Agreement on the Conservation of Albatrosses and Petrels

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The industrial demersal floated longline system for Austral Hake and Congrio in Chile: initial sink rates and effect of added floats

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SUMMARY

An experiment was conducted to determine the sink rates near the surface of demersal floated longlines (weighted with 8 kg every 50 m) as used in Chile for Austral hake and Congrio. Sections of line without floats attached mid-way between weights took, on average, 19 sec to reach 2 m depth (0.10 m/s) compared to 80 sec (0.02 m/s) for floated sections, a difference of almost an order of magnitude. Comparative mean distances astern (at 6 knots setting speed) were ~60 m and ~260 m for unfloated and floated gear, respectively. Estimates for the 0-5 m depth range were 39 sec (0.13 m/s) for unfloated sections and 141 sec (0.03 m/s) for floated sections and between ~140 and ~440 m astern with the distance depending on the presence or absence of floats. The differences between gear types were explained mainly by the time taken from water entry to commencement of sinking when gear was held aloft and most available to seabirds. Unfloated sections of the line took ~8 seconds to commence sinking compared to 70-75 sec for floated sections, which 'floated' in the 0-1 m depth range just beneath the surface. The challenge is to implement changes that negate the effect of floats in the first several metres of the water column so the sink profile of gear with floats resembles that of gear without floats.

RECOMMENDATIONS

The following changes to gear and practice are recommended for consideration:

1. Increase the length of the float lines so the floats do not slow the initial sink rates near the surface. Float lines at least 5 m in length would seem to be a reasonable compromise between aspiration and likelihood of adoption by industry.
2. Fit for permanence leaded sleeve sinkers over the float lines at the clip where float lines join the hook line. The purpose is to increase the initial sink rate of the hook line at the float, mid-way between line weights, until the float line pulls taut on the sinking hook line. The metrics critical to achieving expeditious initial sink rates and effective buoyancy at fishing depth might have to be determined experimentally.
3. Eliminate all sources of line tension astern during setting operations. Tension astern slows the initial sink rate and can be eliminated by following the methods outlined in Annex 5.

Sistema industrial de palangre demersal con flotadores para merluza austral y congrio en Chile: tasas iniciales de hundimiento y efecto del agregado de flotadores

RESUMEN

Se realizó un experimento para determinar las tasas de hundimiento cerca de la superficie de palangres demersales con flotadores (con una pesa de 8 kg cada 50 m), utilizados en Chile para la captura de merluza austral y congrio. Las secciones de línea sin flotadores fijados a mitad de camino entre pesas tomaron, en promedio, 19 segundos para alcanzar 2 m de profundidad (0,10 m/s), en comparación con 80 segundos (0,02 m/s) para las secciones con flotador, una diferencia de casi un orden de magnitud. Las distancias medias comparativas a popa (a una velocidad de calado de 6 nudos) fueron de ~60 m y ~260 m para artes sin y con flotadores, respectivamente. Las estimaciones para el rango de profundidad de 0-5 m fueron de 39 s (0,13 m/s) para las secciones sin flotadores y de 141 s (0,03 m/s) para las secciones con flotadores, y entre ~140 m y ~440 m a popa. La distancia dependió de la presencia o ausencia de flotadores. Las diferencias entre los tipos de artes se entienden principalmente si se observa el tiempo transcurrido entre la entrada en el agua hasta el comienzo del hundimiento cuando el arte estuvo elevado y más al alcance de las aves marinas. Las secciones de la línea sin flotadores tardaron ~8 s en comenzar a hundirse, en comparación con los 70-75 s de las secciones con flotadores, que “flotaban” en el rango de profundidad de 0-1 m, justo debajo de la superficie. El reto es implementar cambios que anulen el efecto de los flotadores en los primeros metros de la columna de agua para lograr que el arte con flotadores tenga un perfil de hundimiento similar al del arte sin flotadores.

RECOMENDACIONES

Se recomienda considerar los siguientes cambios en los artes y en la práctica:

1. Aumentar la longitud de las líneas de flotadores para que los flotadores no ralenticen las tasas de hundimiento iniciales cerca de la superficie. Las líneas de flotadores de al menos 5 m de longitud parecerían ser un intermedio razonable entre lo que se aspira y la probabilidad de adopción por parte de la industria.
2. Incluir pesas corredizas de plomo en las líneas de flotadores a la altura del sujetador donde dicha línea se une a la línea de anzuelos. El objetivo es aumentar la tasa de hundimiento inicial de la línea de anzuelos a la altura del flotador, situado a mitad de camino entre las pesas de la línea, hasta que la línea de flotación quede tirante con la línea de anzuelos que se hunde. Es probable que los parámetros que resultan críticos para lograr tasas rápidas de hundimiento inicial y una flotabilidad efectiva a la profundidad de pesca tengan que determinarse de modo experimental.
3. Eliminar todas las fuentes de tensión en la línea a popa durante las operaciones de calado. La tensión a popa ralentiza la tasa inicial de hundimiento y puede eliminarse siguiendo los métodos descritos en el Anexo 5.

Le système de palangres de fond flottantes (démersale) pour le merlu austral et le congre au Chili : vitesses d’immersion initiale et incidence des flotteurs supplémentaires

RÉSUMÉ

Une expérience a été menée aux fins de déterminer la vitesse d’immersion près de la surface de lignes de palangre de fond flottantes (lestées de 8 kg tous les 50 m), comme celles utilisées au Chili pour le merlu austral et le congre. Des sections d’un corps de ligne sans flotteurs entre les lests mettent, en moyenne environ 19 secondes pour atteindre 2 m de profondeur (0,10 m/s), tandis qu’il faut 80 s (0,02 m/s) pour des lignes avec flotteurs, soit une différence de près d'un ordre de grandeur. Les distances moyennes comparées vers l’arrière (à une vitesse nominale de 6 nœuds) étaient d’environ 60 m pour une palangre sans flotteur et 260 m avec flotteur. Les estimations sur une plage de profondeur de 0 à 5 m étaient de 39 s (0,13 m/s) pour les lignes non flottantes et 141 s (0,03 m/s) pour des lignes flottantes et entre environ 140 et 440 m à l’arrière avec une distance dépendant de la présence ou non de flotteurs. La différence entre les types de palangres s’explique principalement par le temps que la ligne met à entrer dans l’eau et à commencer à descendre lorsqu’elle est maintenue hors de l’eau et accessible aux oiseaux de mer. Des sections sans flotteurs mettent environ 8 s à commencer à couler, tandis qu’il faut entre 70 s et 75 s pour des sections avec flotteurs, qui « flottent » entre 0 et 1 m de profondeur sous la surface. Le défi étant ici de mettre en place des modifications qui suppriment les effets des flotteurs sur les premiers mètres de la colonne d’eau afin que le profil d’immersion de la palangre avec flotteurs ressemble à celui d’une ligne sans flotteurs.

RECOMMANDATIONS

Il est recommandé d’envisager les modifications suivantes en matière d’engins et de pratique de pêche :

1. Augmenter la longueur des lignes flottantes de sorte que les flotteurs ne ralentissent pas la vitesse d’immersion initiale près de la surface. Des lignes flottantes d’environ 5 m de long pourraient constituer un compromis raisonnable entre nos aspirations et une éventuelle adoption par l’industrie de la pêche.
2. Attacher de manière permanente des plombs dans des gaines au-dessus des lignes flottantes là où les lignes de flottaison et celles des hameçons se rejoignent. L’objectif est d'accélérer la vitesse d’immersion initiale des bas de ligne garnis d’hameçons au niveau des flotteurs, à mi-chemin entre les lests de la ligne jusqu’à ce que la ligne flottante tende ces avançons. Les indicateurs clés pour une immersion rapide et une flottabilité efficace à la profondeur de pêche souhaitée devront éventuellement être définis de manière expérimentale.
3. Éliminer toutes les sources de tension vers l’arrière pendant la disposition de la palangre. Une tension à l’arrière ralentit la vitesse d’immersion et peut être supprimée en suivant les méthodes présentées à l’annexe 5.

1. INTRODUCTION

Citing a lack of knowledge on the demersal floated longline system to inform decision making, the SBWG Intersessional Work Plan for 2019-2021 sought information on longline sink rates and seabird bycatch associated with the fishing practice. This document presents previously unreported information on the sink rates of demersal floated longlines that might go part way to filling the knowledge gap, at least for gear sink rates. The information presented pertains specifically to the industrial floated longline system of the type used in Chile for Austral hake (*Merluccius australis*) and Congrio (*Genypterus blacodes*). With respect to seabird bycatch, findings from the previous study of Robertson et al., (2014), the only data we know of in the public domain, are included for reference (see Annex 1). This information may be of use if updated information on seabird bycatch is not available to SBWG 10.

1.1. Floated demersal longlines in Chile

Floated demersal longlines are sometimes called ‘semi-pelagic’ longlines due to the various combinations of floats, float lines and sinkers distributed along their lengths. Floating the lines off the seabed enables fish to be targeted at different depths in the water column, and over different seabed topographies. In Chile the industrial version of this fishing practice involves the traditional Spanish system of bottom longlining, but with floats added at intervals to lift the hook line off the seabed. Thus, the demersal floated longline system is the same as the Spanish system with floats. In Chile, the traditional Spanish system is used to target Patagonian toothfish (*Dissostichus eleginoides*) while the floated version is used for Austral hake and Congrio. In Chile, the floated version is referred to as the ‘Merluza system’, a vernacular version of the generic name for Austral hake.

There are risks to seabirds inherent in the traditional Spanish system design resulting in slow initial sink rates (e.g., gear lofting in propellor turbulence, weights of insufficient mass or closeness) that also apply to the Merluza system. But there are three additional factors with the Merluza system that magnify the risks. First, floats attached to hook lines extend sink times near the surface where baits are most available to seabirds. Second, the distribution of weights on the hook line can be changed in accordance with fishing strategy. If fish are detected on the seabed or close to the seabed, weights may be configured closer together to minimise the degree of lofting provided by the floats between the weights. If fish are detected higher up the water column weights on the hook line may be spaced further apart to increase the degree of lofting. Weight spacings of 50 m for the former method and 100 m for the latter are typical for the fishery. Third, the 1 m-long lines connecting weights to the hook line may be lengthened, by 2-8 m, to raise gear further off the seabed. These methods – added floats, extended weight spacings and longer weight lines – extend sink times during setting operations, increasing the likelihood of seabird captures.

The layout of the traditional Spanish system longline as it appears on the seabed is shown in Figure 1.

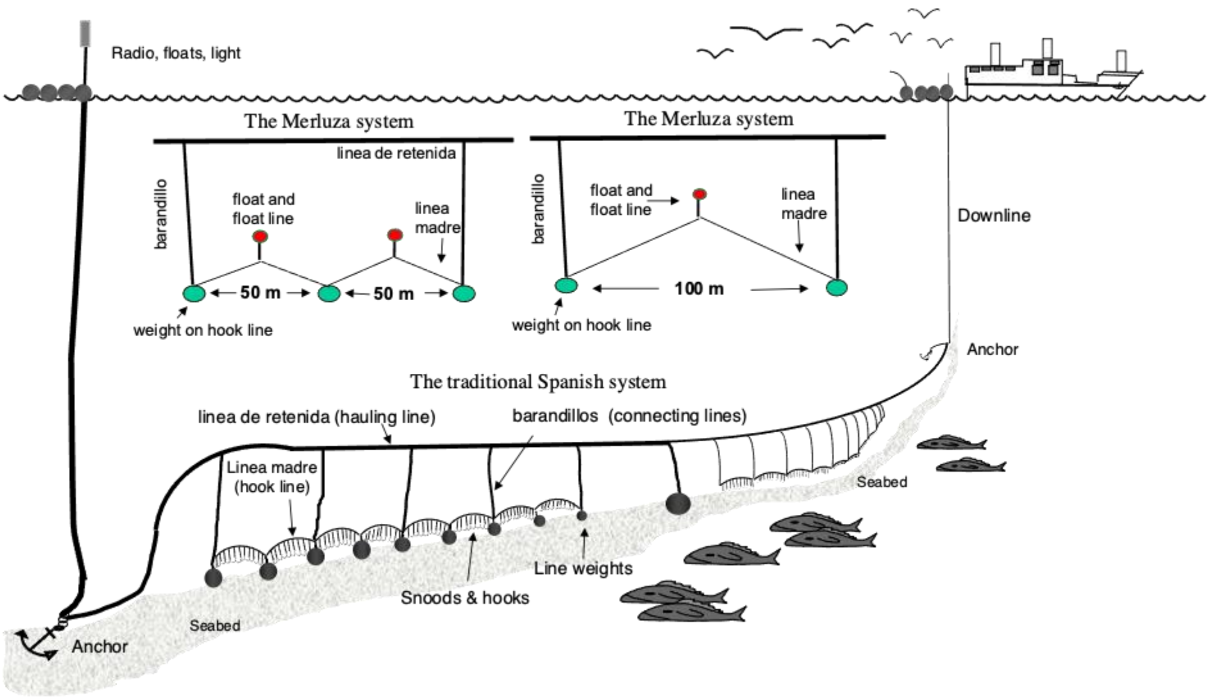

Figure 1. Schematic showing the basic architecture of the traditional Spanish system longline. The inserts show segments (bounded by neighbouring barandillos) of the Spanish system as they would appear following conversion to the Merluza system following fitment of floats. Two line weighting/flotation variants are shown, each designed to target fish at different depths above the seabed: 50 m between weights for fish distributed closer to the seabed and 100 m between weights for fish distributed higher up the water column. Drawing not to scale.

2. METHODS

2.1. Merluza system sink rate experiment

An experiment was conducted on the Merluza system to determine the effect of floats on the sink rates of the hook line. The experiment was conducted in Argentine waters in association with a much larger experiment to determine the factors affecting the sink rates of Spanish system longlines (see Robertson et al., 2008). The vessel used in the experiments was chartered and not fishing commercially. A description of the Spanish system (the Merluza system absent floats) is provided in Annex 2. A description of the fishing vessel, fishing gear, location and date of the Merluza system experiment is presented in Annex 3.

On completion of the Spanish system experiment the gear was rigged to the Merluza system. As mentioned previously, all gear was identical to that for the Spanish system experiment except for the addition of floats, which were attached to the hook line at 50 m intervals. The floats were the hard plastic type measuring 15 cm in diameter and were attached with 1 m-long float lines mid-way between the line weights (8 kg), which were blocks of concrete purpose-built for the study. A mix of floated and non-floated gear was deployed. Time-depth recorders (Wildlife Computers Mk 9s) were attached to the hook line 1 m from the floats on both floated and non-floated segments of the line. The TDRs recorded time and depth at 1 sec and 0.5 m intervals, respectively. TDR water entry times were recorded with a digital watch synchronised with TDR time, and data files adjusted accordingly. A total of 24 TDRs were deployed, 12 for floated and 12 for the non-floated segments. All other methodological aspects were as described for the Spanish system experiment reported in Robertson et al., (2008). The terms of the charter period limited the experiment to just one set of the longline.

Gear was set in accordance with the experimental design shown in Figure 2. Gear was set from individual ‘baskets’ (see Robertson et al., 2008) which contained segments of the hook line, snoods and baited hooks. The segments of hook line were joined as gear was paid out. The idea behind the 300 m connecting lines between the treatments was to allow the treatments to sink independently of one another. Non-TDR baskets were deployed before and after the TDR baskets to create a degree of independence between the sample replicates. Vessel setting speed was 6 knots.

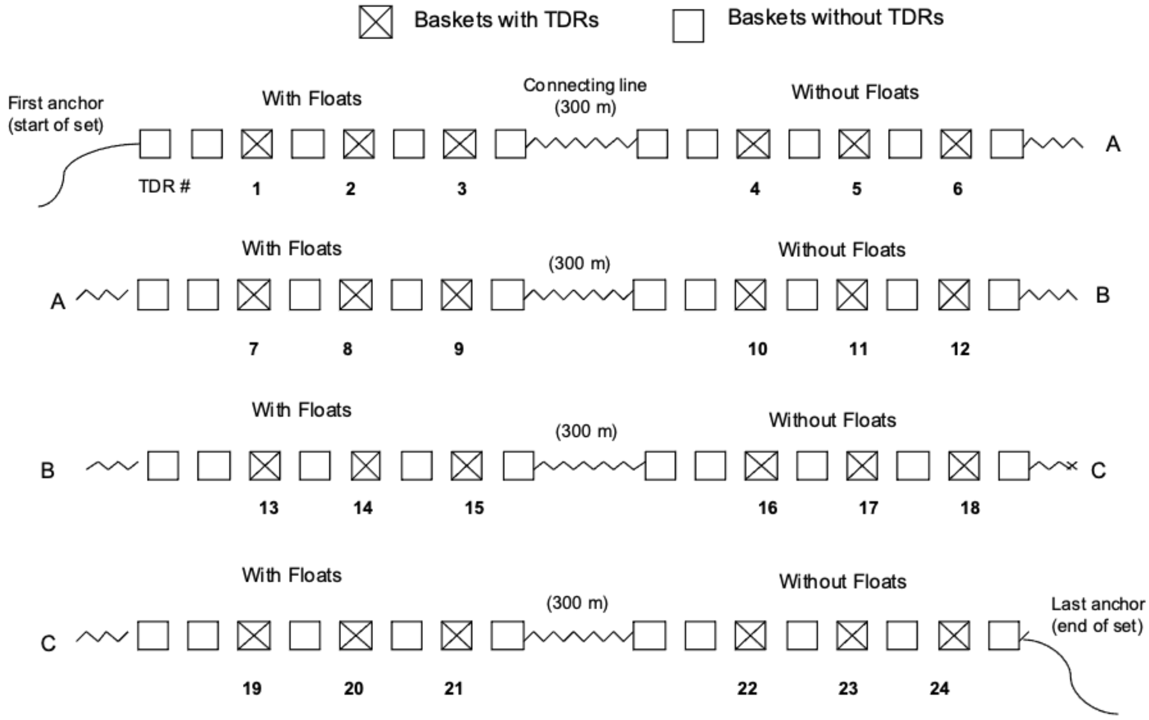

Figure 2. Schematic showing the experimental design and setting order of baskets with floats and without floats, and the distribution of TDRs for each treatment throughout the set. Setting sequence: A joins A, B joins B, C joins C. Shown is the linea madre (hook line) only.

2.2. Statistical methods

The statistical methods are presented in Annex 4.

3. RESULTS

Of the 24 TDRs deployed in the experiment for both floated and non-floated gear, data were available for analysis from 11 of the non-float TDRs and 10 of the TDRs on floated gear. Data from the other three TDRs were rejected due to severe gear hook-ups during line setting, resulting in the hook line being yanked from the water many metres behind the vessel.

The full model gave an AIC and adjusted R-square of -4576.557 and 0.898, respectively. The reduced model that fitted a single mean profile for the pooled 'float present' and 'no float' data gave corresponding statistics of -4416.913 and 0.498, respectively. This shows that the model accounting for the difference between the average sink profiles fits the data much better than the model assuming no difference. Figure 3 shows the degree of difference in the average profiles to 80 sec and 10 m depth relative to sampling variability using the approximate 95 % confidence limits about average profiles as shown. The difference between the average depth-to-time profiles is highly statistically significant ($P<0.05$). The depth-to-time was highly and positively auto-correlated (phi = 0.856) and the residual standard deviation for the 'float-present' profiles was 80 % greater than the 'no floats' profiles

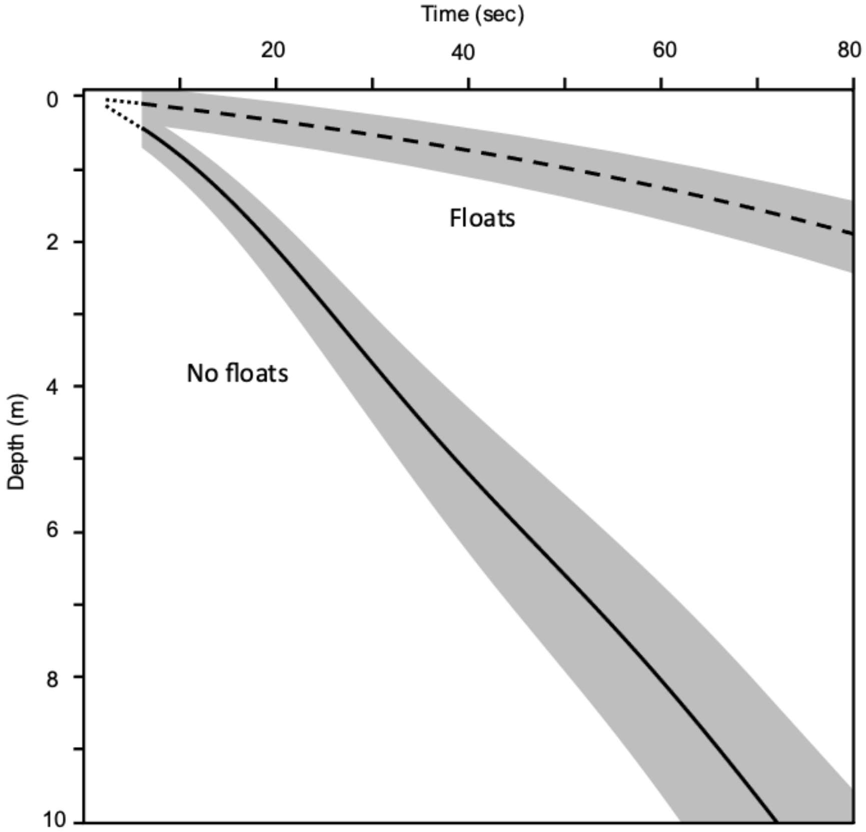

Figure 3. Modelled mean sink profiles and 95 % confidence limits (shaded areas) showing the effect of floats attached to hook lines of the Merluza system. n = 10 TDR baskets and 11 TDR baskets for floated and unfloated gear, respectively. Stippled trend lines near the origin drawn by hand because TDR records immediately after water entry were too erratic to model due to TDR measurement error (+/- 0.5 m) being a higher proportion of actual depth compared to the measurement error several seconds after deployment.

The raw data from two sink profiles, one for each treatment, are shown in Figure 4. These two profiles, chosen because they approximate the time taken to reach the 2 m depth for the modelled averages shown in Figure 3, further emphasise the effect of added floats on initial sink rates in the surface layers of the water column.

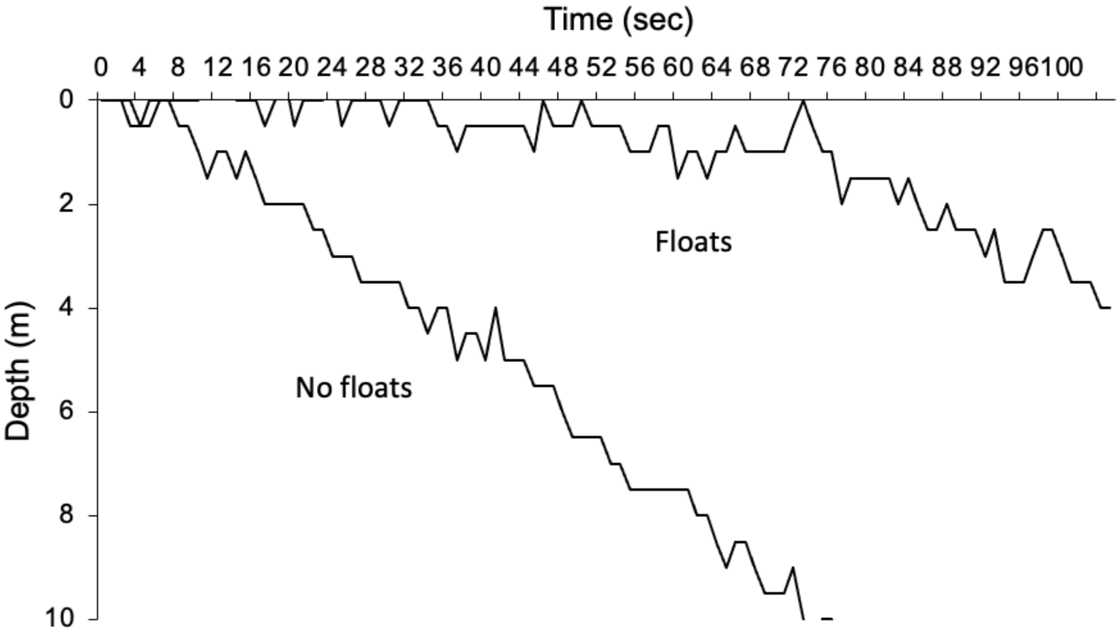

Figure 4. Examples of sink profiles from TDRs attached to floated and unfloated sections of the hook line. The profiles are a close approximation of the modelled averages to the 2 m depth shown in Figure 3 and Table 1.

Mean sink times and sink rates to target depths for floated and unfloated gear are shown in Table 1.

Table 1. Mean time-to-depth and sink rate estimates (± 2 s.e's) for baited hooks on gear with and without floats. n = 10 for floated and 11 for unfloated.

Treatment	Time to depth (sec)			Sink rate (m/s)		
	0-2 m	0-5 m	0-10 m	0-2 m	0-5 m	0-10 m
No Floats	19 ± 2.5	39 ± 5.0	72 ± 8.0	0.104 ± 0.013	0.130 ± 0.02	0.139 ± 0.017
Floats	83 ± 11.0	141 ± 11.0	193 ± 9.5	0.024 ± 0.003	0.036 ± 0.004	0.052 ± 0.007

4. DISCUSSION

4.1. Sample sizes

The samples sizes were limited by the terms of the vessel charter to just 11 TDR estimates for unfloated and 10 estimates for floated gear. Offsetting this was the high level of control over the setting operation. Use of a vessel chartered especially for the experiment avoided many of the confounding effects that sometimes plague experiments conducted while vessels are production fishing. During the Merluza experiment the sea state was consistently moderate throughout the set, the vessel setting direction in relation to the tidal direction was constant, line weights were of fixed mass (8 kg concrete blocks, as opposed to the bags of rocks typically used in the fishery) and all line weights were deployed actively to eliminate line tension astern. Moreover, the longline used in the experiment, as with the Spanish system experiment that preceded it, was purpose built from new materials to standard Spanish system/Merluza system metrics. This level of control over the gear and operational procedures produced sample estimates with minimal variation, as evidenced by the small sizes of the confidence limits presented in Figure 3.

4.2. Floated versus unfloated

The difference between the floated and unfloated sink profiles is stark. Unfloated lines took, on average, 19 sec to reach 2 m depth compared to about 80 seconds for floated lines. Comparative sink rates to this depth were 0.1 m/s and 0.02 m/sec for unfloated and floated, a difference of almost an order of magnitude. Most of this difference is explained by the time between water entry and commencement of sinking as revealed by the examples in Figure 4. Unfloated section of line commenced sinking about 8 sec after deployment, when the section with the TDR (midway between line weights) would have been about 25 m behind the vessel (at 3.1 m/sec vessel speed) and clear of the worst of the upwellings from the propellor. In contrast, floated gear did not commence sinking until about 70-75 sec after deployment, when about 230 m astern. For most of this time the longline ‘floated’ just beneath the surface in the 0-1 m depth range which is the depth most easily accessed by seabirds. The extent of the lag near the surface presumably reflects the 1 m-length of the float lines which must have impeded sinking until gear was well beyond the propellor turbulence zone and the line weights could counteract the buoyancy of the floats. The situation to the 5 m depth is even more striking. Floated gear took, on average, ~140 sec to reach that depth, by which time the longline would be ~440 m astern the vessel while still within the dive range of many species of seabird.

Those estimates pertain to the version of the Merluza system with weights spaced 50 m apart, not to the version with weights 100 m apart. The estimates are conservative compared to sink rates that could be expected with weights twice the distance apart. There is also the issue of the mass of the weights. The weights used in the experiment, 8 kg concrete blocks, may not be typical for the fishery. As for the Spanish system, weights used in the Merluza system fishery are typically comprised of beach rocks enclosed in netting bags. For these, 4 or 5 kg might be probably closer to the norm. It would be difficult to imagine a longline system more dangerous to seabirds than one made from positively buoyant materials, equipped with floats on short snoods for additional buoyancy and weighted with bags of rocks of modest masses spaced as far as 100 m apart on the longline.

4.3. Comparison with the Autoline system

It is informative to compare the sink profiles and statistics with a demersal longline system with a proven track record in seabird deterrence. A standout is the swivelline with 50 g/m integrated lead weight (IW) used by autoline vessels in the CCAMLR Convention Area. Experiments in the New Zealand ling fishery showed that IW swivelline reduced the mortality of white-chinned petrels (*Procellaria aequinoctialis*) by >90 % in each of two season, compared to standard (non-IW) swivelline (Robertson et al., 2006). This outcome was attributed to the superior sink characteristics of IW line. Averaging just 0.2 m/s to 2 m depth

(10 sec) and 0.24 m/s (40 sec) to 10 m depth, IW line does not sink quickly but it does commence sinking the instant it enters the water. Baits that disappear quickly with minimal or no lag at the surface are highly effective in reducing seabird mortality. This sink characteristic is possible with IW longline because the rope components are negatively buoyant, and the line is weighted along its entire length. The architecture and composition of Merluza system gear is completely different. It comprises two longlines deployed in parallel joined by connecting lines with all components positively buoyant; it will not sink without the addition of weights. Further, the connecting lines straddle the worst of the propellor turbulence zone behind the vessel. Given these realities, the 10 sec to 2 m depth metric for IW line will never be attained. But faster sink rates should be possible, and even modest gains should be better than the status quo.

4.4. Options to improve sink rates

The following options to increase the sink rates of Merluza system gear are worthy of consideration: use of longer float lines, equipping float lines with sinkers and the elimination of line tension astern.

Float lines: the float lines in the study were 1 m in length. Use of longer float lines should nullify the effect of the floats in the upper reaches of the water column. With longer float lines the sink profile for floated gear in the shallow depth ranges would be expected to approximate that for unfloated gear, which averaged 19 sec to reach 2 m depth compared to 83 sec for floated gear. As mentioned previously, vessel crews are already in the habit of routinely lengthening the lines connecting weights to the hook line, by up to 8 m, for reasons of fishing strategy. It is reasonable, therefore, to expect the lines connecting the floats to the hook line can also be lengthened. The tasks are the same and neither is arduous (objection to this elementary requirement would be deserving of a regulated kick up the jaxie). Float lines of 5 m in length, or thereabouts, would seem to be a reasonable compromise between aspiration and practicality.

Sinkers: the sink rate of the hook line mid-way between the line weights could be increased by fitting leaded sleeve sinkers to the float line (5 m in length) where it joins the hook line. Knots on each end of the sleeve would stop it from sliding. The leaded sleeve would increase the sink rate of the hook line with almost immediate effect until the float line became taut on the float. The metrics critical to achieving expeditious initial sink rates and adequate buoyancy at fishing depth might have to be determined experimentally. Lead sleeve sinkers in the 300-500 gm range might be a useful starting point.

Line tension astern: Attempts to increase sink rates with the abovementioned (or any other) gear modifications will be derailed unless line tension astern is eliminated. There are two causes of line tension astern. The first is when hooks snag on baskets (usually on their aft edges) or seams, weld beads and even the rusted surface of the setting table and gunwale of the vessel. Gear snagging on the baskets or vessel may hang up for a few seconds, which at 3-5 m/s setting speed (6-10 knots) is sufficient to yank the hook line out of the water for a considerable distance astern. Hook-ups momentarily leave baited hooks dangling in the air and with some flicked off the longline, which attracts seabirds. The second cause of line tension astern is when crew members allow line weights to be pulled from the vessel by the gear already deployed, rather than pushing them pre-emptively. These events are generally not as severe as hookups but, depending on crew aptitude, can occur every time weights are deployed, placing the hook line under near-constant rearward tension. Constant yanks on the hook line undermines efforts to expedite sink rates to reduce interactions with seabirds and must be eliminated.

Hooks snagging in the baskets and hook-ups on the aft end of the setting table and gunwale of the vessel can be avoided by following the procedures in Annex 5. Tension astern from line weights being pulled from vessels can be eliminated by crew pushing weights outboard moments before line tension occurs.

4.5. Comment about seabird bycatch

As reported in Annex 1, line setting in the industrial fishery for Austral hake and Congrio is said to occur at night, presumably including around the full moon, with some lines set near dawn and in daylight. The estimated average bycatch is 0.018 black-browed albatrosses/1000 hooks. With an average effort of 15,000 hooks/day, this equates to just one bird caught every three or four days (or 45,000-60,000 hooks). The reported bycatch level is difficult to reconcile for what appears to be an inherently dangerous fishing practice. High bycatch levels would be expected with sets around the full moon, around dawn and especially with sets made in the daylight (as noted on occasion by the Chilean observer program). The seabird bycatch observations, from 2003 and 2004, may not reflect the current situation in the fishery. Further observations would seem to be justified, both to update the status of seabird bycatch in general and, more specifically, to better understand the impacts of sets made through the full moon period and at times that violate a strict definition of ‘night setting’.

(For the record, the Merluza system experimental set commenced at 0505 h local time and ended at 0545, a duration of just 40 minutes. Shortly after setting began an estimated 300 great shearwaters, up to 10 black-browed albatrosses and up to 10 white-chinned petrels arrived on the scene and started hitting the gear aft of the aerial extent [40-50 m] of the streamer line. The haul indicated four great shearwaters, four white-chinned petrels and one magellanic penguin were killed on the set. A mismatch between the shearwater bill size and bait/hook size might be implicated in the low number of shearwaters caught).

4.6. Alternative Merluza system design

An alternative to the conventional Merluza system gear design with the potential to minimise seabird mortality is presented in Annex 6.

5. RECOMMENDATIONS

The following changes to gear and practice are recommended for consideration:

1. Increase the length of the float lines so the floats do not slow the initial sink rates near the surface. Float lines at least 5 m in length would seem to be a reasonable compromise between aspiration and likelihood of adoption by industry.
2. Fit for permanence leaded sleeve sinkers over the float lines at the clip where float lines join the hook line. The purpose is to increase the initial sink rate of the hook line at the float, mid-way between line weights, until the float line pulls taut on the sinking hook line.

The metrics critical to achieving expeditious initial sink rates and effective buoyancy at fishing depth might have to be determined experimentally.

3. Eliminate all sources of line tension astern during setting operations. Tension astern slows the initial sink rate and can be eliminated by following the methods outlined in Annex 5.

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ANNEX 1

Seabird bycatch: Industrial demersal floated longline in Chile (from Robertson et al., 2014)

This fishery commenced in 1987 and operates in the open ocean (and sometimes inside the Chilean channels and) from 45-57°S at depths from 200-600 m. The number of vessels peaked at 52 in 1990 and decreased thereafter (Subsecretaría de Pesca 2012c). Hook effort ranged from 9.1 million in 1987 to 65.5 million in 1990 (Figure 2). In 2010 only eight vessels operated in the fishery with a fishing effort of 13.5 million hooks. Vessels use the Spanish system (as for Patagonian toothfish) with floats attached mid-way between weights on the hook line to raise sections of the line off the seabed. Lines of ~15,000 hooks are currently set almost exclusively at night, typically near midnight, although some lines may be set near dawn and in daylight. Observations on 96 sets on two vessels in October/November 2003 and March 2004 suggest that sets undertaken in daylight or near dawn could result in significant albatross bycatch. An average of 0.0181 black-browed albatrosses/1000 hooks and no grey-headed albatrosses were killed (unpublished data from Moreno et al., 2003 and Moreno and Arata, 2004). This estimate was scaled on hooking effort and extrapolated for the period 1987-2010 to derive an overall estimate of albatross mortality for the fishery.

ANNEX 2

The Spanish system (from Robertson et al., 2008)

Spanish system vessels set two parallel lines – a heavy hauling line (línea de retenida) and a light hook-bearing line (línea madre). The hauling line is stored on vessels as a continuous length of line and the hook line is stored in separate plastic baskets (cajones). Baskets are square, open-topped containers with one compartment for the coiled-up hook line and one for the baited hooks. During line setting the hauling line and hook line are deployed simultaneously from opposite sides of the setting window. The hauling line is paid out as a continuous length of rope whereas the hook line is paid out of the baskets as multiple sections of line that are joined manually as the setting operation progresses. The baskets are organized on a setting table and moved in continuous procession towards the stern. The ends of the hook lines in the baskets are joined to the ends of lines in adjacent baskets such that the hook line becomes a continuous length of line, albeit coiled-up inside the baskets. As the baskets are moved toward the stern the strings on the line weights (pesos) are attached to the hook line – one weight to both ends of the line in the baskets and one to the line in the center of the baskets – and both baskets and line weights are shuffled in unison towards the stern (the weights are moved in a separate compartment of the setting table so as not to foul the hook line). At the very stern of the vessel connecting lines (barandillos) attached to the hauling line are tied to the hook line moments before the hook line is paid out of the baskets. The number of joining lines varies with fishing strategy, but usually joining lines are attached at the location of every second line weight. Lastly, the line weights are released, either by pushing from the vessel or, more typically, yanked from the vessel by the gear already deployed.

ANNEX 3

Merluza experiment: fishing vessel, fishing gear and location (from Robertson et al., 2008)

The Merluza (and Spanish) systems experiments were conducted on the F/V *Argenova* XV from 10-25 March 2006, about 100 km east of Puerto Deseado (47º45'S; 65º54'W), Argentina. The *Argenova* XV is a 55-meter Japanese-made (1969) tuna vessel converted to the Spanish rig. The vessel was chartered specially for the experiment and was not fishing commercially. The ship had a single 2.5 m diameter four-blade constant pitch propeller (nominal rpms: 170 at 7 knots). The propeller rotated in a clockwise direction and the hook line was set into the upswing area of the propeller wash. The setting window was 4.3 m above sea level and the longline entered the water 8-10 m astern (depending on vessel speed and sea state). All fishing gear used on the vessel was typical of the Spanish system. The vessel used a 16 mm diameter polypropylene hauling line, 8 mm diameter 20 m long polypropylene joining lines and 3.5 mm monofilament nylon hook line. Hook-bearing snoods were 1 mm diameter, 0.7 m long, monofilament nylon attached to the hook line by swivels every 1.6 m. To ensure baskets contained the correct length of hook line the lines were measured with a 50 m tape measure when the baskets of gear were built. All components of the gear except the line weights were buoyant in water. Hooks were baited with whole, thawed, sardines (*Sardina pilchardus*, mean weight: 126 gms). Sardines are commonly used in toothfish fisheries and are more buoyant than squid. Wave height during the experiment varied from <1-2.5 m and all lines were set across the current (range: 0.2-1.5 knots). Line weights were purpose-built blocks of concrete wrapped in the traditional rope netting and attached to the hook line by 1 m-long snoods. To reduce the risk of catching seabirds all lines were set at night (0400 hours local time) and paired streamer lines were deployed from purpose-built poles erected on the upper rear deck.

ANNEX 4

Statistical methods

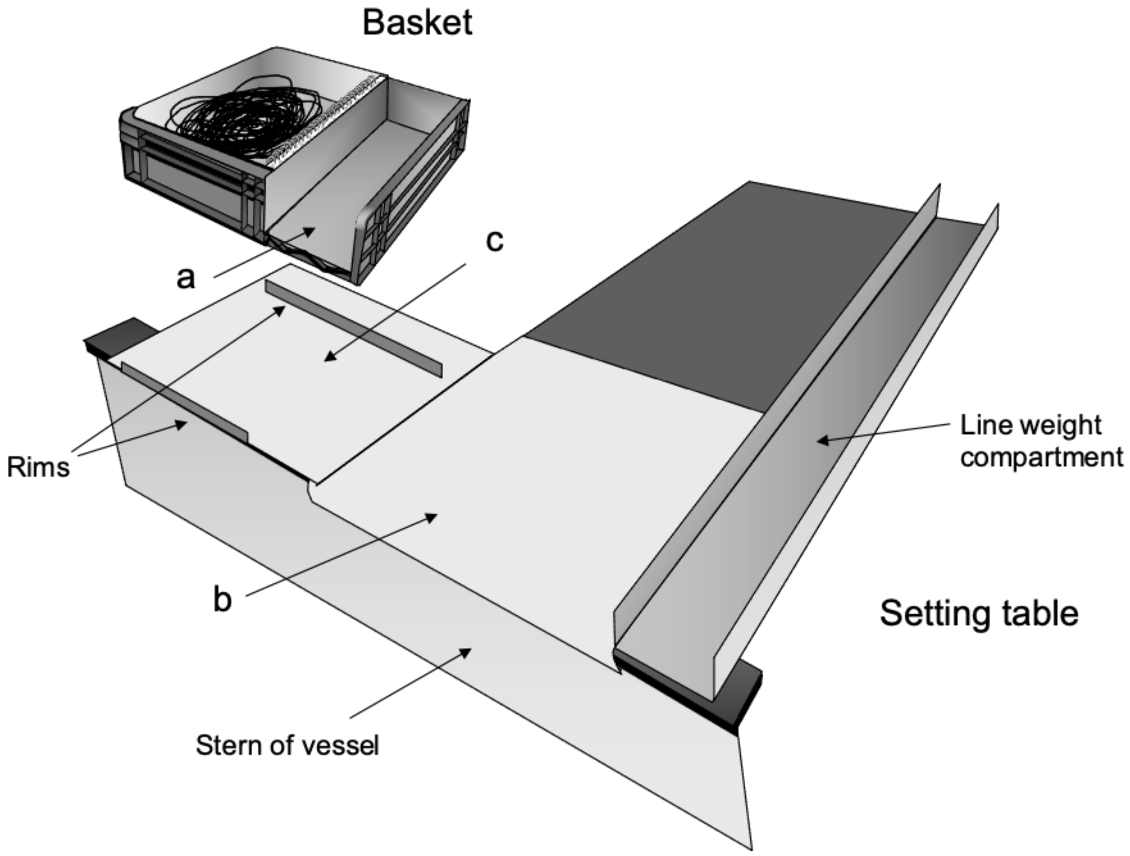
The data were analysed using linear mixed models (LMMs) as described in Robertson et al. (2008; 2010a, b) and Robertson and Candy (2013). The repeated observations of depth (i.e. depth-to-time profiles) to times of 1–200 s in 1 s units were modelled using LMMs (Diggle et al., 2002) fitted using the gamm function from the mgcv library (Wood, 2006) in the R software package (R Development Core Team, 2018). The parametric form of the LMM was fitted using thin-plate smoothing splines (i.e. the default method in mgcv combined with the default method of selecting knot points) to give smooth curves of depth as a function of time. The LMM time was fitted as a linear trend along with smoothed random deviations where the sum of linear and random deviation terms corresponds to fitting the thin-plate smoothing spline (Crainiceanu et al., 2005). The mgcv library uses the lme function within the nlme library (Pinheiro and Bates, 2004) to fit the LMM formulation of the gamm. This allowed nonlinear interpolation between time points and the prediction of time to nominal depth from the modelled profiles. By this approach the predictions 'gain strength' because the entire profiles are a sequence of related values, rather than a set of time-specific means to target depths. The random term in the LMMs (apart from spline random deviation terms in the parametric LMM) was the profile number (i.e. individual TDRs).

The terms in the gamm were a "Float" vs "No_Float" main effect ("Float_f") and the interaction of this factor with the spline term [i.e. "s(Sec,by=Float_f)"]. To account for the increasing variance of depth with time given the treatment combination, data were log transformed so that the response variable fitted by the LMM was y = log(Depth + 1) and predictions on this scale could be back-transformed to give a predicted depth. The autocorrelation between depths within a profile were modelled using an exponential power model (Diggle et al., 2002; Pinheiro and Bates, 2004). The correlation between time points separated by 'x' time units is given by the estimated autocorrelation parameter to the power of x. This model corresponds to that of Diggle et al. (2002) with experimental sink profiles as random effects plus residual variance with autocorrelation but no measurement error. In addition, the residual variance was modelled to have a different (i.e. increased value) for the Floats-present ("Float") depth-time profiles. Double-standard error bounds were placed around average profiles in a graphical assessment of significance. This was complemented by comparing the difference in mean profiles for each nominal time point to the double standard error bounds of these differences. Further the AIC (Akaike, 1998) penalised goodness-of-fit statistic was compared for the above model to a gamm the dropped the Float_f factor from both the intercept and spline terms. A lower AIC indicates a better model in terms of fit and parsimony (i.e. minimum number of parameters to obtain a good fit). Further the adjusted R-square statistic (which does not penalise for reduced parsimony) output from gamm was also compared.

To estimate time-to-depths the mean depth-to-time profiles were searched for the closest time (in seconds) to achieve the target depth ranges of 0-2 m, 0-5 m, and 0-10 m. Approximate 95 % fiducial intervals for the time-to-depth estimates were obtained by carrying out the corresponding search of the upper and lower 95% confidence bounds for the mean depth-to-time profiles. The sink rates or velocities (depth-to-time/time) averaged over the above depth ranges were obtained by dividing the depth profiles by the nominal time and corresponding standard errors and approximate 95% confidence intervals (i.e. +/- 2 times the standard error) were obtained by dividing the standard errors for estimated average depth-to-time from the gamm output by nominal times.

ANNEX 5

Schematic showing methods to minimise longline tension astern (from Robertson et al., 2008)



The diagram above shows the areas of setting basket and line setting table and that must be modified to minimise the incidences of foul hooking - and line tension astern - during line setting. To minimise foul hooking in the baskets the compartment for baited hooks (a) should be lined with marine grade stainless steel. To prevent foul hooking on the aft end of the setting table (b) the table can either be lined to 1.5 m inboard with marine grade stainless steel or a basket holding plate (c) fixed to the aft end of the setting table. If the former option is used the lining of the setting table should be wrapped under the gunwale to create a rounded, smooth, edge and linings must be seamless and contain no weld beads or screws. If the latter option (basket holding plate) is adopted the plate should be the same area (54 x 54 cm) as a basket and comprise rims forward and aft as shown. During line setting the crewman holding the basket stands in the corner between the setting table and holding plate, places the aft edge of the basket behind the rim on the plate (prevents the basket from being pulled from the vessel in the event of hook-ups) and the other side of the basket on the rim at the bow end of the plate (tilts the basket to seaward to facilitate emptying). The rim on the plate must be shaped so as to not interfere with the passage of baited hooks from the bait compartment of the basket.

ANNEX 6

In 2005 a Spanish system fishing master operating in the industrial Patagonian toothfish fishery in southern Chile modified his fishing gear to minimise depredation of toothfish from longlines by sperm whales and orcas. The gear change was driven by the economic imperative to increase the number of intact fish landed on deck. The hook line (linea madre) was removed and barandillos (connecting lines) left open ended to which weights (the traditional bags of rocks) were attached during the sets. A single branching snood with clusters of hooks was attached immediately above the weights and the barandillos were fitted with sliding net sleeves to cover caught toothfish when hauled. These changes essentially transformed the double line system (an alternative name for the Spanish system) into a single line system similar to trotline gear used in the artisanal toothfish fishery. The modified rig became known and the 'Cachalotera system' after the Spanish word 'Cachalote', meaning sperm whale. Changes to the structure of the gear are shown in Figure 4.

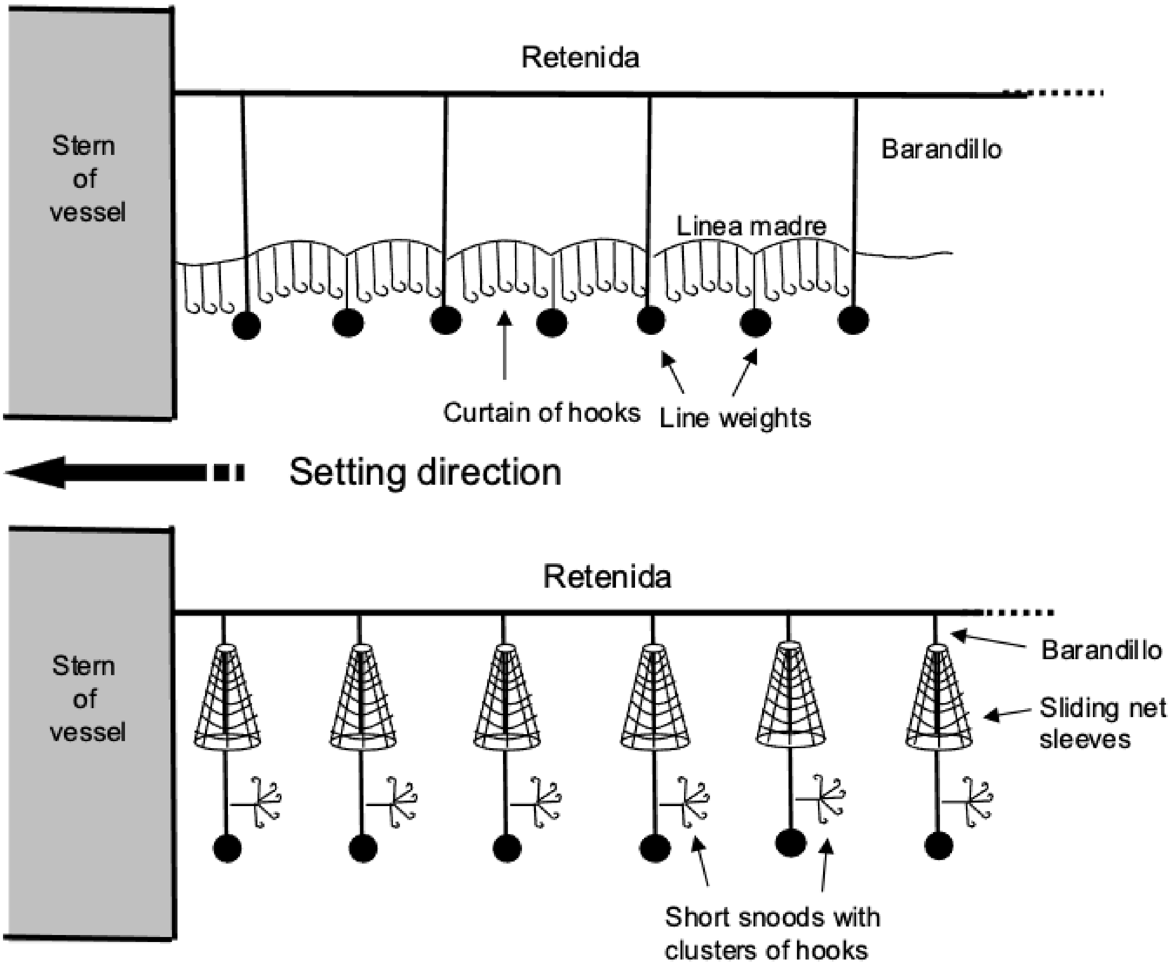


Figure 4. Schematic showing conversion of the traditional Spanish system (top) to the Cachalotera system to minimise toothfish depredation by sperm whales and orcas. Diagram not to scale.

An unintended positive consequence with the new gear design was the almost total elimination of seabird bycatch (Moreno et al., 2008). This was due to the five-fold increase in initial sink rates with hooks sinking vertically (not with the horizontal, or ‘flat’, profile of Spanish system gear) very close to the vessel stern (Robertson et al., 2008). As with fishing practices in general, the Spanish system’s history is one of strong cultural inertia and allegiance among practitioners, traits that frustrated attempts for improvement in the early years of the toothfish fishery in CCAMLR waters when seabird mortality was extremely high and the Spanish method the only fishing practice in operation. For a fishing practice evidently set in stone the changes leading to the Cachalotera system are nothing short of remarkable and highlight the importance of imperatives in driving change. Could structural alternatives to the current Merluza system design be developed and still be practical to fish with? One such alternative, shown in Figure 5, could be worth a try. The basic architecture of the gear is the same as the Cachalotera system but includes several clusters of hooks (instead of one cluster) distributed vertically along the barandillos. Small floats could be fixed to the tops of each barandillo to ensure gear assumes a vertical posture at fishing depth. The floats would not affect the initial sink rates of the hook clusters because they would be located several metres below the floats.

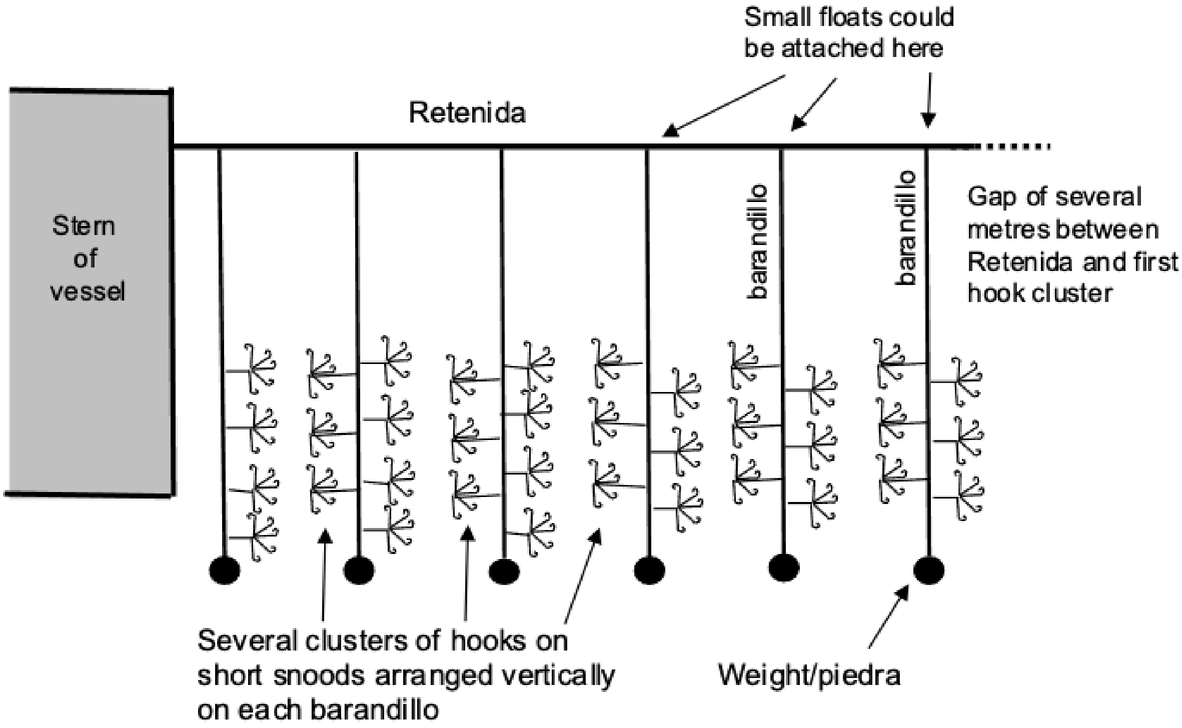


Figure 5. Schematic of an alternative to the current Merluza system which is designed to ensure both a vertical distribution of hooks in the water column at fishing depth (good for fish catch) and rapid sink rates near the surface (good for seabird conservation). The barandillos are about 15 m in length and the weights weigh several kilograms. Drawing not to scale.