New branch line weighting regimes to reduce seabird mortality in the Australian pelagic longline fishery

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Abstract

Concern by Australia's pelagic longline fishing industry about the effect on target fish catch rates of the amount of weight in branch lines and the proximity of weight to the hook, has restricted adoption of gear with faster sink rates that reduces the incidental capture of seabirds. Trials of two new branch line weighting regimes involving custom-made lead weights were conducted to determine effects on catch rates of target and non-target fish species. There were no statistically detectible differences in the catch rates of the main target and non-target fish species between branch lines with 60 g lead weights 3.5 m from hooks (the fishing industry standard) and those with either a 120 g lead weight ≤ 2 m from the hook or a 40 g lead weight placed at the hook. Branch lines with 40 g weights at the hook – which have the greatest potential to be adopted in the fishery - commenced sinking immediately upon deployment and took, on average, 4.5 seconds (0.43 m/s) to reach 2 m depth, 33 % less time than industry standard gear. The 40 g leads placed at the hook also improved crew safety, reduced the amount of time spent in gear construction and facilitated gear inspection for compliance purposes. The findings provide the fishing industry with new line weighting options that have the potential to reduce seabird bycatch without affecting target fish catch.

1. Introduction

The Australian Antarctic Division and Australian Fisheries Management Authority recently completed two line weighing trials of relevance to Australian and other pelagic longline fisheries. Three major seabird bycatch mitigation measures are currently required in Australia's pelagic longline fisheries; the measures are line weighting, bird scaring streamer lines and the retention of offal during setting. Night setting is also used in some areas on occasions. These measures used in combination are also considered 'best practice' by the Agreement on the Conservation of Albatrosses and Petrels (ACAP, 2011) and meet or exceed those required by Regional Fisheries Management Organisations responsible for managing high seas tuna fisheries. Despite the use of these mitigation measures, a generally low level of intermittent seabird bycatch has continued to occur in Australian pelagic longline fisheries, indicating that the current measures are not fully effective in all conditions and that further research was needed on ways to improve their effectiveness.

Improvements to line weighting regimes were considered the likely best way to improve the effectiveness of bycatch mitigation and thus the best focus for further research; there were several reasons for this. For reasons related to operational flexibility and fishing efficiency, most fishers prefer to set lines at the timing of their choice rather than be restricted to night setting only. Additionally, while night setting can greatly reduce albatross bycatch, it is much less effective at preventing bycatch of seabird species which feed at night; by contrast, line weighting remains effective at night. With respect to streamer lines, observer records indicate that streamer line configurations can fall short of the required specifications, especially in respect of the aerial extent achieved (short aerial extents limit effectiveness in deterring seabirds). While such deficiencies can be addressed through education and compliance activities, including aerial surveillance and greater use of at-sea inspections or observers, these activities are costly. In contrast, ensuring compliance with line weighting is relatively simple and cheap. Once lead weights are built into the branch lines they become an intrinsic part of the fishing gear. Compliance can be monitored by port-based inspection of branch lines in gear bins before and after fishing trips. Finally, the known effectiveness of line weighting in deterring seabirds, suggested that line weighting should be the subject of further research aimed at reducing seabird mortality in the fishery.

The first trial compared branch lines configured with 60 g leaded swivels ≤ 3.5 m from hooks, as currently required by permit conditions (hereafter referred to as the industry standard), with branch lines configured with 120 g ≤ 2m from hooks. This trial was recommended by Robertson et al. (2010) following research to improve understanding of the effect of a range of factors (bait species and life status, sinker weight, bottom end length) on the sink rates of baited hooks. The second trial compared the industry standard with 40 g weights at the hook. Because both trials were conducted from Mooloolaba, Queensland (a collaborator could not be found south of 30^{o}S), which is an area of relatively low abundance of longline-vulnerable seabirds, we were unable to collect data on seabird interactions. Hence the objective of the trials was to determine the effect, if any, of line weighting regimes designed to sink hooks faster than the industry standard on the catch rates of target and non target fish species. In the event that no effects could be detected an important impediment to the adoption of fast sinking gear would be removed. Assessment of likely benefits of the new line weighting regimes to seabird conservation were based on comparison of the hook sink profiles/rates of the regimes used in the fish catch trials.

Here we report the results of the two trials. Most emphasis is given to the 40 g hook lead trial because of the greater potential for these leads to be adopted in the Eastern Tuna and Billfish Fishery (ETBF), Australia's major pelagic longline fishery.

2. Methods

2.1. Understanding hook sink profiles

Because seabirds were in low abundance during the trials, inferences about potential conservation benefits to seabirds must be drawn from the sink profiles. To do this we first must understand the influence of line weighting on the sink characteristics of baited hooks. The following information is drawn from Robertson et al. (2010).

The sink profile of tuna hooks varies depending on the weight (typically a leaded swivel) and the length of the bottom end (distance between weight and hook) of the branch line. Hooks on branch lines with long bottom ends sink in two distinct two stages – slow initially then faster. The initial sink rate is slow because the weight does not fully engage with the hook until the bottom end is pulled taut by the sinking weight. Until that occurs the effect of the weight is minimal. Several seconds could elapse between when baited hooks land in the water and when the bottom end becomes taut, with the exact duration depending on the length of the bottom end, mass of the weight and amount of drag caused by the bait. For any given weight, the longer the bottom end, the slower the initial sink rate. Baited hooks that sink slowly initially remain on or near the surface for longer and are more likely to be attacked by seabirds than those that sink quickly from the surface. Ideally, gear should sink as fast as is practicable (for fishing operations) with a linear profile (i.e. sink rate) from the surface until the branch line becomes taut on the mainline. Fast initial sink rates are achieved by placing an appropriate amount of weight at – or very close to – the hook.

2.2. General: fishing vessel and gear

Both trials were conducted on the F/V *Samurai*, which is a 20-m fiberglass planning hull "Westcoaster". The *Samurai* operates out of Mooloolaba (26.68ºS; 153.1ºW) in south-eastern Queensland, Australia. The *Samurai* set a 3.2 mm monofilament mainline through a line shooter to vary the depths targeted. The mainline was suspended on floats on a mix of 10 m and 20 m droppers. Branch lines were 1.8 mm monofilament nylon and 16 m long. Bait was a mix of squid (*Illex argentines*) and pilchard (*Sardinus pilchardus*). All baits were dead. Branch lines with squid bait were always accompanied by a light stick placed 2 m from hooks. Light sticks were never used with pilchard bait. A typical set on the *Samurai* involved deploying 1,200-1,450 hooks at 8 knots vessel speed with 10 branch lines between floats and branch lines

35 m apart. Branch lines were set from bins every eight seconds off both sides of the vessel. Radio beacons were deployed every 200 hooks.

2.3 Trial design

2.3.1. 120 g at 2 m versus 60 g at 3.5 m

This trial, hereafter referred to as the 120 g trial, was conducted over six fishing trips and 30 sets of the longline between March and December 2010. The design involved setting gear in pairs with each pair comprising 200 branch lines with 60 g weights at 3.5 m from the hook and 200 branch lines with 120 g at 2 m from the hook. Each group of 200 branch lines was flanked by a radio beacon. Three pairs – i.e., 1,200 branch lines in total – were deployed in each set of the longline. The order in which weighting regimes were set was alternated between sets to avoid systematic bias associated with setting order. ‘Sleeves’ and ‘skirts’ (considered to attract fish) were distributed randomly thought the branch lines and some branch lines were not equipped with either. Sleeves are 10 cm x 0.5 cm tubes of fluorescent rubber latex fitted tightly over branch lines immediately above the hooks. Skirts are placed in the same position and comprise a rosette of multi-coloured rubber latex strands that resemble squid tentacles and designed to dangle over the top section of the hook. At the start of the trial the proportion of the 600 branch lines with 120 g at 2 m fitted with sleeves, skirts or nothing was 38%, 21% and 41%, respectively. The equivalent figures with 60 g at 3.5 m were 54%, 21% and 25%. By the third set of the first trip of the trial the gear had been re-configured so that the proportions were equal for both gear types and those proportions were maintained for the remainder of the trial. Bait species – squid alone, pilchard alone or an even mixture of both - and setting depth were kept constant within pairs but occasionally changed between pairs. Light sticks were attached 2 m from hooks to all branch lines with squid bait but never to branch lines with pilchard baits. The 120 g weights were ‘safe’ leads (weights designed to avoid recoiling if a branch line breaks suddenly during hauling; see Sullivan, et.al*.,* submitted) and were custom made for the trial (Figure 1). The main species targeted in this trial were yellow-fin tuna (*Thunnus albacores*) and big-eye tuna (*T. obesus*).

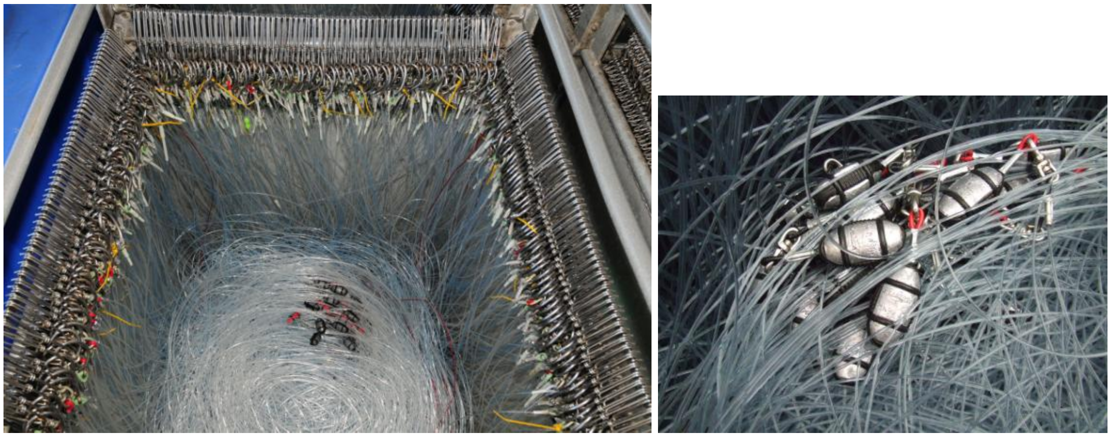

Figure 1. Branch line bin of the F/V Samurai *as used in the 120 g trial (left). Clips (one end of the branch line) are attached to horizontal runners around the top of the bin and hooks (the other end of branch lines) are suspended from the clips. The branch lines joining clips and hooks are coiled in the bin along with the line weights. Some branch lines shown are fitted with sleeves adjacent to the hooks. The yellow cable ties shown were attached for the trial and are not a normal part of the fishing gear. The weights in the photo on the left are 60 g safe leads. The 120 g 'safe' leads weights used in the trial are shown in the photo on the right.*

The variables recorded on each weighting regime during line sets were time of deployment of radio beacons associated with each group of 200 hooks (allows estimation of the time lines were in the water fishing). The variables recorded during line hauling were the taxa of all fish caught, time of landing, fate, life status, length and sex.

2.3.2. 40 g hook lead versus 60 g at 3.5 m

This trial (hereafter called the 40 g hook lead trial) involved the development of a new type of lead weight designed to be placed at the hook. Two prototype versions were available for the trial – 40 g and 60 g. Both weights are identical except that the end of the 40 g version is rebated (i.e., hollow) to fit over the crimp whereas the 60 g version is flat-ended and abuts the crimp. The weights are screw-tightened by hand onto the monofilament and are capable of sliding in the same manner as 'safe' leads. They are coated with 2 mm luminescent nylon and glow in the dark (Figure 2). The 40 g weights were chosen for the trial following comparison of the sink profiles of various weighting regimes in still seawater (Appendix 1).

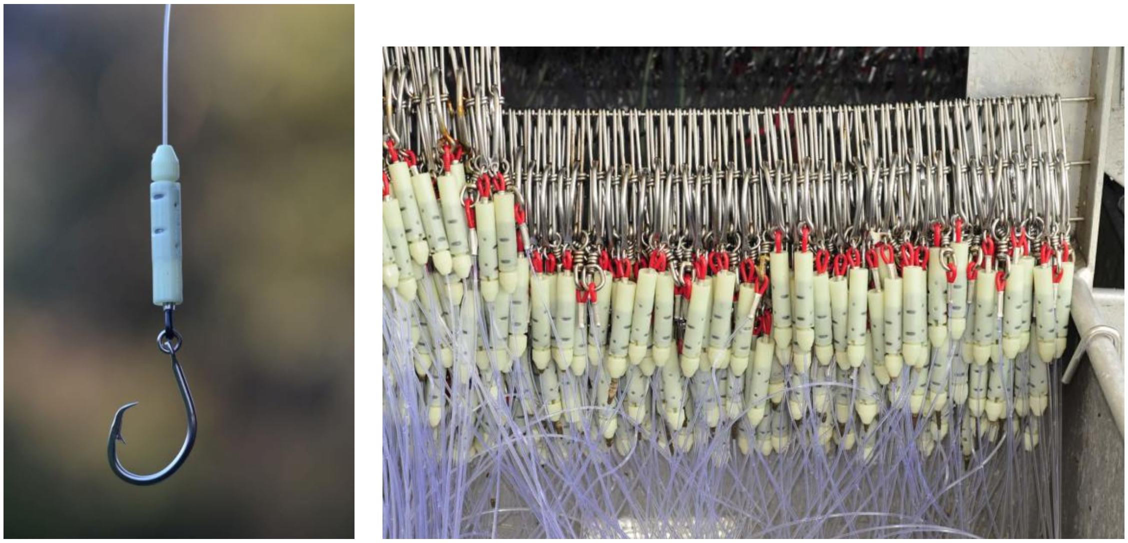

Figure 2. A 40 g hook weight and a # 14/0 circle hook showing the luminescent nylon coating and its position on the branch line (left). The lower one-third of the lead is rebated to fit over the crimp. The photo on the right shows 40 g weights attached to layers of branch lines in a gear bin.

The hook lead trial ran from February to November 2011 and involved a total 10 fishing trips and 53 sets of the longline. The design of this trial followed that for the 120 g trial except that instead of alternating between groups of 200 branch lines of each weighting regime the two regimes were alternated with each consecutive branch line deployed. The fishing gear and its specifications, bait species and the number of branch lines deployed in sets were the same as for the 120 g trial. Before the first set of each fishing trip, 200 branch lines were counted to determine the proportion of hooks with skirts, sleeves or were plain ended. Skirts and sleeves were only fitted to 60 g gear, not to branch lines with 40 hook leads, and were phased out of the gear throughout the trial. The use of light sticks was consistent between weighting regimes. Light sticks were always attached to branch lines with squid bait and occasionally (rarely) to branch lines with pilchard baits. On sets with light sticks, blue, green, pink, white light sticks were deployed in equal numbers. As in the 120 g trial the main species targeted were yellow-fin tuna and big-eye tuna.

2.4. Estimating hook sink rates

The sink rates of the two weighting regimes compared in the trial – 40 g at the hook and 60 g at 3.5 m – were estimated from the *Samurai* on 21 November under charter conditions (all extraneous factors controlled). The sink rate of gear with 60 g at the hook and 60 g at 1 m from the hook was also assessed. The first regime was included in case faster sink rates are required in the future as a seabird deterrent option south of 30^{o}S., and the second regime was included as a potential option to reduce the number of leads lost due to shark bite offs. A total of 10 branch lines of each of the four weight configurations were purpose built for the trial from new materials. Branch lines were 14.5 m total length and fitted with # 14/0 circle hooks (15 g). Dead pilchard hooked through the eye was used as bait. Three radio beacons were deployed at the start of the longline to prevent dragging. Branch lines were deployed by one crew member to consistently land 2-3 m outside the wake zone on the starboard side of the vessel. Branch lines were deployed in groups of four – one branch line of each of the four regimes – throughout each set to minimise the chances of bias associated with setting order. Each branch line was deployed three times using three sets of the longline (30 replicates/weight regime). Floats on 7 m dropper lines were deployed every eight hooks (following every second group of the four different weighting regimes). Vessel setting speed averaged 6.8 knots. The mainline was set through a line shooter in the surface set tight configuration (see Robertson et al., 2010b) and entered the water 25-30 m astern beyond the main area affected by propeller turbulence. Sink rates were estimated with Cefas G5 time-depth recorders (2 g in water, 3 cm resolution) attached to branch lines < 10 cm from the hook and programmed to record time and depth at 1 second intervals.

2.5. Gear loss and line repairs

Leads at the hook are more vulnerable to being bitten off by sharks than leads located away from the hook. The number of leads of each type that were lost from bite offs was recorded in 23 hauls over five fishing trips (trips 6-10). The number of branch lines of each weighting regime that required maintenance was also recorded. The reasons branch lines of both weighting regimes required repair were hook loss (from bite-offs), chafing of the monofilament near the hook (occurs when sharks rub against the line under tension) and kinks caused by the incorrect attachment of light sticks.

2.6. Statistical methods

For both the 120 g trial and 40 g hook lead trial, the fish counts were analysed as a Poisson generalized linear mixed model (GLMM) with log link (see Robertson et al. 2006) using the R-software (R Development Core Team, 2008) and the ASREML-R library (Gilmour *et al*. 1999). This approach uses penalised quasi-likelihood to carry out the estimation. For each trial the number of each species (or species group in the case of sharks) caught was tabulated for treatment combinations within trip and set within trip combinations. The 120 g trial had 200 branch lines deployed for each weight regime within each set as a "pair" in that all 200 consecutively set lines were from one or the other of the weight regimes. There were three pairs per trip for each of six trips used in the analyses.

For the 40 g trial the two weight regimes were set alternately and although the total number of branch lines in the set varied there were always equal numbers set for each weight regime. Two data sets of fish counts were constructed. Firstly, to account for the effect of bait species and any possible interaction between bait species and weight regime, these two factors were included in the cross-tabulation giving 53 sets across 10 trips. Secondly, since light sticks were deployed routinely on squid bait during the 40 g trial it was important to determine the effect of light stick colour (but not presence or absence) as a possible confounding effect. The fish counts were tabulated by weight regime and light stick colour from 35 sets in 7 trips where squid baits were used exclusively.

The response variable was the number caught in each set for a given species or group of species. In the case of swordfish for the 40 g trial the GLMM for the bait species type by weight regime analysis failed to converge so a linear mixed model was fitted to the log of the count data after adding 1 (this model converged). For the 120 g trial each of these regimes were deployed in alternate 200 branch lines sets with these 'pairs' being uniquely identified as the random effect factor. For the 40 g hook lead trial, the weighting regimes were alternated by branch lines, however the count of fish caught was obtained within each nominal set of 1200 hooks (although some sets had close to 1800 hooks), along with the combination of bait species if mixed baits were used within a set. Since the number of hooks set/weight regime by bait species or light stick colour combination varied from as low as 300 up to 920, the log of the number of hooks was included as an "offset" in the Poisson GLMM. The unique set within trip identifier, where set was equivalent to pair for the 120 g trial, was used as the random effect factor and although "fishing trip number" was also included as a random effect factor it was consistently estimated to contribute a non-significant (P>0.1) amount to the total variation.

The depth of setting varied depending on the main fish species targeted (sword fish shallower, tunas deeper). In the analysis of the 120 g trial depth was kept constant within pairs. Therefore depth was not a confounding factor in the comparison between weighting regimes. Similarly, in the 40 g hook lead trial depth was varied with fishing strategy but only between (not within) sets. Thus, in both trials depth of setting was excluded from the analyses.

Catch rates for both trials for comparison between factors levels are expressed as number of fish caught per 1200 hooks. To compare mean rates for statistical significance, the standard error of the difference (SED) between means was approximated by the average standard error of the difference on the log-link scale, obtained from *ASREML-R* function *predict*, multiplied by the mean rate.

The statistical method used to analyse time-to-depth profiles and corresponding sink rates was that reported in Robertson et al. (2010a, b).

3. Results

3.1 Fish catch effects: 120 g trial

The trial comprised six fishing trips, 30 sets of the longline and a combined total of 36,000 hooks.

3.1.1. Yellow-fin tuna

A total of 644 yellow-fin tuna were caught (both weighting regimes and all bait groups combined). Overall, there was a statistically significant effect of baits species (Table 1). Irrespective of weighting regime, gear with pilchard baits caught more yellow-fin tuna than gear with squid bait or a mix of squid and pilchards. This result was, however, strongly influenced by one of the six fishing trips when a large number of yellow-fin tuna were caught with pilchard baits by both weighting regimes (see below). There was no significant effect of weighting regime on the catch rates of yellow-fin tuna (Table 1). Mean catch rates on sets employing only pilchard baits were very similar: 63.1 fish/1,200 hooks and 66.08 fish/1,200 hooks by 60 g and 120 g gear with SED of 21.03, respectively (n = 30 sets for a combined total). Mean catches with sets employing only squid baits were 4.55 fish/1,200 hooks on 60 g gear and 3.66 fish/1,200 hooks on 120 g gear, with a standard error of the difference (SED) of 0.69. Mean catches for sets which deployed a mix of pilchards and squid were estimated but are not interpretable because the exact proportions of the two bait species deployed across all hooks in a set were not known. Within these three bait groups the effects of weighting regime on catch rates were not statistically significant (Table 1).

Source	Df	SS	Wald statistic	Probability. (chi squared)
Bait species	2	23.79	37.34	<0.0001
Weight regime	1	0.23	0.36	0.55
Bait spp. x weight regime	2	0.11	0.17	0.92
Residual (Mean Square)		0.64		

Table 1. Results of an analysis of variance testing for the effect of bait species and line weighting regime (60 g at 3.5 m from hooks versus 120 g at 2 m from hooks) on the catch rates for sets of 200 branch lines (#/200 hooks) of yellow-fin tuna.

3.1.2. Other commercial species

Other commercial species caught include big-eye tuna, albacore tuna (*T. alalunga*), swordfish (*Xiphias gladius*) and mahi mahi (*Coryphaena hippurus*). The numbers caught of these species were too low to be treated separately so the data were pooled. There was no significant effect of bait species (pilchards, squid and a mix of pilchards and squid), nor was there an effect of weighting regime (Table 2). Within bait group the mean catch rates per 1,200 hooks were similar. The mean catch rates on 60 g gear and pilchard bait was 12.82 fish/1,200 hooks compared to 14.87 fish /1,200 hooks on 120 g gear (SED: 5.19). Mean catch rates with sets employing only squid baits were 20.03 fish/1,200 hooks on 60 g gear and 16.42 fish /1,200 hooks on 120 g gear (SED: 3.05). The SED for the comparison of the mean catch rate of the two bait species for a given gear type was 4.69. Therefore, the difference in the mean catch rate for sets using only pilchard baits of 12.82 and sets using only squid baits for the 60 g gear (20.03) is not statistically significant (P>0.05). The difference in mean catch rates for the two bait types on 120 g gear was also not statistically significant (Table 2).

Source	Df	SS	Wald statistic	Probability (chi squared)
Bait species	2	8.9	4.71	0.095
Weight regime	1	2.14	1.13	0.287
Bait spp. x weight regime	2	1.35	0.71	0.699
Residual (Mean Square)		1.89		

Table 2. Results of an analysis of variance testing for the effect of bait species and line weighting regimes on the catch rates for sets of 200 branch lines (#/200 hooks) of other commercial species (see text).

3.2. Fish catch effects: 40 g hook lead trial

At total of 69,870 hooks were set in the trial. The vast majority of these had squid baits (61,710 hooks) and the remainder (8,160) pilchard baits (squid to pilchard ratio: 7.6:1). Data from all 53 sets over the 10 trips were used in the analysis.

3.2.1. Yellow-fin tuna

A total of 1,026 yellow-fin tuna were caught during the trial (both bait species combined). Of these 447 yellow-fin tuna were caught on squid baits and 579 on pilchard bait. There was no statistical difference in catch rates of yellow-fin tuna between bait species or between the two weighting regimes (Table 3). Mean catch rates over both bait species types were 10.95 tuna /1,200 hooks with the 40 g hook leads and 10.68 tuna/1,200 hooks with 60 g at 3.5 m gear (SED: 0.64). Mean catch rates for squid baits were 10.80 tuna /1,200 hooks with the 40 g hook leads and 10.53 fish/1,200 hooks with 60 g at 3.5 m gear (SED: 0.63).

Source	Df	SS	Wald statistic	Probability (chi squared)
Bait species	1	0.015	0.02	0.895
Weight regime	1	0.149	0.17	0.677
Bait spp. x weight regime	1	0.719	0.84	0.360
Residual		0.859		

Table 3. Results of an analysis of variance testing for the effects of line weighting regime and bait species group on the catch rates of yellow-fin tuna.

3.2.2. Big-eye tuna

A total of 100 big-eye tuna were caught on squid and pilchard bait groups combined. Of these 92 big-eye tuna were caught on squid baits. The catch rates of big-eye tuna over both bait species types on 40 g gear averaged 0.25 fish/1,200 hooks compared to 0.28 fish/1,200 hooks on 60 g gear with SED of 0.04 across both bait species types. The difference was not statistically significant (Table 4). Mean catch rates for squid baits were 0.34 fish /1,200 hooks with the 40 g hook leads and 0.39 fish/1,200 hooks with 60 g at 3.5 m gear with SED of 0.05.

Source	Df	SS	Wald statistic	Probability (chi squared)
Bait species	1	0.053	0.123	0.725
Weight regime	1	0.324	0.761	0.383
Bait spp. x weight regime	1	0.009	0.020	0.887
Residual		0.426		

Table 4. Results of an analysis of variance testing for the effects of line weighting regime and bait species group on the catch rates of big-eye tuna.

3.2.3. Albacore tuna

A total of 421 albacore tuna were caught on all bait groups combined; 355 of these were caught on squid baits. The catch rates of albacore tuna over both bait species types on 40 g gear averaged 0.68 fish/1,200 hooks compared to 0.77 fish/1,200 hooks on 60 g gear (SED: 0.05). The difference was not statistically significant (Table 5). Mean catch rates for squid baits were 1.233 fish /1,200 hooks with the 40 g hook leads and 1.389 fish/1,200 hooks with 60 g at 3.5 m gear (SED: 0.090).

Source	Df	SS	Wald statistic	Probability (chi squared)
Bait species	1	0.412	0.911	0.340
Weight regime	1	1.396	3.084	0.079
Bait spp. x weight regime	1	1.390	3.069	0.080
Residual		0.453		

Table 5. Results of an analysis of variance testing for the effects of line weighting regime and bait species on the catch rates of albacore tuna.

3.2.4. Swordfish

A total of 219 swordfish were caught on all bait groups combined. Virtually all (217) were caught on squid baits. The catch rates of swordfish over both bait species types on 40 g gear averaged 1.84 fish/1,200 hooks compared to 2.25 fish/1,200 hooks on 60 g gear (SED: 0.23). The difference was not statistically significant (Table 6). Mean catch rates for squid baits were 2.28 fish /1,200 hooks with the 40 g hook leads and 2.78 fish/1,200 hooks with 60 g at 3.5 m gear (SED: 0.28).

Source	Df	SS	Wald statistic	Probability (chi squared)
Bait species	1	0.549	1.717	0.190
Weight regime	1	1.026	3.210	0.073
Bait spp. x weight regime	1	0.160	0.499	0.480
Residual		0.320		

Table 6. Results of an analysis of variance testing for the effects of line weighting regime and bait species group

3.2.5. Mahi mahi

A total of 227 mahi mahiwere caught on all bait groups combined. Squid bait accounted for 170 of the number caught. The catch rates of dolphin fish over both bait species types on 40 g gear averaged 1.90 fish/1,200 hooks compared to 1.85 fish /1,200 hooks on 60 g gear (SED: 0.25). The difference was not statistically significant (Table 7). Mean catch rates for squid baits were 1.98 fish /1,200 hooks with the 40 g hook leads and 1.92 fish/1,200 hooks with 60 g at 3.5 m gear (SED: 0.26).

Source	Df	SS	Wald statistic	Probability (chi squared)
Bait species	1	0.033	0.037	0.849
Weight regime	1	0.043	0.048	0.826
Bait spp. x weight regime	1	0.460	0.516	0.473
Residual		0.892		

Table 7. Results of an analysis of variance testing for the effects of line weighting regime and bait species group on the catch rates of dolphin fish.

3.2.6. All shark species combined

The species considered were dusky (*Carcharhinus obscures*), silky (*C. falciformis*), smooth hammerhead (*Sphyrna zygaena*), blue (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus)* and longfin mako (*I. paucus*) sharks. There was no significant effect of line weighting regime on the catch rates of sharks, nor was there an effect of bait species (Table 8).

A total of 158 sharks were caught on all bait groups combined. Of these 135 sharks were caught on squid baits. The catch rates of all shark species combined over both bait species types on 40 g gear averaged 1.67 sharks/1,200 hooks compared to 2.05 sharks/1,200 hooks on

60 g gear (SED: 0.29). The difference was not statistically significant (Table 8). Mean catch rates for squid baits were 2.190 sharks/1,200 hooks with the 40 g hook leads and 2.684 sharks/1,200 hooks with 60 g at 3.5 m gear (SED: 0.384).

Source	Df	SS	Wald statistic	Prob. (chi squared)
Bait species	1	2.02	2.06	0.151
Weight regime	1	1.61	1.64	0.200
Bait spp. x weight regime	1	0.45	0.46	0.498
Residual		0.98		

Table 8. Results of an analysis of variance testing for the effects of line weighting regime and bait species group on the catch rates of all shark species combined.

3.3. Sink rate profiles

The sink rate profiles followed the order expected from the static water trial. Branch lines with 60 g at the hook sank the fastest followed by 40 g at the hook, 60 g at 1 m from the hook and 60 g from the hook 3.5 m (Figure 2). The differences between all four profiles were statistically significant throughout their entire ranges.

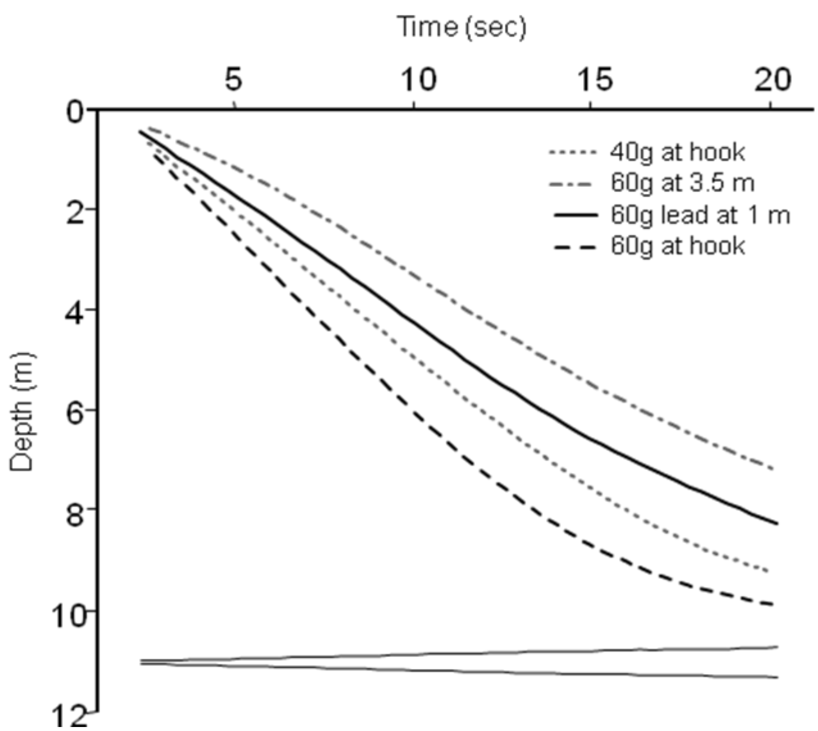

Figure 2. Average sink profiles of the two weighting regimes compared in the trial and two additional regimes with potential relevance to the fishery. The 95 % confidence bounds are shown as horizontal bars at the bottom of the figure. If the difference between any two average

profiles for a given time exceeds the difference between the upper and lower arms of the confidence bounds then the difference is statistically significant. N = 30 replicates for each regime.

3.4. Sink times and rates

The average time taken for the various regimes to reach various depths in the water column and associated average sink rates are shown in Table 9. The results are presented to 8 m depth only. The results for greater depths indicate the branch lines were being held up by the mainline, nullifying the relevance of further comparison. The 40 g hook leads averaged 4.5 s to 2 m deep (0.43 m/s) compared to 6.7 s (0.29 m/s) for 60 g at 3.5 m. The results to 5 m were 9.7 s (0.5m/s) and 13.5 s (0.36 m/s) for the 40 g hook lead and 60 g at 3.5 m, respectively.

Line weight regime	Nominal depth (m)	Time to depth (sec)	Sink rate (m/s)
40 g at hook	2	4.52	0.43
60 g at hook	2	3.96	0.51
60 g at 1 m	2	5.22	0.39
60 g at 3.5 m	2	6.76	0.29
40 g at hook	5	9.7	0.50
60 g at hook	5	8.2	0.61
60 g at 1 m	5	11.1	0.44
60 g at 3.5 m	5	13.5	0.36
40 g at hook	8	15.58	0.51
60 g at hook	8	13.06	0.61
60 g at 1 m	8	18.94	0.42
60 g at 3.5 m	8	20.9	0.38

Table 9. Mean sink times and sink rates to target depths of the two weighting regimes in the 40 g hook lead fish catch trial. Also included are results for 60 g hook leads and 60 g leads 1 m from hooks (see text). N = 30 replicates/weight regime.

3.5. Gear loss and line repairs

Twenty three sets and hauls, comprising a total of 33,050 branch lines were monitored for lead loss and branch line repair. Half (16,525) of these branch lines were weighted with 60 g at 3.5 m from the hooks and the other half with 40 g hook leads. The number of branch lines that required repair was 964 and 858 for the 60 g gear and 40 g gear, respectively. Of these, leads were lost from a total of 24 branch lines of the former regime and 179 branch lines from the latter regime. All lead losses from both gear types also involved loss of the hooks. These figures equate to an average of 1.5 and 10.8 leads/1,000 hooks for the 60 g and 40 g hook leads, respectively. The average mass of lead lost was 0.0087 kg/1,000 hooks of 60 g leads and 0.43 kg/1,000 hooks of 40 g hook leads.

The numbers of branch lines that required repair for reasons other than lost leads and hooks (line chafing, line kinks) were 940 of 60 g gear (i.e., 964 – 24, see above) and 679 of 40 g gear (858 – 179) for the 23 sets monitored. Thus, an average of 16 fewer branch lines /1,000 hooks of 40 g hook weight gear required repair than 60 g gear (679 ÷ 16.525 c.f. 940 ÷ 16.525).

4. Discussion

4.1. Fish catch effects: 120 g trial

The duration of this trial was limited by the number of observer days available. The trial spanned six months and involved 30 sets of the longline and a total of 36,000 hooks. Catch rates were insufficient for all species except yellow-fin tuna to permit statistical analysis at a species level. There were no statistically detectible effects of weighting regime on the catch rates of yellow-fin tuna and on the combined catch of big-eye tuna, albacore tuna, swordfish and mahi mahi . Although the sample size is small relative to that for the 40 g hook lead trial, the evidence suggests that branch lines configured with weights that are twice as heavy as those on standard gear and located much closer to the hook did not affect the catch rates of the main species targeted. This is a significant finding because it counters the traditional opinion that using heavy weights and placing them relatively close to the hook will compromise fish catch (by reducing the mobility of bait in the water column). There is no evidence to support this assertion.

Regarding adoption in the fishery, the use of 120 g weights would add an extra 30 kg to the weight of bins of 500 branch lines fitted with standard 60 g leaded swivels. This is a substantial amount of extra weight for crew to move during setting and hauling operations. Because of the extra lead involved, the weights are also likely to cost more than 60 g leaded swivels. The importance of these two negatives must be weighed against the operational and economic effects on fishing operations of a day setting prohibition due to breeching of the seabird bycatch limit. Use of faster sinking gear may avoid future prohibitions or reduce their frequency. At the very least, the results of this trial should enable decisions on seabird bycatch mitigation strategies to be made without undue concern about detrimental effects on fish catch of line weighting designed to increase the sink rates of baited hooks.

4.2. Fish catch effects: 40 g hook lead trial

At the start of the trial, of the 1,200 branch lines on board with 60 g swivels 87 (7 %) were fitted with skirts, 460 (38 %) with sleeves and the remainder (55 %) were plane ended. Skirts and sleeves were progressively removed from the gear during routine line maintenance. By the first set of the sixth trip (of 10 trips in total) the proportions had reduced to < 1 %, 3.5 % and 95.5 %, respectively. The effect, if any, of skirts and sleeves on fish catch rates is unknown. However, the number of skirts involved was very minor and although sleeves were more numerous in the first part of the trial they were used to have the same effect as the nylon coating on the hook weights, which was to glow in the dark. Overall, we consider the effect of skirts and sleeves on fish catch rates by 60 g gear to be minor and unlikely to significantly affect the comparison between the two line weighting regimes.

The 40 g hook lead trial spanned nine months of the year, included times of year of contrasting fish catch rates (possibly indicating variation in abundance and/or feeding activity levels), involved 53 sets of the longline and the deployment of 69,870 hooks for both weight regimes combined. As is typical in the fishery, fish catch rates during the trial were highly variable and some species were caught very infrequently. As with the 120 g trial the sample sizes are statistically adequate only for the commonest species caught - it would be time and cost prohibitive to gather statistically adequate sample sizes for all species of fish caught in the fishery. Fish taxa or groups of taxa for which there was adequate data for analysis include yellow-fin tuna, big-eye tuna, albacore tuna, swordfish, mahi mahi and five species of sharks combined. Although yellow-fin tuna and big-eye tuna were the main species targeted, albacore tuna, swordfish and mahi mahi are also commercially valuable species. There were no statistically significant differences in the catch rates of the abovementioned species/groups between branch lines with 40 g hook weights and those with 60 g weights at 3.5 m. Mean catch rates of yellow-fin tuna, big-eye tuna, albacore tuna and mahi mahi were virtually identical among the two gear types.

Similarly, there were no detectible differences between the two gear types in catch rates of five species of sharks treated as a group. This finding pertains only to sharks that were still attached to the branch lines in the final stages of hauling, not those that had bitten themselves free (see gear loss, below). With respect to capture and bite-offs, some fisheries prohibit the use of wire traces to reduce the number of shark landings (with monofilament traces it is possible for sharks to bite their way free). By shielding the lower 10 cm of the branch line, hook leads could potentially increase the number of sharks caught. This study suggests this did not occur because the number of sharks identified during hauling caught on both gear types was statistically indistinguishable. While the far higher loss rate of hook leads compared to standard gear (see below) suggests that sharks were as likely to free themselves from gear with hook leads as they were from gear with a long bottom end, it should be noted only a limited number of hauls was undertaken and this issue might benefit from further research to ensure there are no unforeseen impacts on any shark species.

To our knowledge this is the first time a systematic trial of this kind - which compared two line weighting regimes, one with weight placed at the hook - has been conducted in a pelagic longline fishery. The results are important because they provide evidence that weight at or in very close proximity to the hook does not reduce the number of fish caught. The results of the trial should allay concerns about the potential detrimental effects of leads at the hook on the economics of fishing. The results reinforce the fact that weights at, or close to, the hook are a more effective mitigation measure due to their significantly faster sink rate than the current industry standard.

4.3. Sink times/rates

While the comparison of sink rates between the two gear types is instructive, the most relevant measure of the potential to seabird conservation benefits is the difference in the time taken for baited hooks to reach a target depth. This provides a measure of time hooks are available in the surface zone immediately after deployment. The sooner that baited hooks commence sinking, and the faster they sink, the less time there is for seabirds to access them. The sink profile of the hook weight gear was far superior to that of the 60 g gear with a 3.5 m bottom end. Baited hooks with 40 g leads at the hook reached 2 m deep in just 4.5 seconds, 33 % less than the time taken for hooks with 60 g at 3.5 m. Between 2 m and 5 m deep this difference had reduced to 23 %, which is still a substantial difference. The time saved near the surface is explained by the instantaneous sinking (no lag at the surface) of the hook weight baits due to the absence of a bottom end in branch lines. Although the 60 g leads were 20 g heavier, the loss of time at the surface was not made up deeper in the water column (see Figure 2). The results of the hook weights to 2 m deep are faster than any other tuna gear for which there are published records. Branch lines configured with lead weights at the hook have considerable potential to reduce the catch rate of seabirds in pelagic longline fisheries.

4.4. Gear loss and line repairs

The results indicate that the 40 g weight option resulted in an increased number of weights and hooks lost. Weights and hooks were lost at seven times the rate of the 60 g weights, this is most likely due to bite offs by sharks. Hook losses occurred unevenly throughout the trial and occurred in areas of known high shark activity. The 60 g gear was bitten off just as regularly but the weights were not lost as frequently (24 versus 179 weights for the hook weights) because of the 3.5 m bottom end. Blue sharks, which are the commonest sharks caught in the fishery, are presumed to be the principal reason for the bite offs. The main concern is not the economic loss (see below) but the number of lead weights lost to the seabed or swallowed by sharks. Ingested lead may affect the health of sharks and be deposited in the meat, which in some parts of the world is used for human consumption. The frequency of lead loss should be monitored in the future. The option for replacing lead with another material (such as already occurs in some recreational fishing) could also be investigated.

Regarding economic loss, the average loss rate of weights and hooks/1,000 branch lines reported above (1.5 and 10.8 for 60 g and 40 g gear, respectively) equates to $2.70 for 60 g gear and $14.25 for 40 g gear. These estimates are based on the current unit cost of 60 g leaded swivels (AU$1.00), the estimated AU$0.50/weight for commercially-available 40 gm hook weights (Fishtek Pty Ltd., personal communication) and the current unit cost of AU$0.82 for the #14/0 circle hooks used in the trial. The extra cost is offset to some degree by the lower overall repair rate for hook weight gear, which averaged 16 branch lines/1,000 lines fewer than 60 g gear. Unfortunately, we did not quantify the exact reasons why each line type required repair, which included line chafing and line kinks in addition to loss of leads and hooks. However, while the loss of hook weight always resulted in the loss of the hooks (from bite offs), with 60 g gear sharks often took the hooks but not the weights, due to the 3.5 m distance between them. Assuming half of the extra 16/1,000 branch lines of 60 g gear were repaired due to lost hooks, the cost difference would reduce to < AU$5.00 (8 lines x AU$0.82/hook + $2.70 for the lost leads). When considered against the costs of other aspects of fishing operations (fuel, bait, lights sticks, vessel and gear maintenance) the extra cost associated with the higher loss rate of hook weight gear is trivial.

Ultimately, however, the loss of hook weights must be weighed against their potential benefits to seabird conservation and other important aspects of fishing operations (see below).

4.5. Advantages of hook weights

There are a number of advantages with the use of hook weights of the type use in the trial over leaded swivels crimped into branch lines several meters from the hook:

Crew health and safety: Hook weights improve crew safety in the following three ways. First, they reduce the incidence of dangerous fly-backs, which occasionally occur when big fish are hauled and the branch line stretches and thins under tension. During the final stages of hauling a fish the 60 g swivels on 3.5 m bottom ends are suspended in the air on the branch line. If the line breaks or pulls out of the fishes mouth the swivel is propelled, sometimes at great speed (see Sullivan et. al., submitted), unimpeded towards the vessel. By virtue of its position at the hook, hook weights are either underwater or flush with the water surface (not suspended in the air) when fish are hauled towards the vessel. When a branch line breaks the water tends to dampen the speed of the recoil towards the vessel. Second, since they are hand-tightened onto branch lines (not attached by compression or crimped into gear, as would be the case with plane lead sinkers) hook weights have the ability to slide toward the clip end of the branch line when under load. Thus, if a branch line breaks at the hook or tears from a fish's mouth, the resultant fly backs are relatively harmless because there is no added weight at the hook. The third safety feature is the nylon coating. Conventional weighted swivels and sinkers without swivels are typically made of lead, which is a toxic heavy metal. These weights are handled whenever gear is being constructed, set, hauled and repaired. In contrast, the nylon coating on hook leads completely covers the lead component, thereby preventing crew from coming into contact with lead when handling gear.

<u>Inspection and compliance</u>: It is often stated that line weighting facilitates compliance monitoring more easily than other seabird bycatch mitigation measures because gear bins can be inspected in port before and after fishing trips. In practice, however, this is not the case. Gear bins may hold up to 500 branch lines, each layered on top of one another in the order in which they were hauled. As shown in Figure 1, the weights on 3.5 m bottom ends in a full gear bin are distributed throughout a pile of monofilament branch line about 0.5 m deep. It would be an onerous and time consuming task (and unpopular with crews, who may have just returned from a fishing trip) to remove all branch lines before and after fishing trips to measure the bottom end lengths. In contrast, as revealed in Figure 2, hook weights are suspended together with clips and hooks on wire runners in the top section of the bins (not amongst the monofilament) and are highly visible for inspection. If the weights are not correctly positioned at the hook (i.e., if they have slid along the branch line or up to the clip) it would be immediately apparent upon inspection. Weights placed at the hook allow a more accurate and faster port-based gear inspection before and after fishing trips.

<u>Labour saving</u>: Branch lines with weighted swivels are constructed of two lengths of monofilament (the top and bottom sections) which are measured, cut and crimped to either side of the swivel. The length of the industry standard bottom section must be measured to ensure it conforms to the length required by permit conditions. By contrast, branch lines with hook weights consist of a single straight through section of monofilament joining clip and hook. The weight is threaded onto the mono before the hook is attached. The swivel attached to the clip is sufficient to prevent the line from twisting. Branch lines with hook weights can be constructed in about half the time taken for branch lines with a weighted swivel crimped into the line.

<u>Ease of deployment</u>: Branch lines with hook weights are easier to deploy than industry standard gear. Deploying standard gear requires crew to bait the hook then feed out branch line for a light stick to be attached. They then feed out more line into the water until the weighted swivel is clear of the bin. This must be done to avoid line tangles. Hook weight gear requires crew to bait the hook then span out the appropriate length for the light stick then throw the bait. Since the hook, bait and weight are together they can be picked up with one hand and thrown as one.

<u>Bin tangles</u>: The hook weights reduce the incidence of line tangles in the bins. The weights on gear with leaders are scattered throughout the monofilament branch lines (see Figure 1) and occasionally tangle during deployment. In contrast, the hook weights are not mixed in with the

branch lines - they hang directly beneath the hooks on the horizontal runners (see Figure 2). Bin tangles associated with line weights are unlikely to occur with weights at the hook.

Bin weight: A standard bin with 500 branch lines of 60 g at 3.5 m gear contains 30 kg of lead in the swivels compared to 20 kg of lead with 40 g hook weight gear. The 10 kg reduction in bin weight makes it significantly easier and safer for crews to move the bins around vessels during fishing operations.

Cost: Because hook weights do not contain swivels they are considerably cheaper to produce than weighted swivels. When produced commercially they are estimated to cost about half the cost of a 60 g weighted swivel. This cost saving must be weighed against the cost of replacing weights bitten off by sharks.

Seabird capture at hauling: When branch lines with 60 g swivels at 3.5 m are hauled with an automatic snood puller the line must be removed from the puller at the swivel. This leaves the hook, sometimes with intact bait, dangling in the water beside the vessel. This provides an opportunity for seabirds feeding on lost bait at the hauling area to attack these baits and become hooked. Because the weight is situated at the hook, virtually the entire branch line can be hauled onboard before being removed from the puller, thus removing bait-taking opportunities for seabirds.

Summary

The key conclusions of this study are that weights placed at the hook offer fishers a new way to reduce seabird bycatch without affecting target fish catch and that 40 g weights placed at the hook also improved crew safety, reduced the amount of time spent in gear construction and facilitated gear inspection for compliance purposes.

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Appendix 1

Mean (n = 12) sink profiles of the 60 g at 3.5 m, 120 g at 2 m and 40 g at the hook line weighting regimes recorded under controlled conditions (Hobart aquatic centre dive pool). Profiles of gear with leaders (60 g at 3.5 m and 120 g at 2 m) should not be compared below ~3 m deep (horizontal dashed line) because at that point the sinkers will have reached the bottom of the pool and ceased pulling on the hook. The profile for 60 g at 3.5 m reveals the lag at the surface (slow initial sink rate) associated with long bottom ends.