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Australian Government
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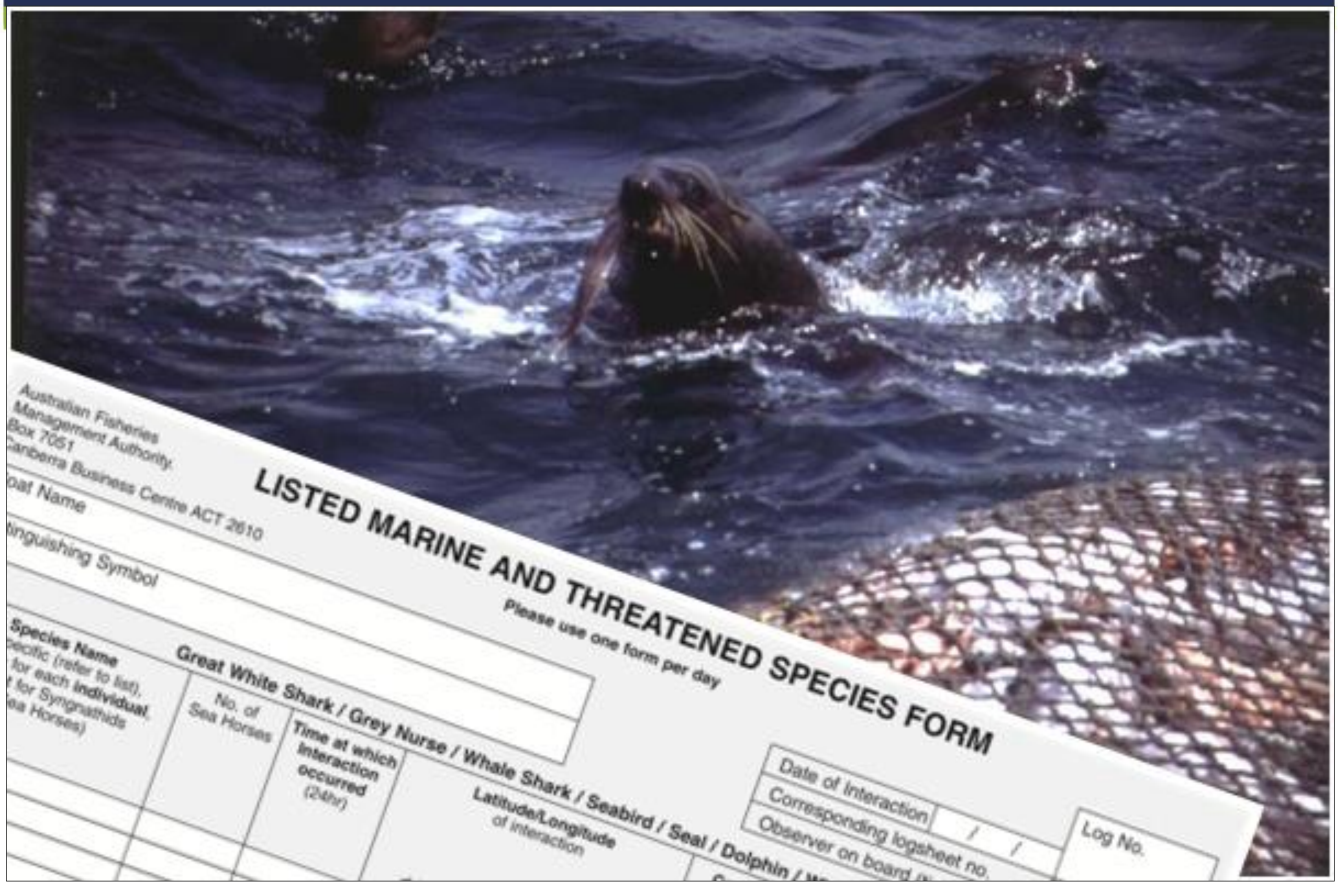
Assessment of the use of shortened codends to mitigate seal interactions in the SESSF



Matt Koopman, Simon Boag and Ian Knuckey
October 2014

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Introduction

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a multi-species, multi-gear fishery situated off the south-east coast of Australia, and comprises the Commonwealth Trawl, East Coast Deepwater Trawl, Great Australian Bight Trawl and Gillnet, Hook and Trap sectors (Figure 1). The Commonwealth Trawl Sector (CTS) is Australia's largest scalefish fishery. In 2012/13 the sector landed 10,724 tonnes of fish, and in 2011/12 the GVP was AUD$45.9 million (Woodhams *et al.* 2013). Most of the vessels in the fishery are 'wet boats' (fishing vessels that store fresh fish on ice or brine) that use demersal trawl methods; there are also a small number of factory boats using midwater trawls.

CTS vessels occasionally catch Australian Fur Seals (AFS - *Arctocephalus pusillus doriferus*) and New Zealand fur seals (*Arctocephalus forsteri*) in their nets during commercial operations. This occurs because much of the fishery overlaps with the seals' distribution (Arnould and Hindell 2001; Arnould and Kirkwood 2008; Kirkwood *et al*. 2006), and because seals are foraging for fish species often caught in the sector (Hume et al. 2004, Littnan *et al.* 2007). Further, seals feed on the fish caught in trawl nets as well as offal and bycatch discarded from the vessels (Knuckey and Stewardson 2008). While many of the interactions between seals and fishing gear/vessels do not result in any harm to the seal, they can become caught in the nets, which can result in injury or death (Knuckey and Stewardson 2008).

Seals are protected in Commonwealth waters under the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*). Under the Act it is the responsibility of fishers to "take all reasonable steps to ensure that members of listed marine species are not killed or injured as a result of fishing". All incidents involving seals (alive or dead) must be reported to the Australian Government Department of the Environment (DoE).

Interactions between the fishery and seals received increasing attention throughout the 2000s (e.g. Wilson *et al*. 2010; Tilzey *et al*. 2006; Hamer 2004; Knuckey *et al.* 2002). There have been several projects aimed at either increasing reporting of seal interactions, or improving mitigation, handling and release techniques. During 2005 a project (FRDC Project 2005/049) was initiated with the following four objectives: 1) to develop a Code of Practice to Minimise Interactions with Seals; 2) raise industry awareness; 3) encourage increased reporting of seal/fishery interactions; and, 4) to quantify the extent of reporting of seal interactions (Knuckey and Stewardson 2008). The project led directly to an increased number of seal interactions being reported in fishery logbooks, improved compliance with the *EPBC Act 1999* with regards to data collection and reporting standards for seal interactions (Knuckey and Stewardson 2008).

More recently, The South East Trawl Fishing Industry Association (SETFIA) did a lot to improve the reporting of seal interactions. They revised their *Industry Code of Practice* in relation to seal interactions and ran training courses for CTS fishers that included information on reducing interactions, and what actions to take if an interaction did occur (see FRDC project 2009/330 Boag *et al*. 2011). Shortly after completion of that education program, a review of industry reporting of seal interactions showed that reporting increased immediately after FRDC project 2005/049 (Knuckey and Koopman, 2011), and further increased during 2010 as a direct result of FRDC project 2009/330 (Boag *et al.* 2011).

While there are generally few concerns for the sustainability of AFS populations as a result of mortality from fishing operations, they are a protected species under the *EPBC Act*. Industry members have been proactive in attempting to reduce interactions with seals, experimenting with seal excluder devices and other gear modifications. Grid-style seal exclusion devices (SEDs) and codes of practice for fishing have been shown to work on large factory trawlers in the winter Blue Grenadier fishery (Tilzey *et al.* 2006). Comparatively little work has been conducted in the remainder of the fishery operated by the small "wet boat" fleet. Analysis of data collected by observers onboard wet boats indicated that seals were caught in about one in every fifty shots, but this incidental catch rate varied greatly across the fishery and in different seasons and depths (Knuckey *et al.* 2002). However, trials of SEDs on wet boats resulted in unacceptable loss of commercial catch as the SED became clogged by skates and rays (SETFIA, 2009). Furthermore, there were concerns about occupational health and safety using SEDs on smaller vessels that do not have the deck space and deck equipment to safely handle SEDs.

Because of difficulties associated with operating a grid-style SEDs and smaller SESSF wet boats, industry has continued to look for other ways to address the seal interaction problems. One option for which there was anecdotal support was that shortened cod-ends enabled improved egress of seals out of the cod-end and the net. This idea arose from inferences by a CTS skipper that suggested that the incidence of seal captures could be reduced by 60–80% using a shortened codend. Seals have been observed by cameras to swim into trawl nets at depth to eat fish from the codend and then getting disorientated as they try to escape. The theory was that a shorter coded would reduce the distance required for seals to swim back out of the net, thereby reducing the risk of obstruction of egress and improving the chance of the seal escaping from the net.

An important consideration in trailing mitigation devices is the effect of the device on commercial catches. If the use of a device will adversely effect profitability, there will be little support from industry members or the fisheries management agency. Support from the industry members is important, as this may facilitate voluntary take-up without the need for a change in legislation, otherwise if it is legislated, then support will improve compliance. To address this, comparisons of commercial catches between nets will also be made during this project.

SETFIA actively works towards improving on-the-water operations of its fishing fleet to reduce interactions with protected species, and increase compliance levels and reporting of interactions. Further, supporting industry members who are attempting to improve the sustainability of their fishing operations encourages continued ownership, innovation and improvement. This project was initiated by SETFIA to collect information to examine the veracity of claims that using shortened codends in nets reduces seal interactions.

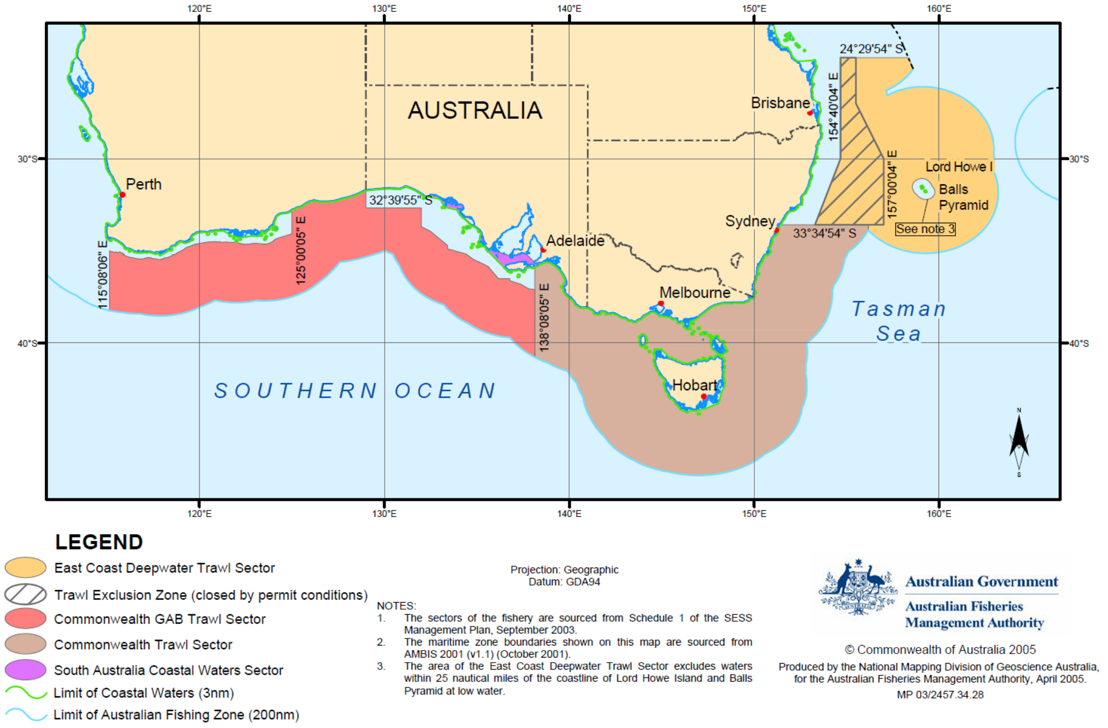

Figure 1. The Commonwealth Trawl Sector of the Southern and Eastern Scalefish and Shark Fishery.

Objectives

1. Measure and compare the seal catch rates using standard "control" trawl net and a shortened "test" trawl net on a CTS vessel during commercial fishing operations.

2. Compare total and retained fish catches between the control and test nets.

Material and Methods

Field methods

The trial was undertaken on the commercial fishing vessel Western Alliance, a 25.7 m length trawler, with gross tonnage of 170 t and 500 hp of power.

Two codends were manufactured that were near identical apart from their length. The lengths of the “Short Net” and the “Long Net” from the ground line to the back of the cod-end were 27 m and 39 m respectively. Back-up nets of similar dimensions to the main nets were held in reserve in case of gear loss, or major damage. The back-up Long Net was used, but data from those trips was omitted through the data filtering described below.

Because of the infrequency of seal interactions, a large sample size was required to detect a statistically significant change in seal catch rates. Preliminary power analyses suggested that at least 1000 shots would be needed to have an 80% chance of detecting a 50% decrease in seal interaction rates (at p=0.05). Under normal commercial fishing operations, vessels only usually conduct three or four shots per day. Thus, the carriage of an observer for the entire survey was going to be prohibitively expensive. Instead, the project relied on industry-collected data as the only viable way of collecting sufficient information with the funding available. SETFIA agreed to run the experiment over 12 months, during which time it could be expected that about 1,400 shots would be monitored based on typical annual effort of CTS operators. To introduce accountability and enable verification of the industry monitoring, a video system was installed on the trial vessel. The video system had a sensor attached to the hydraulic system of the net drum that activated it when in operation (setting and hauling). This provided the ability to review landings and ensure reporting of interactions was accurate.

The vessel used in the trial was not under charter so the trials were conducted during normal commercial fishing operations. Ideally, alternate tows of short and long nets (also alternating nets for first shot each day) would be conducted. The vessel has two net drums to enable easy alternation of gear. It was recognised that the practicality of commercial fishing operations meant that this would not always be possible. Causes of interruptions to alternating gear between each shot may include net damage, mechanical failure and suspension of commercial fishing to undertake surveys – all of these occurred. To provide the necessary flexibility, skippers were asked to alternate gear every shot "where practical" and this was recorded to enable the results to be analysed accordingly. There were times when excessive periods of non-alternation were observed, and data from those times was omitted from analysis. This is described more fully in the results section.

All catch, effort and interaction data were collected by skippers and reported via their logbook to AFMA. Prior to the start of the experiment, each net was allocated net identification number. This number was used by fishers to classify which net was used for each shot (the logbook field is titled "Gear No. Net). This delineation enables reporting of catch and TEP interactions to be matched to the different nets. Fishers were also requested to provide as much detail about each interaction on the Listed Marine and Threatened Species forms. Operational data recorded by the skippers in fishing logbooks included depth (average depth in metres), latitude and longitude, start and end time and date. Tow duration (minutes) was calculated from the start and end times, and catch rates (kg/shot and kg/hr) were calculated from the catch of each species or total catch per shot and catch duration. Because of the large area fished by the trial vessel and the shape of the fishing ground along the coast, latitude and longitude are not meaningful factors themselves. For that reason, region was assigned as either "East" or "West", delineated by longitude 147˚. Depth was also assigned as categories "<200 m" or ">200 m" to reflect fishing on the continental shelf and on the slope respectively. Depth could also be considered as a proxy of distance offshore.

To obtain the fishing information for analysis, data requests were made to AFMA for the vessel's commercial logbook and TEP interaction data. Data from 14 February 2013 to 17 August 2014 is used in this report.

Data analysis

The effect of net type and other explanatory variables was examined using GLM. Because seal interaction data was expressed in counts with a very high proportion of zero values, a negative binomial model was used. Factors considered in modelling seal interactions were Net Type, Region, Depth, Tow Duration and Month. The model was fitted using the *glm.nb* function of the R package (http://www.r-project.org/). Model selection was undertaken using the backwards stepwise regression (using the *step* function in the R package). Collinearity in the final model was evaluated using the *vif* function in the *car* package to calculate the variance inflation factor. The same approach was used to models total catch rate and catch rate of main fish species, with the difference that a negative binomial model was not used, and the model was fitted using the *lm* function of the R package. Zero catches of main fish species examined were not included because small catches of individual species are sometimes combined with catches from previous / successive shot and reported once a full bin has been caught. Factors considered in modelling catch rates were the same as for seal interactions.

Results and Discussion

Fishing operations

Because of the diversity of target species, substrate types, depths fished and vessel sizes, a wide range of otter trawl designs are used in the CTS. A recent study found that net lengths used in the CTS, as measured between the codend draw-strings and the headline, ranged 15–50 m (AFMA, 2013). Most nets used were 25–40 m and the most common length was 35 m. The Short and Long nets used were 27 m and 39 m from ground line to the back of the cod-end respectively, equating to headline to codend draw string lengths of about 32 m and 44 m (approximately 5 m overhang on all nets - Brad Cooke, Corporate Alliance Enterprises, pers. comm.). The lengths of nets chosen for the trial represent realistic range of net sizes used in the CTS.

The trial began on 14 February 2013. During 14 February 2013 to 17 August 2014, the Western Alliance recorded 1,117 shots in the commercial logbook, however data filtering was required for a number of reasons. Nets used were alternated for much of the trial period, however there were significant times when either the nets were not alternated, or that the Long Net was alternated with the back-up Long Net (Figure 2). Lack of alternation was largely due to heavy net damage and hydraulic problems that rendered one of the net drums inoperable for some time. The Western Alliance also conducted two different fisheries surveys during the trial period, each time using a standardised survey net (Figure 2). Data from the periods of lack of alternation (317 shots) and during surveys (87 shots) were omitted from analyses. Additional shots were omitted because of incomplete reports of vital information such as net number resulting in a final data set comprising 683 shots.

Of the final 683 shots, the Long Net was used 341 times, and the Short Net 342 times (Table 1). Most fishing was undertaken in the West region, where the Long Net was used slightly more for shallow shots (56%), and the Short Net slightly more for deep shots (54%). In the East region, the Long Net was also used more for shallow shots (57%); very little fishing was undertaken in the deep in that region.

Table 1. Distribution of shots by zone and depth category.

	East	West	Total
<200m			
Long	64 (57%)	75 (56%)	139 (56%)
Short	48 (43%)	60 (44%)	108 (44%)
>200m			
Long	7 (70%)	195 (46%)	202 (46%)
Short	3 (30%)	231 (54%)	234 (54%)
Total	**122**	**561**	**683**

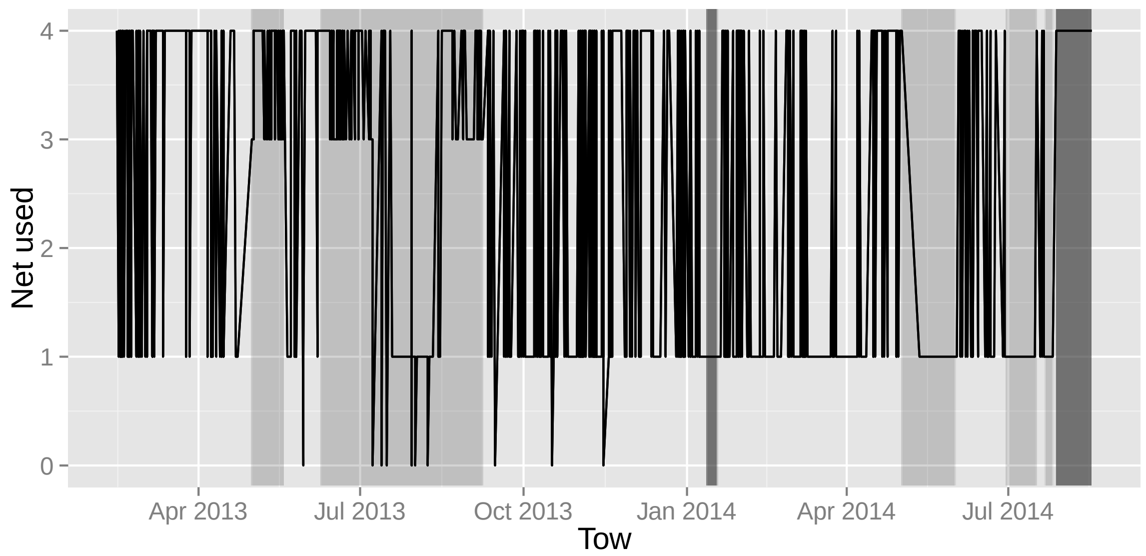

Figure 2. Alternation of net use by skippers on the participating vessel. Nets 1 and 2 were the short net and 3 and 4 the long nets. A value of 0 indicates net number not recorded. Light blocks of shading indicated shots omitted due to lack of net alternation, and dark shading blocks indicate shots omitted due to the vessel undertaking surveys.

Seal Interactions

Interactions with a total of 44 AFSs were recorded during the 1,117 fishing operations conducted by the Western Alliance during 14 February 2013 to 17 August 2014 (Table 2). This information is valuable as it the single-most long-term verifiable reporting of TEP interactions of a vessel in the CTS. Of the total of 44 AFSs, 9 were recorded as released alive, while 35 were dead. A total of eighteen AFSs were recoded as being 4 ft long, seven as 5 or 5.5 ft long and five ranged 6–8 ft long. No length data was recorded for 14 AFSs, but four of those were reported as adults, one as a young adult, and two as juveniles. The sex of only three AFSs was recorded, all being males. 22 AFSs were recorded during periods of non-alternation of nets or fishing surveys, and were thus omitted from analysis of influence of net type on interaction rates.

Of the remaining data that was used for analysis of influence of net type on seal capture, 11 interactions with AFSs were recorded from both Short and Long nets, in 7 and 6 different shots respectively (Table 3) ie there were single shots with multiple AFS capture. Interaction rates for Short and Long nets were both 0.032 AFSs per shot. The proportion of shots in which at least one interaction occurred was 0.020 and 0.018 for Short and Long nets respectively. If the entire dataset is used, the overall interaction rate (proportion of shots with interactions) was 0.026 or 0.039 AFSs per shot.

Published information on seal interaction rates is uncertain and vary from year to year and between data sources. Knuckey *et al.* (2002) found about one seal interaction per 50 shots (about 2%) on average in data from the Independent Scientific Monitoring Program (ISMP). Knuckey and Koopman (2011) reanalysed those data and found that interaction rates (defined as the percentage of shots with at least one interaction) reported by the ISMP were higher during 2000 (2.4%) and 2001 (2.6%) than during the 1990s after major changes to sampling deign and staffing changes. More recently, seal interaction rates from observer data from 2007–2010 ranged 1.9–5.2%, with the increase believed to be related to increasing populations of AFS (Knuckey and Koopman, 2011). This was based on the increasing trend in AFS population size to 2007–08 (of 120,000 seals), the last year in which total population size was estimated (McIntosh *et al*. 2014). Interaction rates (proportion of shots with at least one interaction) from this study are comparable to those reported in previous studies based on observer data, however care must be taken in extrapolating observations of one vessel across the fishery.

The distribution of fishing effort and seal interactions is shown in Figure 3. Most shots were undertaken on the west coast of Tasmania, and this is also where historically most interactions occurred, especially around latitudes 41.0^{o} and 42.5^{o} (Knuckey *et al.* 2002; Tilzey *et al*. 2006). In the eastern region, there was a spread of interactions up the east coast of Tasmania and off eastern Victoria.

Table 2. Records of seal interactions reported by the trial vessel, showing date, whether it was included or omitted from analyses looking at the influence of net type, if it was omitted the reason for the omission, location, number of seals, life status, sex, size of seals and comments. * Denotes that there were multiple lines on TEP sheet for a single shot. # Denotes probable error in recoding or keypunching of position.

Date	Treatment	Reason omitted	Latitude	Longitude	# Seals	Life status	Sex	Size	Comment	Net
18/02/13	Included		-43.48333	147.9	1	Dead	Male	6ft	Vessel was stationary for some time before setting, allowing seals to come close.	Long
27/03/13	Included		-43.73333	147.63333	1	Dead	Male	Juvenile 5.5ft		Short
30/03/13	Included		-38.8	148.3	1	Dead	Male	Juvenile 4ft	Caught while towing	Long
1/05/13	Omitted	Sequence	-41.15	148.61667	1	Dead	Unk	juvenile 5ft	No seals seen in area	Short
3/05/13	Omitted	Sequence	-40	148.76667	1	Dead	Unk	Juvenile 4ft	No seals seen in area	Long
19/05/13	Omitted	Sequence	-38.73333	148.3	1	Dead	Unk	juvenile 5ft	Seals seen during setting. Rough weather.	Long
3/07/13	Omitted	Sequence	-41.43333	144.36667	2	Alive	Unk	Adults	Released unharmed.	Short
30/07/13	Omitted	Sequence	-41.56667	144.43333	2	Dead	Unk	Unknown		Short
31/07/13	Omitted	Sequence/no depth	-41.51667	144.38333	1	Alive	Unk	Unknown	Jump overboard immediately.	Short
11/08/13	Omitted	Sequence	-41.9	144.55	1	Dead	Unk	Unknown	Caught while hauling	Short
14/08/13*	Omitted	Sequence	-41.66667	144.43333	1	Dead	Unk	5ft	Caught on setting. Rough weather.	Long
14/08/13*	Omitted	Sequence	-41.66667	144.43333	1	Alive	Unk	5ft	Caught on setting	Long
22/08/13	Omitted	Sequence	-41.96667	144.55	1	Alive	Unk	Young adult.	Rough weather. Lots of seals around. Jumped overboard immediately.	Long
29/08/13*	Omitted	Sequence	-41.75	144.56667	1	Dead	Unk	6-8ft		Long
29/08/13*	Omitted	Sequence	-41.75	144.56667	2	Alive	Unk	6-8ft	Returned unharmed.	Long
5/09/13	Omitted	Sequence	-41.91667	144.56667	2	Dead	Unk	Juvenile		Long
6/09/13	Omitted	Sequence	-41.83333	144.53333	1	Dead	Unk	4ft		Long
9/11/13	Included		-41.56667	144.4	1	Dead	Unk	Unknown		Long
12/11/13	Included		-40.95	143.8	1	Dead	Unk	Unknown		Short
8/12/13	Included		-39.48333#	146	1	Dead	Unk	4 ft	No seals seen in area. Calm weather.	Long
12/12/13	Included		-43.31667	145.55	2	Dead	Unk	5.5 ftand 4 ft	Rough weather.	Short
20/12/13	Included		-38.85233	148.317	2	Dead	Unk	4 ft	Calm weather.	Short
5/06/14	Included		-37.1555	138.8405	1	Dead	Unk	4 ft	Caught while setting. Net changed - logbook said short, TEP sheet said long. Believed TEP sheet.	Long
6/06/14	Included		-37.2685	139.15183	2	Dead	Unk	4 ft and 5 ft	No seals seen in area while setting or hauling.	Short
19/06/14	Included		-41.78433	144.51983	6	Dead	Unk	2 adult, 4 juvenile.	Have caught seal here in the past.	Long
20/06/14	Included		-42.63383	144.87183	1	Alive	Unk	Juveline, 4 ft	Caught while hauling, maintained low revs and loose net to allow it to breath. Took 5 mins to return to water unharmed.	Short
8/07/14	Omitted	Sequence	-42.07	144.69017	1	Alive	Unk	Unknown		Short
20/07/14	Included		-41.972	144.57733	2	Dead	Unk	Juveniles, 4 ft		Short
2/08/14	Omitted	Survey	-37.09667	150.32233	1	Dead	Unk	Juveniles, 4 ft	Lots of seals around. Tried to avoid them by keeping gear moving during setting / hauling.	Survey
5/08/14	Omitted	Survey	-39.22417	148.579	1	Dead	Unk	Juveniles, 4 ft	No seals seen in area.	Survey
15/08/14	Omitted	Survey	-41.09717	148.571	1	Dead	Unk	Adult, 6 ft.	Smelt bad, possibly already dead.	Survey

Table 3. Number of seals caught and number of shots with seals. Interaction rates are in parenthesis.

Net	Number of shots	Number of seals	Number of shots with seals
Short net	342	11 (0.032)	7 (0.020)
Long net	341	11 (0.032)	6 (0.018)
Grand Total	683	22 (0.032)	13 (0.019)

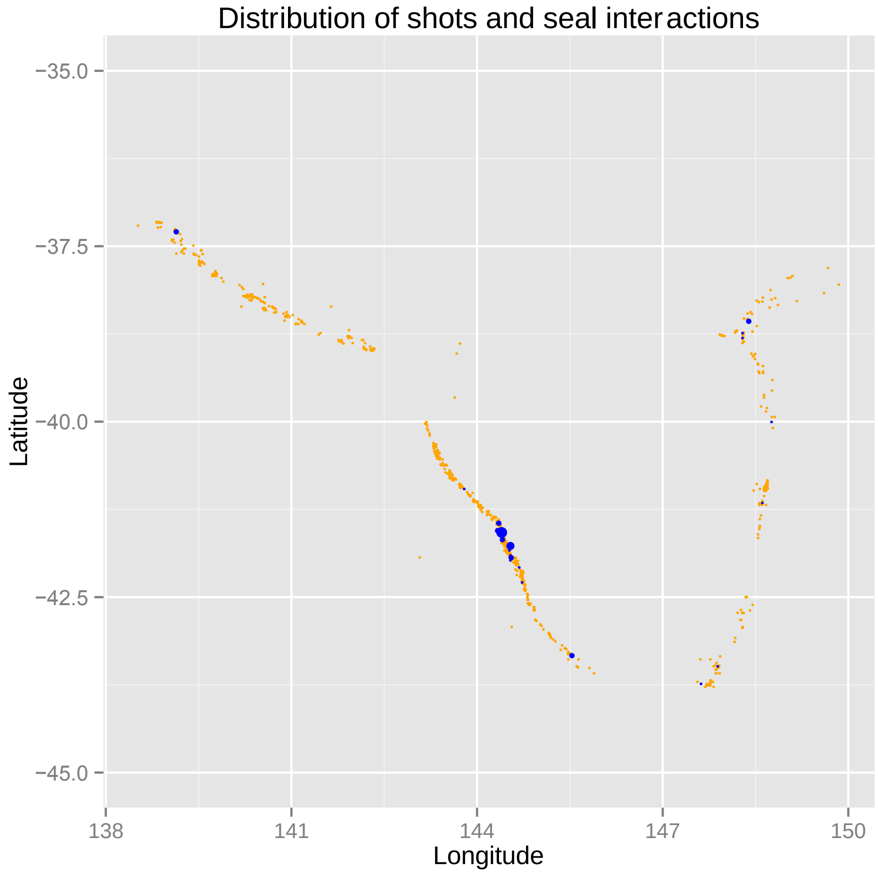

Figure 3. Distribution of shots undertaken (in the complete dataset) shown in yellow, with seal interactions shown in blue — the size of the point indicates number of interactions. Note that some shots with obvious errors in latitude and longitude were omitted from his figure.

Influence of Factors on Seal Interactions

Analysis of the influence of a range of explanatory variables including Net Type was undertaken using a negative binomial General Linear Model (GLM) on the filtered dataset. During stepwise regression, Net Type was omitted from the model during the first step (Table 4) suggesting that it had little influence on seal interactions. The final model included the explanatory variables Tow Duration, Month and Depth. Of those, Depth was the only significant factor (Table 5). There was no indication that the variables included in the final model were collinear, as all VIFs were smaller than 1.6 — Heiberger and Holland (2004) suggested the threshold for avoiding collinearity problems is 5.

Results obtained provide no evidence to suggest that the use of the Short Net reduced AFS interactions. The numbers of AFSs caught by each net were identical, and the number of shots with AFSs was slightly higher for the Short Net but not significantly different. During stepwise model selection, Net Type was removed from the full model during the first step. We must note however that for a variety of reasons, the sample size was lower than anticipated, but because there was no indication of an effect and because the trial somewhat inconvenienced a commercial fishing operation, the trial was ended before 1000 valid shots were reported.

The complete dataset (including shots omitted because of lack of alternation of net types but not survey data) was also modelled to examine the effect of potential explanatory variables other than Net Type. These data included interactions with 40 AFSs after removal of four interactions due to surveys and missing data. The reduced model included only Month and Depth (Table 4), of which Month was the only significant factor (Table 6).

Of the factors considered, results suggest that Depth and Month are the most important factors influencing seal interactions. Depth comprised two levels (<200 m and >200 m) with the mean interaction rate at <200 m more than twice as high as >200 m (Figure 4), reflecting the foraging behaviour of AFSs which is predominantly restricted to shelf waters (Kirkwood *et al*., 2006). Mean seal interaction rates were low during January–May and highest during June – September as well as December (Figure 4). Lyle and Wilcox (2008) similarly found much higher interaction rates between seals and the Small Pelagic Fishery during winter months, who suggested that it was possible that observed seasonality in interaction rates was to some extent influenced by learning and habituation.

Table 4. AIC values for CPUE of each model tested during model selection. The final models selected are in bold. * denotes the final model selected from data that included previously omitted shots.

Models	AIC
Number of Seals ~ net +region + duration + month + depth	160.89
Number of Seals ~ region + duration + month + depth	158.89
Number of Seals ~ duration + month + depth	**157.35**
Number of Seals ~ month + depth*	

Table 5. Results of statistical analysis for seal interactions; p < 0.001*, p < 0.01** and p< 0.05*.**

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-4.792	1.210	-3.961	***
Depth	-0.005	0.002	-2.500	*
Minutes	0.006	0.004	1.642	
Month	0.147	0.087	1.683	

Table 6. Results of statistical analysis for seal interactions with data that included previously omitted shots; p < 0.001*, p < 0.01** and p< 0.05*.**

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-3.817	0.675	-5.658	***
Depth	-0.002	0.001	-1.910	.
Month	0.206	0.075	2.755	**

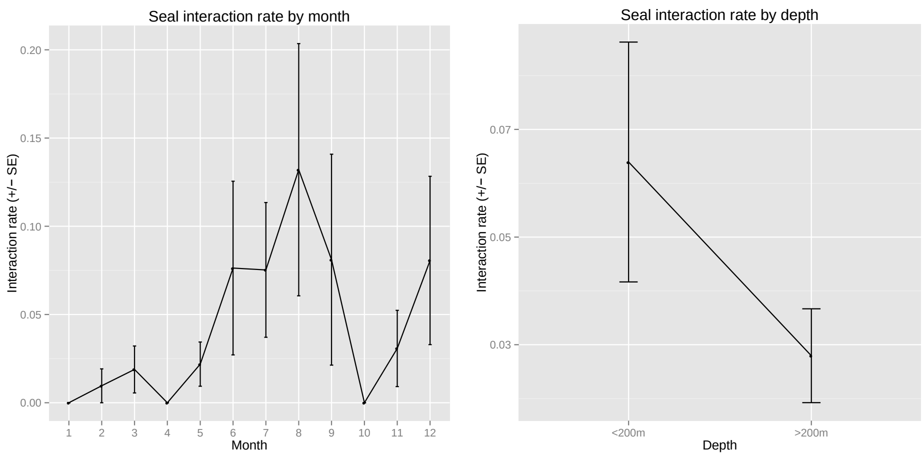

Figure 4. Mean (± se) seal interaction rate by month (left panel) and depth (right panel). Note data includes complete data set including shots omitted in some analysis because of non-alternation of nets.

Fish catch rates and catch composition

In most area / depth combinations there appears to be no consistent difference in average catch rates between nets (Table 7, Figure 5). If there are any differences, they are inconsistent across zones and areas. On average, catch rates (kg/shot) of the Short Net were higher in <200 m in the East, and in >200 m in the West, however when shot duration is taken into account, average catch rates (kg/hour) was slightly higher in >200 m depth in the West (Figure 6). Average catch rates were very similar at <200 m depth in the West, and higher in >200 m in the East (although sample size is very small). For example, in shallow shots (<200 m) off Eastern Tasmania and Eastern Victoria, and in deep shots (>200 m) off Western Victoria, the Short Net appears to have slightly higher catch rates, while the opposite is true for shallow shots of Western Victoria.

There was very little difference in catch composition between nets in <200 m depth in the East, with both nets catching mostly Jackass Morwong, Flathead, Gould's Squid and Stargazer (Figure 7). There were some difference in catch composition in <200 m in the West where Butterfly Gurnard comprised the greatest portion of the catch (20%) by the Short Net, but this species was not in the top five species by the Long Net. Red Gurnard, Jackass Morwong and Spotted Warehou were all in the top five species of both nets caught in >200 m in the West.

Pink Ling comprised the greatest proportions of catches by both nets in >200 m in the East, and Blue Grenadier and Mackerel comprised the second greatest proportions of catches by Long and Short nets respectively (Figure 8). Spotted Warehou and Mirror Dory were both important consonants of the catch of both nets in the East. Catch composition of nets was very similar in >200 m in the West, with Blue Grenadier and Spotted Warehou and Ling the top three species, and Ribaldo fourth and fifth for the Short and Long nets respectively.

Catch rates (kg/hour) for main species caught by each net in <200 m are shown in Figure 9. In the East, average catch rates were higher for Flathead and Gould's Squid by the Short Net, and in the West, average catch rates were higher for Butterfly Gurnard by the Short Net, but higher for Spotted Warehou and Gould's Squid by the Long Net. Catch rates (kg/hour) for main species caught by each net in >200 m are shown in Figure 10. Sample sizes in the East are too small to enable meaningful comparison. In the West, catch rates were similar for most species, however the average catch rate of Blue Grenadier was much higher by the Long Net, but there was a large amount of variability in catch rates of that species by the Long Net.

Table 7. Average catch (kg/shot + SE) of each net by zone and depth category.

Depth	Zone	Short net	Long net
<200 m	East	481 (48)	388 (36)
>200 m	East	117 (22)	229 (52)
<200 m	West	527 (47)	583 (65)
>200 m	West	803 (54)	678 (41)

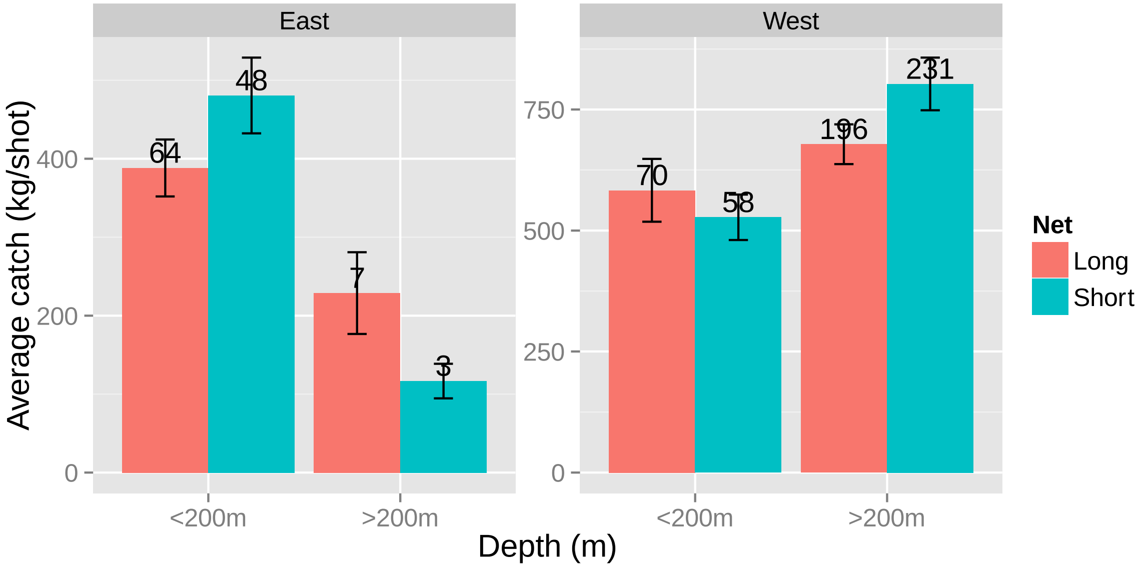

Figure 5. Average total catch rate (kg/shot ± se) for each net in the East and West. Number of shots is shown annotated.

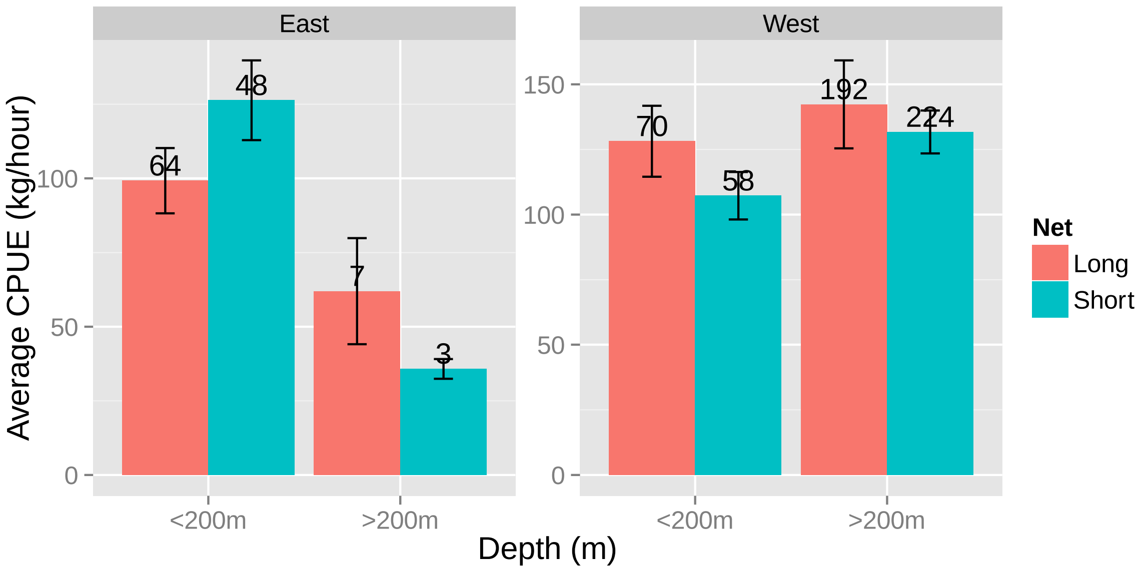

Figure 6. Average total catch rate (kg/hour ± se) for each net in the East and West. Number of shots is shown annotated.

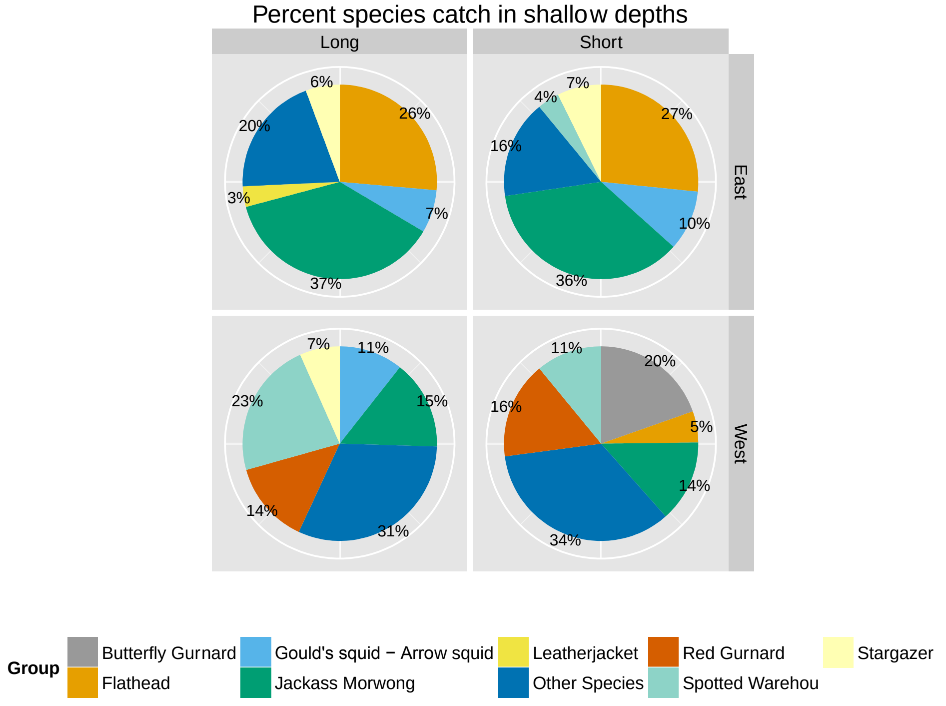

Figure 7. Percent catch composition of each net from shallow depths in the eastern and western regions.

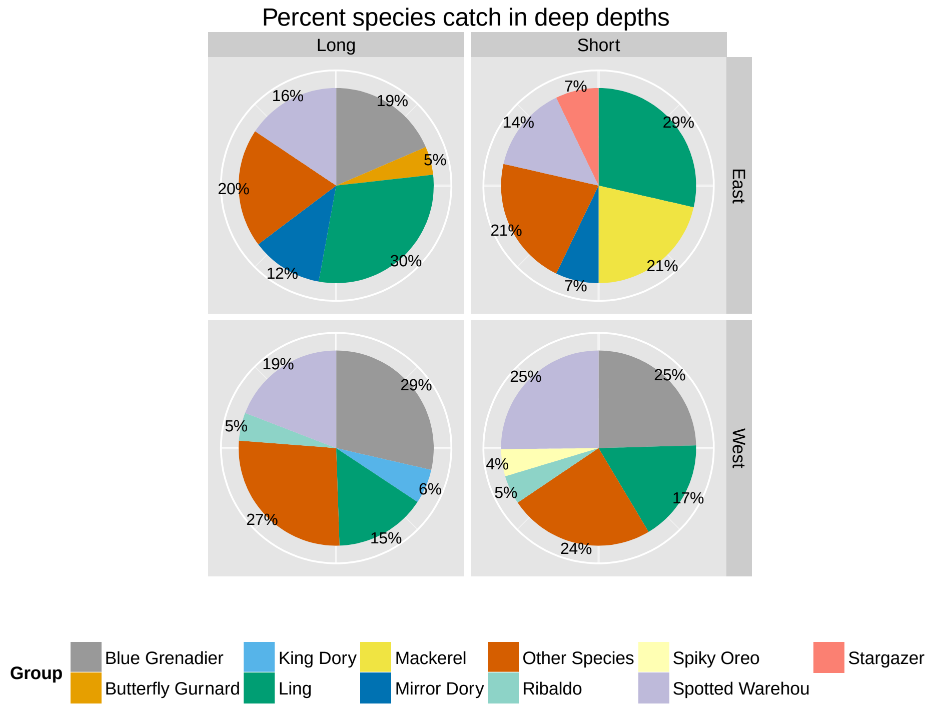

Figure 8. Percent catch composition of each net from shallow depths in the eastern and western regions.

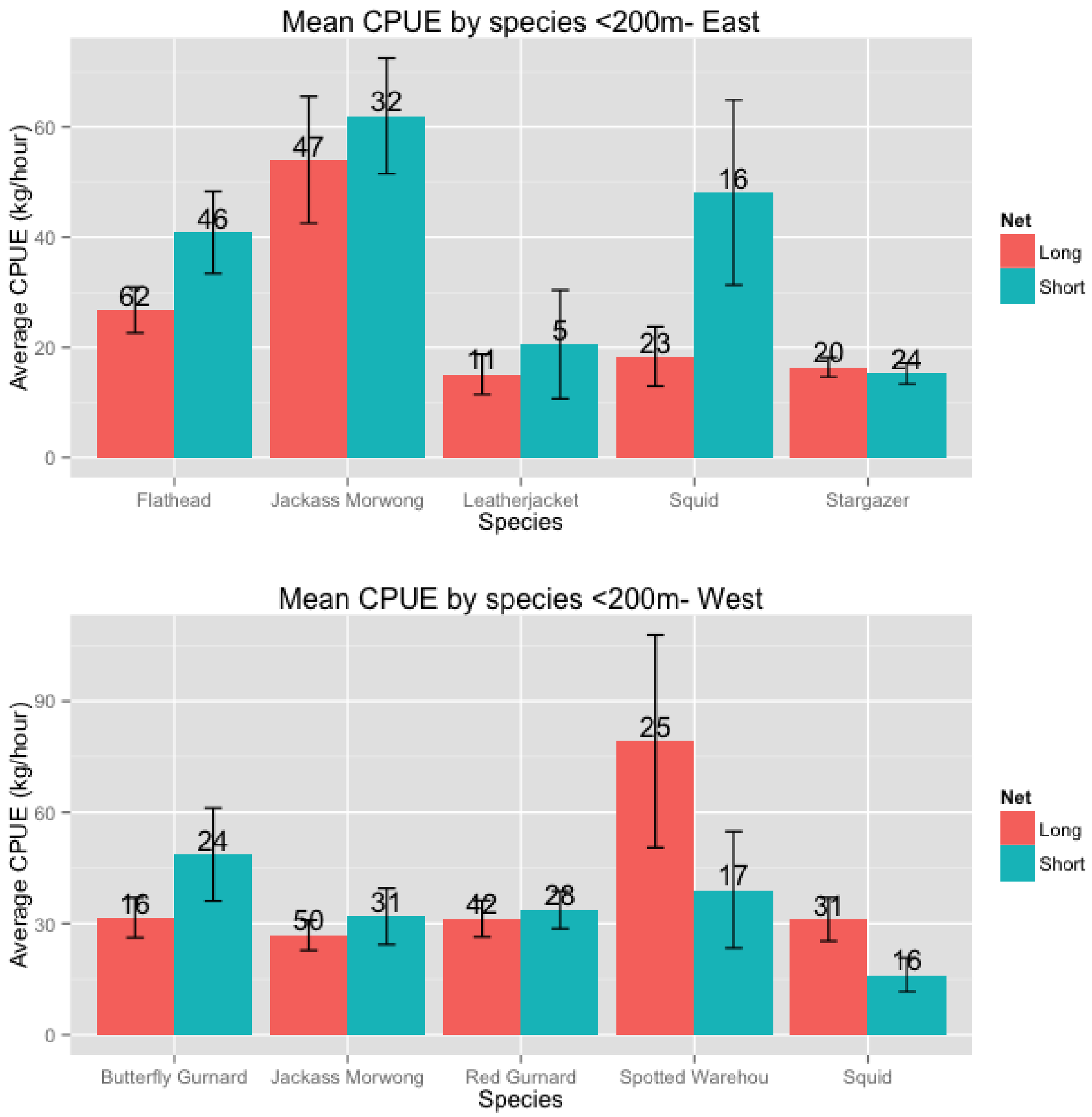

Figure 9. Average catch rate (kg/hour + se) for main species by each net in <200 m depth. Number of shots is shown annotated.

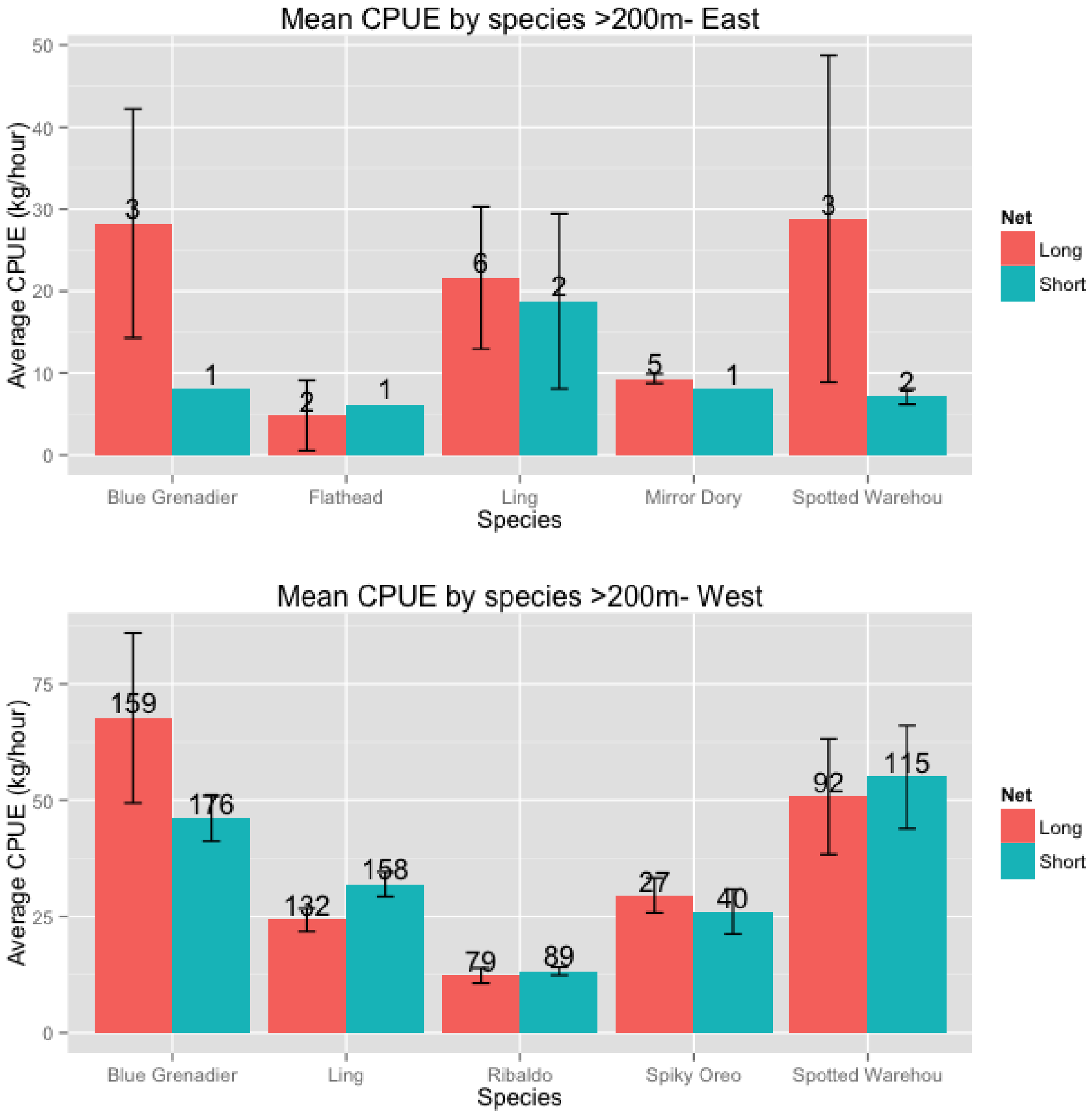

Figure 10. Average catch rate (kg/hour ± se) for main species by each net in >200 m depth. Number of shots is shown annotated.

Influence of Factors Fish Catch

The influence of a range of explanatory variables including Net Type of total catch and catch of main species was undertaken using GLM on the reduced dataset (with shots removed for non-alternation and surveys). Final models resulting from the backward model selection procedure are shown in Table 8. Net Type was retained in the final models for Stargazer, Jackass Morwong, King Dory and Pink Ling, and GLM results indicate a significant effect for all except King Dory (Table 9). The positive coefficient estimates for Jackass Morwong and Pink Ling indicate that catch rates were high by the Short Net for those species, while the negative estimates for Stargazer and King Dory indicate catch rates were higher by the Long Net. Most common factors in final models are shot duration (13 models) and month (11 models). Depth and region would most likely have had a greater influence on results if zero catches had of been included.

Conclusion

While there was evidence to suggest that there was some influence of Net Type on fish catch rates varied for species, no one net provided overall higher catch rates. Results of this study show no definitive proof that short nets had fewer interactions with seals, caught fewer seals, or resulted in a lower rate of mortality of caught seals.

Table 8. Reduced models for CPUE of all species combined and main species. * denotes species for which there was no data for the eastern region, and so region was removed from the full model. The full model was log(CPUE) ~ net +region + duration + month + depth

Species	Final models
Total catch	log(CPUE) ~ region + duration + month
Blue Grenadier	log(CPUE) ~ region + duration + depth
Squid	log(CPUE) ~ region + duration + month + depth
Leatherjacket	log(CPUE) ~ region
Red Gurnard	log(CPUE) ~ region + duration + month
Stargazer	log(CPUE) ~ net +duration + month + depth
Flathead	log(CPUE) ~ region + duration + depth
Jackass Morwong	log(CPUE) ~ net + region +duration + month
Spotted Warehou	log(CPUE) ~ region + duration + month
King Dory	log(CPUE) ~ net +region + duration + month + depth
Mackerel	log(CPUE) ~ duration + month
Spikey Oreo*	log(CPUE) ~ month
Ling	log(CPUE) ~ net + region + duration + month+ depth
Mirror Dory	log(CPUE) ~ region + duration + month
Ribaldo*	log(CPUE) ~ duration + depth

Table 9. Results of statistical analysis for total catch and ten main species; p < 0.001*, p < 0.01** and p< 0.05*.**

	Coefficient	Estimate	Std. Error	t value	Pr(>|t|)
Total catch	(Intercept)	4.739	0.103	45.938	***
	Region	0.363	0.081	4.489	***
	Duration	-0.001	0.000	-4.699	***
	Month	-0.014	0.008	-1.789	
Blue Grenadier	(Intercept)	3.899	0.493	7.900	***
	Region	1.640	0.489	3.352	***
	Duration	-0.004	0.001	-5.368	***
	Depth	-0.002	0.001	-3.394	***
Squid	(Intercept)	3.770	0.409	9.212	***
	Region	1.081	0.319	3.392	***
	Duration	-0.003	0.001	-2.168	*
	Month	-0.159	0.040	-3.996	***
	Depth	-0.002	0.001	-1.843	
Leatherjacket	(Intercept)	2.481	0.193	12.836	***
	Region	-0.484	0.262	-1.843	
Red Gurnard	(Intercept)	0.540	0.336	1.607	
	Region	1.138	0.242	4.707	***
	Duration	0.003	0.001	2.100	*
	Month	0.088	0.028	3.112	**
Stargazer	(Intercept)	2.589	0.296	8.745	***
	Net	-0.330	0.145	-2.274	*
	Duration	0.002	0.001	2.052	*
	Month	-0.041	0.022	-1.816	
	Depth	-0.002	0.001	-3.503	***
Flathead	(Intercept)	4.052	0.284	14.262	***
	Region	-0.374	0.167	-2.238	*
	Duration	-0.002	0.001	-2.189	*
	Depth	-0.005	0.001	-3.421	***
Jackass Morwong	(Intercept)	4.125	0.388	10.640	***
	Net	0.405	0.204	1.985	*
	Region	-0.364	0.209	-1.744	
	Duration	-0.003	0.001	-2.578	*
	Month	-0.041	0.026	-1.570	
Spotted Warehou	(Intercept)	2.251	0.338	6.667	***
	Region	1.814	0.296	6.136	***
	Duration	-0.003	0.001	-2.991	**
	Month	-0.053	0.028	-1.925	
King Dory	(Intercept)	1.077	0.737	1.462	
	Net	-0.190	0.099	-1.919	
	Region	1.125	0.685	1.642	
	Duration	-0.003	0.001	-4.289	***
	Month	-0.027	0.015	-1.882	
	Depth	0.002	0.001	3.549	***
Mackerel	(Intercept)	0.588	0.589	0.999	
	Duration	0.002	0.002	1.386	
	Month	0.107	0.030	3.533	**
Spikey Oreo	(Intercept)	3.580	0.193	18.564	***
	Month	-0.158	0.046	-3.408	**
Ling	(Intercept)	2.488	0.343	7.254	***
	Net	0.322	0.109	2.946	**
	Region	0.497	0.313	1.587	
	Duration	-0.001	0.001	-1.464	
	Month	0.082	0.016	4.954	***
	Depth	-0.001	0.001	-1.476	
Mirror Dory	(Intercept)	2.828	0.466	6.072	***
	Region	0.691	0.381	1.816	
	Duration	-0.003	0.001	-2.271	*
	Month	-0.078	0.036	-2.167	*
Ribaldo	(Intercept)	2.804	0.478	5.871	***
	Duration	-0.003	0.001	-2.259	*
	Depth	0.001	0.001	1.020	

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