Lumo Leads: a potential, new, safe line weighting technique to reduce seabird bycatch for pelagic longline fisheries

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ABSTRACT

Seabird bycatch from pelagic longline fisheries can be reduced when Best Practice mitigation measures are used in combination; however widespread adoption of Best Practice remains a problem, threatening many seabird species globally. Lumo Leads provide a line-weighting technique for seabird bycatch mitigation that works without compromising fish catch, fishing operations efficiency or crew safety. Unlike conventional weighted swivels, Lumo Leads are attached to monofilament lines in such a way that they can slide up and down the line and simply slip off the line during a bite-off. Lumo Leads of different mass (45 and 60 g) and colour (black or glowing), were tested onboard Korean pelagic longline vessels, at varying distances from the hook (5 cm, 60 cm, 100 cm and 200 cm), with their impact on seabird bycatch, target catch, fishing operations and crew safety recorded. Trials were completed over three trips in two years onboard three vessels, representing 217,000 experimental hooks. Only two seabirds were caught throughout the study; one on unweighted branchlines and one on a weighted (lumo lead) branchline. Lumo Leads had no significant impact on catch rates of southern bluefin tuna (*Thunnus maccoyii*); neither 45 g ($p = 0.287$) nor 60 g ($p = 0.332$) glowing lumo leads placed at 5 cm from the hook. Catch rates of yellowfin and bigeye tuna were very similar between weighted and unweighted branchlines when Lumo Leads (45 and 60 g) were placed 100 cm from the hook ($p = 0.100$ and 0.135, respectively), and were almost identical when using 60 g Lumo Leads 200 cm from the hook. Some treatments on tropical and temperate tunas-directed effort did significantly reduce target catch: 45 g black Lumo Leads 5 cm and 60 cm from the hook. The use of 45 g black Lumo Leads 60 cm from the hook reduced the combined catch of yellowfin *T. albacares* and bigeye tunas *T. obesus* ($p = 0.009$) as well as the catch rate of albacore tuna *T. alalunga* ($p = 0.035$). Only albacore tuna catch was negatively affected when using 45 g black Lumo Leads 5 cm from the hook ($p < 0.001$). Crew safety was not compromised when using Lumo Leads, with line flybacks occurring as regularly on weighted branchlines as on unweighted branchlines. Fishing operations were generally unaffected by the addition of Lumo Leads, however branchline entanglements were significantly increased when using 60 g lumo leads at 100 cm (p =0.037) and at 200 cm ($p < 0.001$) from the hook. These were generally minor entanglements with only the line entanglement rate for 60 g at 200 cm from the hook believed to impact operational aspects. Although too few birds were caught in this study to evaluate the impact of lumo leads on seabird bycatch, the addition of weight to branchlines is known to reduce seabird bycatch. Lumo leads did not show significant reductions in target fish catch for bluefin tunas, did not compromise crew safety, and did not seriously affect fishing operations. Lumo leads appear to be an effective seabird bycatch mitigation measure for Korean-style pelagic longliners, which allows Korean vessels to fish in compliance with IOTC Resolution 12/06 when using line weighting and bird scaring lines as their two preferred seabird bycatch mitigation options.

1. Introduction

With the introduction of a number of simple mitigation measures, seabird bycatch from global fisheries has seen a significant decrease in recent years, however, it still remains a problem in many fisheries worldwide, particularly the pelagic longline fishery (review by Anderson et al., 2011). Some of the most important mitigation measures which have proven to reduce seabird bycatch include: the use of bird-scaring lines (BSLs; Melvin et al., 2013; Yokota et al., 2011), night-time setting (Petersen et al., 2008) and the addition of weight to branchlines (Robertson et al., 2010). Other mitigation devices such as hook pods (Sullivan, 2011) and smart tuna hooks (Baker et al., in review) are also effective in reducing seabird bycatch. These measures all ensure that baited hooks are either entirely unavailable to scavenging seabirds or are available for a less time during the setting process.

For any devices or techniques to be accepted by fishing companies worldwide, crew safety, target fish catch and fishing operations cannot be compromised (Gilman, 2011; Sullivan et al., 2012). It is also important to note that different fleets use very different fishing gear and techniques, so a seabird mitigation device which works in one fishery may not necessarily work identically in another.

Most seabird bycatch mitigation measures that have been adopted by pelagic longline fisheries can, at times, compromise fishing efficiency. BSLs are widely used as a preferred option. Despite this, some fishing masters complain of line entanglements with BSLs particularly when setting lines during strong cross-winds (DR pers. obs.). Increasing the sink rate of baited hooks by adding weight to branchlines is widely accepted as the most important method of reducing seabird bycatch (Robertson et al., 2006), yet can still compromise crew safety (Sullivan et al., 2012). If a bite-off occurs during line hauling, the weight can shoot dangerously towards crew members on the hauling deck when the monofilament line recoils (Sullivan et al., 2012).

The Lumo Lead is a seabird bycatch mitigation technique that enables additional weight to be added to branchlines without compromising crew safety. Lumo Leads make use of the sliding lead concept: they have the ability to slide off branchlines in the event of a bite-off. Additionally, the Lumo Lead can be encased in a luminescent nylon sheath which effectively replaces the need for glow sticks to attract fish, which are a significant source of marine pollution (Sullivan, 2011).

We used Lumo Leads during production fishing onboard Korean tuna longliners, to test their effectiveness and practicality in reducing seabird bycatch. We had four objectives: (i) determine differences in seabird bycatch and target fish catch rates between branchlines weighted with Lumo Leads at differing distances from the hook and unweighted branchlines, (ii) assess crew safety implications of weighting branchlines with Lumo Leads, (iii) measure line sink rates of weighted and unweighted branchlines, (iv) determine whether the use of Lumo Leads will have any impact on fishing operations (e.g. increased line entanglements).

2. Methods

2.1 Fishing trips, vessel and gear setup

Research trials were conducted onboard three Korean pelagic longline vessels operating off western Australia and southern Africa between 2014 and 2015 (Fig. 1). Fishing gear consisted of braided monofilament mainline, 40 cm diametre floats (at ~500 m intervals along mainline), radio beacons and branchlines. Branchlines were attached to the mainline at ~ 40 m intervals and measured ~ 40 m in length consisting of varying lengths of braided nylon, braided monofilament and monofilament sections, with all branchlines ending in a minimum of 5 m of monofilament with a steel leader (~40 cm) attached to the hook. No light sticks were used on any of the experimental or non-experimental sections. The number of hooks deployed between floats, is referred to as a basket; they were consistent within a trip but differed between vessels (either 11 or 12 hooks). Setting usually lasted ~ 5 h and generally commenced between 0430 h and 0730 h, with hauling commencing ~ 4 h after completion of setting and generally lasting ~ 12 h. Roughly 3000 hooks were set daily with a target fishing depth of approximately ~150 m. Depending on target fish and area, bait consisted of sardine (*Sardinops* sp.), horse mackerel (*Trachurus* sp.), Argentine squid (*Illex argentinus*) and round scad (*Decapterus maruadsi*). Vessels A and B targeted southern bluefin tuna (SBT, *Thunnus maccoyii),* and retained butterfly kingfish (*Gasterochisma melampus*) and blue sharks (*Prionace glauca*). Vessel C fished in warmer waters of the east coast of southern Africa and therefore primarily targeted tropical and temperate tunas (TTT) including yellowfin (*T. albacares*), bigeye (*T. obesus*) and albacore tunas (*T. alalunga*), however also retained blue sharks, mako sharks (*Isurus oxyrinchus*), swordfish (*Xiphias gladius*) and marlin species (*Makaira* spp.).

2.2 Lumo Leads

Lumo Leads are attached to monofilament branchlines in such a way that they are able to move up and down the line, unlike conventional weights/swivels. The monofilament line is passed through the Lumo Lead and can be fixed at any distance from the hook by simply tightening the tapered screw-cap. If a branchline is put under extreme pressure, whilst a fish is being hauled, the monofilament line will stretch (10-20% before breaking) and constrict slightly; the reduced diameter of stretched monofilament means that, if the line snaps it will pass through the Lumo Lead, often resulting in the Lumo Lead falling off the end of the line and not shooting back dangerously towards the vessel. Several versions of Lumo Leads were tested, varying in mass and nylon coating colour: a black coating (hereafter known as black Lumo Leads) of mass 45 g and a luminescent nylon coating (hereafter known as glowing Lumo Leads) of masses 45 g and 60 g.

2.3 Lumo Lead experimental design

Treatments (weighted or unweighted) were arranged in alternating baskets which ensured that treatment sizes remained consistent. Trials onboard SBT-directed vessels only used two-way experiments between weighted and unweighted baskets (Fig. 2a) while trials onboard Vessel C used both two- and three-way experiments (Fig. 2b). It is important to note that a basket never included a mix of treatments, only one treatment per basket. For SBT-directed sets (Vessels A and B), glowing Lumo Leads (45 g and 60 g) were tested at a distance of 5 cm from the hook only. For Vessel C, 60 g glowing and 45 g black Lumo Leads were tested at varying distances from the hook (5 cm, 60 cm, 100 cm and 200 cm; Table 1). For all sets on which Lumo Leads were placed at 5 cm from the hook, Lumo Leads were attached to the wire trace, while for those sets testing Lumo Leads > 5 cm from the hook, Lumo Leads were attached to the monofilament line above the wire trace.

2.4 Setting and hauling data

Data including GPS co-ordinates, time, wind speed and swell height were collected from vessel logbooks for the start and end of each set and haul. To collect haul data observers positioned themselves on the haul deck with a clear view of the hooks as they were brought onboard. All experimental brachlines were observed and for those hooks which recorded fish catch the following were recorded; treatment (weighted or unweighted), basket number, species, mass, condition of catch (scavenged/intact), catch fate (retained/discarded) and processing method (if retained). Observers onboard SBT-directed vessels recorded both retained and discarded fish catch per set, while observers onboard TTT-directed vessels recorded retained and discarded fish catch per basket for all sets.

2.5 Hook sink rate

Sink rates of all the different weighted and unweighted treatments were measured using G5 Cefas time-depth recorders (TDRs, 35 x 11 mm, 6.2 g) and G5 Host software (Vessel C only). The TDRs were taped to the monofilament branchline using waterproof Tesa tape ~ 40 cm from the hook (~ 10 cm above the wire trace) and were programmed to sample depth and temperature every 1 s. Water entry time was accurately recorded using a digital wristwatch and the number of seconds to reach a depth of 10 m was obtained from the data file.

2.6 Impact on fishing operations

Fishing masters have suggested Lumo Leads are likely to have negative effects on fishing operations by increasing bait loss and branchline entanglements during setting operations. Therefore both of these factors were assessed on Vessel C by recording rates of bait loss during line setting and branchline entanglements upon line hauling. During line setting observers would observe a portion of the experimental section (from above the setting deck) and recorded bait loss upon branchline entry into water after line casting. If, upon entry into water, bait had become dislodged from the hook it would remain floating on the surface instead of rapidly sinking and thus could be recorded easily. Treatment type for each basket cast was noted.

During line hauling a small section of the experimental section was closely observed and all branchline entanglements per treatment were noted. A branchline was considered 'entangled' if upon line hauling any section of the branchline contained a knot or was tangled in any way.

During hauling operations some Lumo Leads were noted to have moved up or down the monofilament line (Vessel C only). For branchlines where the Lumo Lead had shifted significantly, the Lumo Lead was repositioned to the correct distance from the hook by crew members during hauling. On completion of trials testing Lumo Leads at either 100 or 200 cm from the hook, 200 weighted branchlines were put aside to quantify movements of Lumo Lead relative to the hook.

2.7 Crew safety

To test the safety aspect of Lumo Leads, several parameters for all flyback events were recorded. A flyback was defined as a line break or accidental loss of fish during line hauling which caused the branchline to shoot back towards the vessel. Data collected included; treatment, fish species hooked, whether line was intentionally or unintentionally broken, where along the line the break occurred, where the hook/weight landed/struck, whether the Lumo Lead slipped off the line and if any injuries to the crew occurred.

2.8 Statistical analyses

T-tests were performed to test for differences in bait loss rate between different Lumo Lead/distance groups against unweighted branchlines, and were also performed to test for differences in entanglement rates between the different Lumo Lead/distance groups and unweighted branchlines.

A non-parametric Kruskal-Wallis test was used to compare line sink rates between the different Lumo Lead/distance groups at three different depth strata; 0-2 m, 2-4 m, 4-10 m and 0-10 m. A Dunn test was used to determine differences between the individual groups.

To understand the impact of different line weighting treatments on fish catch, vessels targeting SBT and TTT were analysed separately. As fish catch data were recorded at a different scale (catch per set versus catch per basket), this further enforced the decision to treat these data separately. Generalised linear models (GLMs) with a Poisson distribution (logarithmic link) were developed for SBT-directed vessels while GLMS with a negative-binomial distribution (logarithmic link) were used for non-SBT effort. Target catch was the response variable for all models; for SBT-directed vessels target catch included SBT tuna only, while for the TTT-directed vessels, albacore tuna and the combined catch of yellowfin and bigeye tuna were modelled separately. A full suite of models, with all variables and two-way interaction terms were constructed, and the model with the lowest Akaike's Information Criterion (AIC) score was selected as the most appropriate model.

3. Results

3.1 Impact on catch and bycatch

Experimental effort totalled 13,832 baskets (or >150,000 hooks) using glowing Lumo Leads onboard vessels targeting SBT (Table 1). The use of glowing Lumo Leads (both 45 and 60 g) at a distance of 5 cm from the hook did not significantly reduce the target catch of SBT-directed vessels; target catch was only influenced by vessel identification (Table 2). Overall SBT catch rates when using 60 g Lumo Leads 5 cm from the hook were similar to unweighted branchlines (weighted; 6.8 fish/1000 hooks, unweighted; 5.8 fish/1000 hooks, Fig. 3), as were catch rates when using 45 g Lumo Leads 5 cm from the hook caught (weighted; 5.1 fish/1000 hooks, unweighted; 6.1 fish/1000 hooks, Fig. 3).

Research onboard the only vessel targeting TTT amounted to 13,335 baskets (or >150,000 hooks). Only two experimental treatments (45 g black Lumo Leads 5 cm from hook and 45 g black 60 cm from hook) significantly decreased target catch rates (Table 2 and 3). The combined catch of yellowfin and bigeye tuna was significantly reduced when using 45 g black Lumo Leads 60 cm from the hook (15.8 vs 9.3 fish/1000 hooks, $P = 0.009$, Fig. 4a) and albacore tuna was significantly reduced when using 45 g black Lumo Leads at both 5 cm (27.7 vs 11.6 fish/1000 hooks, $P < 0.001$) and at 60 cm from the hook (3.9 vs 2.0 fish/1000 hooks, $P = 0.035$, Fig. 4b). Target catch rates (albacore tuna and yellowfin + bigeye tuna) on weighted branchlines were were not significantly different when using Lumo Leads (both 45 and 60 g) 100 cm from the hook. Target fish catch rates were statistically indistinguishable between weighted and unweighted branchlines when using 60 g glowing Lumo Leads 200 cm from the hook. Fish bycatch (defined as any catch that was not retained) was significantly reduced when using 45 g black Lumo Leads at a distance of both 5 cm ($P = 0.014$) and 60 cm from the hook ($P = 0.005$).

Only two birds were caught during the SBT-directed trials, and none during the TTT-directed trials. Both were caught using the 60 g glowing Lumo Lead at 5 cm treatment (unweighted branchline; grey-headed albatross *Thalassarche chrysostoma*, 1 weighted branchline; black-browed albatross *T. melanophris*).

3.2 Hook sink rate

Useable TDR data were retrieved from 111 TDR deployments for six different treatments (Table 4). Differences in sink rates at different depth strata were not apparent from our study and thus sink rate to 10 m was recorded. Significant differences in sink rate to 10 m were found between unweighted hooks and all weighted treatments (Table 4), however no significant differences were found between sink rates of any of the weighted treatments. Unweighted branchlines took an additional 10 s to reach a depth of 10 m compared to the slowest weighted treatment (60 g at 200 cm from the hook).

3.3 Impact on fishing operations

Bait loss was observed during the setting of 14,751 hooks. No significant differences were found between any of the weighted treatments (45 g at 100 cm from hook, 60 g at 100 and 200 cm from hook) and unweighted (control) treatments, with very low levels of bait loss during setting (c. 1%) for all treatments (Table 5).

In total 26,216 branchlines were closely monitored during line hauling to check for entanglements from four treatments: unweighted (control), 45 g Lumo Leads 100 cm from hook, 60 g Lumo Leads 100 cm from hook and 60 g Lumo Leads 200 cm from hook (Table 6). Entanglement rates did not differ statistically between branchlines weighted with 45 g Lumo Leads 100 cm from the hook (9.0%) and unweighted branchlines (7.5%, P=0.090), however did differ significantly between branchlines weighted with 60 g 100 cm from the hook (10.8 %, P=0.036) and 60 g 200 cm from the hook (21.0%, P < 0.001), compared to unweighted branchlines.

Very few of the Lumo Leads had shifted significant distances (> 25 cm) from the original positions for either 45 g at 100 cm (87%) or 60 g at 200 cm (86%).

3.4 Crew Safety

In total of 17 flybacks (14 line breaks, 3 accidentally unhooked fish) were observed during hauling (onboard Vessel C) which could have compromised crew safety. These potentially dangerous line breaks occurred on both weighted (40% black Lumo Leads, 30% glowing Lumo Leads) and unweighted branchlines (30%), with all but one involving hooked sharks. Most (82%) of the flybacks occurred when the fish/shark was right alongside the hauling station and the line was purposely broken to avoid having to bring the shark onboard before dehooking. One minor injury resulted from a flyback of an unweighted branchline, which was purposely broken. All three of the accidentally unhooked fish were on weighted branchlines, however none of these resulted in dangerous flybacks;

two of the branchlines lost all momentum in the water before reaching the vessel while one branchline flew back onto the hauling deck however had lost nearly all momentum on landing.

4. Discussion

4.1 Impact on catch and bycatch

The results of the branchline weighting trials onboard SBT-directed vessels were encouraging: adding weight did not affect target fish catch rates. However the effect of branchline weighting on TTT catch was more complex. There was a significant reduction in albacore tuna catch when using 45 g black Lumo Leads close to the hook (5 cm or 60 cm from the hook), with none of the other Lumo Lead treatments having any significant effect on albacore tuna catch. Yellowfin and bigeye tuna catch was only significantly reduced when using 45 g black Lumo Leads at 60 cm from the hook, all other Lumo Lead treatments did not have any significant effects on target catch, however was slightly reduced when using 45 and 60 g Lumo Leads at 100cm from the hook. Catch rates for yellowfin and bigeye tuna were most similar when using 60 g glowing Lumo Leads 200 cm from the hook (weighted = 9.0 fish/1000 hooks, 8.9 unweighted = fish/1000 hooks).

The fishing industry is cautious about adopting the use of weight at or close to the hook due to concerns that this will negatively impact fish catch (Robertson et al. 2013). Robertson et al. (2013) did not find any difference in catch rates (bigeye, yellowfin or albacore tuna) between branchlines using 40 g at the hook compared to branchlines using 60 g at 3.5 m from the hook. Those results are contrary to ours, which show weight at or near the hook reduces albacore tuna catch as well as the combined catch of yellowfin and bigeye tuna. Robertson et al. (2013) used glowing Lumo Leads, therefore it is possible that Lumo Lead colour played an important role in determining fish catch; all trials conducted during the TTT trials at or close to the hook used black Lumo Leads only. Gianuca et al. (2013) performed weighting trials onboard TTT-directed vessels and tested catch rates between branchlines using weighted swivels at 5.5 m and 2 m. No differences in catch rates of target species were noted, however they did find a difference in yellowfin tuna catch, with higher catch rates on lines weighted at 2m from the hook. Melvin et al (2013) did not find any difference in target catch rate between weighted (60 g safe leads at 70 cm from the hook) and unweighted branchlines while onboard a TTT-directed vessel.

No birds were caught on the TTT-directed vessel, this is because almost all fishing was conducted in low-latitude, warm waters with very low seabird abundance. Previous research suggests that due to increased line sink rates, Lumo Leads should reduce seabird bycatch rates; Melvin et al. (2013)

and Jimenez et al. (2013) concluded that seabird bycatch rates are much higher on unweighted branchlines compared to weighted branchlines. Attacks on baited hooks were reduced by as much as 59% when using weight at 1 m from the hook compared to weight at 4.5 m from the hook (Jimenez et al. 2013). Due to the low numbers of seabirds killed during this study, we cannot assess the efficacy of Lumo Leads at reducing seabird bycatch. Despite SBT-directed vessels fishing in areas where high seabird abundances are common, just two birds were killed from > 83,000 hooks, three on unweighted branchlines. Korean-style unweighted branchlines sank relatively fast compared to other studies (e.g. Melvin et al., 2013, Jiminez et al., 2013), which might explain some of the low observed seabird bycatch.

4.2 Hook sink rate

The sink rate of baited hooks depends on both the amount of weight applied to branchlines as well as the distance of the weight to the hook (Robertson et al., 2010). Line sink rates can be divided into two phases; the initial stage when line sink rates are comparatively slow and the final stage when line sink rates are faster (Robertson et al., 2010). Initial sink rate depends on proximity of weight to hooks (branchlines sink faster the nearer weights are placed to the hook), and final sink rate which depends on the mass of the weights. Differences in line sink rate could not be identified in our study, with sink rates to a depth of 10 m similar across all weighted treatments. All treatments of weighted branchlines sank significantly faster than unweighted branchlines, with no difference noted within the weighted treatments. Average sink rates of unweighted branchlines from our study were considerably faster (0.27 $m.s^{-1}$) than sink rates of unweighted branchlines (0.19 and 0.16 $m.s^{-1}$) from previous studies (Anderson and Mcardle, 2002; Melvin et al., 2013). Melvin et al. (2013) found that line sink rate differed between branchlines weighted with 40 g and 60 g (both at 1 m from the hook), thus it is perhaps surprising that line sink rates did not differ between branchlines weighted with 45 g and 60 g 1 m from the hook in our study, however sample sizes were low for some treatments. It is generally accepted that hooks should be protected to a depth of 10 m, a depth to which a number of bycatch-prone seabird species are able to dive (Melvin et al., 2013, Favero et al., 2016). At sink rates achieved from our study, if a vessel were to set lines at a speed of 9 kn, unweighted hooks would reach a depth of 10 m at a distance of 167 m, compared to a distance of 112 and 122 m for the fastest and slowest sinking weighted treatments (45 g at 100 cm and 60 g at 200 cm from the hook) from this study, respectively. Thus a BSL achieving 100 m aerial coverage would protect 60, 82 and 89% of hooks, respectively, when using unweighted branchlines,

branchlines weighted with 60 g at 200 cm and branchlines weighted with 45 g at 100 cm from the hook.

4.3 Impact on fishing operations

Fishing masters thought that bait loss during setting would be a problem when using Lumo Leads. They suspected that as the bait was cast, either by hand or a bait-casting machine, it could be dislodged due to the 'hinge' effect created as the weight overtakes the baited hook into the water. Encouragingly there was no difference in bait loss during line casting between unweighted and weighted (45 g and 60 g 100 cm from hook, and 60 g 200 cm from hook) treatments. Due to the lack of a 'hinge' effect for treatments with weight close to the hook, bait loss is unlikely to be an issue for these treatments, however this was not tested.

Entanglements only became noticeably more frequent when Lumo Leads were furtherest (200 cm) from the hook; branchlines on this treatment were three times more likely to become entangled than unweighted branchlines. Although weighted branchlines (both 45 g and 60 g) 100 cm from the hook became entangled at higher rates than unweighted branchlines, the difference between the unweighted branchlines was not significant and did not add considerable time to hauling operations (unlike 60 g at 200 cm from the hook). When weight was positioned further from the hooks, the movement of the branchlines as they were cast was less predictable and Lumo Leads became more likely to slip through loops in the line created during casting, resulting in entanglements. During treatments with Lumo Leads closer to the hook (5-60 cm) entanglements were so rare that no data were collected. The setting team alternated between using a bait-casting machine and hand-casting when setting weighted branchlines. There were no problems with using the bait casting machine for treatments with Lumo Leads at 5-60 cm, however they preferred to hand-cast the lines when Lumo Leads were further away from the hook (100 and 200 cm). For treatments with Lumo Leads further from the hook, hand-cast lines seemed to result in a smoother cast of the line compared to machine-cast lines; the latter appeared to create a 'hinge' effect before hitting the water.

The fishing masters also raised concerns about entanglements during weighting trials by Melvin et al. (2013), as they did in our study, primarily because entanglements could decrease fish catch. Entanglements create additional work for the hauling crew, who need to disentangle or unknot lines before they can be coiled. However in this study, the vast majority of tangles consisted of a single slip-knot on the line, which was a trivial matter for the crew to repair. Similarly to Melvin et al. (2013) crews of the two SBT-directed vessels thought that weighted branchlines were cumbersome to coil, however the crew of the TTT-directed vessel thought that the weighted branchlines represented no additional effort to coil.

As Lumo Leads have the ability to be moved up and down the branchline to specific distances from the hook, there is the concern that Lumo Leads may shift position at some stage during the fishing process which may affect fishing efficiency. To ensure Lumo Leads were kept at the required distance from hooks, the crew would routinely adjust Lumo Leads to the correct position when coiling them after hauling; this did not complicate hauling operations and would have very little or no effect on hauling time. During our study only a small number of Lumo Leads had shifted position significantly (> 25 cm) and thus Lumo Lead slippage is unlikely to be a problem.

4.4 Crew Safety

The addition of Lumo Leads to branchlines was not observed to compromise crew safety onboard Vessel C. Unfortunately the effect of Lumo Leads on crew safety was not recorded from vessels A and B. Nearly all flybacks occurred when sharks were right alongside the hauling station when the crew would apply extreme tension to the branchline often resulting in the hook being ripped out of the shark's mouth, or the breaking of the monofilament line. These actions would often result in the branchline shooting back towards the vessel; however these were intentional actions by the crew. During these intentional line breaks, an unweighted branchline appeared just as likely to flyback and cause injury to the crew. On all observed accidental flybacks, branchlines had either lost all momentum before reaching the vessel, or had lost nearly all of their momentum before landing on the hauling deck, as such none of these observed accidental flybacks posed any danger to the crew. Neither the fishing master nor the crew appeared particularly concerned of the potential danger of using Lumo Leads throughout the trip, possibly as wire tracers were used on all branchlines, which are believed to reduce the possibility of flybacks. These results are similar to the findings of Sullivan et al. (2012) who concluded that Safe Leads (a precursor to Lumo Leads that exploited the same principle as Lumo Leads, of sliding along stretched monofilament) significantly reduced the danger of flybacks, compared to the use of weighted branchlines.

4.5 Future research

Despite a large number of trials conducted on different Lumo Lead weighting regimes there is still the need for more research on branchline weighting to better understand how they affect fish catch and seabird bycatch. Only two different coloured Lumo Leads were trialled in our study, however the effect of Lumo Lead colour (particularly glowing versus non-glowing) on fish catch is still not understood and thus future trials to investigate this are recommended. Research testing glowing Lumo Leads close to the hook will help understand whether it was the colour of the black Lumo Leads which reduced fish catch, rather than the application of weight close to the hook. Due to the low numbers of seabirds caught in our study, the effects of Lumo Leads on seabird bycatch are not yet apparent, however line weighting is known to reduce seabird bycatch. Further trials in areas known for high seabird bycatch are required. Seabird bycatch and abundance as well as seabird attack rates (during line setting) will all be investigated.

4.6 Recommendations

Due to the low seabird bycatch from our study we were unable to assess how Lumo Leads effect seabird bycatch, however results from previous studies have proven the effectiveness of line weighting as a seabird mitigation measure (Favero et al. 2016). As a number of different Lumo Lead treatments did not impact fish catch, significantly impact fishing operations or compromise crew safety, we suggest that LLs could be used by pelagic longline fisheries to reduce seabird bycatch. Lumo Lead mass and distance from hook are important factors which affect both line sink rates, fish catch and operations efficiency. As glowing Lumo Leads applied at the hook did not affect southern bluefin tuna catch rates, fishing operations or crew safety, we suggest that this Lumo Lead treatment be used by SBT-directed.

For TTT-directed vessels fishing in high seabird abundance areas (south of 25^{o} S) we suggest that 60 g Lumo Leads should be placed 100 cm from the hook. Our results show that this treatment will ensure fish catch is unaffected, while still maintaining high sink rate speeds, without an increase in bait loss. Entanglements were higher than unweighted branchlines however the difference was minor (3%) and would not significantly affect fishing operations. Our recommendations are in line with recommendations made by the Agreement for the Conservation of Albatrosses and Petrels (ACAP), which suggests 40 g or greater within 0.5 m of the hook or 60 g or greater within 1 m of the hook (Favero et al. 2016).

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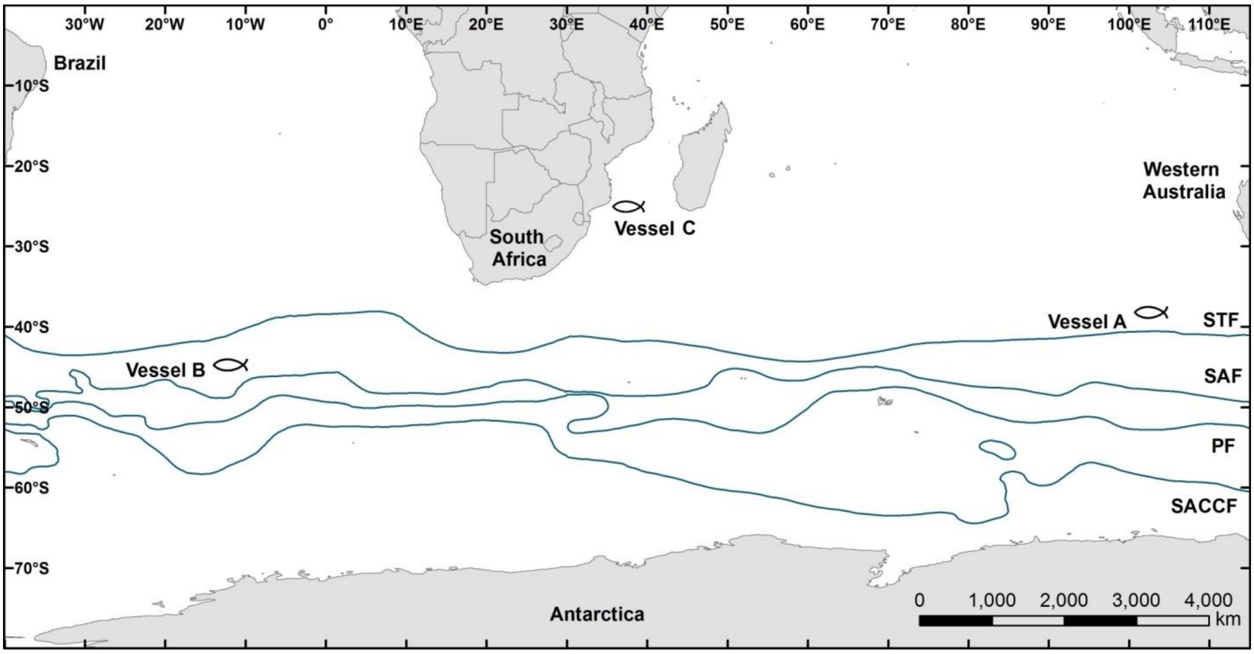


Fig. 1. Map showing approximate fishing locations of the tropical and temperate tuna-directed vessel (Vessel D) and southern bluefin tuna- directed vessels (Vessels A, B and C), with the Subtropical Front (STF), Subantarctic Front (SAF), Polar Front (PF) and Southern Antarctic Circumpolar Current Front (SACCF) all indicated.

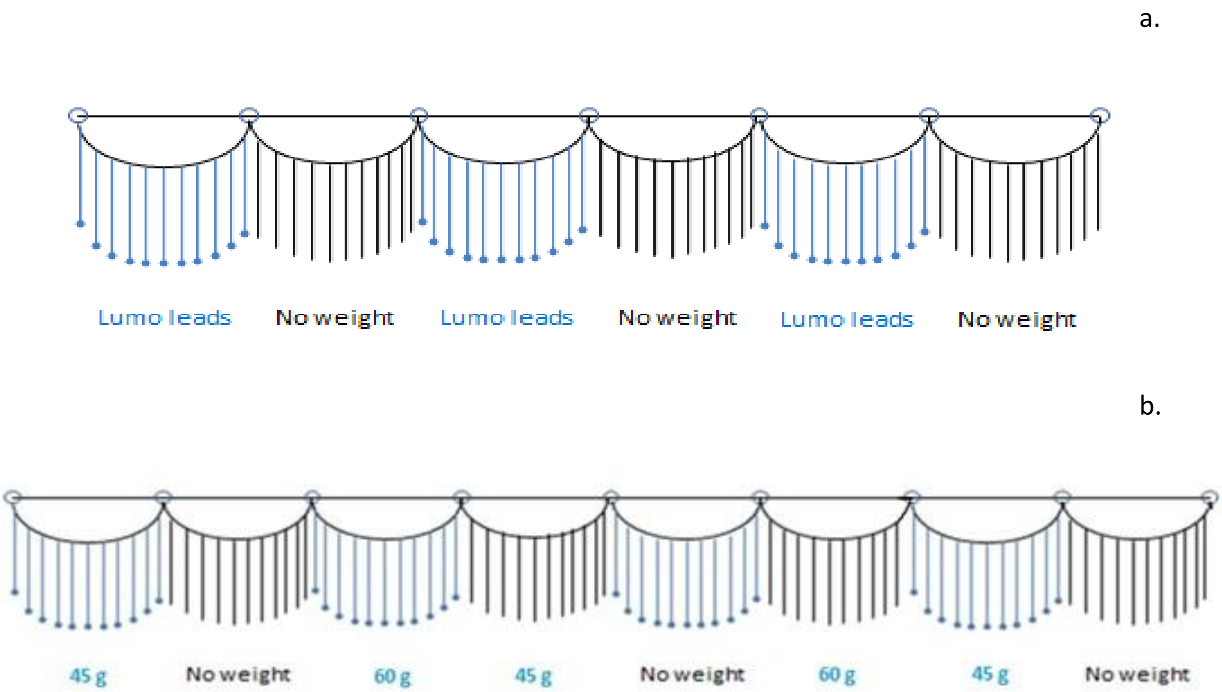


Fig. 2. Lumo Lead configuration of a. two-way trials between weighted and unweighted baskets (as performed on all vessels), and b. three-way trials between two different Lumo Leads and unweighted baskets (as performed by Vessel C only).

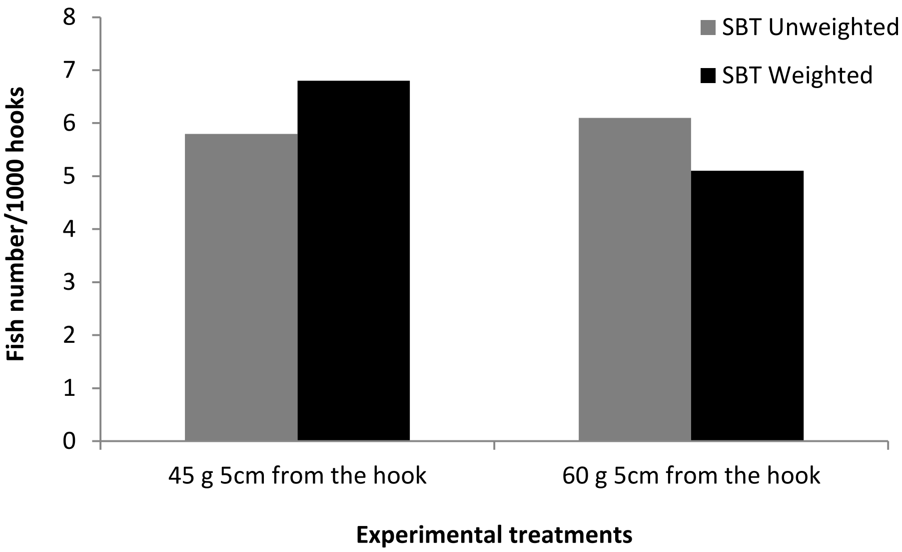
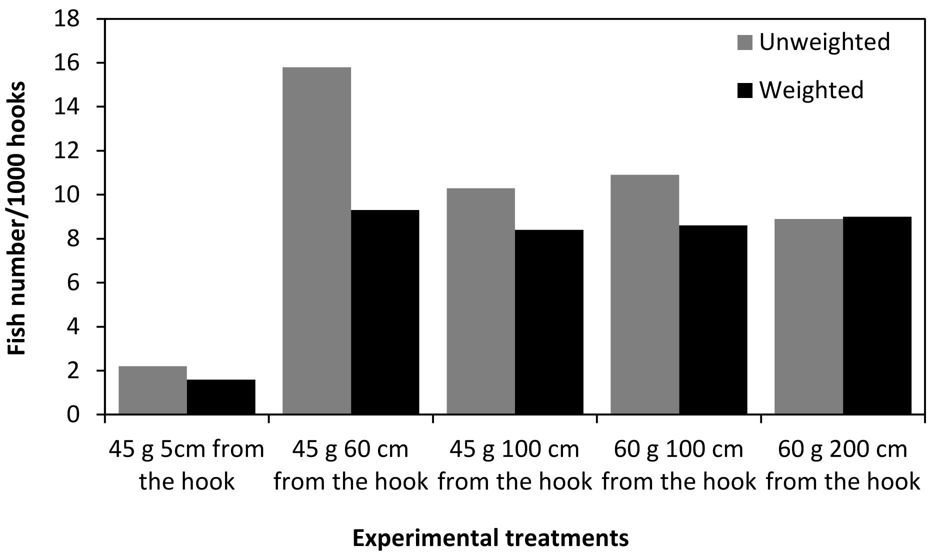


Fig. 3. Summary of southern bluefin tuna catch between different treatments for southern bluefin tuna-directed vessels (Vessels A and B).

a.



b.

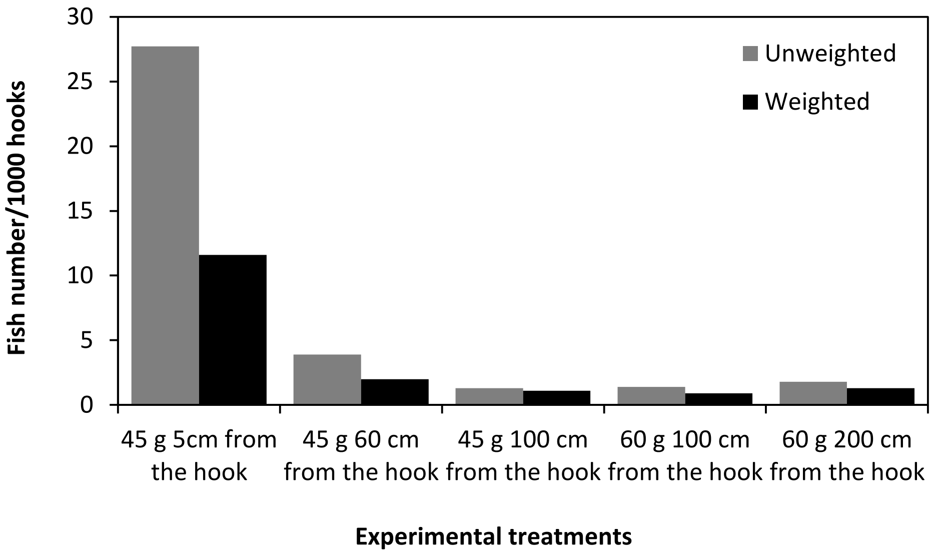


Fig. 4. Summary of fish catch between different treatments of the tropical and temperate tuna-directed vessel for a. combined yellowfin and bigeye tuna and b. albacore tuna.

Table 1

Experimental configuration and trip information for the four vessels used to conduct Lumo Lead trials between 2014-2015, targetting southern bluefin (SBT), yellowfin (YFT), bigeye (BET) and albacore tunas (ALB).

Vessel	A	B	C	
Lumo Lead mass (g)/colour	45/Glowing	60 / Glowing	45/ Black	60/Glowing
Distance from hook (cm)	5	5	5, 60, 100	100, 200
Experimental sets/baskets	48/2410	59/6250	23/3540, 10/1445, 45/4477*	30/2996*, 23/2375*
Fishing area	37~39ºS, 100~103ºE	30~38ºS, 83~103ºE	19~29ºS, 36~37ºE	
Target species	SBT	SBT	ALB,YFT, BET	

* A number of sets tested a combination of black and glowing Lumo Leads against unweighted control baskets. Lumo Leads were however never mixed within baskets.

Table 2

The effect of different variables for the best selected models.

* The best selected model did not include Treatment as a variable for bluefin tuna-directed vessels.

Variable	**Estimate**	**SE**	**z-value**	***P***
*Southern bluefin tuna**	-	-	-	-
Intercept	-5.181	0.082	-63.246	>0.001
Vessel ID: B	-0.580	0.111	-5.232	>0.001
Yellowfin & bigeye tuna	-	-	-	-
Intercept	-3.626	0.159	-22.742	>0.001
Experiment: Lumo Lead 60 cm from hook	1.862	0.208	8.949	>0.001
Experiment: Lumo Lead 100/200 cm from hook	1.375	0.197	6.986	>0.001
Experiment: Lumo Lead 100 cm from hook	1.475	0.185	7.970	>0.001
Experiment: Lumo Lead 200 cm from hook	1.215	0.229	5.305	>0.001
Treatment: 45 g/5 cm/black	-0.323	0.243	-1.329	0.184
Treatment: 45 g/60 cm/black	-0.528	0.203	-2.596	0.009
Treatment: 45 g/100 cm/black	-0.201	0.121	-1.649	0.099
Treatment: 60 g/100 cm/glowing	-0.215	0.144	-1.494	0.135
Treatment: 60 g/200 cm/glowing	-0.021	0.161	-0.127	0.899
Albacore tuna	-	-	-	-
Intercept	-1.099	0.046	-24.035	>0.001
Experiment: Lumo Lead 60 cm from hook	-2.067	0.188	-11.002	>0.001
Experiment: Lumo Lead 100 cm from hook	-3.188	0.207	-15.424	>0.001
Experiment: Lumo Lead 100/200 cm from hook	-3.160	0.240	-13.159	>0.001
Experiment: Lumo Lead 200 cm from hook	-2.322	0.244	-9.518	>0.001
Treatment: 45 g/5 cm/black	-0.866	0.081	-10.718	>0.001
Treatment: 45 g/60 cm/black	-0.657	0.311	-2.114	0.035
Treatment: 45 g/100 cm/black	-0.185	0.261	-0.707	0.479
Treatment: 60 g/100 cm/glowing	-0.326	0.328	-0.992	0.321
Treatment: 60 g/200 cm/glowing	-0.458	0.313	-1.463	0.143

Table 3

Summary of target fish catch numbers and rates for vessels targeting southern bluefin tuna (SBT; Vessels A and B) and tropical and temperate tunas; albacore (ALB), yellowfin (YFT) and bigeye tuna (BET; Vessel C).

Vessel	Treatment (mass/cm from hook/colour)	Hooks	Species	Control total (fish/1000 hooks)	Black total (fish/1000 hooks)	White total (fish/1000 hooks)
A	45 g/5/glowing	26510	SBT	81 (6.1)	-	68 (5.1)
B	60 g/5/glowing	28446	SBT	83 (5.8)	-	96 (6.8)
C	45 g/5/black	42480	YFT & BET	47 (2.2)	34 (1.6)	-
C	45 g/5/black	42480	ALB	588 (27.7)	247 (11.6)	-
C	45 g/60/black	15930	YFT & BET	126 (15.8)	74 (9.3)	-
C	45 g/60/black	15930	ALB	31 (3.9)	16 (2.0)	-
C	45 g/100/black	49428	YFT & BET	253 (10.3)	208 (8.4)	-
C	45 g/100/black	49428	ALB	31 (1.3)	26 (1.1)	-
C	60 g/100/glowing	32956	YFT & BET	179 (10.9)	-	142 (8.6)
C	60 g/100/glowing	32956	ALB	23 (1.4)	-	16 (0.9)
C	60 g/200/glowing	26126	YFT & BET	116 (8.9)	-	117 (9.0)
C	60 g/200/glowing	26126	ALB	23 (1.8)	-	16 (1.2)

Table 4

Summary of TDR sink rate results to a depth of 10 m, from Vessel C

Treatment	n	Mean sink rate ($m.s^{-1}$ ± sd)	Seconds to 10 m	*P* (Unweighted vs weighted)
Unweighted	41	0.27	37.0	-
45 g at 5 cm from hook	15	0.41	24.4	<0.001
45 g at 60 cm from hook	14	0.39	25.6	<0.001
45 g at 100 cm from hook	9	0.40	25.0	<0.001
60 g at 100 cm from hook	11	0.38	26.3	<0.001
60 g at 200 cm from hook	21	0.37	27.0	<0.001

Table 5

Summary of bait loss between different weighting treatments, with the significant difference (P) between unweighted branchlines indicated.

Treatment	Hooks observed	Bait loss (%)	*P*
Control	4048	51 (1.3)	-
45 g at 100 cm from hook	4048	49 (1.2)	0.884
60 g at 100 cm from hook	1441	14 (1.0)	0.223
60 g at 200 cm from hook	2607	31 (1.2)	0.856

Table 6

Summary of entanglements between different weighting treatments, with the significant difference (P) between unweighted branchlines indicated.

Treatment	**Hooks observed**	**Entanglements (%)**	***P***
Control	16, 261	1217 (7.5)	-
45 g at 100 cm from hook	10, 175	920 (9.0)	0.090
60 g at 100 cm from hook	4589	497 (10.8)	0.036
60 g at 200 cm from hook	6086	1277 (21.0)	< 0.001