged between 3.1-3.5 knots and operations were conducted between 6:30 pm and 6:30 am each night.

For each pair of nets (control and experiment) in each shot the total target species and bycatch weights were recorded and a bycatch subsample (~10 kg) was retained. Subsamples were measured for catch composition, species weight and count, and length frequency.

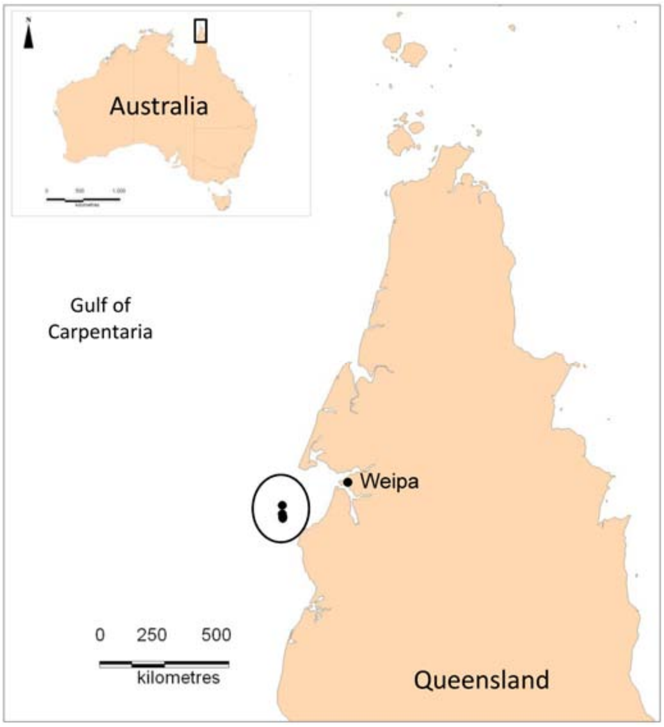


Figure 6: Location of experimental trawl sites in the Torres Strait prawn trawl fishery.

For each night the nets on one side of the vessel were illuminated (experiment) for all trawls, while the nets on the opposite side remained in the dark (control).

Data analysis

All five (5) shots were conducted under controlled conditions where net illumination and trawl time were regulated. A total of 13.94 hours of trawling were conducted under controlled conditions. Catch per unit effort (CPUE) by weight and abundance was standardised for sub-sample size and trawl time. All values presented in the text are mean ± SE.

A 2-way analysis of variance (ANOVA) was used to test for significant changes in bycatch weight and abundance per trawl hour (factors: side of vessel – port or starboard and lights status – off or on). Data was ln(x+1) transformed if variances were not homogeneous (determined using Cochran's test). Tukey's post-hoc test was performed if a factor (or interaction) was significant ($p<0.05$). Changes in bycatch weight and abundance for groups (fish, non target crustaceans, and other invertebrates) were compared between lights on and lights off using independent samples t-test. Changes in bycatch weight and abundance for selected families were compared between lights on and lights off using the Klomogorov-Smirnov test for length frequencies and the Mann-Whitney *U* test for median lengths. The Kolmogorov-Smirnov test calculates a statistic based on the maximum difference in the cumulative frequency distributions of each sample (this is based on shape, skewness and kurtosis of the frequency histograms). The Mann-Whitney *U*-test for unmatched samples is a non-parametric test comparing the median value of two samples.

Results

The five trawls (13.94 hours trawling) resulted in 400.5 kg of tiger (*Penaeus esculentus* & *P. semisulcatus*) and endeavour prawns (*Metapenaeus endeavouri* & *M. ensis*) and 4978 kg of bycatch. In terms of gross weights the prawn : bycatch ratio for this trial more than doubled when lights were used (Table 1).

Table 1: Ratio of target species weight to bycatch weight (kg) under control and experimental conditions.

	Lights off (control)	Lights on (experiment)
Target species (kg)	244	156.5
Bycatch (kg)	1983	2995
Ratio	1 : 8.1	1 : 19.1

The reduction in prawn CPUE (Figure 7) was 21.8 ± 3.5 kg/hr to 14.8 ± 3.2 kg/hr (not statistically significant); in terms of reduced commercial production (-36%), the trials could not continue.

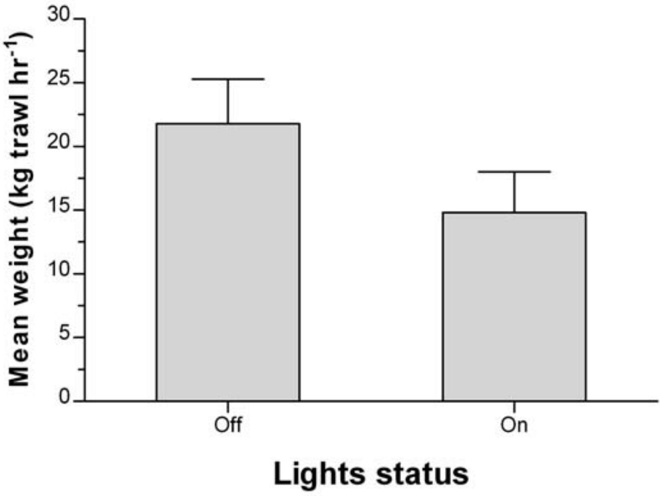


Figure 7: Change in target species catch weight (kg per trawl hour) due to lights (t=1.501, df 8, p= 0.172)

There was a significant increase in catch per unit effort (CPUE) of bycatch in terms of weight (t=-6.404, df=4, P=0.003, Figure 8a) and estimated abundance (t=-13.9228, df=4, P=0.000, Figure 8b).

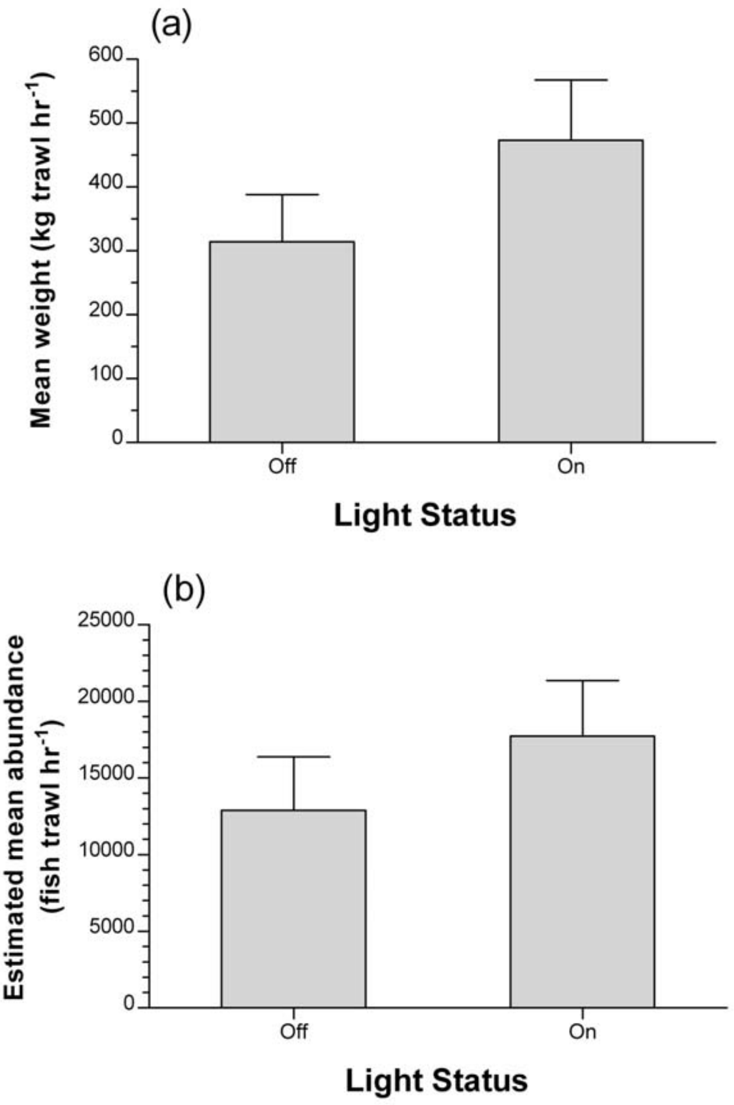


Figure 8: The effect of light on the estimated bycatch a) weight (kg) and b) estimated abundance per trawl hour.

A total of 4590 animals representing 44 families and more than 72 species were measured in the subsamples. Based on these samples the catch was divided into three groups:

1) non-target crustaceans (coral prawns (*Metapenaeopsis* spp.), undifferentiated mantis shrimps (Order Stomatopoda), juvenile and berried bugs (*Thenus orientalis*) and crabs (dominated by family Portunidae)),
2) finfishes, and
3) molluscs (saucer scallops (*Amusium balloti*) and cuttlefishes (*Sepia* sp.).

The subsamples did not contain any sharks, rays, reptiles or benthos.

The changes in CPUE (estimated weight and abundance) are plotted in Figure 9. The CPUE of fishes increased due to lights although this was not a statistically significant result. The changes in CPUE for non-target crustaceans and molluscs reduced due to lights, although only estimated abundance was significantly reduced (t=2.588, df=4, P=0.032).

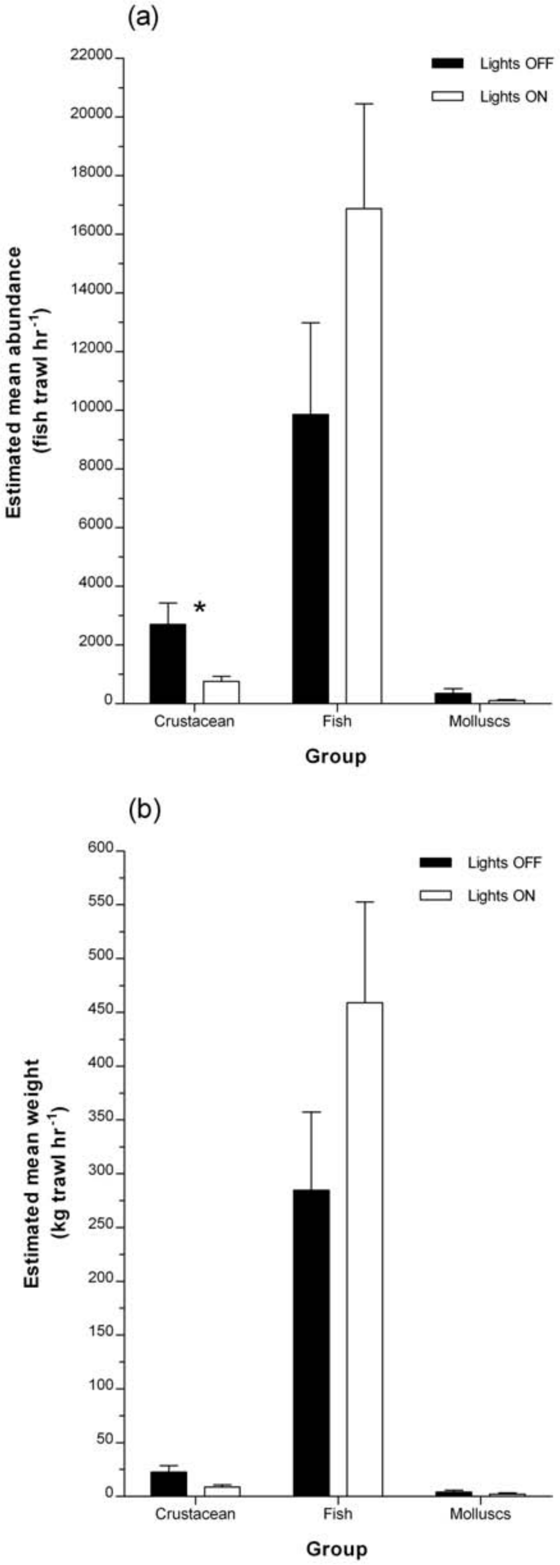


Figure 9: Estimates of a) mean abundance and b) mean weight for main bycatch groups.

The subsample data has been identified at family level, with investigation to species level limited to ponyfishes (family Leiognathidae). Based on standardised subsample measurements ponyfishes dominate the control catch in terms of weight and abundance (Figures 10 & 11). More than 60% of the bycatch weight is represented by just four families of finfish (Figure 10), while just three families comprise more than 60% of the bycatch abundance (Figure 11). Bycatch reduction devices that affect these dominant families will be most effective at reducing the gross bycatch weight in this particular fish assemblage.

Control catch

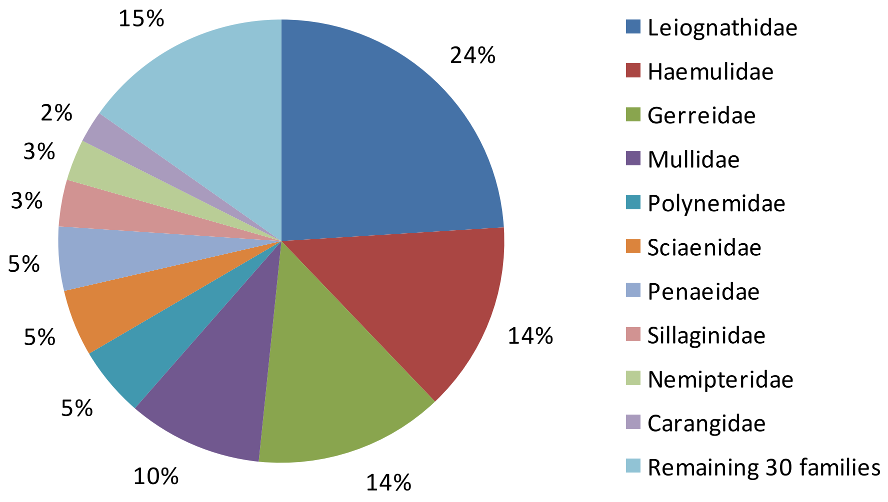


Figure 10: The family composition of the control catch in terms of weight.

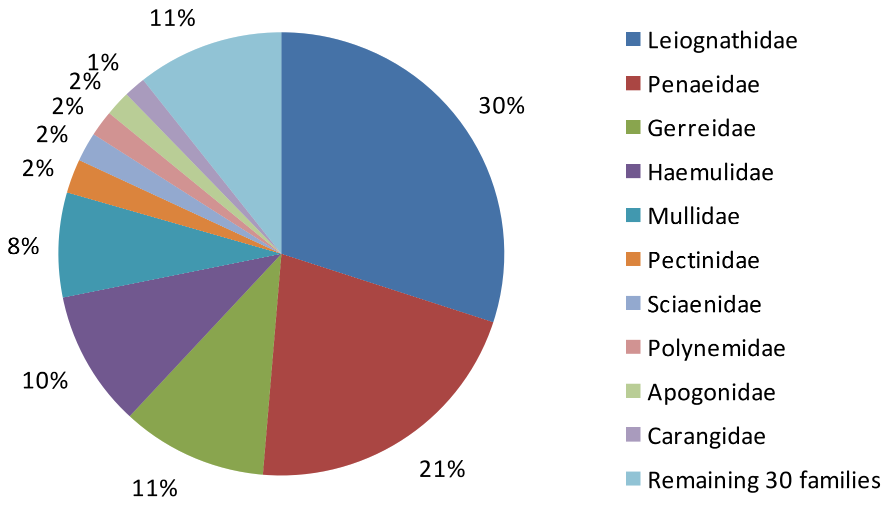


Figure 11: The family composition of the control catch in terms of abundance.

Experimental catch

The affect of light (experimental conditions) in the trawl system was to increase the gross bycatch weight by 51%. This increase is mostly attributable to an increase in ponyfishes captured (Figures 10 and 12).

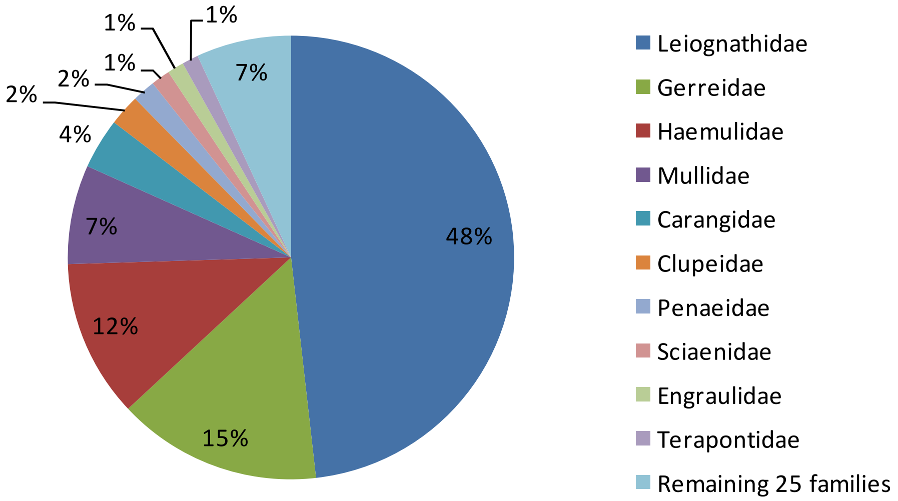


Figure 12: The family composition of the experimental catch in terms of weight.

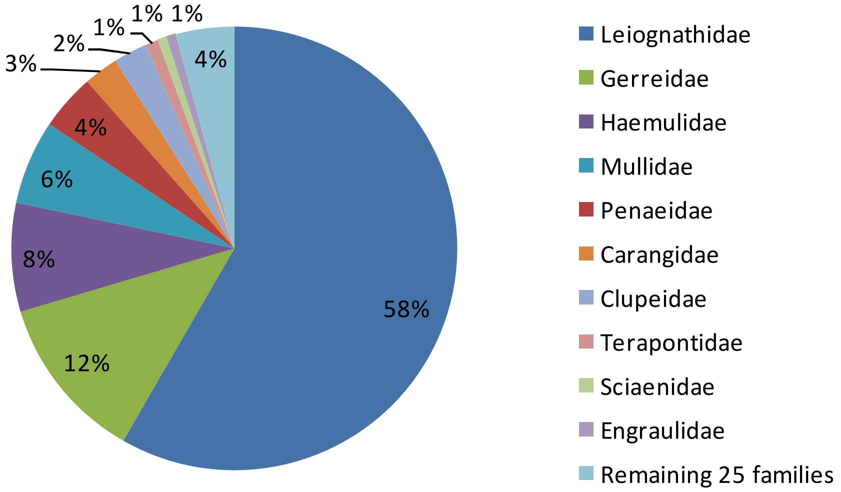


Figure 13: The family composition of the experimental catch in terms of abundance.

The importance of each family to bycatch, in terms of both weight and numbers is best represented as a mean ranking based on the control catch. Table 2 shows the mean ranks for the top 20 families contributing to bycatch. Ponyfishes are the highest ranked family, with sweetlips and biddies equal third and non-target prawns and goatfishes rounding out the top five.

Table 2: Mean ranking for control bycatch families by weight and abundance (top 20 families)

FAMILY NAME	COMMON NAME	ABUNDANCE RANK	WEIGHT RANK	MEAN RANK
Leiognathidae	ponyfishes	1	1	1
Gerreidae	biddies	3	3	3
Haemulidae	sweetlips	4	2	3
Penaeidae	non-target prawns	2	6	4
Mullidae	goatfishes	5	4	4.5
Polynemidae	threadfin salmon	8	5	6.5
Sciaenidae	croaker	7	7	7
Carangidae	trevallies	10	10	10
Nemipteridae	threadfin breams	11	9	10
Sillaginidae	whitings	12	8	10
Pectinidae	saucer scallops	6	15	10.5
Apogonidae	cardinalfishes	9	18	13.5
Scyllaridae	bugs	16	11	13.5
Ariidae	catfishes	15	13	14
Terapontidae	grunters	14	14	14
Paralichthyidae	flounders	17	12	14.5
Platycephalidae	flatheads	13	17	15
Synodontidae	lizardfishes	19	16	17.5
Bothidae	soles	22	20	21
Pristigasteridae	herrings	21	21	21

Analysis of changes in the mean weights and estimated abundances of the top 10 families appear in Table 3 and Figure 14.

Table 3: Wilcoxon tests for changes in the weight and abundance of the top ten families. Values in bold are significant (P<0.05).

Family	Weight		Abundance	
	z	*p*	*z*	*p*
Carangidae	-2.023	**0.043**	-2.023	**0.043**
Gerreidae	-2.023	**0.043**	-2.023	**0.043**
Haemulidae	-0.944	**0.345**	-0.674	0.5
Leiognathidae	-2.023	**0.043**	-2.023	**0.043**
Mullidae	-0.674	0.5	-0.944	0.345
Nemipteridae	-1.214	0.225	NA	NA
Penaeidae	-2.023	**0.043**	-2.023	**0.043**
Polynemidae	-2.023	**0.043**	-2.023	**0.043**
Sciaenidae	-1.483	0.138	-1.483	0.138
Sillaginidae	-1.826	0.068	NA	NA
Pectinidae	NA	NA	-1.753	0.08
Apogonidae	NA	NA	-2.023	**0.043**

In terms of both weight and abundance, there were significant increases in ponyfishes (P<0.05), biddies (P<0.05) and trevallies (P<0.05) due to the inclusion of light, while non-target prawns and threadfin salmon significantly reduced. Cardinalfish (P<0.05) reduced in terms of estimated abundance, but not weight.

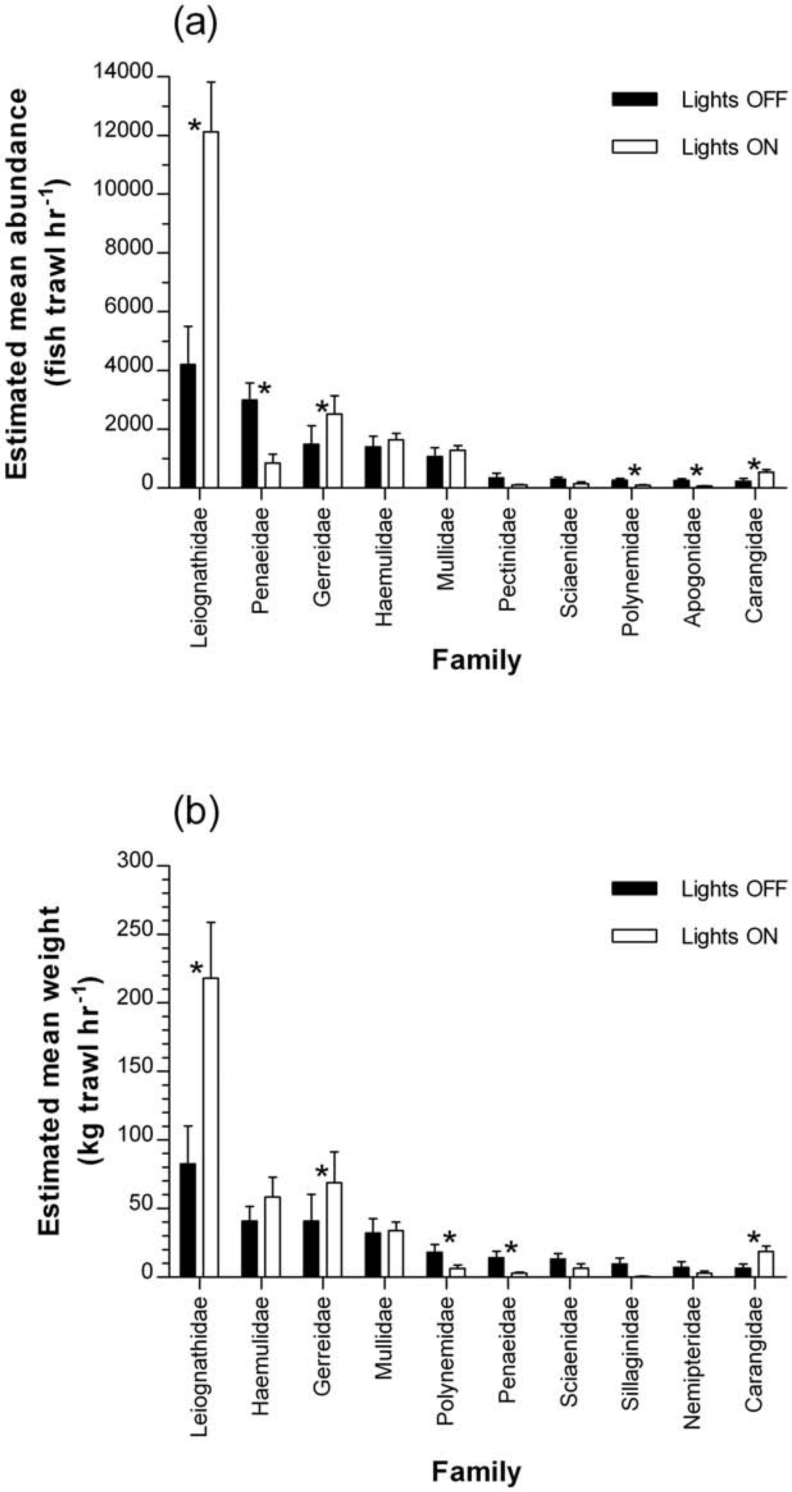


Figure 14: The effect of light status on the estimate of mean bycatch a) abundance and b) weight per trawl hour (±SE).

Length frequency data from 4590 animals was collected from control and experimental codends There was a significant difference in the length frequency distributions of ponyfish (family Leiognathidae; D = 2.674, *P*<0.05)) and sweetlips (Family Haemulidae, D = 2.167, *P*<0.05) due to the affect of lights (Table 4). The change in length frequency for ponyfishes is attributable to a small but significant increase in the median size from90 mm to 92 mm CFL when lights were turned on (Mann-Whitney test Z=-5.46, P<0.05). Similarly, the median value of biddies increased significantly from 110 mm to 113 mm CFL (Mann-Whitney test Z=-4.241, P<0.05) (Figure 15).

Table 4: Kolmogorov-Smirnov results for dominant families.

Family	D	*P*
Leiognathidae	2.674	**<0.05**
Haemulidae	2.167	**<0.05**
Gerridae	1.111	>0.05
Mullidae	1.061	>0.05
Polynemidae	0.539	>0.05
Sciaenidae	0.876	>0.05
Nemipteridae	0.391	>0.05
Carangidae	0.678	>0.05
Apogonidae	0.991	>0.05
Scyllaridae	0.79	>0.05
Terapontidae	0.398	>0.05
Ariidae	0.832	>0.05

For the remaining families there was no significant difference in the length frequency. The length frequencies for these families (Polynemidae, Sciaenidae, Carangidae, Nempiteridae, Silliganidae, Apongidae, Scyllaridae, Ariidae, Terapontidae and Platycephalidae) appear in Figure 15 (e – n). Sample sizes for these species are low (n<100) and differences in length frequency and abundance are not necessarily significant, however some light induced behaviour can be inferred from the data. Threadfin salmon (family Polynemidae) and cardinalfishes (family Apogonidae) showed significant reductions in CPUE (Table 3) across all size ranges due to light (Figure 15(e) & (j)). Inversely, trevallies (family Carangidae) significantly increased in weight and abundance (Figure 14; Table 3) across all size ranges (Figure 15 g).

Although not significant, croakers (family Sciaenidae) reduced in numbers across all sizes due to light (Figure 15 f), and although not tested (due to small sample sizes), whiting (family Silliganidae, catfishes (family Ariidae) and flatheads (family Platycephalidae) (Figure 15 l and n) show potential for reduction in numbers due to light.

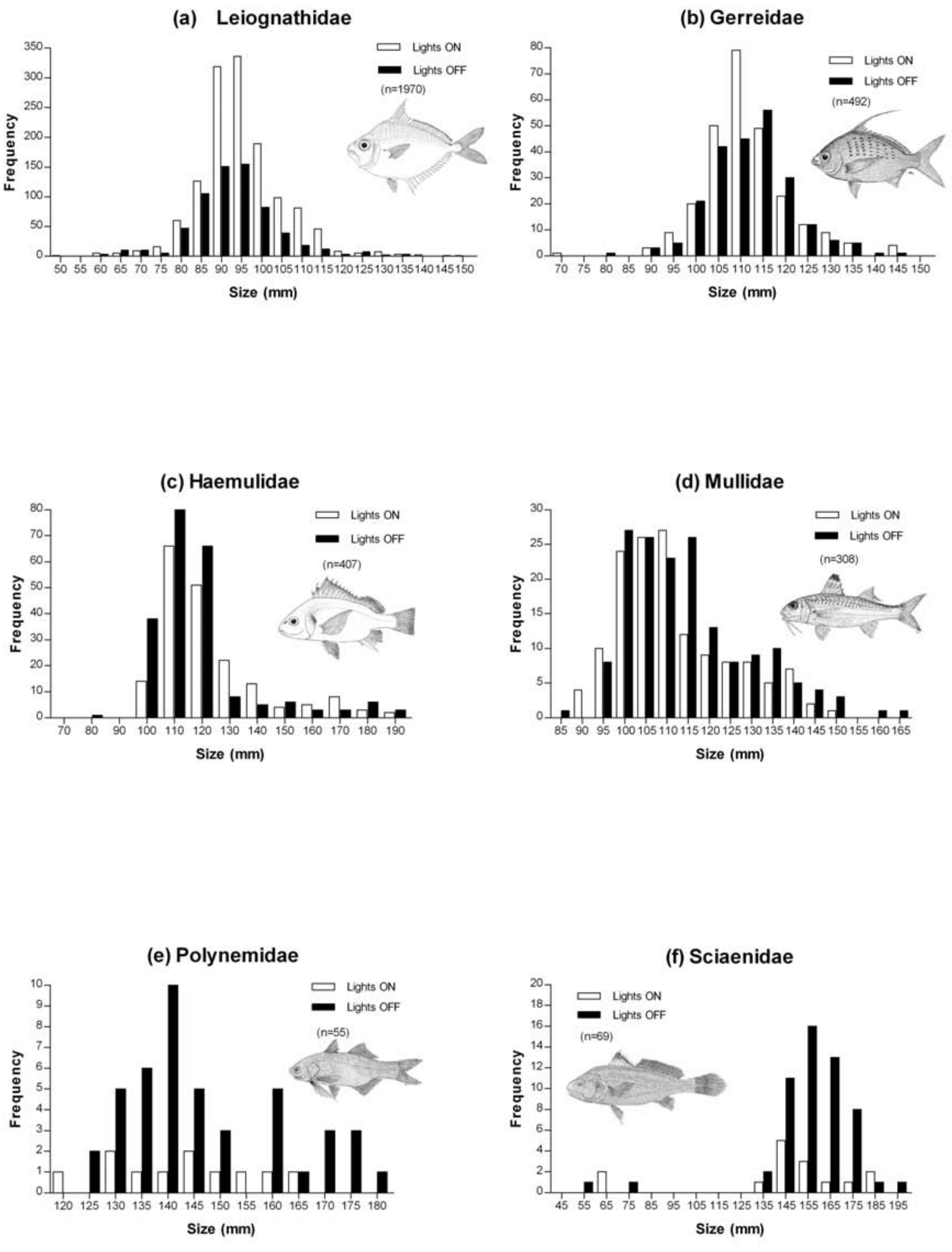


Figure 15: Length frequency distributions for finfish under control and experimental conditions (continued over page).

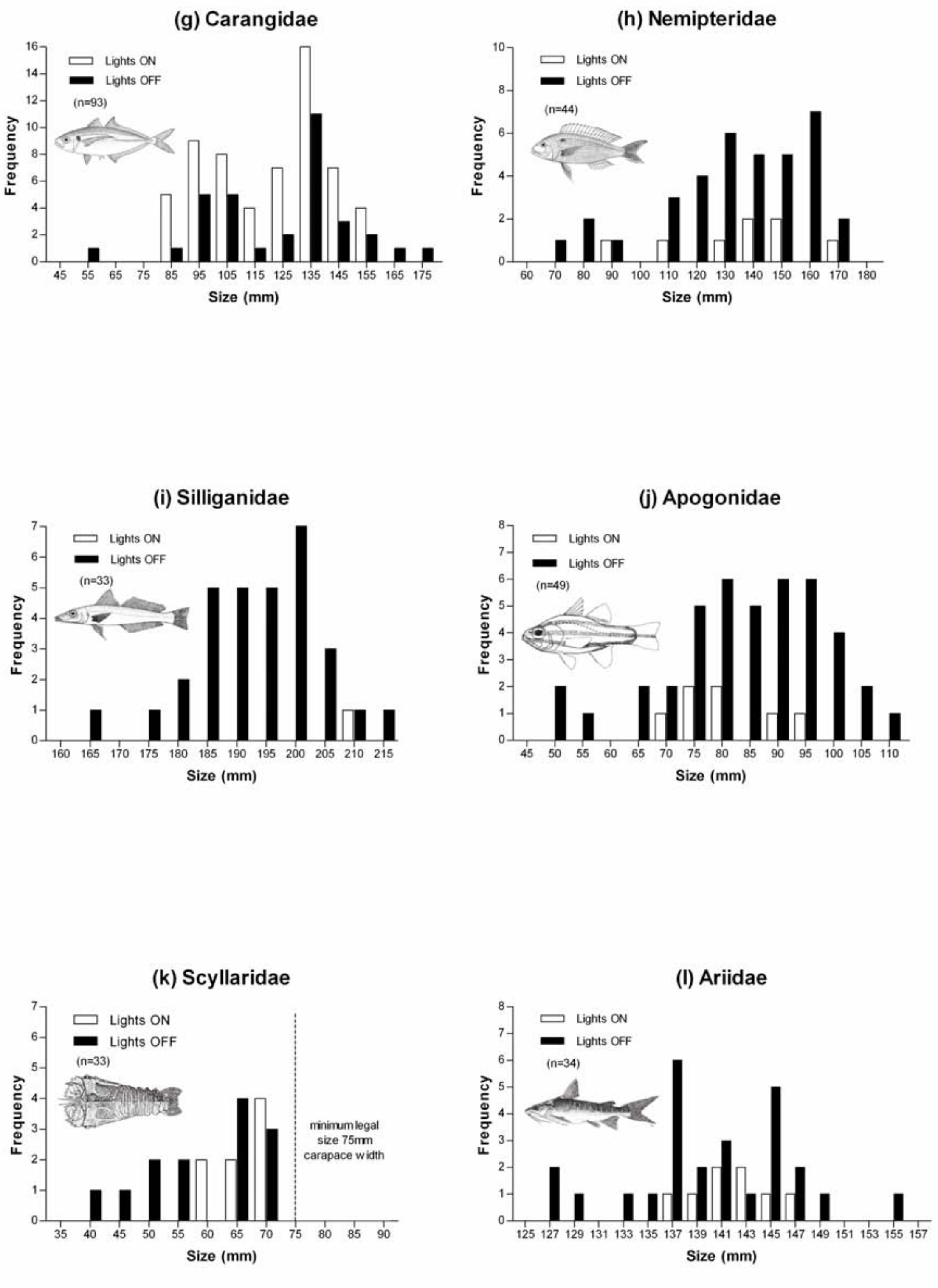


Figure 15 (*continued*): Length frequency distributions for finfish under control and experimental conditions (continued over page).

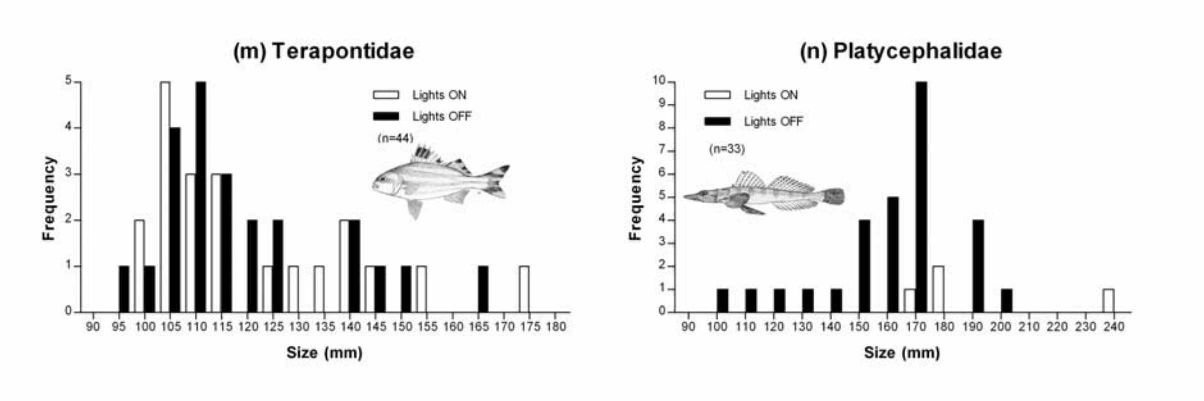


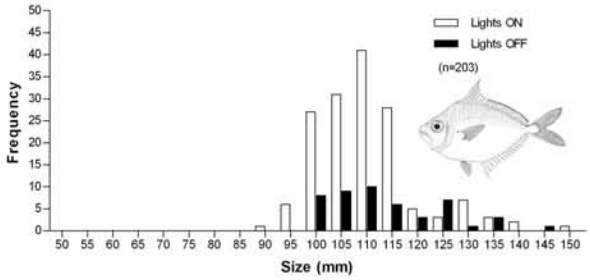
Figure 15 (*continued*): Length frequency distributions for finfish under control and experimental conditions.

Ponyfishes were analysed at species level. A total of 1957 ponyfish, representing five, possibly six species were measured in the subsamples. *Leiognathus leuciscus* and *L. moretoniensis* are very similar species in appearance. These two species were combined into a single species, here called *L. leuciscus*, due to concerns that fishes identified as *L. moretoniensis* had 1) relatively smaller median lengths, and 2) these fish were the only ponyfish species to have a negative phototactic response. It is possible that adult and maturing males were identified as *L. leuciscus* and females and juveniles were identified as *L. moretonensis.* The combined length frequency distribution appears acceptable, and the phototactic response of the combined dataset better reflects the overarching response of the ponyfishes in the experiment. Saying this, expert advice recommended further analysis with the species separated to highlight the complexity of behavioural reactions between species (N. Rawlinson, pers. com., January 2010).The remaining species of ponyfishes were *L. equulus*, *L. splendens*, *Photopectoralis bindus* and *Secutor insidiator*.

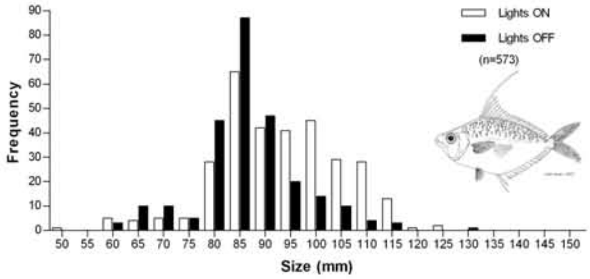
The only significant difference in ponyfish length frequency distributions was for *L. leuciscus* (the combined data set; D = 3.641, $P<0.05$). This may be interpreted an ontogenetic behavioural response or, may support the expert advice not to combine the data.

The sample sizes for *P. Bindus* and *S. Insidiator* are small (n = 107 and 54 respectively), but have been included due to the magnitude in change of abundance due to light.

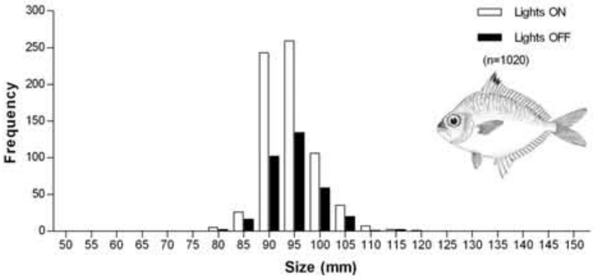
(a) Leiognathus equulus



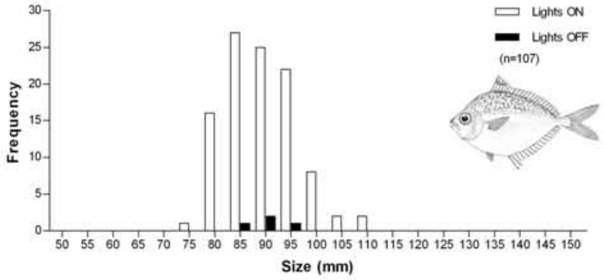
(b) Leiognathus leuciscus



(c) Leiognathus splendens



(d) Photopectoralis bindus



(e) Secutor insidiator

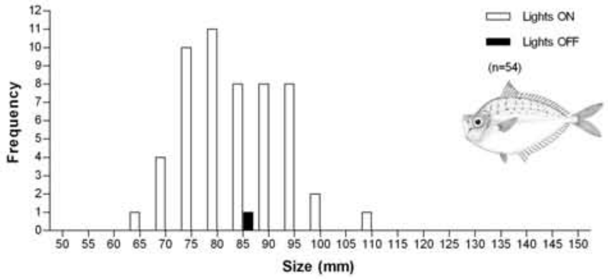


Figure 16: Length frequency distributions for ponyfish species under control and experimental conditions (note: y axis differs in magnitude for each species).

Discussion

In this trial the inclusion of submerged artificial light in the trawl system increased total bycatch weight by 51%. This increase is directly related to the fish assemblage at the location and time of the trials and the downward orientation of the lights. Two similar trials in other fisheries, using the same lighting system and orientation have resulted in significant reductions in bycatch weight (30% and 18.2%) and numbers (32% and 54%) (Maynard 2008; Maynard & Gaston 2009).

Each of the three trials has been conducted on differing fish assemblages. The earlier studies were conducted on fish assemblages where the overarching phototactic response was negative. Within the fish assemblage are fish that exhibit 1) a positive phototactic response, 2) a negative phototactic response or 3) not response. This NPF trial was conducted on a fish assemblage dominated by species with a positive phototacic response, hence the significant increase in bycatch.

The orientation of the light system within the trawl net influences where fish move to (toward or away from the illuminated area). In all field experiments the lights have illuminated the area below the headline. In two experiments this light orientation has reduced bycatch, however this was not the case in this NPF experiment. It is likely that lights orientated to face upwards would have an equal and opposite effect on bycatch rates but this remains untested.

The trial was suspended due to reduced prawn catches in the experimental trawls. This reduced prawn catch is likely a result of increased bycatch loads in the codend reducing wingend spread, rather than a negative phototactic response. Reduced bycatch in previous lights experiments resulted in increases in prawn catch rates (Maynard 2008; Maynard & Gaston 2009). This link between bycatch rates and wingend spread/prawn catches should serve to further motivate industry to reduce bycatch.

It should be noted that the decision to halt the trials after five trawls (instead of the 20 – 30 shots required by the protocol (Appendix 1), does not provide industry or management with rigorous, defendable data. For example, the CPUE of target species dropped by 36% in this trial however, with only five replicates, this reduction was not statistically significant. It is in industry's (and managements) best interest to ensure any BRD trial is conducted in accordance with the experimental design in the protocol. This can be achieved by budgeting to compensate the crew for potential loss of catch.

This trial was unsuccessful of meeting the criteria (10% reduction in bycatch weight) for approval as a bycatch reduction device in the NPF, however, changes within the bycatch composition offer fishers and managers opportunities in the future to reduce the catch rate of components of the bycatch. For instance, a number of bycatch families had a negative behavioural response to the lights. The catch of non-target prawns and threadfin salmon significantly reduced due to lights, while whiting, flathead, threadfin breams and croakers show reductions in catch rates. While the change in catch rates of these families not all statistically significant, their ecological value and potential commercial value may increase pressure in the future to reduce their capture. It should be noted that a number of these bycatch families (even ponyfishes, biddies, sweetlips and non-target prawns) have commercial value in Southeast Asia. Economics drives the targeting of these species, however, changes in market demands into the future need to be considered.

The affect of catch related drag on wingend spread is unknown in this trial. It is likely (but unknown) that increased bycatch weight in the experimental trawls reduced the swept area, in turn reducing the catch rate of some benthic species (e.g., non-target prawns) and importantly, the target species. Without this information it makes it difficult to draw solid conclusions about the impact of lights on truely benthic species. Future trials should include the use of SCANMAR (or similar) hydroacoustic systems to measure changes in swept area. An added bonus to the collection of this information would be to show fishers the benefits of bycatch reduction in terms of maintaining wingend spread throughout the trawl duration.

Conclusions/recommendations

Light is effective at manipulating the composition of prawn trawl catches, however it did not cause a significant reduction in bycatch weight in this trial. More work is required to understand the appropriate location and orientation of lights systems to optimise the bycatch reduction potential for NPF fishers. Different bycatch families react differently to light. As fishers move between fishing grounds the fish assemblage will change and fishers need to understand how and when lights can be used. Any future lights trials should include 1) budget for compensating crew for loss of catch (as this would allow the trials to continue longer so that statistically robust data can be collected) and 2) the collection of wingend spread data.

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