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Safe Leads for safe heads: safer line weights for pelagic longline fisheries

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Safe Leads for safe heads: safer line weights for pelagic longline fisheries

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Abstract

In many pelagic longline fisheries around the world there is reluctance to adopt a line weighting regime that will sink fishing gear rapidly to reduce seabird bycatch. In many cases this is due to safety concerns caused by traditional weighted swivels causing serious injuries, and even fatalities, when they recoil back at the crew in the event of line breakage (e.g., from shark bite offs) during line hauling. This paper presents the results of at-sea and on-shore trials to test the safety and operational effectiveness of an alternative line weight (the Safe Lead) which is designed to slide down or off the line in the event of a bite-off, virtually eliminating danger to the crew from line weights. At-sea trials in Australia and South Africa revealed that Safe Leads can reduce the incidence of dangerous fly-backs to very low levels. In South Africa, only one Safe Lead fly-back out of 25 (4 %) reached the vessel (the remainder fell in the sea) whereas 7 out of 15 (46.7%) fly backs by leaded swivels hit the vessel and one hit a crewmen in the head. Simulated bite-off events on shore revealed the degree of slippage (influences whether leads slide but remain on the branch line, or slide off the end of the line) varied as a function of distance from Safe Lead to hook (1 – 4 m range) and tension on the line (20 – 120 kg range). All (100%) of Safe Lead replicates placed within 2m of the hook slid off the line under all four tension treatments. Under the higher tension categories of 80kg and 120kg, 80% of Safe Leads positioned 3m from the hook position slid off the line after a simulated bite-off (cut-away). High speed photography of fly backs showed a significant ($P<0.05$) reduction in the velocity on impact of Safe Leads compared to leaded swivels and an associated >80% reduction in kinetic energy on impact. Our results suggest that Safe Leads are a cost-effective and operationally simple alternative to traditional weighted swivels with considerable benefits to crew safety.

Introduction

Preventing contact between seabirds and baited hooks before the gear sinks beyond the diving depth of seabirds is critical to achieving effective seabird bycatch mitigation[1]. It is widely recognized that increasing the sink rate of the baited hook is one of the single most effective means of reducing seabird bycatch in longline fisheries (Agnew et al. 2000, Robertson et al., 2006; Dietrich, et al., 2008). Traditionally, line weighting in pelagic longline fisheries has involved crimping lead swivels to branchlines/snoods and many pelagic longline fisheries around the world adopt this practice to deliver hooks to target fishing depths as efficiently as possible and as part of regulatory measures to reduce seabird bycatch.

However, many fishermen are understandably reluctant to use weighted swivels due to safety concerns. Conventional leaded swivels can be dangerous for fishermen with many accounts of crew being injured, and in rare cases, killed, when the swivels flyback at the vessel after a bite-off. Bite-offs occur when sharks are hauled to the surface and swim hard away from the vessel; this stretches the branchline to breaking point and causes a line breakage at or near the hook. This causes the weighted swivel to slingshot back toward the boat at extremely dangerous speeds. Another potentially dangerous event occurs when the hook is pulled from the fishes mouth when the line is on the surface and under hauling tension.

In response to these crew safety concerns, Fishtek (U.K) and BirdLife International developed the "Safe Lead", an alternative means of weighting snoods to traditional lead swivels. The Safe Lead rather than being crimped into the line, slides onto the monofilament and slides down or off the line in the event of a bite-off. In addition, when the hook is pulled from the fish's mouth (or on rare events when the hook straightens under tension) near or on the surface, the Safe Lead slides down the line, dampening the energy of the recoiling line and hook. Thus, the likelihood of injury to the crew is greatly reduced

In this paper we report the results of on-shore and at-sea trials in Australia and South Africa to test the operational effectiveness of Safe Leads, both in terms of their likely improvement to crew safety and their operational and economic practicality.

[1] Noting that baited hooks are potentially accessible to birds for the duration of the soak period of some 'surface' longline fisheries.

Methods

Safe Leads

Safe Leads are held in place on monofilament line by internal force on the line created by silicon rubber rings which squeeze together the two halves of the leads (Figure 1, figure to be added). During a bite-off, the line is stretched 10-20% before breaking. This stretch imparts an accelerating force on the lead equivalent to over 100 kg force. This is far more than the 5 kg internal gripping force of the Safe Lead. Thus, the weight simply slides towards the end of the branch line (or off the end of the branch line, depending on the distance to the hook) and greatly reduces the recoil force of the stretched line. Safe Leads are quick and easy to fit by threading the line through a hole in the centre of the rubber carrier (Figure 1). Squeezing the rubber buttons on the side of the carrier partially releases the pressure of the O rings and enables the Safe Lead to be easily slid up or down the line.

At sea trials

To investigate the operational effectiveness of Safe Leads, at-sea trials were conducted on domestic pelagic longliners in South Africa and Australia. The key research questions investigated were:

a) Do Safe leads slip up and down the line with usage, and if so how much?

b) Are Safe Leads safer for fishermen when a bite-of occurs (i.e. once flybacks of the Safe Lead and weighted swivels are quantified)?

c) Is there a difference in catch rates between branch lines with Safe Leads and weighted swivels of an equivalent weight?

d) Is there a difference between the incidence of bite-offs with branchlines fitted with Safe Leads and weighted swivels?

South Africa: In 2008 ,two trips were conducted during commercial operations onboard the South African flagged F/V *Admiral de Ruiter*, a 29 m pelagic longliner operating from the port of Cape Town to investigate the performance of 65 g Safe Leads compared to 60 g leaded swivels. The first trip (8-20/10/08) included 12 experimental sets over 12 d, and the second trip included 10 experimental sets over 13 d (4-17/12/08).

To avoid any potential negative impact of the experiment on fish catch rates only half the branchlines of each set were included in the research. Each set therefore contained 698 experimental branchlines (349 Safe leads treatments and 349 weighted swivel or control treatments). To simplify data recording during setting and hauling, each Safe Lead treatment line was marked with a green band adjacent to the clip that attached the branch line to the mainline. The experimental section of the line (698 branchlines) was randomly deployed at the beginning, middle or end of the longline set.

During setting operations, the two experimental treatments were stored in separate setting bins, with control treatments on the port side and the Safe Lead treatments on the starboard side of the deck. Each branchline was made of 2 mm monofilament and consisted of upper and lower sections. Each upper section measured 13.5 m and was attached to the main line with a ‘snap’. The SafeLead treatments were connected to the lower section with an unweighted swivel and a 65 g Safe Lead placed 1cm from the distal side of the swivel. Control treatments had a 60 weighted swivel joining the upper and lower sections (see Figure 2). Light sticks were placed above the swivel on both treatments. Each lower section measured 3.5 m and had a J/9 hook baited with squid.

Line setting operations commenced between 1830 h and 2030 h and lasted approximately 5 h. All operations complied with South African tuna fishing permit conditions, which include the deployment of a streamer lines during line setting and a restriction to night setting.

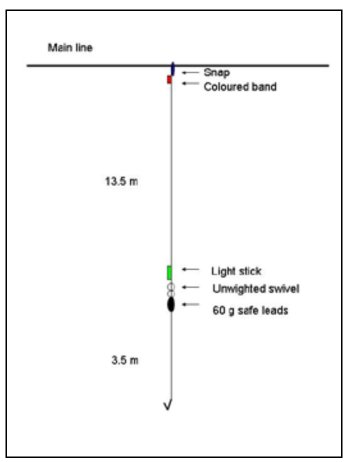


Figure 2 Safe Lead treatment branchline onboard the *Admiral de Ruiter*

Hauling usually commenced at first light. On all branch lines with catch, Safe Lead slippage was measured as the distance (cm) that Safe Leads moved towards the hook, from the point of attachment. All bite-offs and fly-backs on experimental lines were recorded. The outcome of fly-back events for both treatments were recorded on a scale of 1-4 (Table 1).

Table 1. Categorisation of weight fly-back behaviour during longline hauling

Value	Weight behaviour
1	Entered the water without striking the vessel
2	Struck the side of the vessel <1 m above water level
3	Struck the side of the vessel >1 m above water level
4	Flew over the side of the vessel

All experimental branch lines were observed and for each hook with catch the following were recorded: time, hook number, treatment species caught, size or gross length, and the condition of catch (intact/scavenged, dead /alive),when observed. The treatment of sharks varied from being cut-away before landing to landing followed by hook removal and release, to retaining for processing. Therefore, sharks were assigned to one of three size classes: small (>1m), Medium (1-2 m) and large (>2 m). For targeted catch species (i.e. tunas and swordfish), gross length was taken; swordfish were measured from mouth to tail fork and tuna from gills to tail fork.

<u>Australia</u>

To investigate the operational effectiveness of Safe Leads in the Eastern Australian Tuna and Billfish (ETBF) fishery managed by the Australian Fisheries Management Authority (AFMA), six at-sea trips were conducted in 2008. All trips were onboard the FV *Demi Maddison* operating from the port of Mooloolaba (26.41' S, 153.07' E). Two AFMA observers were deployed across the six trips to record these data. Six hundred branchlines were purpose-built for the trials. These consisted of 300 lines with 65 g Safe Leads and 300 lines with 68 g weighted swivels. As with the South African at-sea trails, fishing gear was purchased (monofilament, clips, hooks, crimps, safe leads) and branchlines were manufactured specifically to ensure standard configuration. Safe Leads and weighted swivels were placed 2.4 m from the hook on branch lines of 13 m. Branch lines with Safe Leads were marked with a cable tie on the clip and randomly mixed with normal gear in two gear bins.

On the haul measurements were made to record the degree and direction (toward the hook versus toward the clip) of each safe lead and catch by species. After being measured for slippage, Safe Leads were re-positioned to 2.4 m before being placed into gear bins, ready for the next shot. Slippage was recorded on 1298 branchlines.

Unfortunately, due to difficulties experienced with data recording and entry data on the frequency and behaviour of Safe Leads and weighted swivels during fly-backs it was not possible to analyse these data. Therefore, only data collected on Safe Lead slippage was analysed for the Australian trials.

On-shore trials

Given that bite-offs are statistically rare, a large data set would be required to facilitate a statistically robust analysis of the performance of Safe Leads under standard operational conditions. To better quantify their performance, an experiment was conducted at the Australian Antarctic Division to simulate bite-offs. Mk 3 version Safe Leads (the latest version) weighing 65 g and 60 gm lead swivels were used in the experiment. The trials were divided into two parts.

Part I: Slippage of Safe Leads

Four levels of line tension (20 kg, 60 kg, 80 kg and 120 kg) and four bottom lengths (1 m, 2 m, 3 m and 4 m) were examined in the experiment. Safe Leads were positioned on the line at 1 m, 2 m, 3 m and 4 m from the distal end of the snood and a permanent marker was used to mark the position of the Safe Lead to enable slippage to be measured. Ten replicates were conducted for each treatment (10 x 4 x 4 = total 160 replicates, Figure 3)

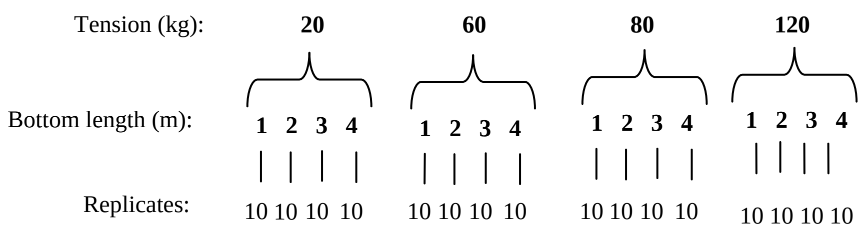


Figure 3 Treatment design for the on-shore simulated bite-off experiment

Each replicate was placed on a 12 m snood of 1.8 mm monofilament. This length was chosen to represent an ‘average’ bottom length for many Southern Hemisphere pelagic longline fisheries. To simulate the angle of a bite-off, each snood was attached 2.6 m above the ground.This height was chosen to replicate the ‘average’ height of a line hauler on a domestic tuna longliner. Snoods were passed through and attached behind a 10 cm sheet of Styrofoam (1 m x 2 m) glued to a 10 mm thick 3-ply back-board.

To investigate any potential influence in ‘ageing’ of the rubber sleeve through which the line passes, for 20 kg, 60 kg and 80 kg treatments the same Safe Lead was re-used for the first five replicates and new Safe Leads were used for replicates 6 to 10 for these three tension treatments. The 120 kg treatment was conducted on a separate day of trials and new Safe Leads were used for all 120 kg tension replicates.

Tension was applied by connecting each snood (via a crimped loop) at ground level to a digital Dillon load-cell (rated to 2000 kg in 0.1 kg increments), which was attached to a car by a block and tackle. Tension was applied by slowly driving the car forward and using the block and tackle to fine tune tension when required. When the correct tension was reached for each replicate/treatment, the line was cut at the distal end, adjacent to the attachment point onto the load cell. To simulate at-sea conditions, immediately prior to applying tension the snood was doused with water below the Safe Lead.

Three measurements were made for each replicate:

(1) Whether the safe lead slipped off the end of the end of the snood,
(2) The degree of slippage of the safe lead down the snood, when the safe lead did not slip off the end of the snood
(3) The height from ground level (*cf*: sea surface) that the Safe Lead struck the styrofoam back board

Slippage of Safe Leads was modelled using a Poisson generalized linear model (GLM) with log link function using the method described by Aitkin and Clayton (1980) for modelling censored survival time data. The GLM models the total slippage of Safe Leads under a range of tension treatments. Length of slippage was considered as a "survival time" with those trials where the Safe Lead slipped of the end of the bottom length of line considered "censored" observations with "survival time" equal to the bottom length. For trials where the Safe Lead was retained on the line, the length of slippage was treated as an "uncensored survival time". Two survival time distributions were considered the exponential and Weibull distributions. The Weibull allows more flexibility in shape of the distribution via a shape parameter, a where a must be greater than or equal to 1. If a is equal to 1 the Weibull corresponds to an exponential distribution. The estimation of a requires the GLM to be fitted in an iterative loop using the full likelihood for the data (Aitkin and Clayton, 1980). The mean slippage length was modelled both non-parametrically using tensions as discrete factor levels of 20, 60, 80, and 120 kg and parametrically using linear and quadratic terms in a tension as a continuous variable with these terms contributing to the linear predictor (McCullagh and Nelder, 1989). To test whether the number of times a Safe Lead had been re-used affected slippage distance, the number of usages (i.e. 1 = used once, to 5 = re-used 4 times) was included as a continuous linear term in the linear predictor for the quadratic model.

Part II: Safe Lead and weighted swivel velocity calculations

High speed camera equipment was used (add specs/detail of equipment) to compare the velocity at which the Safe Leads and the weighted swivels recoiled after a cut-away (*cf*: bite-off). Velocities were calculated using Motion Measure Analysis Function (Version 1.0.1.6). For these trials, a range of snoods made by Australian commercial fishermen based in Mooloolaba (New South Wales) and Hobart (Tasmania) were used to try to determine the upper breaking limit of 1.8 mm monofilament and to compare the velocity at which weighted swivels and Safe Leads recoil. Sixteen snoods with a 60 g weighted swivel crimped into the line and with bottom lengths ranging from 2.9 – 5.7 m were placed under tension until they broke. The point at which the snood broke (e.g. crimp at hook, crimp at weighted swivel or monofilament line) was recorded. The breaking strains for this professionally made gear ranged from 23 kg to 130 kg (mean 78.8 ± 7.4 kg).

Twelve replicates with a Safe Lead positioned at 3 m (n=5) and 4 m (n=7) were conducted at three tension treatments: 60 kg (n=5), 80 kg (n=6) and 120 kg (n=1). To calculate their velocity after a cut away it was essential that the Safe Lead passed through the calibration stands, which was placed adjacent to the backboard. Therefore the shorter bottom lengths of 1 m and 2 m were not used in this part of the trials because our previous trials had indicated that under all tension treatments the Safe Leads placed at short distances from the hook slip off the end of the line. Due to need for the recoiling weight to pass directly through the calibration markers it was possible to calculate the velocity of only 14 replicates (seven weighted swivel and seven Safe Leads).

Because of the relatively small sample size the tension treatments and bottom length of snoods with weighted swivels and Safe Leads were combined. A gamma/identity link GLM (McCullagh and Nelder, 1989) was used to model the velocity of Safe Leads and weighted swivels with separate intercept and linear terms in tension for each type of weight.

TTtTranslational kinetic energy is a measure of the magnitude of negative force required to return a body to a state of rest from a given velocity; e.g. the force at which the Safe Leads and swivels would impact the backboard (cf: vessel/crew). It is dependent upon two variables: the mass (m) of the object and the speed (v) of the:

$$KE = \frac{1}{2} * m * v^2$$

where **m** = mass of object and **v** = speed of object

This equation reveals that the kinetic energy of an object is directly proportional to the square of its speed. That means that for a twofold increase in speed, the kinetic energy will increase by a factor of four. The standard metric unit of measurement for kinetic energy is the Joule. As might be implied by the above equation, 1 Joule is equivalent to 1 kg*$(m/s)^2$.

Results

<u>At sea trials</u>

a) Do Safe Leads slip up and down the branchline, and if so by how much?

Australia: Safe leads are designed to slip after a bite off. On branch lines where slippage occurred, average positive slippage (± S.E.) was 53.3 ± 6.58 cm, with a range of 2 – 1077 cm. Negative slippage (towards the clip) averaged 57.9 ± 8.26 cm, with a range of -2 – 1062 cm (Figure 4). It is clear from this figure that the majority of slips that occurred were relatively small in size, with a few large slips occurring.

However, not all Safe Leads slipped on the line. Out of 1289 branch lines where the degree of slippage was recorded, there was no slippage in 568 cases. Therefore, the Safe Leads slipped on the line to some degree on 44.0% of branch lines.

In cases in which a bite-off occurred and some slippage was recorded, average positive slippage was 117.3 ± 33.8 cm and average negative slippage was -233.3 ± 107.5 cm. In comparison, in cases in which a bite-off did not occur and there was slippage recorded, average positive slippage was 51.1 ± 6.69 cm and average negative slippage was -53.0 ± 7.81 cm.

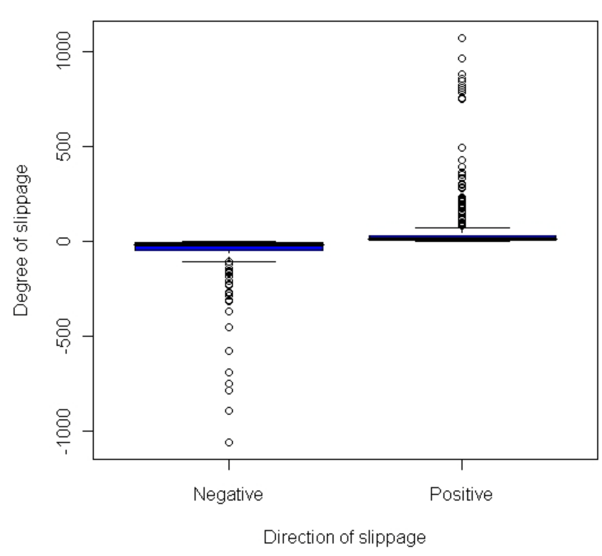


Figure 4 Direction and degree of slippage of Safe Leads in Australian trials. The central line within the box is the median, the box represents the upper and lower quartiles and the whiskers the 95% confidence intervals. Open circles are outliers beyond the 95% confidence intervals**.**
The differences in slippage between cases where a bite-off did not and did occur was not significant in the case of negative slippage (N = 258, W = 32885, p = 0.0509), but was significant in the case of positive slippage (N = 462, W = 101657, p = 0.0003).

A GLM was performed to determine whether any of the recorded factors (observer, trip, shot number, occurrence of bite-off, whether a fish was caught or not and the type of fish species caught) had a significant effect on the degree of slippage recorded. The only factors affecting the degree of slippage were the observer ($F_{1,1270} = 19.374$, $p = 0.000$) and species caught ($F_{17,1286} = 7.7066$, $p < 0.000$).

South Africa: On branch lines where slippage occurred, average slippage (± the standard error) was 39.1 ± 3.34 cm, with a range of 0.4 – 338 cm (see Figure 5). As for the Australian data, most slips that occurred were small with a few large slips recorded.

Unlike in Australia, data on slippage was only recorded on branch lines on which fish were caught. Out of 554 branch lines where the degree of slippage was recorded, no slippage occurred in 157 cases, therefore the safe leads slipped to some degree on 71.7% of branch lines on which fish were caught.

In cases in which a bite-off occurred and some slippage was recorded, average slippage was 132.8 ± 15.0 cm. In comparison, in cases in which a bite-off did not occur and there was slippage recorded, average slippage was 30.6 ± 2.99 cm.

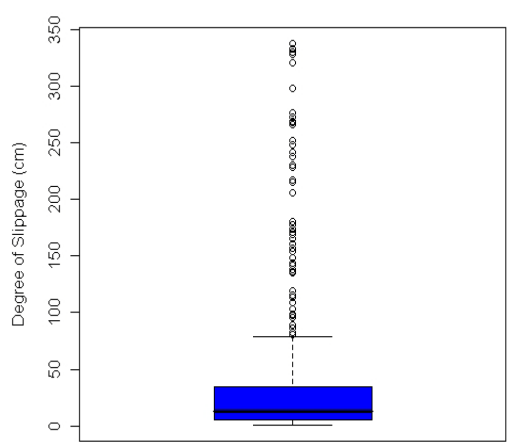


Figure 5 Degree of slippage of safe leads in South African trials. The central line within the box is the median, the box represents the upper and lower quartiles and the whiskers the 95% confidence intervals. Open circles are outliers beyond the 95% confidence intervals.

A GLM was performed to determine whether any of the recorded factors (trip, shot number, whether a bite off occurred, the species and size of fish caught and whether it was alive or dead) had a significant effect on the degree of slippage recorded. The only factors affecting the degree of slippage were whether a bite off occurred ($F_{1,522} = 137.79$, $p < 0.0000001$) the species caught ($F_{18,539,\ p} = 0.0001364$, $p < 0.001$) and the size of the fish ($F_{3,524} = 4.2344$, $p = 0.006$).

The remaining analysis relates only to data collected in South Africa.

b) Are Safe Leads safer for fishermen?

A total of 607 fish were caught with the leaded swivels and 608 fish were caught with the safe leads. There were 15 flybacks with the leaded swivels and 25 flybacks with the safe leads. This difference is not statistically significant ($X^2 = 2.5$, $p > 0.05$).

Critically, none of the flybacks from Safe Leads flew over the side of the vessel, whereas 7 of the flybacks from leaded swivels (46.7% of the total number of flybacks from leaded swivels) flew over the side of the vessel, including one which hit acrewmen in the head. The number of flybacks of each type for the two different leads is given in Figure 6.

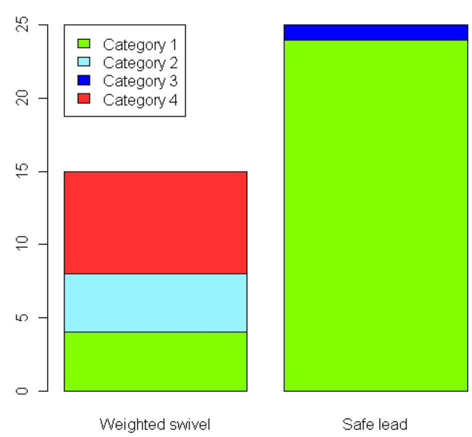


Figure 6 Number of flybacks of each category from weighted swivels and safe leads. Category 1 = entered water without striking the vessel; category 2 = struck side of vessel , 1 m above water level; category 3 = struck side of vessel > 1 m above water level; category 4 = flew over the side of vessel.

c) Weight type and catch rates

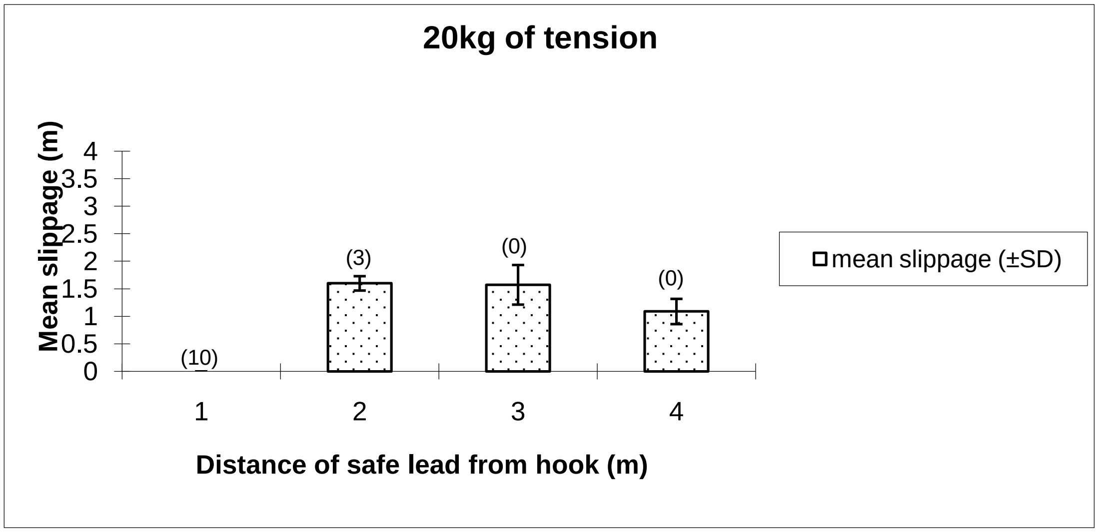
There were 698 experimental branch lines (349 treatment and 349 control) in each set for the two trips conducted onboard the *Admiral de Rutier*. Within each trip, sets were therefore considered as replicates (by considering them as independent of one another) for statistical analysis. These data were examined to investigate whether there was a significant difference in the catch depending on both the trip number and type of weight (Safe Lead or weighted swivel). Trip number (two trips were conducted) had a significant effect on the catch per set, with catch being higher in trip one than in trip two (GLM with poisson errors, $X^2_{1,36} = -26.1$, $p < 0.00001$), however the weight used on a branch line had no significant effect on catch rate (GLM with poisson errors, $X^2_{1,36} = -0.001$, $p = 0.977$).

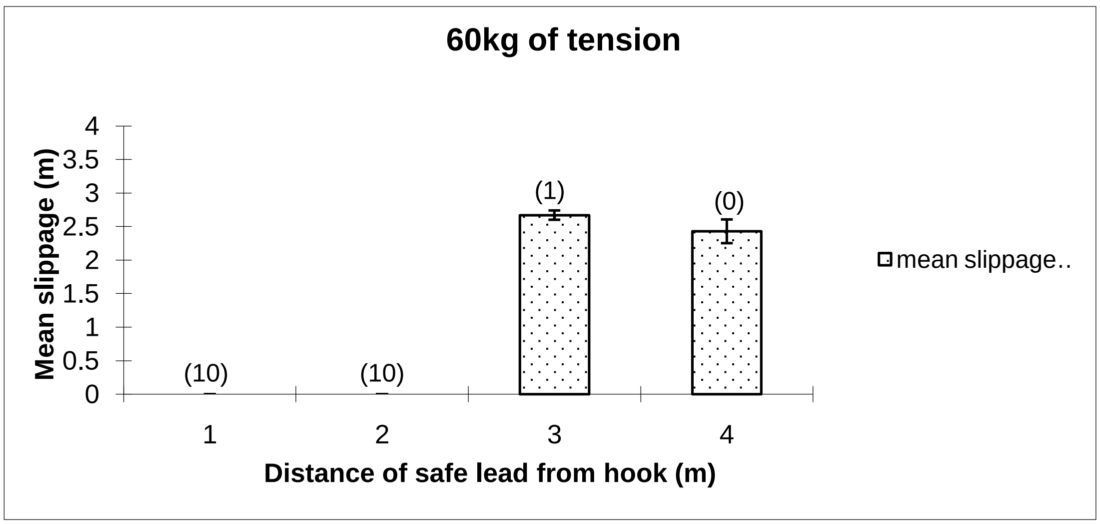
d) Rate of bite-offs

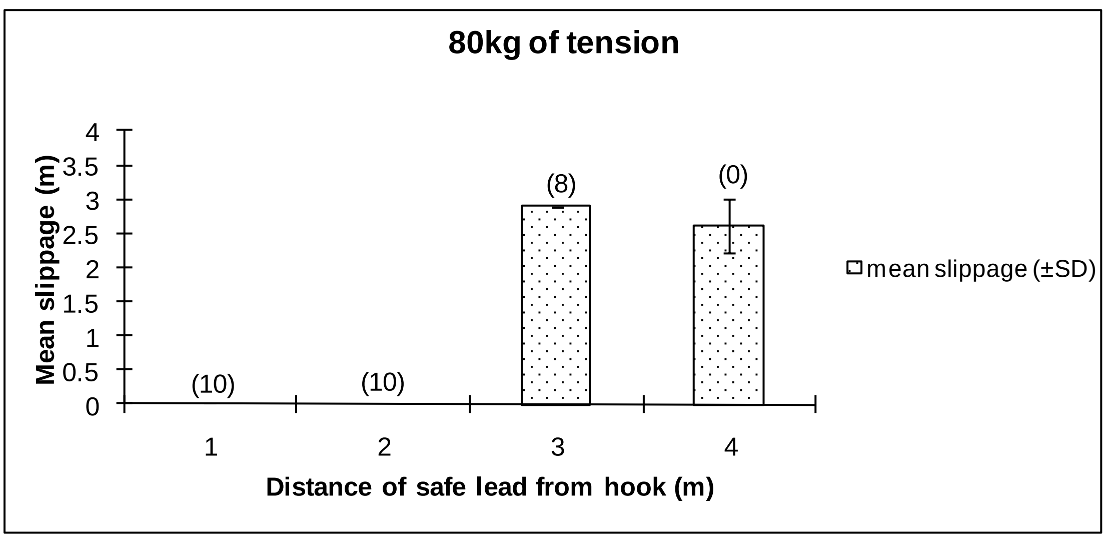
A total of 57 bite-offs occurred during the South African trials, 34 involving Safe Leads. The same number of branch lines with Safe Leads and weighted swivels were deployed during this trial. There was no significant difference in the incidence of bite-offs between branchlines fitted with Safe Leads and weighted swivels ($X^2 = 2.12$, $p > 0.05$).

<u>Part I: Safe Lead slippage</u>

Figure 7 shows the mean slippage each of the 160 replicates conducted during the on-shore cut-away trials. These data clearly show that with the exception of the lowest tension treatment (20 kg) all ten replicates placed within 2 m of the hook slipped off the line after a cut-away (*cf*: bite-off). As the tension was increased the degree of slippage also increased with 8 and 9 Safe Leads placed 3 m from the hook slipping off the end of the line under 80 and 120 kg treatments, respectively.


20kg of tension
Mean slippage (m)
4
3.5
3
2.5
2
1.5
1
0.5
0
(10)
(3)
(0)
(0)
1
2
3
4
Distance of safe lead from hook (m)
mean slippage (±SD)


60kg of tension
Mean slippage (m)
4
3.5
3
2.5
2
1.5
1
0.5
0
(10)
(10)
(1)
(0)
1
2
3
4
Distance of safe lead from hook (m)
mean slippage..


80kg of tension
Mean slippage (m)
4
3.5
3
2.5
2
1.5
1
0.5
0
(10)
(10)
(8)
(0)
1
2
3
4
Distance of safe lead from hook (m)
mean slippage (±SD)

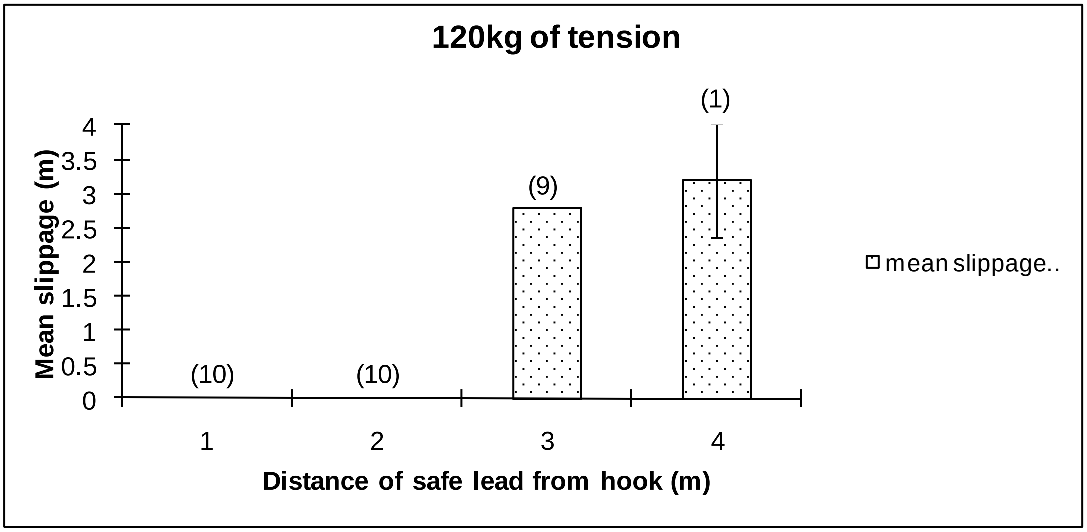


Figure 7 (a-d) Slippage of Safe leads from the four tension treatments conducted during on-shore cut-way trials. Cases with no plot for mean slippage represent those when the Safe Lead slid off the end of the line. Bracketed numbers represent the number that slipped off the end of the line.

The estimate of *a* for the Weibull survival time distribution was sufficiently close to 1 (maximum likelihood estimate of 1.05) to allow the exponential model to be used for the remainder. Figure 8 shows the relationship between expected slippage distance and tension for the non-parametric model (points showing single SE bars) and predictions at 5 kg intervals using the quadratic model (solid line, with dotted lines showing +/-SE of predictions). The parameter estimates corresponding to the terms in the quadratic model were: intercept -0.133 (SE=0.384), linear -0.0293 (SE=0.0142), quadratic 0.984 x 10-4 (SE=1.071 x 10-4). The residual deviance for the non-parametric model was 86.763 on 155 degrees of freedom (DF) while that for the quadratic model was 87.085 on 156 DF so that there was no significant lack of fit for the quadratic model. In fact, using the linear term alone showed no significant lack of fit with residual deviance of 87.923 on 157 DF, however, this model gave an exponential increase in slippage distance with tension, due to combination of the log link function with a linear predictor that is linear in tension, which was considered unrealistic. In contrast, the quadratic model gives realistic predictions for the higher tensions (i.e. > 80 kg) (Figure 8). When the number of uses was included in the quadratic model the estimate of the associated parameter was 0.0051 (SE=0.0719, P>0.10) indicating that there was no deterioration detected in performance of the Safe Leads for the range tested of up to four re-uses.

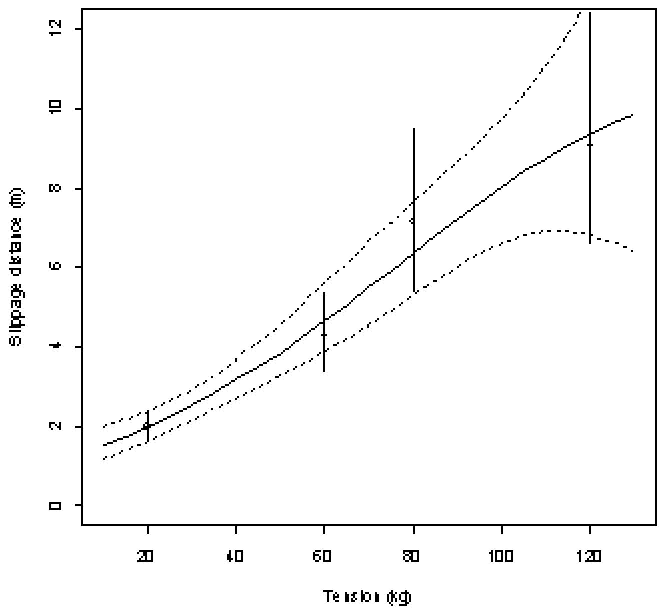


Figure 8 The non-parametric modeled relationship between tension and the degree of Safe Lead slippage

Part II: Safe Lead and weighted swivel velocity calculations

The mean impact height for all Safe Lead treatments in which the weight reached the backboard (either on the line or released) was 1.59 ± 0.059 m (, n=55). This height is well below the estimated average height above water (2.4 m) of the line hauler (and crew's upper body) on a typical domestic pelagic longliner.

The mean velocity of the seven 60 g weighted swivels was 267.2 ± 18.5 km/h and the mean velocity of the Safe Leads was 109.4 ± 5.82 km/h This represents a 60% mean reduction in velocity for the Safe Leads compared to the weighted swivels across all combined tension treatments, which ranged from 34-100 kg for the weighted swivel and 60-119 kg for the Safe Leads.

The GLM highlighted a significant difference in the velocity of Safe leads (WeightSL) and weighted swivels (WeightWSW) (Figure 9). In addition, a significant increase is velocity was identified for weighted swivels under increasing tension (P=0.007). (Figure 9). The estimated terms in the fitted GLM are given in Table 2.

Table 2 Gamma GLM Coefficients

Term	Estimate	SE	t-value	Pr(>|t|)
(Intercept)	68.328	23.508	2.91	0.017 *
WeightWSW	71.538	42.430	1.69	0.126
WeightSL:Tension	0.533	0.298	1.79	0.107
WeightWSW:Tension	1.739	0.504	3.45	0.007 **

Note that the intercept for the WeightWSW regression is given by 68.328+71.538

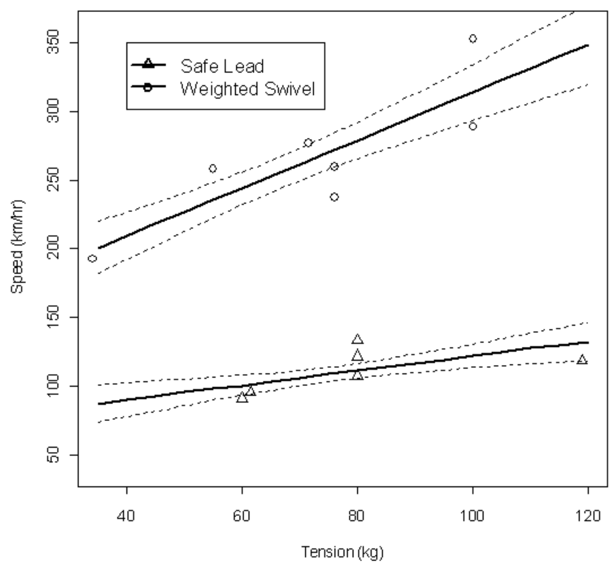


Figure 9 Predictions from fitted gamma GLM for the velocity of Safe leads and weighted swivels under a range of tension treatments (±SE of prediction given by dotted lines).

The mean kinetic energy calculated for the seven weighted swivel replicates was 168.9 ± 23.6 joules, whereas the average for the Safe leads was 27.7 ± 2.8 (joules, which represents a mean reduction in the kinetic energy of Safe Leads of 83% compared to weighted swivels.

Discussion

Slippage of Safe Leads

Evidence from both at-sea and on-shore trials highlight that in the event of a bite-off (or simulated bite-off/cut-away) Safe Leads slip down the line as they were designed to do. The at-sea trials conducted in Australia highlight the degree of slippage under operational conditions and the on-shore trials provide valuable insight into the degree of slippage under varying degrees of tension.

Most pelagic longliners operate with a swivel in the line to reduce twisting and entanglement of the line. Swivels are usually made from lead to add weight to the line. The distance between the leaded swivel and hook and the weight of the swivel have a critical bearing on sink rates at various depths in the water column (e.g. Robertson et al., submitted) and form the basis of line weighting requirements in Australia to reduce seabird bycatch (Threat Abatement Plan, 2006). The Australian trials were conducted with no swivel in the branchline, which allowed for slippage of the Safe Lead both toward and away from the hook. The use of Safe Leads without a swivel also greatly reduced the time and labour required to build branchlines as no crimps were required.

The Australian at-sea trials highlighted that a low degree of slippage is relatively common with 44% of Safe Leads slipping to some degree. A highly significant relationship was identified between the degree of slippage and the species caught. Interestingly, the swimming behaviour of fish caught influenced the direction of slippage of Safe Leads on the branchline. For example, marlin (*Tetraoturus audax*, *Makaira indica* and *M. nigricans*) which typically swim deep after being caught caused slippage toward the hook, and Big eye (*Thunnus obesus*) and Yellow fin tuna (*Thunnus albacares*) which typically swim for the surface once hooked caused slippage toward the clip/mainline. The significant relationship identified for only the degree of positive slippage (toward the hook), and not negative slippage (toward the snap/branchline) in cases when a bite-off occurred was a surprising result as an examination of the raw averages suggests the relationship would be significant with negative slippage. This is likely to be an artifact of an increased number of positive slippage events, particularly in cases of slippage where a bite-off occurred.

If slippage occurs over time, or when a fish is caught, it may be necessary to place a small box swivel in the branchline to ensure the position of the Safe Lead is compliant with regulations stipulating its position relative to the hook. While this would negate the savings in labour and gear from not having to fit a swivel in the branchline, the added safety of using Safe Leads probably more than compensate for this reduction in cost savings. In general terms, the addition of a swivel in the branchline aids fishermen by reducing line entanglements and also maintains the concept of ‘top end’ and ‘bottom end’ sections of the branchline. Separating the two sections of the branch line with a swivel means only the bottom end is shortened (until eventually replaced) during routine maintenance (to eliminate sections chewed by sharks), which reduces the amount of monofilament required to maintain branch lines. The distinction between top and bottom sections is also useful with respect to compliance and enforcement, and in fisheries which may adopt Safe Leads, it prevents their slippage away from the hook.

Figure 7 (a-d) shows that 100% of Safe Lead replicates placed within 2 m of the hook slid off the line under all four tension treatments (20 kg, 60 kg, 80 kg and 100 kg), with the exception of those placed at 2 m under only 20 g of tension, when only 30% had sufficient energy to slide off the line. The higher tension categories of 80 kg and 120 kg resulted in 80% of Safe Leads positioned within 3 m sliding off the line after a simulated bite-off only one Safe Lead slipped off the line when positioned 4 m from the hook (Figure 7d) However, it is important to note that these Safe Leads slid > 3 m toward the end of the line, which would greatly dissipate the energy at which the line and Safe lead would recoil toward the boat (see velocity discussion below). The Poisson GLM further supports these findings by clearly showing that the degree of slippage increases under increased tension (Figure 8).

While it is possible that the carriage sleeve of the Safe Lead may wear over time, the outputs of the quadratic GLM indicate that over 5 uses (4 re-uses) the performance of the Safe Leads was not affected by deterioration of materials. Furthermore, research and development is on-going to identify the most robust materials for the manufacture of Safe Leads to ensure their durability is suited to long-term use.

Operational practicality

Crews from both sets of at-sea trials noted that they liked using Safe Leads as they were easy to assemble, handled well in and out of the setting bins, and created a less stressful work environment as the Safe Leads practically eliminated potentially dangerous fly-back events during hauling (Captain John Malin- Captain *Demi Maddison*; Captian Bruce Kerb, *Admiral de Ruiter, pers. comm.*). It has also been suggested that using Safe Leads could markedly reduce vessel damage caused by fly-backs of weighted swivels as they ‘bounce’ off the vessel, where as weighted swivels cause significant chips and dents in steel boast all of which add to on-going maintenance issues; fly-backs can be particularly damaging for fiberglass boats (Steve Hall, AFMA, *pers. comm*.).

There were occasions during both sets of at-sea trials when the Safe Leads became entangled with the branchline or lost one or more lead halves while submerged. Ten cases (0.6% of branchlines) of this were recorded in the Australian trials; in the South African trials 15 (2.4 %) entanglements and 4 (0.66%) broken Safe leads were recorded. These entanglements and breakages (lost Safe Leads) are thought to be caused by a series of large fish being captured in relatively close proximity on the line and the percussion effect created by their fighting on the line creating pressure that forces the ‘o’ rings to either break of ‘pop’ off the Safe Lead. Such entanglements create difficulties during line hauling and also require gear maintenance, all of which take time and create an operational and capital cost. While it should be noted that our data suggest that these are relatively rare events further research and development is underway to source new materials and/or refine the design of the Safe Lead to further reduce the occurrence of such events.

Monofilament versus wire tracers

Safe Leads are designed specifically to operate on monofilament and will not work in fisheries which use wire tracers or ‘bottoms’. In some fisheries, wire tracers are used to increase the catch rate of sharks, which often bite-off monofilament adjacent to the hook (Gilman *et al*. 2008). In northeastern Australia, the number of fish escaping from monofilaments was virtually the same as those escaping from wire tracers. (Ward *et al*. 2008). By contrast, the catch rate of bigeye tune was higher on nylon line than on wire leaders. Thus, the benefits of increased catch of bigeye tuna may outweigh the costs associated with banning wire leaders, such as increased gear loss (Ward *et al*. 2008). By improving crew safety, the development of Safe Leads could further assist in reducing shark bycatch in many fisheries by encouraging a switch to monofilament bottoms.

Breaking strain of monofilament

The manufacturers specified breaking strength of the 1.8 mm monofilament used in the on-shore trials was given as 150 kg.. However, our on-shore trials highlighted that even with professionally built gear it is extremely difficult to reach even 120 kg of tension, and in most cases with the addition of crimps for swivels and snaps most branchlines broke at considerably lower tensions. The average breaking strain recorded was 78.8 ± 7.4 kg with a range of 23-130 kg. To mimic the hauling conditions at-sea we had two people haul a wet branchline (with a load cell *in situ*) by hand and found that it was not possible to hold more than 35 kg. We tested commercially made branchlines to breaking strain and of the sixteen replicates conducted in 4 cases (25%) the monofilament broke, in one case (6 %) the swivel broke and in the remaining eleven cases (69%) the monofilament either slipped through the crimp at the swivel, hook, or snap, or it broke adjacent to the crimp. This suggests that as expected, in the majority of cases the crimps are the weakest point in the branchline. It also indicates that bite-offs occur at much lower tensions than commonly thought by many fishermen, who suggest that the line breaks at around the commercially specified breaking strain of the monofilament.

Fly-backs and crew safety

The primary finding of this research is that both at-sea trials in South Africa and on-shore trials in Australia indicate that Safe Leads significantly reduce the potential danger to crew posed by fly-back events. From 15 flybacks with the leaded swivels and 25 flybacks with the Safe Leads recorded South Africa none of the Safe Leads flew back over the side of the vessel, and only one reached the side of the vessel. Whereas, 7 of the flybacks from leaded swivels (46.7%) flew over the side of the vessel, including one which hit a crewmen in the head. Although the sample is small, these data indicate that under operational conditions Safe Leads perform as intended, and make a significant contribution to improving crew safety on pelagic longline vessels. The on-shore trials supported these findings as Safe Leads that did reach the backboard after recoiling (i.e. those positioned 3-4 m from the hook) impacted at an average height of 1.5± 0.059 m, which is well below the estimated 2.4 m of a crewmen's head on typical domestic pelagic longliner.

On average across all combined tension treatments, the velocity of Safe Leads was reduced by 60% compared to weighted swivels and the GLM highlighted a significant difference between the velocity of Safe leads and weighted swivels under the range of tension treatments (Table 2, Figure 9). Possibly the most convincing evidence of the increased safety of using Safe Leads is the 83% reduction in kinetic energy (or force) of Safe Leads compared to weighted swivels.

Cost

It is estimated that Safe Leads will cost USD $1 per unit, which is comparable with traditional 60 g weighted swivel in South Africa which cost around USD$1.00. However, in Australia they can be sourced for around USD$0.60. It is likely that an additional cost will be incurred by replacing Safe Leads lost after a bite-off, but the frequency of loss will depend largely on their position in relation to the hook. In South Africa, only one Safe Leads placed 3.5 from the hooks lipped off the end of the line after a bite-off. Our on-shore trials indicate that under higher tensions (e.g. 80 and 120 kg) most Safe Leads placed at 3 m slid off the line but at lower tensions (20 and 60 kg) most slipped down the line, but not off the end. The number of potentially lost Safe Leads appears to be determined by a combination of the position relative to the hook and the tension under which a bite-off occurs. Whatever the cost of replacing lost Safe Leads, given that bite-offs are a statistically rare event, albeit a potentially lethal one, added crew safety is likely to outweigh the expected additional costs.

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