Novel approaches to line-weighting in New Zealand's inshore surface-longline fishery

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EXECUTIVE SUMMARY

Seabird bycatch has been reported from surface-longline fisheries for more than two decades. Characteristics of surface-longline gear that exacerbate the likelihood of seabird captures include its light weight, the long length of lines and snoods to which hooks are attached, and the attractiveness of baits to seabirds. Despite a well-researched suite of measures that have been shown to be effective in reducing seabird bycatch on this fishing gear, ongoing bycatch occurs in New Zealand and internationally. This continuing bycatch may be due to the inconsistent or insufficient implementation of existing measures, or the incompatibility of existing measures with gear types or fishing operations. In particular, safety issues associated with line-weighting — one effective method proven to reduce seabird bycatch risk — appears to have reduced uptake of this measure in New Zealand.

Globally, there is ongoing research into new measures to reduce seabird bycatch in surface-longline fisheries. Improved safety is a key component of the development of some of these measures. In this project, we trialled four devices intended to reduce the risk of seabird bycatch in surface-longline fisheries. These devices were (i) safe leads, weighing 60 g and comprising two lead pellets secured with O-rings around a rubber core, through which the monofilament snood passes, (ii) luminous plastic-covered "lumo" leads, weighing 40 g (iii) lumo leads weighing 60 g, respectively comprising a partly or fully lead-filled tapered plastic cylinder which attaches to longline snoods via a screw cap, and (iv) hook pods, which completely enclose longline hooks during setting until the fishing depth is reached. Safe leads and lumo leads are designed to move on snoods when monofilament stretches, and tension is suddenly released. This situation can arise during longline hauling, and the movement of the weights is designed to reduce the potentially dangerous recoil resulting in a weight flying back towards the vessel. Hook pods also move on the snood, though less readily than the other weight types.

In 2013, we trialled safe leads and 60-g lumo leads on one vessel each. In 2014, we tested 40-g lumo leads and hook pods on a third vessel. All vessels operated in New Zealand's surface-longline fishery, and targeted tunas and swordfish. The deployments of safe leads and 60-g lumo leads were overseen by government fisheries observers. A dedicated technician implemented the 40-g lumo lead and hook pod trials. Trials of safe leads and lumo leads followed a broadly balanced design with half the snoods on longlines being weighted with the devices being tested, and the other half comprising "normal" fishing gear, configured and deployed as per the skipper's typical operations. Across the experimental and normal snoods, weighted swivels and lightsticks were deployed in accordance with the skipper's preference. Time-depth recorders (TDRs) were deployed on snoods to measure sink rate, generally at three approximately equally-spaced locations in a longline basket.

For hook pods, the smaller number of pods available led to an approach of deploying approximately 50 pods on a longline. TDRs were also deployed

on hook pods (and snoods in these sets not carrying pods) to document sink rates.

For all devices tested, snood characteristics (e.g., lightstick attachment) and fish catch were documented at hauling, and TDRs were retrieved for downloading. The location of experimental weights on snoods was also documented. Finally, the operational characteristics of the experimental weights were documented, including feedback from skippers and crew. For the trips during which 40-g lumo leads were deployed, fish catch was compared using permutation testing. The effects of weighted swivels at the clip and lightsticks were also explored using a model-based approach.

Over seven trips on the three vessels, weighting methods were examined on 6–21 sets. Sets comprised 600–1400 hooks. Across the weighting methods trialled, 41–130 TDR records were retrieved. Although not the focus of the project, captures of three albatross (*Thalassarche* spp.) and two New Zealand fur seal (*Arctocephalus forsteri*) were recorded.

There was considerable variation in longline sink rates amongst the experimental weighting approaches tested and the sets using skippers' normal gear setups. To depths of 7 m, safe leads sank slightly faster, on average, than normal gear. Beyond 7 m, average sink rates of gear carrying safe leads and normal gear were extremely similar. Below 2 m depth, gear carrying 60-g lumo leads sank faster, on average, than normal gear. Average sink rates of 40-g lumo leads were faster than normal gear. On average, snoods carrying hook pods sank more rapidly than normal gear, to a depth of around 6 m. Beyond that depth, normal gear sank more rapidly. In addition to the weights themselves, factors affecting gear sink rate included the presence of lightsticks on snoods and the deployment method used to set snoods.

Fish catch was dominated by tunas, swordfish (*Xiphias gladius*) and blue shark (*Prionace glauca*). For tunas and swordfish, catch rates on snoods carrying 40-g lumo leads did not differ from catch on normal snoods. However, the catch rate of sharks on snoods carrying lumo leads was significantly lower than for normal gear. Shark catch was also reduced on snoods with weighted swivels at the clip, whereas snoods with weighted swivels and lightsticks showed reduced tuna catch.

The crews of all vessels readily adapted to the addition of the experimental weights to the fishing gear. One incidence of potentially dangerous recoil involved a safe lead, and there were 12 incidents involving the recoil of lumo leads. However, cases where the experimental weights had slid under tension were also recorded. Recommendations for improving the design of lumo leads and hook pods include refining the shape of the devices and how they attach to the monofilament snoods. While the experimental weights tested were designed to reduce safety risks associated with weighting surface longline snoods, they do not eliminate them. Caution and vigilance is still required to minimise ongoing safety risks, especially when hauling longline gear.

1. INTRODUCTION

Significant seabird bycatch issues were first identified in longline fisheries (e.g., Brothers 1991), and international management responses were initially focused on addressing this fishing method, ahead of others (FAO 1995). However, despite prolonged management and considerable scientific and advocacy efforts, surface longlines still catch and kill significant numbers of seabirds worldwide (Anderson et al. 2011). In New Zealand, surface-longline fisheries pose a bycatch risk for seabird species including Antipodean and Gibson's albatross (*Diomedea antipodensis antipodensis*, *D. a. gibsoni*), Campbell albatross (*Thalassarche impavida*), Salvin's albatross (*Thalassarche salvini*), southern Buller's albatross (*Thalassarche bulleri bulleri*), white-capped albatross (*Thalassarche steadi*), black petrel (*Procellaria parkinsoni*), Westland petrel (*Procellaria westlandica*), and white-chinned petrel (*Procellaria aequinoctialis*) (Abraham & Thompson 2011). It is highly likely that some of these species are caught in commercial fisheries in New Zealand waters at levels exceeding their sustainability limits (Richard & Abraham 2013), and they are also caught internationally (e.g., Baker et al. 2007).

Characteristics of surface-longline gear that exacerbate the risk of seabird bycatch include its relatively light weight, which keeps hooks within reach of seabirds for significant periods, the attractiveness of baits to seabirds, and the very long lengths of lines that are deployed with hooks attached (Bull 2007). Mitigation measures for this fishing method are focused on reducing the availability of hooks to seabirds. Measures recognised as current global best practice for achieving this goal are the combined use of line-weighting (which increases hook sink rates), deploying tori lines (which restricts bird access to hooks and lines during setting) and setting at night (when some species of seabirds, especially albatrosses, are less active) (ACAP 2013). The implementation of these measures has been required in specified forms and combinations in New Zealand surface-longline fisheries (e.g., New Zealand Government 2008, Ministry for Primary Industries 2014) and varies amongst vessels (e.g., Ramm 2012a, 2012b).

Despite the existence of measures that are effective in reducing seabird bycatch in surface-longline fisheries, continued captures in these fisheries demonstrate that the available approaches do not preclude the existence of significant bycatch risk (Richard & Abraham 2013). This may be due to a variety of reasons including inconsistent (or lack of) implementation, incompatibility with gear configurations, or implementation of insufficient measures (e.g., night-setting without line-weighting). Furthermore, the need to manage safety risks may hamper the uptake of new measures, e.g., line-weighting (e.g., Maritime New Zealand 1996, 2003).

Globally, there is ongoing research into new measures aiming to reduce seabird bycatch in surface-longline fisheries (e.g., Sullivan et al. 2012). Improved safety is a key component in the development of some of these methods. Following promising results from trials of such innovative devices, the overall objective of this project was to test one or more mitigation methods that reduce the availability of surface-longline hooks to seabirds at line setting. This objective encompassed two specific objectives:

Specific Objective 1. To test the safe use and mitigation effectiveness of one or more mitigation methods that are not currently in common use in New Zealand surface-longline fisheries and that reduce the availability of surface-longline hooks to seabirds at line setting.

Specific Objective 2. To assess and quantify any impacts on catch rates between target and bycatch species between snoods with and without the target mitigation method.

To address these objectives, we deployed 60-g safe leads, 40- and 60-g lumo leads, and hook pods from domestic surface-longline vessels fishing in New Zealand waters. Safe leads comprise a rubber core through which the monofilament snood passes. A lead weight is attached on each side of this core, secured by two O-rings. The safe lead is able to move down the snood when the snood stretches (becoming narrower in diameter) and tension on the snood is released suddenly (Sullivan et al. 2012). Lumo leads comprise a lead-filled plastic cylinder which can be fluorescent, through which the snood passes. The grip of the unit on the snood is adjusted by a screw cap. Similar to safe leads, lumo leads move on snoods when the monofilament becomes stretched (and therefore narrower in diameter) and then tension is suddenly released. Therefore, both safe leads and lumo leads can slide down the snood and fall off if a fish bites off the snood below the weight (Robertson et al. 2013). This action dampens potentially dangerous recoil (Sullivan et al. 2012). Hook pods reduce seabird exposure to baited hooks in two ways. First, and similar to safe leads and lumo leads, the pod itself adds some weight to the snood, which is expected to increase the sink rate of the gear. In addition, the pod covers the barb of the hook until the unit opens under the pressure of submersion at a certain depth (Sullivan 2011). Further, hook pods are also able to slide on monofilament line under tension. However, they do so less readily than the other two weighting methods.

2. METHODS

We conducted two sets of at-sea trials (see characteristics of vessels and gear used in these trials summarised in Table 1). The first set involved the deployment of two observers, one on each of two vessels, on a series of voyages during May to August 2013. The second set involved a dedicated technician deployed on one vessel for five voyages during April to August 2014. In 2013, research focused on testing an experimental protocol and assessing the feasibility of collecting data as part of normal vessel coverage by government fisheries observers. This approach proved challenging (see, Pierre & Goad 2013), such that in 2014, the approach to data collection was amended. Then, a third vessel was engaged for experimental trips on a semi-charter basis independent from government observer coverage.

One experimental line-weighting method was tested on each vessel in the 2013 trials (60-g safe leads and 60-g lumo leads). In 2014, 40-g lumo leads and hook pods (that weighed 60 g in air, and approximately 6 g in water) were tested from the same vessel (Table 1). In 2013, sets were conducted in Fisheries Management Areas (FMAs) 1 and 9. In 2014, sets were conducted

Table 1: Characteristics of vessels and gear used during testing of different line-weighting methods in New Zealand domestic surface-longline fisheries. The table gives the number and length of the vessels, the height above water at which the line left the vessel at the stern (H) and the diameter (D) of the backbone, the number of snoods per basket for baskets without and with moneymaker floats (MM), and the length of float ropes. Vessel 1 had a timber displacement hull, vessel 2 had a fibreglass, semi-displacement hull, and vessel 3 had a hard-chine steel displacement hull.

Gear tested	Vessel		Backbone		Snoods per basket		Float rope length (m)
	No.	Lgth. (m)	H (m)	D (mm)	No MM	MM	
60-g safe leads	1	18.6	2.0	3.5	5–9	–	8
60-g lumo leads	2	20	2.0	3.2	10–15	9–14	7–10
40-g lumo leads, hook pods	3	19.5	2.2	3.5	9–14	12–24	6–12

in FMAs 1 and 2.

2.1 Trials conducted in 2013

For the gear trials, it was intended that the length of longline normally deployed by fishers would be divided into two sections to separate snoods carrying experimental weights from snoods deployed with the skippers' "normal" weighting treatment. However, fishers were reluctant to split lines physically or to leave a stretch of monofilament mainline (backbone) with no snoods to separate the experimental and normal weighting treatments. On vessel 1, snoods with safe leads were all set in consecutive baskets. However, the group of baskets could occur along any part of the longline. On vessel 2, approximately half the longline was set with normal snoods and half with snoods carrying lumo leads. On each of the experimental and normal sections of longline, 300–500 hooks were set. (The number of snoods decreased throughout the trials due to gear losses). On vessel 1, 60-g safe leads were the experimental weight, and were deployed at 0.5 m from the hook. Approximately 10% of the gear was also fitted with 40-g weighted swivels. On vessel 2, 60-g lumo leads were deployed as the experimental weight at 1.5 m from the hook. Observers were tasked with checking the distance from the hook at which weights were deployed before the longline was set. On both vessels, skippers used lightsticks on gear in accordance with their own preferences. When deployed, lightsticks were attached to snoods immediately prior to setting. Tori lines were also deployed at the skippers' discretion.

Star Oddi DST centi Time Depth Recorders (TDRs) were deployed on experimental and normal gear on both trips in 2013. TDRs weighed approximately 20 g. Protocols used for deploying TDRs were developed from those used for previous work in longline fisheries (Goad et al. 2010, Goad 2011). TDRs were programmed using Sea Star software. Initially TDRs were set to record every 30 seconds for 30 minutes prior to the set, in order to record them acclimatising to seawater temperature in a bucket of seawater. After this was deemed impractical, this sampling period was dropped. TDRs were then set to record at one second intervals for a period sufficient to cover the set.

TDRs were deployed on separate snoods without bait (TDR-snoods). On vessel 1, all TDRs were deployed on unweighted clips. On vessel 2, all clips had weighted swivels. TDRs were attached at the end of the snood in place of the hook, or immediately above an unbaited hook. TDR-snoods were handed to the crew, deployed as part of normal setting operations, and clipped onto the backbone by the crew.

TDRs were positioned along longlines with the exception of baskets deployed in the initial or last 15 minutes of setting. Except for avoiding these first and last parts of the longline on setting, baskets were not pre-selected for TDR deployment. TDRs were systematically deployed at different basket positions, one quarter, half-way and three-quarters through a basket. Generally, 12 TDRs were deployed per set, six on experimental gear and six on normal gear. For each gear type, the TDRs were deployed in two batches of two or three consecutive baskets. Typically, at least half an hour passed between the setting of TDR batches.

When TDRs were deployed from vessels 1 and 2, the observer placed the unit over the side of the vessel before handing the snood to a crew member to clip onto the longline backbone after the previous snood had travelled a suitable distance from the vessel. This method of TDR deployment was denoted a "dragging" deployment. The time the TDR-snoods were clipped onto the mainline was used as the start time to determine how long the TDRs took to reach a given depth. If this time was not recorded, then an estimate of the average time between the TDR hitting the water (recorded on a watch, or based on TDR temperature records) and when the snood was clipped on was used to adjust water entry times recorded. The latter approach was taken for two sets on vessel 1 and one set on vessel 2.

At hauling, observers retrieved TDRs and downloaded the data. Observers were also tasked with documenting fish catch on a snood-by-snood basis. This data collection involved identifying the species caught, recording the fork length, weight, sex, and time of landing of each fish, and its status on landing (e.g., alive, dead). At hauling, observers were requested to document the snood-by-snood deployment of lightsticks and line-weights (including any weights that were additional to the experimental treatments, e.g., weighted swivels), and record any movement of safe leads or lumo leads up or down snoods. The loss of weights, e.g., due to bite-offs, was also documented, including any information available on when or how losses occurred. Finally, given the focus of the trials was on the safety advantages of safe leads and lumo leads, any safety-related observations or crew feedback was recorded.

2.2 Trials conducted in 2014

2.2.1 Lumo lead trials

In 2014, the operator of the vessel on which novel mitigation measures were tested had the option of using "normal" lumo leads, with the luminous plastic coating, or "non-lumo" lumo leads, which still had a plastic coating but it was not luminous. This was because luminous and non-luminous units were thought likely to result in different catch. The vessel operator chose to use lumo leads.

During trials conducted using 40-g lumo leads, weighted and unweighted clips were deployed on snoods amongst gear comprising both experimental and normal treatments. TDRs were deployed in place of the hook. In other aspects, trials of 40-g lumo leads conducted in 2014 were broadly similar to the 2013 trials. Methodological differences were the separation of experimental and normal weights using longline backbone, the method by which TDRs were deployed from the vessel during part of the third trip testing lumo leads, and how fish catch was documented on hauling.

On vessel 3, the sections of the longline carrying experimental and normal weights were separated by at least 100 m, and typically around 1 000 m of backbone. For the first two voyages and part of the third, TDRs were deployed using the dragging deployment method. Then, during part of the third and for the fourth trip on Vessel 3, TDRs were deployed by feeding the middle portion of the TDR-snood over the stern, and then passing the TDR (and lumo lead if attached) to one crew member and the clip to another crew member. The crew then waited for the snood-setting timer beep before placing the TDR in the water. As soon as it reached the water, the TDR-snood was clipped to the mainline. This method was referred to as "slack" deployment of TDRs.

Generally on Vessel 3, TDR placements during lumo-lead trials were paired such that a record from an unweighted snood and a weighted snood were available from the same set, ensuring that the following variables were the same for each pair: dragged or slack deployment, normal basket or basket in which a moneymaker float was attached, position in the basket, presence or absence of a lightstick, and presence or absence of a weighted swivel at the clip. However for 10 of the pairs, when TDRs failed, the combination was resampled on a subsequent set such that the weighted and unweighted TDR records were from different sets.

As the 2014 trials were not part of the government observer programme, fish sampling duties at the haul could be simplified significantly. The technician aboard the vessel during these trials was tasked with recording fish catch at landing snood-by-snood, by fish species and estimated length. Losses occurring during sets and on the haul were also documented, according to the location of the snood when the loss occurred (i.e., in the hand, or on the backbone), the loss type, and the outcome of the loss.

Six loss types were recorded, when:

- the fish removed the hook from the snood at the haul ("bite-offs"),
- the hook ripped out of the fish,
- the weight, hook, and fish were cut off,
- the hook and fish were cut off,
- the hook was already missing at the haul (i.e., a bite-off had occurred during the soak) and,

- the weight and hook were missing at the haul.

For each of these loss types, five outcomes were categorised, depending in part on the gear type (e.g., lumo lead deployment compared with normal gear):

- the weight did not move on the snood,
- the weight slid but stayed on the snood,
- the weight slid off the snood,
- the weight flew back towards the vessel at a height <1 m above the sea surface and,
- the weight flew back towards the vessel at a height >1 m above the sea surface.

2.2.2 Hook pod trials

The approach for testing hook pods differed from that used to test safe and lumo leads, as hook-pod tests were more exploratory and focused on the operational feasibility of this device, rather than any particular effects on fish catch. A set of 50 hook pods was deployed, for a total of 272 hook pod deployments over six sets. For the first two sets, hook pods were deployed at 1.8 m from the hook. For the subsequent four sets, hook pods were deployed at 1.4 m from the hook to facilitate loading baited hooks into the hook pods before setting.

As for safe and lumo lead trials, TDRs were deployed to explore sink rates achieved when hook pods were used. Overall, 76 TDR deployments were achieved. In each set, six to nine TDRs were deployed on normal gear and also on snoods carrying hook pods. On TDR-snoods, TDRs were taped immediately above the hook. TDRs were generally deployed using the slack method. Further, crew attempted to throw all hooks outside the propeller wash to minimise the chance of tangles amongst hook pods on setting. Only gear without lightsticks and with a weighted swivel at the clip was included in hook pod trials.

2.3 Data analysis

2.3.1 Time depth recorders

Data collected by TDRs were downloaded at sea. A correction to the raw TDR data was applied which comprised of two parts. First, when necessary, an offset was applied such that TDR readings were 0 m at the sea surface. Second, readings of surface temperature were corrected because TDRs take some time to acclimatise to a change in temperature, and use temperature readings when converting pressure readings to a depth.

In 2014, TDR records were discarded under the following conditions:

- if a TDR record of any given configuration was only available for either normal or lumo gear, then this was discarded to ensure there was no bias due to unequal samples of a given snood configuration,

- when sink rates were unusually slow due to identifiable abnormal circumstances, for example, when the snood was seen to tangle during deployment, if a snood was landed tangled at the haul, when the tori line tangled with the mainline, or when there was a tangle on the line drum,
- when basket sizes were not representative of normal practice, and,
- TDRs were attached at an incorrect position

Generally TDR records were paired such that the same configuration was sampled on each gear type on the same line, but due to TDR failure and mistakes some (10) records had to be repeated on separate sets. Gear was generally fished progressively shallower over the four trips on vessel C, such that 'slack deployments' sampled during later trips had shorter baskets.

One TDR record had a gap in the depth data from 1-5 m which was filled in by linear estimation. A second didn't sample until 5m so this data was not included in average depths above this.

2.3.2 Fish catch

Analysis was carried out using data from vessel 3 to identify whether the treatment (40-g lumo lead weights) was associated with a change in the fish catch rate. This analysis could not be carried out on data from 2013, given the challenges in following the experimental protocols during those trials. Fish catch during hook pod trials is also summarised, given the exploratory nature of those trials and the limited number of pods deployed.

For catch data collected from vessel 3, firstly, each fish caught was categorised based on a broad classification of target (tuna and swordfish) or less preferred catch. The categories were labelled either "tuna-group" (albacore, swordfish, southern bluefin, bigeye, or Pacific bluefin), "shark" (blue, mako, porbeagle, hammerhead, thresher, or bronze whaler), or other. Each snood or fish was assigned to a basket, based on the sequence of snood numbers. When snood numbers were missing (as a result of a tangle, for example) the snood was assigned to the basket of the previous snood with a known number. In all cases, whole baskets were designated as either lumo treatments, or normal gear (i.e., without lumo). A data set was prepared which aggregated the number of snoods, the number of sharks caught, and the number of tuna-group species caught, to the basket level.

Two analyses were carried out on the groomed data for "tuna-group" and "shark" catch. Firstly, a permutation analysis was performed. The permutation analysis is non-parametric. The catch rate of shark and tuna-group species (fish per hook) was calculated across the whole dataset, and the ratio of the catch rate was calculated for snoods with lumo, relative to those without. The treatment status of the baskets was then randomly shuffled within each set, and the catch rates were recalculated. By repeating this shuffling 10 000 times, a distribution of catch rates was obtained. If the catch rate ratio fell within this distribution, then the experiment had insufficient power to detect a difference in catch rates between snoods with lumo leads fitted and snoods of normal gear.

A second parametric analysis was carried out, estimating the catch rate as a function of the treatment (lumo or not lumo), whether a snood had a weighted swivel, whether a snood had a lightstick, and the number of the set. A binomial logistic generalised linear model (GLM) was used, with the probability, p, of catching a tuna-group species on a hook, i, being estimated as:

$$\text{logit}(p_i) \sim \beta_0 + w_i\beta_w + l_i\beta_l + f_i\beta_f + s_i\beta_s + \epsilon_s(s_i), \tag{1}$$

where the β coefficients are the weight of the covariates, w_i indicates whether hook i has a weighted snood, l_i indicates whether the snood has a lumo lead, f_i indicates that the snood carried a lightstick, and s_i is the set number of the hook. By fitting the model to the data, the coefficients β are estimated. There was a trend in the catch over time (a higher catch rate on later sets), and the set number is included as a linear effect. The set number is also included as a random effect, ϵ_s, to allow for variation in the catch rate between sets. The set random effect is drawn from a normal distribution,

$$\epsilon_s \sim \text{Normal}(0, \sigma_s), \tag{2}$$

where the standard deviation is estimated during the model fitting. The model is fitted using Bayesian methods, in the software JAGS (two chains were used, with a burn-in of 10 000 iterations, and a run of 100 000 iterations). The β coefficients have normal priors (mean zero and precision 0.0001), while the standard deviation of the set random effect has a half-Cauchy prior (with scale 25).

During fitting of the model, data were restricted to snoods that were recorded as either having lumo, weighted swivel, or no weighting. If the weighting of the snood was not recorded (for example, because the snood was part of a tangle from which individual snood details were not clear) then these snoods were not included in the analysis. This allowed an examination of the specific effects of gear components, given snood characteristics were precisely known.

3. RESULTS

Over seven trips on three vessels, each weighting method was examined on six to 21 sets. Observers or a dedicated technician implemented the trials over 10 to 80 days per weighting method. The number of hooks deployed per line set during experimental trips varied from 600–1400. The main species retained during trips included blue shark, albacore, swordfish, and Southern bluefin tuna (Table 3).

Quantifying protected species bycatch as a measure of mitigation efficacy was not a focus of this project. However, three seabirds were caught during

Table 2: Summary of trials of line - weighting measures conducted on three domestic vessels in New Zealand's surface longline fishery. The table gives the gear, the vessel number, the distance from the weight to the hook (m), the number of sets, the number of observer or technician days, and the number of hooks per line set.

Gear	Vessel	Dist. (m)	Sets	Days	Hooks per line
60 g safe leads	1	0.5	8	80	1 000–1 400
60 g lumo leads	2	1.5	12	31	600–950
40 g lumo leads	3	0.5–1.0	21	39	730–980
Hook pods	3	1.4–1.8	6	10	720–910

Table 3: Fish species caught during trials of line - weighting measures conducted on three domestic vessels in New Zealand's surface longline fishery. For each species, the table gives the common name, scientific name, and the number caught by each vessel. Fish caught during hook - pod trials by Vessel 3 are not included.

Common name	Scientific name	Vessel 1	Vessel 2	Vessel 3
Blue shark	*Prionace glauca*	977	901	1506
Albacore tuna	*Thunnus alalunga*	127	120	310
Broadbill swordfish	*Xiphias gladius*	63	8	130
Southern bluefin tuna	*Thunnus maccoyii*	21	146	26
Rays bream	*Brama brama*	133	1	5
Mako shark	*Isurus oxyrinchus*	13	26	88
Porbeagle shark	*Lamna nasus*	23	36	46
Lancetfish	*Alepisaurus ferox*	0	70	7
Pelagic stingray	*Pteroplatytrygon violacea*	0	0	47
Moonfish	*Lampris guttatus*	3	10	19
Sunfish	*Mola mola*	0	4	24
Dolphinfish	*Coryphaena hippurus*	0	0	25
Butterfly tuna	*Gasterochisma melampus*	3	5	13
Oilfish	*Ruvettus pretiosus*	6	0	9
Shortsnouted lancetfish	*Alepisaurus brevirostris*	0	3	10
Escolar	*Lepidocybium flavobrunneum*	2	1	7
Other		7	12	50

trial sets. One white-capped albatross was landed dead from an unweighted snood Vessel 1 during hauling, following a set during which a tori line was deployed. Vessel 2 did not land any captured seabirds. During trials of lumo leads, Vessel 3 landed two Campbell albatross. Neither bird was caught on a snood bearing a lumo lead. A tori line was not in use during the sets after which these birds were retrieved, but was deployed subsequent to the second capture. No birds were captured during trials of hook pods. However two fur seals (*Arctocephalus forsteri*) were captured on normal snoods set on longlines during hook pod trials. In addition, one toothed whale suspected to be a pilot whale (*Globicephala sp.*) was observed hooked but freed itself during the haul of one normally-weighted longline.

Forty-one to 194 records describing gear sink rates were retrieved from TDRs deployed during trials. Snoods on which TDRs were deployed were maintained at 8 to 12 m in length during trials, and vessel speed during setting varied from 6.0 to 7.5 knots (Table 4). During trips on Vessel 3, one TDR was lost and two were broken during landing.

Table 4: Summary of time depth recorder (TDR) deployments conducted to evaluate sink rates of four novel line-weighting devices tested on three domestic vessels in New Zealand's surface longline fishery. The table gives the weight and type of the experimental gear (SL = safe lead, LL = lumo lead, HP = hook pod), the number of the vessel, the number of sets, the number of TDR records retrieved, the TDR snood length, the setting speed, the position of the TDR on the snood, and the type of TDR deployment.

Weight	Vessel	Sets	TDR records	Length (m)	Speed (knots)	TDR position	Deployment
60 g SL	1	8	41	11	6.0–7.0	At hook	Dragging
60 g LL	2	12	43	8–12	7.5	At hook	Dragging
40 g LL	3	14	130	10	6.8–7.7	In place of hook	Dragging
40 g LL	3	7	64	10	6.6–7.0	In place of hook	Slack
HP	3	6	76	10	6.8–7.0	At hook	Slack

Amongst TDR records collected from Vessel 1, two were discarded due to tangled snoods or incorrect times being recorded, and deployments on three sets were unsuccessful due to problems with TDRs achieving wireless connectivity with electrical interference. TDR records collected from two sets on Vessel 2 are not presented because only one gear type was sampled per set. In addition, two further TDR records were discarded (also due to tangled snoods or incorrect times being recorded).

3.1 Sink profiles of novel weights

There was considerable variation in sink rates for each novel weighting device tested and amongst sets in which the skippers' normal weighting approaches were used. For example, sink profiles recorded by TDRs during safe lead deployments and when 60-g lumo leads were used are shown in Figure 1. Sink profiles recorded on one vessel's normal gear are shown in Figure 2.

In addition to the weighting regimes tested, numerous factors are expected to have contributed to the variation in sink profiles. For example, deployment method affected sink profiles. On Vessel 3, when TDR-snoods were deployed using the dragging method, sink rates of 40-g lumos to approximately 7 m depth were slower than when gear was deployed using the slack method (Figure 3). Lightsticks also showed slower average sink rates below depths of 2 m (Figure 4). While not quantified, propeller turbulence and wave action are also considered likely to have affected sink rates particularly at depths close to the sea surface.

On Vessel 1, TDR records showed that the mean sink rate for normal gear was slightly slower than for gear carrying 60 g safe leads, to a depth of approximately 7 m. On this vessel, normal gear was sometimes fitted with lightsticks. No information was available on the snood by snood deployment of weighted swivels. Below 7 m, the averaged sink profiles of the normal gear and gear carrying safe leads were extremely similar. While the sink rates to 7 m depth were faster for weighted gear compared to normal gear on average, there was more variability in sink profiles and sink rates amongst gear fitted with safe leads compared to normal gear (Figure 5).

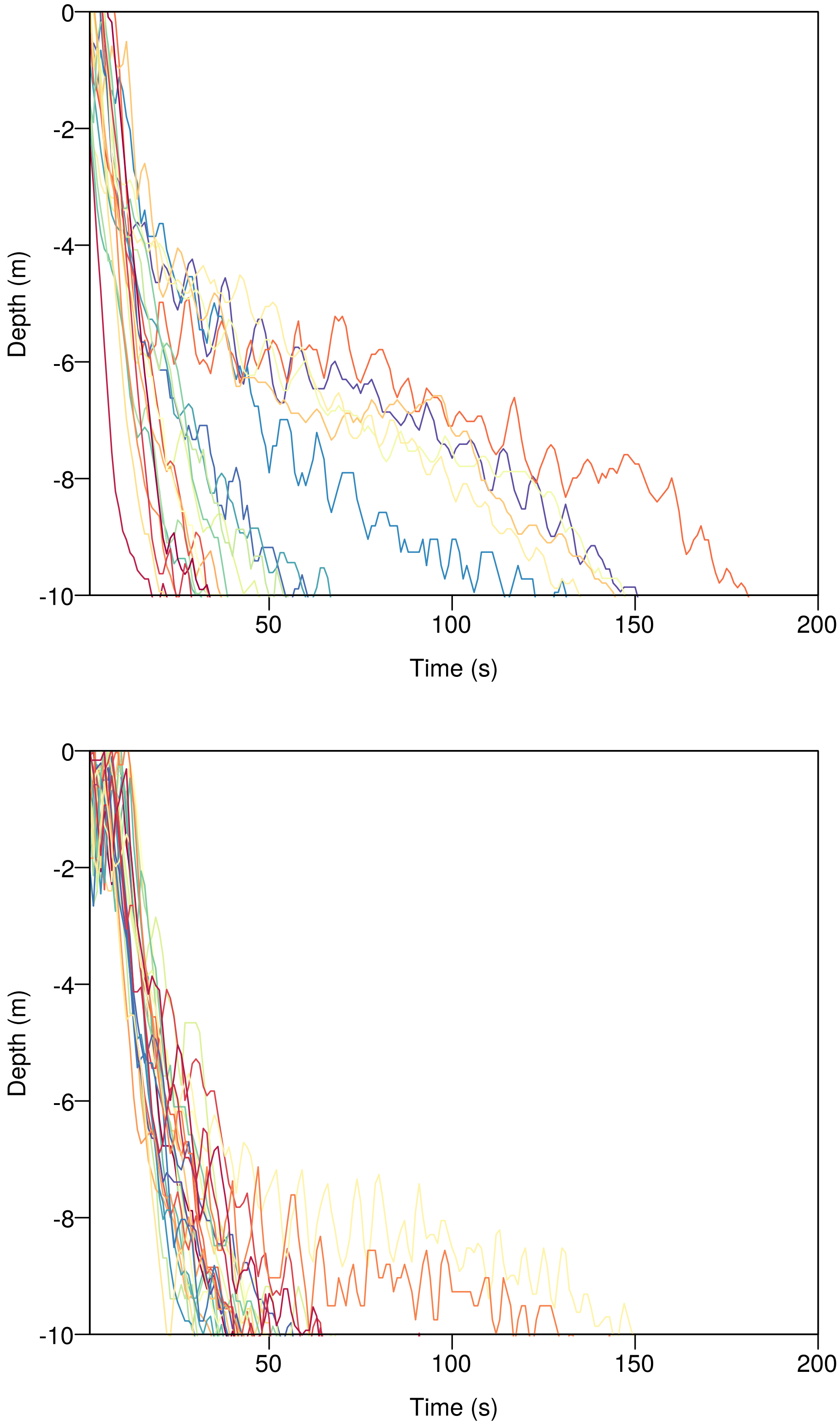

Figure 1: Sink profiles (depth over time) of 60-g safe leads (top panel) and 60-g lumo leads (bottom panel) as described by time depth recorders (TDRs) deployed on surface longlines set by vessel 1 and vessel 2, respectively. Each line represents one TDR. Variation between sink profiles may be due a number of factors, e.g., proximity of snoods with TDRs to floats.

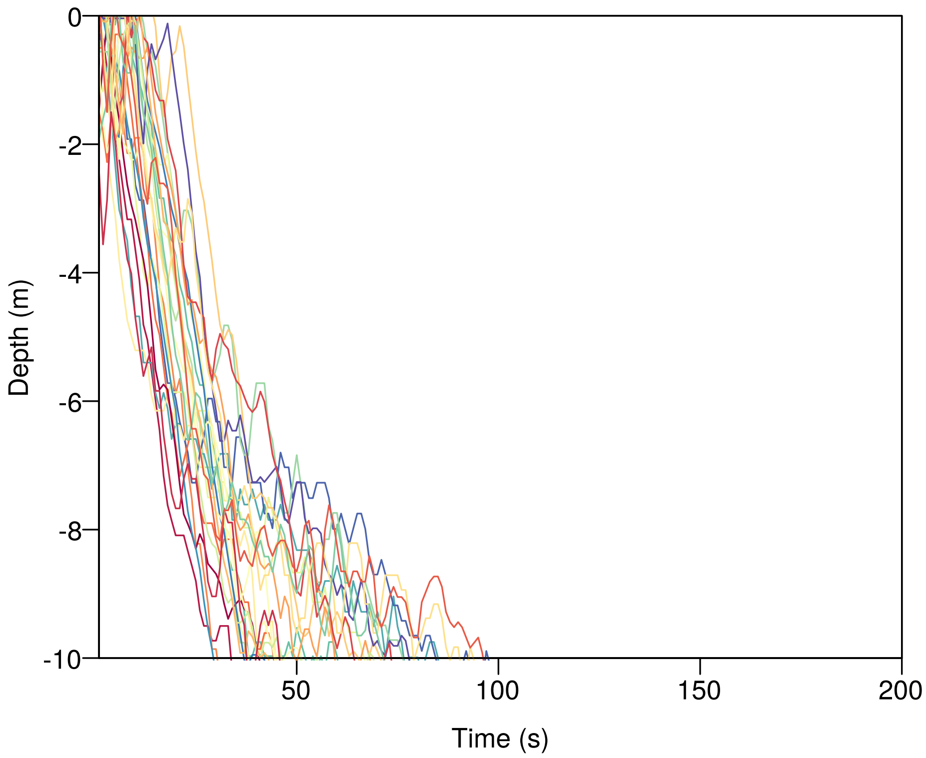

Figure 2: Sink profiles (depth over time) as described by time depth recorders (TDRs) deployed on normal surface longline gear set by vessel 2. Each line represents one time depth recorder. Variation between sink profiles may be due a number of factors, e.g., proximity of snoods with TDRs to floats.

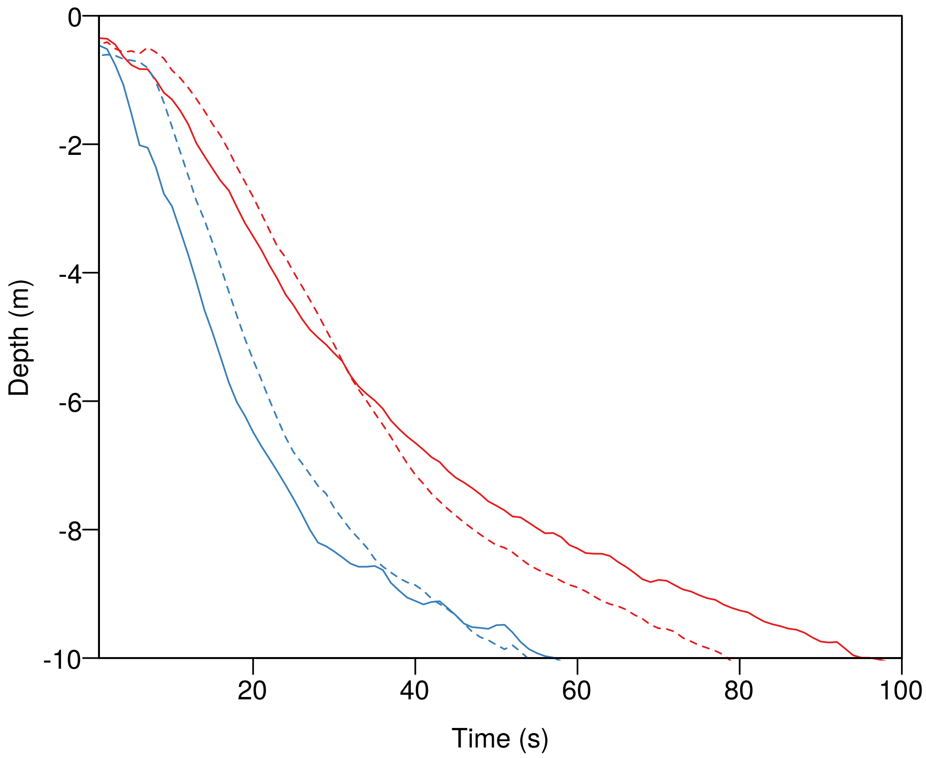

Figure 3: Mean sink profiles (depth over time) for longline snoods deployed from vessel 3, and carrying 40-g lumo leads (blue lines) compared to normal gear (red lines), when snoods were deployed using the "dragging" method (dashed lines) and the "slack" method (solid lines).

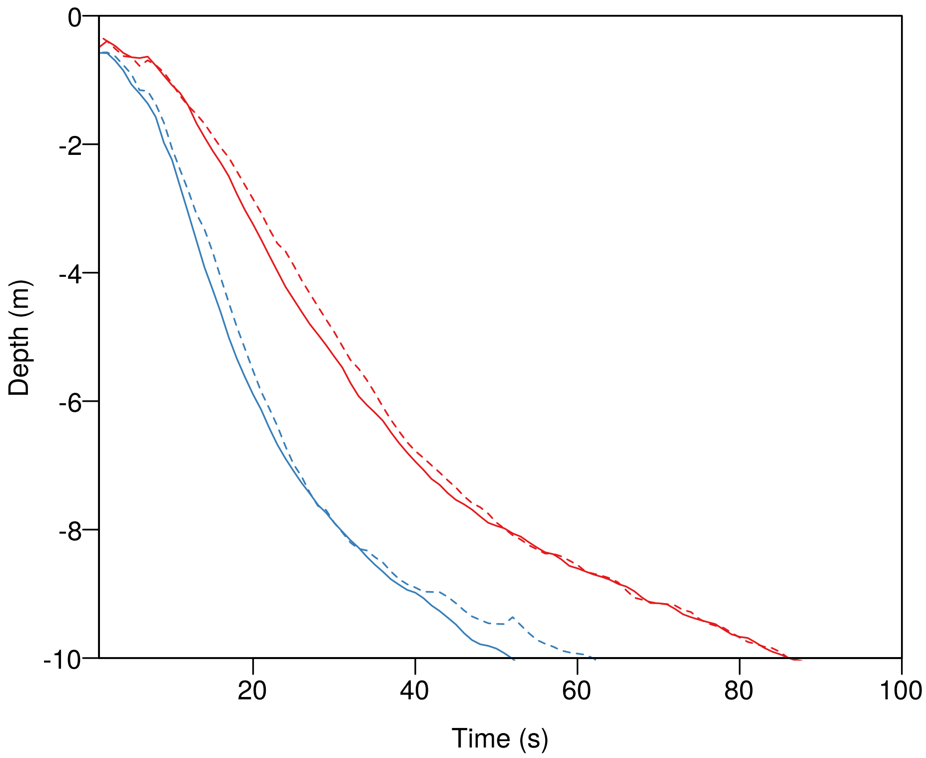

Figure 4: Mean sink profiles (depth over time) for longline snoods deployed from vessel 3, and carrying 40-g lumo leads (blue lines) compared to normal gear (red lines), when snoods carried lightsticks (dashed lines) or were deployed without lightsticks (solid lines).

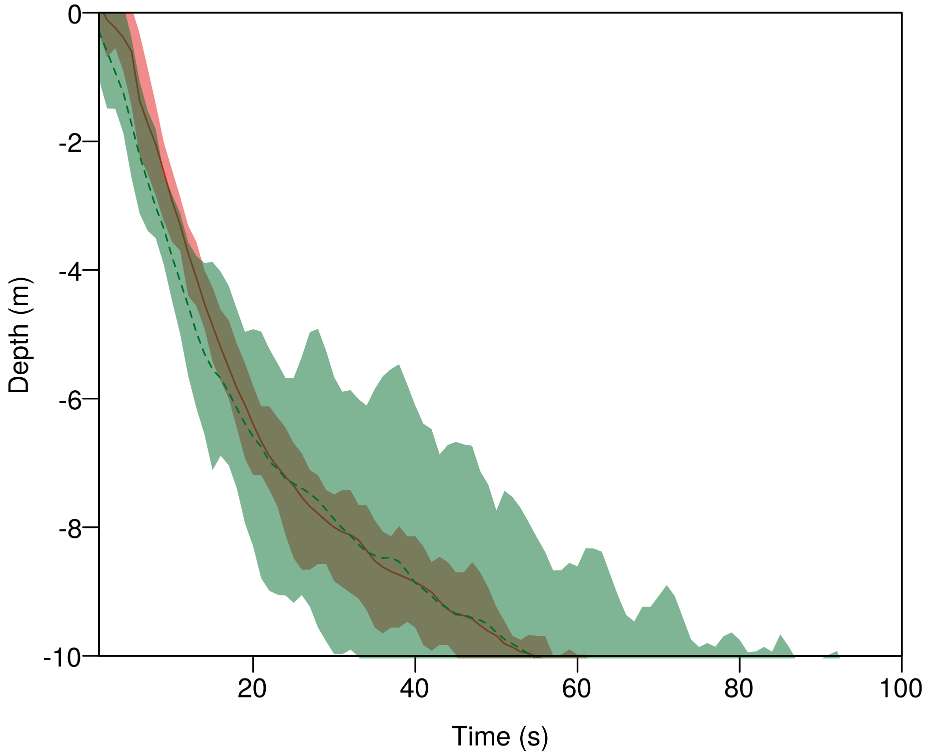

Figure 5: Mean sink profiles (depth over time) and interquartile range for longline snoods deployed from vessel 1, and carrying 60-g safe leads (green) compared to normal gear (red).

Table 5: Mean number of seconds taken ($\pm$1SE) for gear set as normal and gear fitted with novel line-weights (a) to reach selected depths (m), and, (b) distances astern (m) at which gear reached these depths, when deployed from three domestic vessels (V1, V2, V3) operating in New Zealand's surface longline fishery. SL = Safe lead, LL = Lumo lead, HP = Hook pod. In (c), the mean depth (m $\pm$1SE) of gear at 75 m astern the vessel is shown. "Slack" and "Drag" refer to the two methods with which time depth recorders (TDRs) were deployed on Vessel 3.

(a) Time (s) to depth

Weight	Hook	Depl.	Vess.	5 m		7 m		10 m		16 m	
				Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
SL	Yes		1	18	7–29	35	6–64	68	18–118	149	87–211
None	Yes		1	17	13–21	26	17–35	54	33–75	157	138–176
60 g LL	Yes		2	18	15–21	25	20–30	47	27–67	135	138–176
None	Yes		2	22	16–28	30	23–37	60	39–81	143	109–177
40 g LL	No	Slack	3	17	11–23	25	14–36	62	35–89	176	134–218
None	No	Slack	3	27	17–37	43	15–71	91	37–145	227	171–283
40 g LL	No	Drag	3	21	14–28	29	19–39	56	36–76	157	117–197
None	No	Drag	3	32	22–42	45	28–62	81	48–118	183	134–232
HP	Yes		3	31	17–45	46	26–66	108	71–145	218	156–280
None	Yes		3	31	20–42	49	31–67	99	66–132	221	159–283

(b) Distance (m) astern

Weight	Hook	Depl.	Vess.	5 m		7 m		10 m		16 m	
				Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
SL	Yes		1	62	27–97	120	24–216	232	63–401	446	188–704
None	Yes		1	58	41–75	89	58–120	186	107–265	536	449–623
60 g LL	Yes		2	69	57–81	96	76–116	181	103–259	522	323–721
None	Yes		2	84	60–108	117	90–144	232	151–313	552	421–683
40 g LL	No	Slack	3	61	37–85	88	46–130	220	118–322	623	461–785
None	No	Slack	3	96	57–135	151	45–257	310	107–513	772	518–1 026
40 g LL	No	Drag	3	79	54–104	109	73–145	209	135–283	585	438–732
None	No	Drag	3	119	82–156	167	103–231	302	180–424	680	499–861
HP	Yes		3	108	58–158	162	92–232	378	247–509	762	544–980
None	Yes		3	109	72–146	170	106–234	346	231–461	751	504–998

(c) Gear depth at 75 m astern

Weight	Hook	Depl.	Vess.	Mean	±SE
SL	Yes		1	6.8	4.7–8.9
None	Yes		1	6.9	5.7–8.1
60 g LL	Yes		2	6.2	4.9–7.5
None	Yes		2	4.4	2.5–6.3
40 g LL	No	Slack	3	6.8	4.7–8.9
None	No	Slack	3	4.1	2.3–5.9
40 g LL	No	Drag	3	5.4	4–6.8
None	No	Drag	3	2.8	1.9–3.7
HP	Yes		3	4.2	2.3–6.1
None	Yes		3	3.7	2.1–5.3

On Vessel 2, 60-g lumo leads did not sink consistently faster, on average, than normal gear until a depth of about 2 m was reached. On this vessel, normal gear and gear carrying lumo leads was typically (but not always) also fitted with weighted swivels at the clip. No information was available on the snood by snood deployment of lightsticks. Below 2 m, gear fitted with 60 g lumos sank consistently faster, such that lumo gear reached 10 m depth at around 40–45 s, on average, compared to normal gear which reached 10 m at approximately 50–55 s (Figure 6).

When 40-g lumo leads were deployed from Vessel 3, on average, higher sink rates were consistently achieved compared to normal gear. As noted above, deployment method also affected sink rate, such that normal gear set slack sank faster to approximately 7.5 m than normal gear set using the dragging method. From around 7.5–8.5 m, sink profiles were largely identical for normal gear deployed using the slack and dragged deployment method. Below around 8.5 m, normal gear set slack sank more slowly than gear set using the dragging method (Figure 3). For gear fitted with lumo leads, slack deployment also led to a more rapid sink rate compared to that of normal gear, to depths of around 8.5 m. Similarly, lumo leads sank faster than normally-weighted gear deployed by the dragging method (Table 5).

Hook pods deployed from Vessel 3 showed generally faster average sink rates than normal gear, following deployment to a depth of around 6 m. Beyond that depth, normal gear sank more rapidly (Figure 7).

3.2 Fish catch

The main catch species are identified in Table 3. Landed catch was not sufficient to investigate the effects of novel weighting by species caught and implementation difficulties precluded quantitative analysis of catch from 2013.

Vessel 3 carried out 23 sets, with records from a total of 18 699 snoods (Table 6). There were a total of 1652 shark captures, with the most frequently caught sharks being blue shark (1506 captures), followed by mako shark (88 captures). There were a total of 476 tuna-group captures, with most being albacore (310 captures) and swordfish (130 captures). In the raw data, the catch rate of snoods with lumo leads was lower for shark, and higher for tuna-group species (Table 6). Across all the data the catch rate of tuna-group species on snoods in the lumo treatment was 106.6% of the catch rate on snoods without lumo leads; the catch rate of sharks on snoods in the lumo treatment was 81.1% of the catch rate on snoods without lumo leads. The raw data also show a reduction in catch rate of tuna-group species for both weighted swivels at the clip, and for snoods with lightsticks. The highest catch rate of sharks is on snoods with missing data (on either lightstick use or line-weighting). This is because the missing data are often associated with tangles in the line, caused by a shark capture, and with the tangle making identifying the gear associated with the snoods difficult.

The permutation test indicates that the experimental treatment (fitting lumo

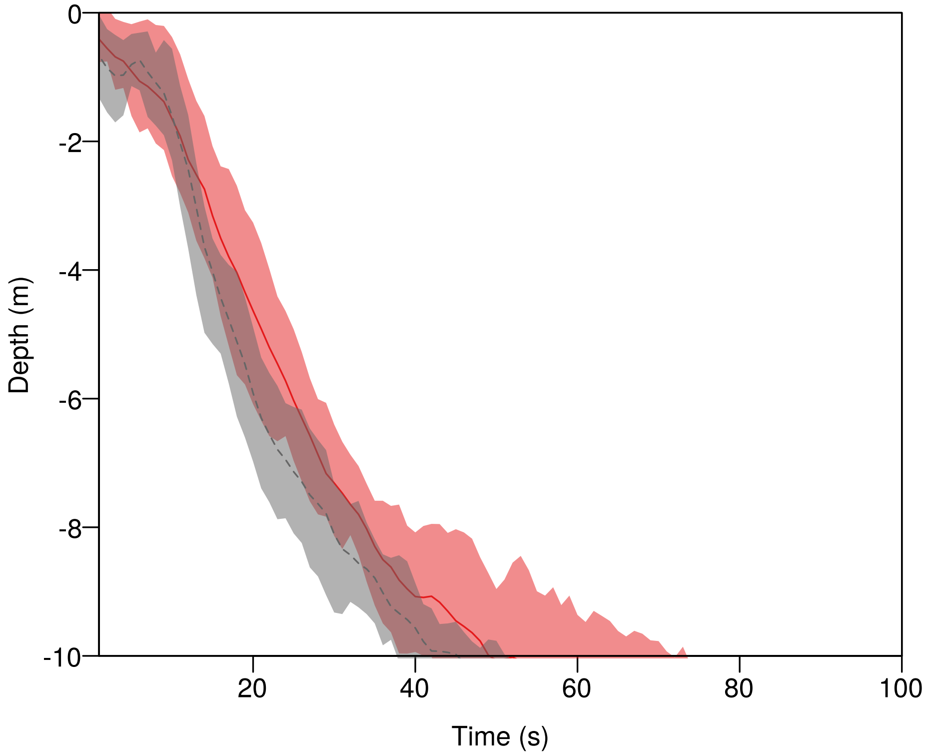

Figure 6: Mean sink profiles (depth over time) and interquartile range for longline snoods deployed from vessel 2, and carrying 60-g lumo leads (grey) compared to normal gear (red).

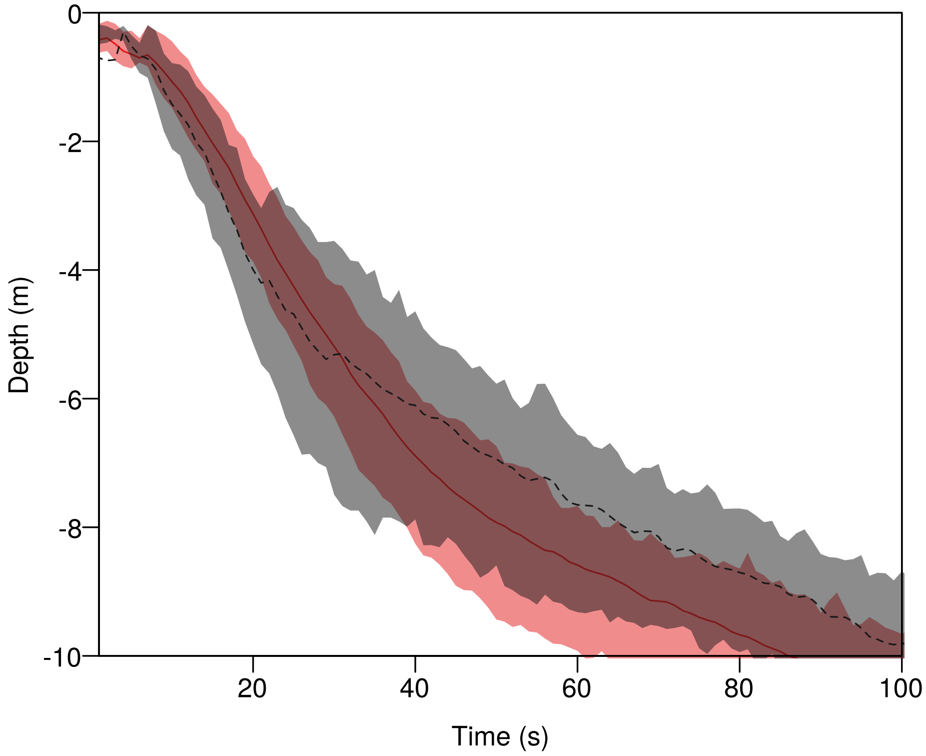

Figure 7: Mean sink profiles (depth over time) and interquartile range for longline snoods deployed from vessel 3, and carrying hook pods (black) compared to normal gear (red).

Table 6: Catch of shark and tuna - group species, in relation to the weighting of the snoods, for fishing by vessel 3. For each combination of lumo lead, swivel weighting, and lightstick, the table gives the number of snoods, the catch of shark and tuna - group species (number of individuals caught), and the catch rate (per 100 hooks) of shark and the tuna group. Records with incomplete information on lumo leads, lightsticks, or swivel weighting are indicated by dashes and are grouped together.

Lumo	Lightstick	Swivel	Snoods	Shark		Tuna-group	
				Catch	Rate	Catch	Rate
No	No	Unweighted	2 510	277	11.0	74	2.9
		Weighted	3 701	346	9.3	104	2.8
	Yes	Unweighted	983	76	7.7	17	1.7
		Weighted	1 632	91	5.6	12	0.7
Yes	No	Unweighted	4 530	393	8.7	148	3.3
		Weighted	1 670	150	9.0	40	2.4
	Yes	Unweighted	1 702	69	4.1	29	1.7
		Weighted	567	41	7.2	7	1.2
-	-	-	1 404	209	14.9	45	3.2
All	All	All	18 699	1 652	8.8	476	2.5

leads) reduces the catch rate of shark, while the relative catch rate of tuna-group species is within the range that would have been found if the lumo leads had been randomly assigned to snoods and if lumo leads had no influence on the tuna-group catch (Figure 8). An advantage of this test is that it makes relatively few assumptions. In particular, it includes all the data (including hooks that were in tangles), as it only relies on the assigned treatment, and not the record for each snood. The permutation was carried out at the basket level, and so it won't be affected by any correlation there may be between the catch on adjacent hooks.

The model-based approach allowed for a multivariate analysis, with the effect of weighted swivels at the clip and lightsticks also being explored. A model that included both lightstick and weighted swivel effects was a better fit to the tuna-group catch data (as measured by the Deviance Information Criterion), than a model with only lumo lead, while for shark catch the best model was one without a lightstick effect (and when a lightstick was included in the model, it was not significant). For sharks there was a reduction in the catch rate of around 20% when snoods were fitted with lumo lead (Table 7). The shark catch rate was also reduced by around 15% when hooks had weighted swivels at the clip. Across the sampling, there was an increase in the shark catch rate. This was accounted for by both the trend, and the inclusion of the set random effect, which allowed for variability between sets that was unrelated to the weighting. For tuna-group species, there was no significant effect of lumo lead on the catch rate, however the catch rate was reduced by around 25% when weighted swivels were used at the clip, and by around 50% when snoods had lightsticks fitted. There was a weaker increase in the tuna-group catch rate as the experiment progressed.

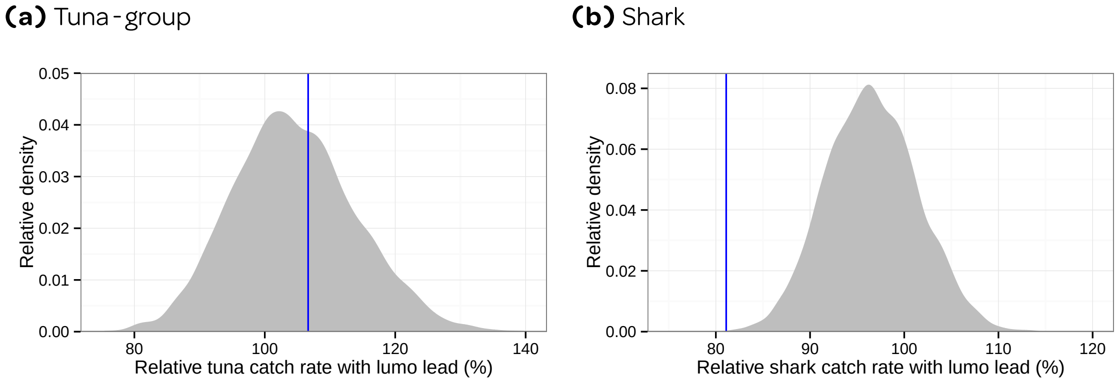

Figure 8: Catch rate on snoods in the lumo lead treatment, relative to snoods without lumo, for (a) tuna-group and (b) shark species. The blue line indicates the value calculated for the actual experimental treatment, and the shading shows the distribution of values calculated by permuting the treatment assigned to each snood within sets.

Table 7: Summary of models estimating the effect of lumo leads, weighted swivels at the clip, and lightsticks on the catch of shark and tuna-group species, showing the estimated parameters expressed as multiplicative effects. In the case of shark, the effect of lightsticks was not significantly different from zero, and a model without a lightstick effect fitted the data better.

Species	Parameter	Expression	Mean	Median	95% c.i.
Shark	Intercept	$\exp(\beta_0)$	0.01	0.01	0.01–0.02
	Lumo	$\exp(\beta_l)$	0.80	0.80	0.71–0.90
	Weighted swivel	$\exp(\beta_w)$	0.85	0.84	0.75–0.95
	Trend	$\exp(\beta_s)$	1.18	1.18	1.14–1.22
	Set variability	$\exp(\sigma_s)$	1.63	1.61	1.40–2.03
Tuna	Intercept	$\exp(\beta_0)$	0.01	0.01	0.01–0.03
	Lumo	$\exp(\beta_l)$	0.98	0.98	0.80–1.20
	Weighted swivel	$\exp(\beta_w)$	0.77	0.77	0.62–0.95
	Lightstick	$\exp(\beta_f)$	0.55	0.55	0.41–0.72
	Trend	$\exp(\beta_s)$	1.06	1.06	1.00–1.12
	Set variability	$\exp(\sigma_s)$	2.08	2.05	1.65–2.91

3.3 Operational performance of novel weighting methods

3.3.1 Safe leads

While the observer reported that safe leads were sometimes fiddly to install on snoods, crew were able to integrate the weights into their normal fishing practices aboard vessel 1. Vessel layout influenced the workability of the 60-g safe leads. For example, the setting and hauling bays were in different places on vessel 1. Therefore, bins of weighted snoods had to be moved around the deck between hauling and the next shot. The weight of gear presented some difficulty when stored in the manner that unweighted gear was stored, and the vessel skipper expressed a preference for a lighter weight in this context. Moving weighted gear was also more difficult when obstacles such as steps or hatches were located between the set and haul locations.

The crew of vessel 1 were comfortable using the weights to the extent that they stopped wearing safety helmets after the fifth set conducted during the trip. Crew reported one incident of safety concern which occurred when the observer was not on the vessel. A bite-off resulting from a blue shark capture removed the hook from the snood on which the shark was caught, but the crimp at the end of the snood remained in place. As a result, the safe lead could not slide off despite extreme stretching of the monofilament. The snood and safe lead flew back and hit the vessel approximately 1 m forward of the hauling station. The safe lead deformed on impact, but the rubber O-rings remained in place.

Safe leads were not reported to abraid the monofilament of snoods, in contrast to lumo leads (see below).

3.3.2 Lumo leads

Crew on vessel 3 effectively worked lumo leads into their normal fishing operations, such that setting and hauling could occur at normal speed (i.e., as when lumo leads were not in use). Initially, lumo leads were set up at 50 cm from the hook. However, from a handling perspective, crew preferred the weights to sit slightly further from the hook (i.e., up to 1 m from the hook). Snoods were stored between sets with the lumo lead at the hook, and the leads were moved up snoods on shooting. At the haul, lumo leads were moved back to the hook for storage. The leads were initially fixed on the line by sliding them freely, then tightening them on the snood with half a turn on the screw-threaded cap. At the haul, the security of the caps was rechecked (as they sometimes came loose), prior to the gear being stored. During the trial, lumo leads abraded the snood monofilament at their point of attachment. Over time, the roughness this abrasion creates may affect the ability of the leads to move along the snood, as well as reducing the strength of the snood and increasing its visbility in the water.

During the haul, similar numbers of hooks on normal gear and gear carrying lumo leads were bitten off by fish, or ripped out from fish. In about half the instances during the haul when fish were cut from snoods with lumo leads

Table 8: Gear and catch losses from snoods recorded during the haul of surface longlines carrying 40-g lumo leads, and from snoods without lumo leads. Some snoods also had weighted swivels at the clip. The table gives the percentage of the total documented losses that were of each loss type. There were 640 documented losses from a total of 9 038 snoods set with lumo lead; and 651 documented losses from a total of 9 079 snoods set without lumo leads.

Loss type	From snoods with lumo (%)	From snoods without lumo (%)
No hook or weight at the haul	9.8	0
No hook at the haul	25.3	34.8
Hook ripped from fish during haul	7.2	6.1
Hook bitten off by fish during haul	10.3	7.8
Hook and fish cut from snood at haul	25.5	51.2
Weight, hook and fish cut from snood at haul	21.9	0

attached, leads themselves were lost overboard (Table 8).

Cutting lumo-lead weights, hooks, and fish catch from snoods generally did not cause weights to move along the snood. When fish and hooks were cut from snoods, weights occasionally slid off snoods (Table 9). However, most lumo-lead movement occurred when bite-offs occurred during hauling. During bite-offs, weights slid on snoods more often than not. In contrast, when hooks were ripped from fish during the haul, weights mostly did not move on snoods (Table 9).

Of particular interest in this trial is the incidence of weights flying back at the vessel, which comprises a safety risk. Twelve fly-backs were recorded when gear was set using lumo leads (Table 9). Amongst these 12 snoods, seven carried lumo leads and five were fitted with both lumo leads and weighted swivels at the clip. In two cases when fly-backs occurred, a knot had formed around the lumo leads. In a further two cases, the lumo lead slid down the snood to the hook. In four cases, the lumo lead had moved slightly on the snood. Of the remaining four cases, three lumo leads had not moved on the snood. For the final snood, there was no record of weight movement. Of the 12 fly-backs, one made contact with the crew and one contacted the vessel.

Of the losses reported, most occurred while snoods were in the hand, rather than attached just to the longline backbone (Table 9). For example, amongst losses occurring from gear carrying lumo leads, 76% of 411 documented losses occurred when gear was in the hand. For losses documented from normal gear carrying weighted swivels at the clip or no weighting, 81% of 470 documented losses occurred when gear was in the hand.

Of the 12 instances when snoods fitted with lumo leads flew back towards the vessel in 2014, six involved the weight moving through the air within 1 m of the sea surface. These instances all occurred while snoods were in the hand. In the other six cases, the snood moved through the air more than 1 m from the sea surface. One of these instances occurred when the snood was on the longline backbone, and the others occurred when snoods were held Table 9. Fly-backs occurred with hooked blue sharks (eight incidents), sunfish (three incidents) and one mako shark.

3.3.3 Hook pods

The crew rapidly became accustomed to working with hook pods as part of their normal setting and hauling operations. Keeping the bait on the back of the hook made enclosing the hook barb in the pod easier at the set. During the trials, three retained fish (one swordfish and two southern bluefin tuna) were caught on snoods carrying hook pods. The pod on which the swordfish was caught was closed at the haul. There were some incidents of sharks damaging the snoods around pods, of closed pods being hauled with shark damage evident and no bait remaining, and of pods being lost from snoods underwater.

There were 12 instances amongst the 292 deployments when pods did not open underwater. These instances occurred amongst six pods. The barb became snagged on one additional pod, preventing it opening completely. Subsequent examination suggested this pod may have been deployed upside down. Two pods popped open at the sea surface during setting. There were three instances during fishing when knots formed in snoods carrying hook pods. Tangles also occurred when snoods with hook pods were in bins (three occasions). (In addition, tangles often occurred when fish were caught, e.g., blue sharks, as would be the case during normal longline operations).

One pod moved on its snood as part of a tangle caused by a thresher shark (*Alopias vulpinus*). This pod moved moved up the snood, and came to rest at the clip securing the snood to the mainline. The movement of another hook pod was documented on a snood that caught a southern bluefin tuna. This pod moved approximately 6.5 m up the snood towards the clip, and the collar of the hook pod was melted in the process. There was one incidence of a pod flying back at the vessel during the haul.

By the fourth haul, water ingress was noted inside the hook pod battery casing. Given batteries were removed prior to deployment to deactivate the pods' built-in LEDs, the battery compartment may not have been closed completely or sufficiently tightly to keep water out throughout prolonged fishing activity.

Overall, skipper and crew feedback about hook pods was positive. The skipper retained three pods at the conclusion of the trial, in order to discuss the pods with his colleagues.

Table 9: Behaviour of 40 - g lumo leads following losses of gear and catch recorded during the haul of surface longlines, from fishing by Vessel 3 in 2014. In addition to the lumo leads, some snoods also had weighted swivels at the clip. The outcome of 292 losses from snoods with lumo leads was documented. For each recorded loss type, the table gives the number of lumo leads that stayed fixed without moving, the number that slid but stayed on the snood, the number that slid off the snood, the number that flew off the snood and stayed within 1 m of the sea surface, and the number that flew off the snood and went over 1 m from the sea surface. Note that in the two cases when hooks ripped from fish but lumos were reported to slide off the snood, the slide - off occurred following the rip - out, when the snood was cut.

Loss type	Lumo fixed	Lumo slid		Lumo flew back	
		Stayed on	Slid off	Below 1 m	Over 1 m
Hook ripped from fish during haul	32	4	2	2	3
Hook bitten off by fish during haul	12	12	24	4	3
Hook and fish cut from snood at haul	135	1	6	0	0
Weight, hook and fish cut from snood at haul	50	1	1	0	0

4. DISCUSSION

This study investigated the operational feasibility and effects on fish catch of non-traditional line-weighting methods in the New Zealand domestic surface longline fishery. It encompassed three vessels and the testing of four devices designed to reduce seabird bycatch: (i) safe leads, (ii) 60-g lumo leads, (iii) 40-g lumo leads, and (iv) hook pods. Broadly, the operational feasibility of the devices was confirmed. Safety caveats and recommendations for design improvements are discussed in detail below. Sufficient at-sea data were collected to explore the effects of 40-g lumo leads on fish catch rates. For tuna and swordfish, catch rates were unaffected on snoods carrying lumo leads compared to normal gear. However, catch rates of sharks were reduced when lumo leads were deployed. The effects of other gear components (i.e., lightsticks and weighted swivels at the clip) are also discussed in detail below.

4.1 Safe leads

On average, 60-g safe leads sank more rapidly than normal gear, to a depth of 7 m. However, particularly below 4 m depth, there was more variation in sink rates amongst safe leads. The position on the longline of the group of snoods carrying safe leads varied between sets, and the length of float ropes and the proximity of the safe leads to a surface float may contribute to the variability observed. Further, the effects of the addition of weighted swivels at the clip and lightsticks to gear may be important but could not be investigated, due to a lack of detailed snood-by-snood information.

The safety of safe leads in terms of the frequency of fly-back events and the force of recoil has been investigated both on land and at sea (Marine Safety Solutions (NZ) Ltd 2010, Sullivan et al. 2012). In this project, one potentially injurious fly-back was reported of a snood fitted with a safe lead. The safe lead could not slide off the snood in this incident as a crimp remained after the hook was bitten off. The safe lead hit the vessel and deformed on impact. The frequency with which this situation arises is expected to be low. However, an analogous situation is created when hooks rip out of fish during the haul. This occurs more commonly, as shown by the data collected during this project, and therefore demonstrates that using safe leads still requires caution and ongoing risk management.

Overall, crew were able to integrate safe leads into their normal fishing operations readily. The weight of the leads on gear stored in the normal way may require amended storage arrangements, especially where gear must be moved between the hauling and setting stations. Safe leads must be added to gear well in advance of fishing, given the time taken and detailed nature of this activity.

Safe leads were not reported to abraid snoods, while abrasion was documented during lumo lead trials (see below). It is expected that the potential for abrasion is ameliorated by the softer rubber core of safe leads, rather than the harder plastic from which lumo leds are constructed.

4.2 Lumo leads

Overall, 60-g lumo leads sank to 10 m depth more rapidly than normal gear, although differences between the two gear types were not consistent from 0 – 2 m depth (possibly due to the effects of propeller wash). The 60-g lumo leads showed similar variability in sink rate to normal gear to around 8 m depth. From there the sink rates of normal gear were more variable. Similarly, snoods carrying 40-g lumo leads achieved more rapid sink rates than normal gear. However, the use of lightsticks slightly reduced sink rates. The method by which snoods were deployed also affected sink rates, with deployments conducted with slackness in the snood sinking faster. Where fishers are able to modify their gear configuration and approaches to setting to maximise sink rates, these results should be considered.

The 40-g lumo leads affected fish catch. The catch of tuna and swordfish species was not affected. However, the catch of sharks was approximately 20% lower when lumo leads were deployed on snoods, compared to normal gear. Further, the catch of tuna-group species and sharks was, on average, 25% and 15% lower on snoods with weighted swivels at the clip during this trial. A particular strength of the permutation method from which these results emerge is that testing is conducted at the basket level. Therefore the potential correlation of catch amongst hooks does not affect the results.

The reduction in shark catch that was achieved using lumo leads has particular relevance for fisheries management in the context of New Zealand's National Plan of Action for the conservation and management of sharks, and associated bans on shark finning (Ministry for Primary Industries 2013). Work examining fish catch rates on 40-g lumo leads deployed at the hook compared to two other experimental weighting regimes (120 g within 2 m of the hook, and 60 g weighted swivels within 3.5 m of the hook) found no effect of weighting regime on catch rate (Robertson et al. 2012). No other work was found that compared fish catch with 40-g weights and unweighted gear, or when weighted swivels were deployed at the clip.

Modelling analyses found that the catch of tuna-group species was 50% lower on average when lightsticks were present, although lightsticks were not significant in accounting for shark catch rates. Modelling provided for a multvariate exploration of the catch data. Therefore, unlike the permutation analysis, the analysis could only consider snoods for which the exact gear configuration was known. In addition, unlike the permutation analysis, a key assumption of the modelling analysis was that catch on each hook of a particular set was independent. This may not have been the case.

In contrast to the findings of this study, other authors generally report an increase in swordfish catch when lightsticks are used on longline gear, although threshold effects have been detected, beyond which the addition of more lightsticks does not increase catch further (Poisson et al. 2010, Anderson et al. 2013). Similarly, studies documenting the effects of lightsticks on tuna catch (specifically bigeye) report an increase in catch per unit effort commensurate with the use of lightsticks (Murray & Griggs 2003, Hazin et al. 2002). An increase in blue shark catch with lightstick use has also been documented (Poisson et al. 2010). While the mechanism by which lightsticks affect catch has not been confirmed, lightsticks may attract (or deter) the fish themselves, or their prey (Poisson et al. 2010). Further, the effects of lightsticks may also depend on the size of fish exposed to them (Anderson et al. 2013). Finally, lightsticks may attract fish to the general area in which longlines are set, but not to the specific snood on which the stick is placed.

In addition to the mechanism by which lightsticks affect catch, a number of factors may contribute to our findings in relation to this component of longline gear. Examining the effects of lightsticks on individual species (e.g., bigeye compared to southern bluefin tuna), rather than the species groups used here due to the preliminary nature of trials, may yield different results. Further, lumo leads also have luminous properties and the extent of that influence combined with any effects of lightsticks is unknown. In addition, in our study, lightstick placement was documented on vessel 3 on the haul. By that time, it is possible that some lightsticks may have been removed (i.e., during the soak by sharks). However, removals are considered unlikely to have occurred at such broad scale that statistical significance would be affected. While the influence of luminosity on catch is confirmed, non-luminous line-weighting methods may be preferred (e.g., including non-fluorescent lumo leads), given skippers can then add simply add lightsticks or not, depending on their preferences. However, if luminous lumo leads are used, cost savings on lightsticks may be attractive to fishers.

Crews using lumo leads during the trial rapidly streamlined the use of these weights into their fishing operation. Some fine-tuning of the storage of leads helped reduce the likelihood of tangles occurring in bins. Gear and catch losses occurred at broadly similar rates for gear carrying 40-g lumo leads and normal gear. On the vessels in this trial, fishers were generally more cautious in their handling of large sharks hooked on lumo gear. Beyond the trial context and perhaps particularly during their initial experiences with lumos, fishers may be more inclined to cut sharks off snoods to minimise injury risk represented by the line-weights, rather than bringing sharks onboard for dehooking. The loss of lead-filled lumos in this context has environmental consequences, as well as economic ones when fishers replace the lost weights.

During the trials conducted with 60-g lumo leads, no fly-backs were reported. Twelve fly-backs occurred during the extended trial of 40-g lumo leads. Leads were reported to slide on snoods in all but one instance and the force of fly-backs overall was variable. As for safe leads, these results demonstrate the potential value of sliding leads in terms of improving safety, while also emphasising the ongoing requirement for risk management, should lumo leads be deployed. Working weights further from the hook may present a safer approach, in that the weight will be in the hand sooner, reducing the opportunity for monofilament between the weight and the hand to become stretched under tension (e.g., caused by a captured shark). Similarly, cutting fish from the line sooner, rather than later during the haul, reduces the opportunity for caught fish to put tension on snoods, as described above.

Internationally, deploying 40-g weights at or close to the hook has been highlighted as one approach to reducing seabird bycatch risk (Robertson et al. 2013). The 40-g lumo leads that we tested comprised a partially lead-filled plastic canister. The empty part of the canister was at the end of the weight closest to the hook. Placing such weights at the hook may be appealing as the open end of the canister may fit over the crimp. However, this is not recommended as it restricts the distance that the weight will be able to slide along the snood to absorb tension in case of recoil. Weights need to be deployed such that bite-offs cleanly remove the hook and crimp, thereby allowing the weight to slide right off the snood if needed. Similarly and as observed in this project, the occurrence of knots in snoods above and below lumo leads impedes weight movement and is a safety risk. Fine-tuning handling practices over time (for example, adjusting storage and deployment practices) may reduce tangling and the occurrence of knots. Finally, skippers felt that covering the crimp with the empty space of the lumo canister may affect how hooks behave (e.g., leading to fish freeing themselves more easily after being hooked).

Design changes that may improve the safety and operational feasibility of lumo leads include modifying the screw cap so that it is less pointed and creating a 40-g weight without the recess in the canister of the current design. Adding an internal chamber to help absorb the force of any impact may also be advantageous. Reducing the extent to which the monofilament of the snood becomes scratched would improve the longevity of snoods on which lumo leads are deployed. On vessel 3, it was noted that tuna generally caused the lumo lead to slide up the snood towards the backbone, whereas sharks did not. If lumo leads could be refined to slide more easily away from the hook, but maintain friction if moving towards the hook, crew would be able to have the leads in hand sooner during the haul. This would further increase safety.

4.3 Hook pods

Crew effectively integrated hook pods into their normal setting operations. Hook pods sank more rapidly than normal gear, to approximately 5.5 m depth. From there, normal gear sank more quickly. The effect of pods on sink rate results from the pod effectively shortening the snood, given it is attached part-way along. Therefore, the sink rate of the backbone itself comes into play earlier than for normal gear with effectively longer snoods.

Hook pods are at an earlier developmental stage than lumo leads, for example, and are not yet commercially available. Recommendations for the ongoing development of the pods which emerged from the trial included modifying the shape into an ovoid form and reducing the pod size. These changes were considered likely to reduce the likelihood of pods tangling with other gear components. When open, pods were more vulnerable to breakage, e.g., at the haul. Therefore, a design that closed on hauling would be expected to be more durable.

One fly-back occurred during the trial of hook pods. Pods were able to move along snoods, but refining the design such that movement occurs more easily would be expected to improve the safety of the device. Also, being able to more readily move pods along snoods would facilitate storage in bins, reducing tangling.

The batteries powering integrated LEDs were removed from hook pods during this trial at the fisher's request. Amending the design such that LEDs can readily be switched on or off would be advantageous. This would also ameliorate potential issues with sealing of the battery compartment.

Sea conditions during the voyage on which hook pods were deployed were rough. This prevented a thorough examination of pod opening depths. Preliminary work suggested pods were opening at depths of 10-20 m. However, some pods didn't open and others opened at the surface on setting. Confirming that pods reliably open at a known depth is important for their marketability in a commercial environment. A new O-ring has been introduced to hook pods manufactured since this trial, to improve the consistency of depths at which pods open (B. Sullivan, pers. comm.). Testing to confirm opening depth could readily be undertaken outside the fishing context, e.g., from a vessel at sea in relatively shallow water during calm weather.

4.4 Seabird bycatch context

This study did not utilise seabird bycatch events as a metric to evaluate the efficacy of the bycatch reduction measures tested. However, bycatch risk can be assessed indirectly, by considering the depths that longline gear reached over time, and at certain distances astern. The results from this study confirm those of other work, in that line-weighting generally increased the sink rates of surface longline gear. However, when depths accessible to seabirds are considered, there is a considerable window of opportunity during which birds could successfully attack hooks. Amongst seabirds, for shallow-diving albatross, there is the least opportunity to attack baits, with gear weighted using safe leads and lumo leads reaching 5 m depth in around 20 seconds. However, for species that dive more deeply, such as petrels and shearwaters, the potential for attacking baits is much greater. For example, 40-g lumo leads took around one minute (on average) to reach 10 m depth and almost three minutes to reach 16 m. That these are average figures is important - considerable numbers of baits on a longline will be available at shallower depths for longer times.

Distance astern the vessel provides another proxy of bycatch risk. For example, if an effective tori line is deployed during setting, seabird access to fishing gear would be reduced for some distance astern. However, the results of this study show that at 75 m astern, weighted fishing gear was at around 4 –7 m deep. This is well within the diving capabilities of seabirds such as the flesh-footed shearwater (*Puffinus carneipes*) and the black petrel

(Thalmann et al. 2007, Bell et al. 2014).

During hauling, weights close to hooks will help keep hooks down in the water column to some degree, potentially reducing the risk of seabird captures. However, this will be affected by the fish catch on the line. Further, skipper preference is an important determinant of the distance from the vessel at which the gear emerges from the water during hauling. Fish caught can also affect the haul profile. For example, swordfish float when caught (D. Goad, pers. obs.), thereby potentially bringing the line closer to the surface and increasing seabird access to hooks and fish catch.

4.5 Conclusions

Line-weighting is a well established component of best-practice approaches to reducing seabird bycatch in surface longline fisheries (Lokkeborg 2011). Best-practice recommendations for minimum standard line-weighting in surface longline fisheries are for more than 45 g of weight to be attached within 1 m of the hook, more than 60 g within 3.5 m of the hook, or more than 98 g within 4 m of the hook (ACAP 2013). The 40-g lumo leads used in this study did not meet this standard, while the 60-g safe leads and lumo leads did.

The results of this study confirm that while line-weighting approaches tested were broadly effective in increasing the sink rate of surface longline gear, hooks on snoods fitted with safe leads or lumo leads would still be accessible to seabirds at significant distances astern. Further, hooks would remain accessible to some species beyond the aerial extent of tori lines described in the New Zealand regulations. Where weighting approaches comprise lumo leads and safe leads, this situation emphasises the value of combination approaches to seabird bycatch reduction, for example, deploying line-weights in addition to night-setting (Lokkeborg 2011). Hook pods address bycatch risk in a different way, by completely covering the hook and thereby preventing seabirds accessing it until pods open. This has obvious advantages in that it may minimise or eliminate the need for other mitigation measures.

In addition to the direct benefits of line-weighting in terms of increasing sink rates of baited hooks, this study demonstrates the importance of other factors influencing sink rate. In particular, the use of a dragging or slack deployment style may be something crews can readily change, thereby increasing the sink rate of whatever gear they are using. Encouraging fishers who have used line-weights safely and effectively, and who utilise other measures (such as slack snood deployment) that increase hook sink rates as a normal part of their operations, to share their practices with fishers not using these approaches may facilitate uptake amongst the fleet.

Beyond considerations of their efficacy in a seabird bycatch context, this project confirms that the weighting methods tested were feasible in an operational context on domestic surface longline vessels operating in New Zealand waters. However, the measures tested in this trial still carry operational safety risks. In addition, expenditure associated with the initial purchase and replacement of lost weights means that weighting represents an ongoing cost of business. Further, amongst the novel measures tested here, there is potential to refine designs to improve safety and operational performance. Establishing that hook pods open reliably at (or on the way to reaching) fishing depth is likely to be an important component of their commercial success. Monitoring fish catch rates over time where line-weighting is deployed, including catch of tuna and swordfish as well as shark species, and in relation to the gear components evaluated here, would also be a valuable next step following this short-term study.

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6. REFERENCES

Abraham, E.R.; Thompson, F.N. (2011). Estimated capture of seabirds in New Zealand trawl and longline fisheries, 2002–03 to 2008–09. *New Zealand Aquatic Environment and Biodiversity Report No. 79*. 74 p.

ACAP. (2013). ACAP summary advice for reducing impact of pelagic longlines on seabirds. Agreement on the Conservation of Albatrosses and Petrels, Hobart.

Anderson, O.F.; Doonan, I.J.; Griggs, L.H.; Sutton, P.J.H.; Wei, F. (2013). Standardised CPUE indices for swordfish *Xiphias gladius* from the New Zealand tuna longline fishery, 1993 to 2012. *New Zealand Fisheries Assessment Report 2013/46*. 24 p.

Anderson, O.R.J.; Small, C.J.; Croxall, J.P.; Dunn, E.K.; Sullivan, B.J.; Yates, O.; Black, A. (2011). Global seabird bycatch in longline fisheries. *Endangered Species Research 14*: 91–106.

Baker, G.B.; Double, M.C.; Gales, R.; Tuck, G.; Abbott, C.L.; Ryan, P.G.; Petersen, S.L.; Robertson, C.J.R.; Alderman, R. (2007). A global assessment of the impact of fisheries-related mortality on shy and white-capped albatrosses: conservation implications. *Biological Conservation 137*: 319–333.

Bell, E.A.; Mischler, C.; Sim, J.L.; Scofield, P.; Francis, R.I.C.C.; Abraham, E.; Landers, T. (2014). At-sea distribution and population parameters of the black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013/14. Unpublished report prepared for the Department of Conservation. Retrieved 15 July 2014, from http://www.doc.govt.nz/Documents/conservation/marine-and-coastal/marine-conservation-services/meetings/pop-2013-04-black-petrel-2013-14-draft-final-report.pdf

Brothers, N. (1991). Approaches to reducing albatross mortality and associated bait loss in the Japanese long-line fishery. *Biological Conservation 55*: 255–268.

Bull, L.S. (2007). Reducing seabird bycatch in longline, trawl and gillnet fisheries. *Fish and Fisheries 8*.

FAO. (1995). International plan of action for reducing incidental bycatch of seabirds in longline fisheries. Food and Agriculture Organization of the United Nations, Rome.

Goad, D. (2011). MIT2010/01 development of mitigation strategies: inshore fisheries. Draft Research Report held by the Department of Conservation, Wellington.

Goad, D.; Temple, S.; Williamson, J. (2010). MIT2009/01 development of mitigation strategies: inshore fisheries. Draft Research Report held by the Department of Conservation, Wellington.

Hazin, F.H.V.; Hazin, H.G.; Travassos, P. (2002). Influence of the type of longline on the catch rate and size composition of swordfish, *Xiphias gladius* (Linnaeus, 1758), in the southwestern equatorial Atlantic Ocean. *Collective Volume of Scientific Paper: ICCAT 54*: 1555–1559.

Lokkeborg, S. (2011). Best practices to mitigate seabird bycatch in longline, trawl and gillnet fisheries - efficiency and practical applicability. *Marine Ecology Progress Series 435*: 285–303.

Marine Safety Solutions (NZ) Ltd. (2010). Safe lead impact study: Impact comparisons between SLL snoods fitted with safe leads, weighted swivels and no line weighting. Research Report held by the Department of Conservation, Wellington. Retrieved from http://www.doc.govt.nz/documents/conservation/marine-and-coastal/fishing/mss-safe-lead-report-april-2008.pdf

Maritime New Zealand. (1996). Maritime New Zealand Guidelines: Boat Notice BN 07/1996 May. Hazards with surface longline fishing. Wellington.

Maritime New Zealand. (2003). Maritime Operations Boat Notice–03/2003 May. Protective clothing on fishing boats. Wellington.

Ministry for Primary Industries. (2013). National Plan of Action for the Conservation and Management of Sharks. Ministry for Primary Industries, Wellington.

Ministry for Primary Industries. (2014). Initial Position Paper: Seabird Mitigation Measures for Surface Longline Fisheries, MPI Discussion Paper No. 2014/12. Ministry for Primary Industries, Wellington. 13 p.

Murray, T.; Griggs, L. (2003). Factors affecting swordfish (*Xiphias gladius*) catch rate in the New Zealand tuna longline fishery. 16th Meeting of the Standing Committee on Tuna and Billfish, Working Paper BBRG-9. Retrieved from http://www.spc.int/DigitalLibrary/Doc/FAME/Meetings/SCTB/16/BBRG_9.pdf

New Zealand Government. (2008). Fisheries (seabird sustainaibility measures - surface longlines) notice 2008 (no. F429). *New Zealand Gazette 31*: 711.

Pierre, J.P.; Goad, D.W. (2013). Seabird bycatch reduction in New Zealand's inshore surface longline fishery. Progress Report on project MIT2012–04. Retrieved from http://www.doc.govt.nz/Documents/conservation/marine-and-coastal/marine-conservation-services/meetings/mit-2012-01-sll-progress-report.pdf

Poisson, F.; Gaertner, J.-C.; Taquet, M.; Durbec, J.-P.; Bigelow, K. (2010). Effects of lunar cycle and fishing operations on longline-caught pelagic fish: fishing performance, capture time, and survival of fish. *Fishery Bulletin 108(3)*: 268–281.

Ramm, K. (2012a). Conservation Services Programme observer report, 1 July 2009 to 30 June 2010. Final Report, Department of Conservation, Wellington, New Zealand.

Ramm, K. (2012b). Conservation Services Programme observer report, 1 July 2010 to 30 June 2011. Draft Report, Department of Conservation, Wellington, New Zealand.

Richard, Y.; Abraham, E.R. (2013). Risk of commercial fisheries to New Zealand seabird populations. *New Zealand Aquatic Environment and Biodiversity Report No. 109*. 58 p.

Robertson, G.; Candy, S.G.; Hall, S. (2012). New branch line weighting regimes reduce risk of seabird mortality in the Australian pelagic longline fishery without affecting fish catch. WCPFC-SC8-2012/EB-WB-09. Western and Central Pacific Fisheries Commission.

Robertson, G.; Candy, S.G.; Hall, S. (2013). New branch line weighting regimes to reduce the risk of seabird mortality in pelagic longline fisheries without affecting fish catch. *Aquatic Conservation: Marine and Freshwater Ecosystems 23*: 885–900.

Sullivan, B.J. (2011). Hook pod update. SBWG-4 Doc 10 Rev1; Sixth Meeting of Advisory Committee, Guayaquil, Ecuador, 29 August - 2 September 2011. Agreement on the Conservation of Albatrosses and Petrels.

Sullivan, B.J.; Kibel, P.; Robertson, G.; Kibel, B.; Goren, M.; Candy, S.G.; Wienecke, B. (2012). Safe leads for safe heads: safer line weights for pelagic longline fisheries. *Fisheries Research 134–136*: 125–132.

Thalmann, S.J.; Baker, G.B.; Hindell, M.; Tuck, G.N. (2007). Longline fisheries and foraging distribution of flesh-footed shearwaters in eastern Australia. *Journal of Wildlife Management 73*: 399–406.