CCAMLR Science, Vol. 7 (2000): 133–150

EFFECT OF LINE SINK RATE ON ALBATROSS MORTALITY IN THE PATAGONIAN TOOTHFISH LONGLINE FISHERY

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Abstract

An experiment was conducted on autoline and Spanish-system longline vessels to derive a sink rate and line-weighting regime that would minimise the capture of albatrosses based on knowledge of line sink rates and albatross diving abilities. Sink rates of lines deployed into propeller turbulence, which tended to keep lines aloft, varied as a function of distance between line weights. Asymptotic sink rates (0.1–0.15 m/s) were achieved with 70 m intervals between 6.5 kg weights. Sink rates to 4 m depth were greatest with 35 m (0.44 m/s) and 50 m (0.33 m/s) between weights. For vessels using bird-scaring lines and setting lines in propeller turbulence, longline sink rates >0.3 m/s should greatly reduce the incidental take of albatrosses. For autoline vessels with gear and line-setting characteristics similar to the experimental vessel, this sink rate should be achievable with 4 kg weights distributed every 40 m on longlines.

Résumé

Une expérience menée sur des palangriers équipés de palangres automatiques et de palangres de type espagnol a permis de dériver une vitesse d'immersion et un régime de lestage des palangres qui, par une meilleure connaissance de la vitesse d'immersion des palangres et des capacités de plongée des albatros, réduiraient au minimum la capture d'albatros. La vitesse d'immersion des palangres déployées dans la turbulence causée par l'hélice, qui a tendance à maintenir les palangres en l'air, varie en fonction de la distance entre les lests. Des vitesses d'immersion asymptotiques (0,1–0,15m/s) ont été atteintes avec des poids de 6,5 kg placés à 70 m d'intervalle. L'immersion la plus rapide à 4 m de profondeur a été atteinte avec des lests placés à 35 m (0,44m/s) et 50 m (0,33m/s) d'intervalle. Pour les navires utilisant des dispositifs destinés à effrayer les oiseaux et posant les palangres dans la turbulence de l'hélice, des vitesses d'immersion des palangres >0,3 m/s devraientcidentelle des albatros. Pour les navires dont l'engin automatique et les caractéristiques de pose des palangres sont semblables à ceux du navire expérimental, cette vitesse d'immersion devrait pouvoir être atteinte avec des lests de 4 kg placés tous les 40 m sur les palangres.

Резюме

На автолайнере и ярусолове с испанской системой был проведен эксперимент по определению скорости погружения и режима установки грузил, позволяющих минимизировать прилов альбатросов, зная скорости погружения и способность альбатросов нырять. В зоне турбулентности за винтом, где ярусы держатся выше, скорость погружения менялась в зависимости от расстояния между грузилами. Асимптотическая скорость погружения (0.1–0.15 м/сек.) была достигнута при весе грузил 6.5 кг и интервале между ними 70 м. Скорость погружения на глубину 4 м была самой высокой при интервалах 35 м (0.44 м/сек.) и 50 м (0.33 м/сек.). Для судов, применяющих поводцы для отпугивания птиц и спускающих ярусы в зоне турбулентности, скорость погружения яруса >0.3 м/сек. должна существенно снизить прилов альбатросов. Для автолайнеров, оснащение и характеристики постановки ярусов которых подобны оснащению и характеристикам экспериментального судна, такая скорость погружения может быть достигнута при весе грузил 4 кг и интервале между ними 40 м.

Resumen

Se realizó un experimento en barcos con palangres automáticos y de tipo español para determinar una tasa de hundimiento y un sistema de lastrado de la línea que reduciría la captura de albatros, en base al conocimiento de las tasas de hundimiento de la línea y la habilidad de buceo de estas aves. La tasa de hundimiento de las líneas caladas en la turbulencia producida por la hélice, que tiende a mantener las líneas en la superficie, varió en función de la distancia entre los pesos de la línea. Se alcanzaron tasas de hundimiento asintóticas (0,1–0,15 m/s) con pesos de 6,5 kg cada 70 m. Las tasas de hundimiento a 4 m de profundidad fueron mayores cuando los pesos se colocaron a intervalos de 35 m (0,44 m/s) y 50 m (0,33 m/s) entre sí. Los barcos que utilizan líneas espantapájaros y calan sus líneas en la turbulencia producida por la hélice reducirían significativamente la captura incidental de albatros si lograran una tasa de hundimiento de los palangres mayor de 0,3 m/s. Aquellos barcos con palangres automáticos que utilizan artes de pesca y calan sus palangres de manera similar a los barcos que realizaron los experimentos, pueden lograr esta tasa de hundimiento con pesos de 4 kg cada 40 m de distancia.

Keywords: Patagonian toothfish, *Dissostichus eleginoides*, longline fishing, longline sink rates, seabird mortality, autoline system, Spanish system, CCAMLR

INTRODUCTION

Longline fishing for Patagonian toothfish (*Dissostichus eleginoides*) commenced in the CCAMLR Convention Area in the late 1980s, and in the 1996/97 fishing season there were 16 longline vessels fishing legally for toothfish in CCAMLR areas. Toothfish is caught on the seabed (c. 800–2 500 m depth) near sub-Antarctic islands and near the southern coasts of South America, which are also areas of high seabird abundance. Longline vessels may deploy up to 20 000 baited hooks per day, and during line-setting procedures, seabirds scavenging baits may become hooked and drown. Seabirds may also become hooked during line-hauling operations when baited hooks once again become available to birds in surface waters. Longlining for toothfish takes a heavy toll on seabirds, with annual estimates in some fisheries being in the order of tens-of-thousands of seabirds killed (SC-CAMLR, 1997).

Two methods are adopted in the CCAMLR Convention Area for the longline harvesting of toothfish: the autoline, or single-line, method and the Spanish, or double-line, method. These two fishing methods differ greatly in line construction, the way lines are set, hauled and managed on board, and in operational procedures that affect seabirds. For instance, autoline vessels deploy negatively buoyant longlines whereas Spanish-system vessels deploy buoyant longlines that would not sink without added weight. Practical efforts to reduce seabird mortality in toothfish longline fisheries must take into account basic differences in equipment used and procedures adopted if results of experiments are to be meaningful. This is particularly so in the case of experiments aimed at increasing line sink rates to reduce seabird deaths.

This paper presents the results of an experiment conducted on autoline and Spanish-system fishing vessels during December 1997 and January 1998 on the Patagonian shelf near the Falkland/Malvinas Islands. Vessels were the *CFL Pioneer* (UK Consolidated Fisheries Limited) and the Korean FV *In Sung 66*, the former being equipped with a Mustad autoline system and the latter using the Spanish system. The objectives of the experiment were to:

(i) determine, based on time-depth recorder measurements of longline sink rates and knowledge of albatross diving abilities, a longline-weighting regime for the *CFL Pioneer* that had the potential to eliminate bait taking by albatrosses and minimise bait taking by other seabird species; and

(ii) to determine the longline sink rate of the *In Sung 66*, a vessel with very low reported catch rates of albatrosses during line-setting operations.

The paper also describes the autoline and Spanish-system methods, as adopted by the *CFL Pioneer* and *In Sung 66* respectively, so that results of sink-rate trials can be placed in context with the fishing operations and gear used. Information on the weights of materials used in the longlines of the *CFL Pioneer* and *In Sung 66* is given in the appendix. The autoline and Spanish systems have also been described by Bjordal and Lokkeborg (1996).

LONGLINE CONFIGURATIONS AND FISHING PRACTICES

CFL Pioneer

Longline Configuration

The *CFL Pioneer* is a 47 x 11.5 m Spanish-built trawler converted for toothfish longlining. The autoline system (Figure 1) operates with a single line and, when lying on the seabed, consists of a single snood-and-hook bearing 11.5 mm mother line with each end attached to 100 kg anchors, which were used to sink the line quickly to target locations and to minimise line drag in currents. About 50 m separated the end of the snoods on the mother line from the anchors. The anchors were attached to 18 mm ropes which rose from the fishing depth (2 000 m) to the surface where they were attached to eight 1 m diameter floats, a radio beacon and a flag: these marked each end of the anchor line and were used to locate the fishing gear (often four of the eight floats would be dragged down by the force of the current on the submerged gear). Hook-bearing snood lines were attached via metal swivels and collars at 1.2 m intervals along the mother line. Snood lines were 3 mm in diameter and 50 cm in length.

Line Setting and Hauling

A typical set for the *CFL Pioneer* was about eight magazines or 10 800 hooks, giving a line length on the seabed of about 13 km (depending on slack in the line). The line was set at any time of day or night, depending on events in the fishing operation. The *CFL Pioneer* set the line at 5.5–6.5 knots and bait shooting rate, which varies as a function of setting speed and snood spacings, averaged 2.72/s. At this rate the *CFL Pioneer* set 10 800 hooks (eight magazines) in about one hour. Bait used was squid (*Illex* spp.), which was cut into 50 mm length blocks and deployed in a half-thawed state. Bait hooking success by the autobaiter was about 80%. During setting the line entered the water about 15 m behind the vessel. The line was hauled at 1–1.5 knots and hauling rate was about 1 magazine/hour.

In Sung 66

Longline Configuration

The *In Sung 66* is a 47.7 m Japanese tuna (pelagic) longliner re-fitted for catching and processing toothfish. The *In Sung 66* employed the Spanish (double line) system, the basic construction of which is shown in Figure 2. The longline on the *In Sung 66* was marked on each end by four to six 1 m diameter floats, a radio beacon and a light to enable the end of the line to be found in case the line broke during hauling. The floats were attached to a 20 mm anchor rope which was about 200 m longer than the 2 000 m fishing depth (this slack was usually taken up by the force of the current). The anchor line was attached to two 50–100 kg anchors which sank the mother line quickly to target depths (thereby reducing drift from the preferred fishing location) and held the ends of the line on the seabed against the force of the current. The anchors were separated from the commencement of the branch lines by 600 m of rope to minimise line tangles during sets and hauls. The anchor line was attached to an 18 mm mother line from which the branch lines, hook line and snoods were suspended. Branch lines were made of 9 mm line and were suspended along the entire length of the mother line to within 600 m of anchors and to within 70 m of weights attached to the mother line at 1 600 m intervals. Branch lines were 18 m in length and descended from the mother line every 76 m. Branch lines were connected by a 5 mm, 76 m long hook line running parallel to the mother line. Hook lines bore 3 mm diameter, 0.7 m long snood lines and baited hooks at 1.5 m spacings. Each hook line (between branch lines) contained a 'basket' of 48 snoods with hooks (a 'basket' being the plastic tray used to contain snoods and hooks during line deployment). The hook line was weighted every 38 m with 3.6 kg jigger weights, providing a weight at the joins between branch line and hook line and a weight in between these locations. Baskets were deployed in batches of 20 (= 960 snoods and hooks), with each batch extending 1 440 m along the hook line. Each batch of 20 baskets was followed by 140 m of mother line with no branch lines attached; a 15–20 kg weight was attached midway (70 m) along this portion of the mother line to sink the mother line independently of the hook line. In summary, the structure of the Spanish-system line consists of multiple snood lines suspended from a single (but discontinuous) hook line connected by multiple branch lines to a single mother line.

Line Setting and Hauling

The *In Sung* 66 set the line at 10–10.5 knots, about maximum cruising speed. During line setting, the mother line was payed out on the starboard side such that it entered the water 15–20 m behind the vessel and about 10 m broadside of the water entry point of the hook line and snoods. At the same time, baskets were lined up on the bench on the port side and fed progressively towards the rear of the ship. As the baskets were moved toward the stern of the ship, hook lines were joined, weights were attached at both ends and the centre of each basket of hook lines, and branch lines (connected to the mother line being payed out of the other side of the ship) were attached to each end of each basket of hook lines. Both mother line and hook/snood lines were payed out passively, line-shooting speed being determined by setting speed, the pull of the line already deployed and hooks jagging on the ship's gear. About every 1 500 m, weights were deployed on the mother line to help sink the gear and to sink it separately from the hook line. The line entered the water as a heavy duty hauling (mother) line on one side of the vessel and light duty (hook and snood lines) fishing line on the other, with branch lines straddling the area in between.

A set for the *In Sung 66* involved the deployment of 100–360 baskets, representing 4 800–17 280 hooks. With the gaps in the hook line to accommodate weights on the mother line (see above and Figure 2), distances on the seabed between the first and last hooks in a set of 100–360 baskets would be 8.3–30 km respectively. The hook-setting rate of the *In Sung 66* was 3.25/s. At that rate the *In Sung 66* could set 4 800 hooks in about 25 minutes and 17 280 hooks in about 90 minutes (plus deployment time for the 140 m gaps in hook line where weights were attached to the mother line; at 10 knots this extra time would be minimal). The hook line on the *In Sung 66* entered the water about 8 m behind the vessel. Bait used was squid (*Illex* spp.) cut into 50–70 mm blocks (three baits from one squid, bait weight: 60 g). Bait was half thawed when cut and thawed when deployed, due to the time that elapsed between manual baiting and deployment. Since the bait was attached to hooks manually, hooking success was 100%. The line was hauled at 1–1.5 knots, and hauling usually took about 8 hours.

LONGLINE SINKING EXPERIMENT

Methods

CFL Pioneer

The effects of weight spacing on line sink rate of the *CFL Pioneer* were determined by varying the distance between weights on the longline. Weight spacings were 35, 50, 70, 100, 140 and 200 m. Line sink rates were measured with Mk 7 dive recorders (Wildlife Computers, USA) which were attached with cord and tape to the main line midway between snoods. Three recorders were used for each weight spacing, and recorders were attached separately in series midway between consecutive weights. Recorders were deployed in triplicate to derive average sink rates (recorders occasionally give anomalous readings). Since it was not possible to manipulate the length of the entire longline (this would have ruined the fishing operation), experimental weight spacings were maintained for three additional spacings either side of the line bearing the three recorders. Thus nine weights were used in each treatment with distances between weights, and recorders, within each treatment being as described above. The intention with this approach was to minimise the effect of the unmanipulated sections of line on the manipulated sections of line. Before deployment, dive recorders were hosed with seawater to minimise effects on recorder accuracy of temperature changes between air and sea.

The dive recorders sampled depth and temperature every second. Line weights (6.5 kg) and setting speed (5.5–6.5 knots) were constant. Data from the dive recorders were downloaded into a portable computer at the end of every haul, and data from the three recorders used on each set were averaged. All deployments of dive recorders were made on the second magazine deployed in a set, a set usually involving eight magazines of longline. Time constraints did not permit replication of experimental weighting regimes, thus it was not possible to gain a measure of within-treatment variance due to effects of the tide, sea state or other factors.

In Sung 66

Dive recorders were deployed on two sets only to examine sink rates of normally configured longline gear used by the *In Sung 66*. Dive recorders were deployed in threes as for the *CFL Pioneer*. Setting speed (10–10.5 knots) and line weights (3.6 kg) were constant during the experiment.

RESULTS

CFL Pioneer

The results of the line sinking experiment are presented as a family of polynomial and logarithmic regressions expressing line sink rate (Figure 3), sink time (Figure 4) and distance astern at certain depths in the water column (Figure 5) as a function of distance between weights on longlines. The three dependent variables (sink rate, sink time and distance astern) were chosen because of their relevance to seabird conservation: sink rate and sink time-to-depth have implications for speed of bait spotting and dive velocity by seabirds, and distance astern pertains to the areas afforded 'protection' by propeller wash and bird-scaring streamer lines. Depths of 4, 8 and 12 m represent the shallowest depth (4 m) at which confidence in recorder accuracy exists (since the recorders measured in 2 m increments, measurements to 2 m depth might be spurious); they also approximate the maximum recorded diving depth (4.5 m) of black-browed albatrosses (*Diomedea melanophrys*) (Prince et al., 1994), the depth (8 m) that exceeds by one dive recorder increment the maximum known diving depth of grey-headed albatrosses (*Diomedea chrysostoma)* (6.5 m; Huin and Prince, 1997) and the maximum known diving depth (12.5 m) of light-mantled sooty albatrosses *(Phoebetria palpebrata)* (Prince et al., 1994) and white-chinned petrels *(Procellaria aequinoctialis)* (Huin and Prince, 1997). Wandering albatrosses (*Diomedea exulans*) have been recorded as diving to 0.6 m only (Prince et al., 1994). Except for these five species of seabird published, no information was found on diving depths of other seabirds likely to attack baits in the toothfish longline fishery.

All relationships shown in Figures 3, 4 and 5 are curvilinear, which is almost certainly a result of the longline being held aloft by propeller upwellings. Sink rates to 4 m depth ranged from 0.44–0.1 m/s with weights at 35 and 200 m intervals respectively (Figure 3). Sink rates to any depth did not vary greatly with weight spacings >70 m, suggesting that at shallow depths (<12 m) there was either enough slack in the longline to nullify the effect of additional weight, that the longline had cleared the propeller wash (resulting in a more linear sink rate) or elements of both. Figure 3 infers that even to 4 m depth with >70 m weight spacings the longline would have cleared the propeller wash (ranges, patchily, to c. 40 m astern), after which a more linear sink rate would be expected. For 35 and 50 m spacings, sink rates to 8 m depth (0.37 m/s and 0.24 m/s respectively) were similar to sink rates to 12 m depth (0.37 m/s and 0.21 m/s respectively). However, sink rates to 4 m depth for these two weight spacings (0.44 m/s and 0.37 m/s respectively) were appreciably greater than to the two deeper depths. Thus, sink rates with weight spacings of 35 and 50 m were greatest close to the surface.

Sink time increased as weight spacing increased (Figure 4), the functional relationship for 4 m depth predicting that for each additional 10 m added to the distance between weights on the longline sink time increased by about 2 s. The longline took 9 s to reach 4 m depth with weights every 35 m and 40 s to reach the same depth with weights every 200 m. With 35 and 200 m between weights 21 and 70 s respectively were required to reach 8 m depth and 33 and 97 s respectively were required to clear the bird strike zone at 12 m depth. Thus, with weights spaced at 35 m intervals, baits would be available, theoretically, to grey-headed albatrosses (and, most probably, black-browed albatrosses) and white-chinned petrels for about 20 and 33 s respectively. At 200 m spacings, these two species of bird would have about 70 and nearly 100 s before the sinking baits exceeded their maximum known diving depths.

Figure 5 shows the relationships between the distance behind the *CFL Pioneer* to particular depths by the longline and the distance between weights on the line (note that the distance between the stern of the vessel and the water entry point of the line – about 15 m – must be added to the distances shown). With 35 m weight spacing at 4 m depth, the longline would be 38 m astern (i.e. 23 m + 15 m), at 8 m depth it would be 70 m astern, and at 12 m depth the line would be 98 m astern – about 35 m beyond the area 'protected' by the bird line used by the *CFL Pioneer*. With 200 m between weights, 4 m depth would be reached 115 m behind the vessel, 8 m would be reached 195 m behind, and 12 m would be reached about 265 m behind. For all weight spacings tested, protection of the bird strike zone by the bird line would only have been achieved to 8 m depth for weights 35 m apart and to 4 m only for weights 50 m apart.

Data on line sink rates can be rearranged to show more clearly the effect of variation in line weight spacings on line sink rate, durations and distance astern (Figures 6, 7 and 8). These figures reveal the advantages of short distances between weights: weights at <50 m produce noticeable increases in line sink rates, reductions in sink time, and reductions in the distance astern that baited hooks are available to seabirds. In contrast, longlines with 70–200 m between weights sank at similar rates, all being appreciably slower than lines with <50 m between weights.

Longline sink rates to 2 m, the depth to which sink rate measurements may be problematic (see above), can be inferred from Figure 6. Linear interpolation between 4 m depth and the 'y' axis suggests sink rates were about 0.5 m/s and 0.4 m/s for 35 and 50 m weight spacings respectively. Sink rates to 2 m depth for all other weight spacings were 0.1–0.15 m/s.

In Sung 66

The *In Sung 66* deployed 3.6 kg weights every 38 m on the hook line and 20 kg weights every 1 500 m on the mother line. The hook line sank at 0.28 m/s to 4 m depth (the same estimate was recorded to 2 m depth), 0.33 m/s to 8 m depth and 0.32 m/s to 12 m depth. Thus, sink rates were fairly constant throughout the depth ranges recorded. Sink durations were 14 s to 4 m depth, 24 s to 8 m depth and 37 s to 12 m depth. At a setting speed of 5.144 m/s (10 knots) at 4, 8 and 12 m depth the hook line would have been 72, 123 and 190 m astern respectively. At all distances, the hook line would have cleared the area 'protected' by the propeller wash and bird line while still well within diving range of grey-headed albatrosses, light-mantled sooty albatrosses and white-chinned petrels.

DISCUSSION

Caveats

The recorders rounded depth readings downwards (i.e. depths from 0–1.9 m were recorded as 0 m and depths from 2–3.9 m were recorded as 2 m), meaning that longlines, and baited hooks, were nearly always deeper than indicated by the instruments. Rounding down should, therefore, have resulted in measurements being conservative in favour of seabirds.

Weights were added to sections of longlines near dive recorders only, not to the entire length of longlines (this would have ruined the fishing operations). The unweighted sections of longline would be expected to slow the sink rate of the weighted sections of line once the weighted sections reached a certain depth in the water column; this should have slowed the sink rate of the weighted sections of line by an unknown amount. Presumably then, the weighting regimes tested would achieve sink rates greater than those recorded in the experiment if entire longlines were weighted.

Line hook-ups (when hooks jag on ships' gear during line pay-out) and weight pull-backs (when line weights are pulled from the vessel by the drag of the line already deployed) may have affected the line sink-rate measurements. Hook-up rate for the *CFL Pioneer* was 1/75 s (no weight pull-backs occurred because weights were deployed while the longline was slack) and that for the *In Sung 66* was 1/95 hooks, or 1/30 s; weight pull-backs occurred about every 8 s. Hook-ups and pull-backs tended to yank longlines upwards, theoretically slowing sink rates. The effect of this on the sink rate measurements is unclear because for all weighting regimes, except 35 and 50 m, propeller turbulence tended to keep longlines aloft anyway, irrespective of the line being yanked due to hook-ups and pull-backs; lines with weights 35 and 50 m apart sank quickly (as verified by eye) in spite of propeller turbulence and upward yanks on the line.

In summary, because of the concerns expressed above, it would be prudent to consider the relationships between longline sink rates and line-weighting regimes as being approximations only of actual sink rates induced by adding weights to longlines.

Seabird Numbers and Mortality

During line setting 150–300 black-browed albatrosses hunted for bait behind the *CFL Pioneer* and 50–100 black-browed albatrosses followed the *In Sung 66* (black-browed albatrosses were a useful test species in the experiment because of their great abundance in the CCAMLR Convention Area, dexterity in the air, speed across the water to reach baits, aggression with other species of albatross and diving ability). During line hauling, about 250 wandering albatrosses, about 500 giant petrels (*Macronectes* spp.) and about 500 black-browed albatrosses attended both the *CFL Pioneer* and *In Sung 66* (to feed on offal), however wandering albatrosses and giant petrels generally did not follow vessels when lines were being set.

At the beginning of the voyage the *CFL Pioneer* used 40 m long paired bird-scaring streamer lines, slung 10 m apart from the deck hand rail with 1 m long streamers, made of wet-weather gear, every 3–4 m. The line-weighting regime in use was 12 x 6.5 kg weights/magazine as described above. After four days fishing the *CFL Pioneer* caught in one daytime set of eight magazines 19 black-browed albatrosses and 1 giant petrel; 5 black-browed albatrosses were caught the next day. Streamer lines were then extended to 60 m in length and streamers were placed every 1.5 m; streamer lines were slung from poles 3 m above the deck (so the lines would reach further behind the vessel) and weights were deployed every 70 m (i.e. 16 weights/magazine) on the longline. No further fatalities were recorded, even though the number of albatrosses around the vessel during line setting remained unchanged. This streamer line was in constant use during the line sinking experiment. This suggests that weights at 70 m intervals on longlines and an elaborate streamer line were sufficient deterrents for albatrosses (see below). The bird line on the *In Sung 66* consisted of a single 80 m long piece of rope with three 1 m long pieces of scarf about halfway down its length. The *In Sung 66* had been under continual observation from October 1997 to June 1998 and in this time no seabirds were reported caught during line-setting operations.

Sink Rates and Line Weighting

The regressions shown in Figures 3, 4 and 5 allow predictions to be made about the effect of changes to weight distribution on longline sink rates. For instance, with 35 m between weights, the line sink rate to 4 m depth is predicted as 0.45 m/s (as against 0.44 m/s measured) and sink rate with 200 m spacings is 0.09 m/s (as against 0.1 m/s). With the *CFL Pioneer*, asymptotic longline sink rates (0.1–0.15 m/s) were achieved with weight spacings of 70 m; spacings greater than 70 m had no effect on line sink rates to any of the depths over which measurements were made (Figures 3 and 6). By contrast, longlines with weights at 35 m (0.44 m/s) and 50 m (0.33 m/s) intervals sank almost immediately, providing virtually no opportunity for baited hooks to be taken by seabirds. With weights spaced <50 m on longlines and sink rates in aerated water of >0.3 m/s, very low seabird catch rates by the *CFL Pioneer* would be expected. This was borne out, more or less, in practice. As mentioned above, the *CFL Pioneer* deployed weights every 140 m until birds were caught, then every 70 m; with the increase in weight, no more albatrosses were observed to be caught. With the extra weight, albatrosses hunting behind the *CFL Pioneer* had difficulty finding the rapidly sinking bait in the propeller wash. If bait is not seized very quickly after deployment and while very close to the surface, the bait may be lost from sight (sink rates to, say, 0.5 m depth, which might render baits invisible to birds, are probably greater than to the 2 and 4 m depths shown in Figure 3). While this might suggest that 70 m weight spacing is suitable for the *CFL Pioneer*, line-weighting regimes should include a safety margin in favour of seabirds because circumstances will sometimes arise where seabirds attack baits with greater intensity than observed during the experiments. Therefore, <50 m between weights is recommended for the *CFL Pioneer*, with the exact distances being influenced by the mass of each weight.

The 6.5 kg weights used on the *CFL Pioneer* were too heavy and tended to burden the crew during both setting and hauling. The *In Sung 66* used 3.6 kg weights every 38 m (on a buoyant line), and these were light enough to be removed from the main line and flicked across the deck one-handed. Judging by the ease of handling of weights by the crew of the *In Sung 66*, the line-weighting regime and low reported seabird catch rates of that vessel, and the results of the sink rate experiments on the *CFL Pioneer*, weights of 4 kg, or thereabouts, might be more suitable for the *CFL Pioneer*. Since weights of this mass are less than those used in the experiment, weight spacings of 40 m, or thereabouts, would seem appropriate. This would result in 28 weights/magazine (as against 16 for the 6.5 kg weights) and a total of 112 kg/magazine (as against 104 with 6.5 kg/70 m) of longline. With this amount of weight, sink rates >0.3 m/s would be expected. Note that it is better to deploy lighter weights frequently than heavier weights infrequently because numerous weights will minimise 'bellying up' of the line between weights and minimise exposure of baited hooks to seabirds.

With the *In Sung 66* it is to be expected that the different line configuration, buoyant line and different line-weighting regime would result in sink rates different to those of the *CFL Pioneer*. Sink rates of the hook line for the *CFL Pioneer* were 0.28 m/s to 4 m depth and 0.32 m/s to 12 m depth. In terms of this vessel, these estimates are equivalent to weights (6.5 kg) every 50–60 m to 4 m depth and every 40 m to 12 m depth. Sink durations were 24 s to 8 m depth and 37 s to 12 m depth. Due to the faster setting speed of the *In Sung 66*, the sink rates would result in the line reaching 4 m depth 72 m astern, 8 m depth 123 m astern and 12 m depth 190 m astern; these distances are roughly equivalent to weights every 100–140 m on the *CFL Pioneer* and suggest that baits would still be vulnerable to attack by seabirds in spite of the low catch rates reported for this vessel.

CCAMLR Conservation Measure 29/XVI seeks to minimise seabird mortality by having Spanish-system vessels deploy 6 kg weights every 20 m on longlines. At a hook deployment rate of, say, 3/s (the equivalent, roughly, of the hook setting rate of both the *CFL Pioneer* and *In Sung 66*) the conservation measure would require the deployment of one weight every 13 hooks, or one weight/4 s (at 1.5 m between hooks). This would be operationally very difficult for fishermen to achieve. Adherence to the conservation measure would also create a problem regarding the total amount of weight on longlines. A set of, say, 10 000 hooks (15 km of line at 1.5 m between hooks) would require the deployment of 750 weights (15 km ÷ 20 m) or 4.5 tonnes of weight, which would have to be hauled in addition to the weight of the fish catch. To my knowledge, no Spanish-system vessel has adopted the CCAMLR-recommended line-weighting regime. For fishing methods where hook lines must float off the seabed, it is important to remember that changing the distance between weights (as against the amount of weight at each point on lines) goes right to the heart of fishing strategy and is unlikely to be viewed sympathetically by fishermen seeking a profitable return. Note that 6 kg/20 m on longlines will sink longlines at about 0.9 m/s (see Brothers, 1995), three times that estimated in this study to minimise the take of albatrosses. Provided sink rates exceed 0.3 m/s and a properly configured streamer line is used, this should be all that is necessary to reduce albatross deaths in toothfish longline fisheries to very low levels.

CONCLUSION

Toothfish longline vessels that deploy lines at about 5 knots in propeller turbulence and use streamer lines should achieve line sink rates >0.3 m/s. For autoline system vessels with gear and line-setting characteristics similar to the *CFL Pioneer*, this will require weight spacings of <50 m on longlines. About 4 kg/40 m on longlines would seem both appropriate and relatively practical for fishermen. If used with effective streamer lines, this line-weighting regime should greatly reduce the capture of albatrosses during line-setting operations.

ACKNOWLEDGEMENTS

I appreciate the tolerance by the fishing masters and crews of the *CFL Pioneer* and *In Sung 66* of my presence on board their vessels and their cooperation during the deployment and retrieval of the instruments. The opportunity to work on both vessels was created by Martin Cox and Dawn Hoy of Consolidated Fisheries Limited. Finally, I was lucky to have spent four days aboard the *In Sung 66* with James Elliott of Consolidated Fisheries Ltd. James is not your average fisheries observer, and the extent to which I have been able to penetrate the Spanish fishing method and its nuances is solely due to James's expert knowledge of that fishing practice and of the art of catching toothfish.

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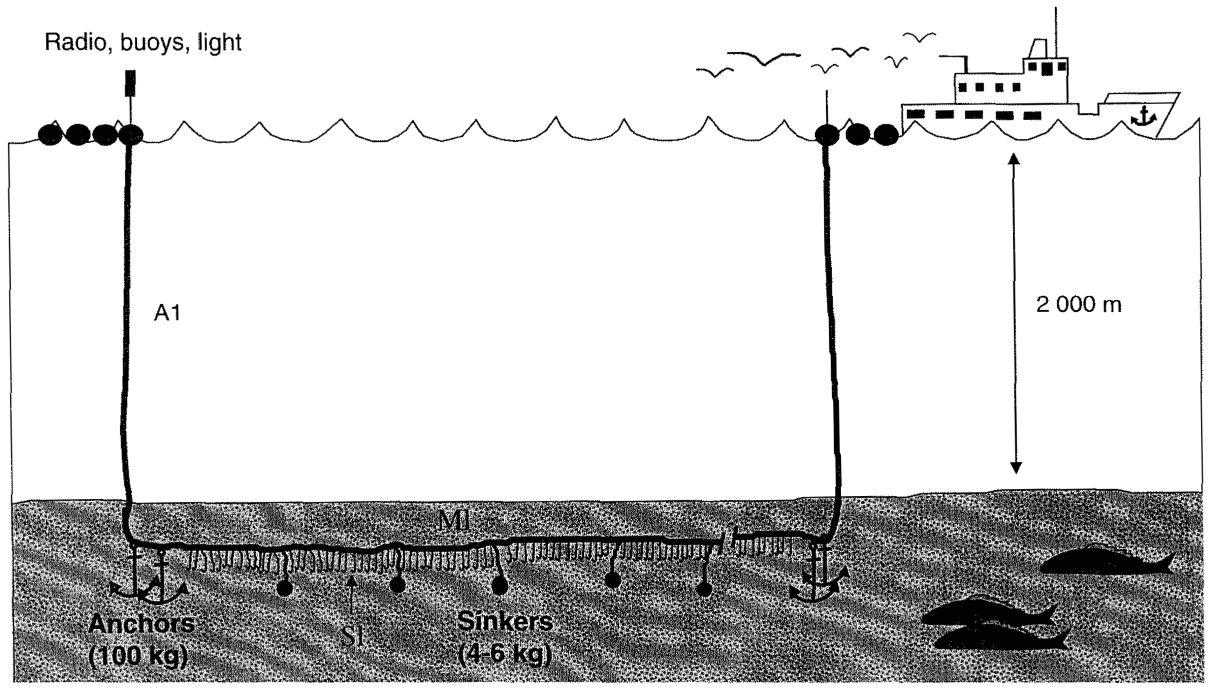

Figure 1: Longline configuration of the *CFL Pioneer* (Mustad autoline (single line) method) used for toothfish fishing. Anchor lines (A1), mother line (M1) and snood line (Sn) are 18, 11.5 and 3 mm in diameter respectively.

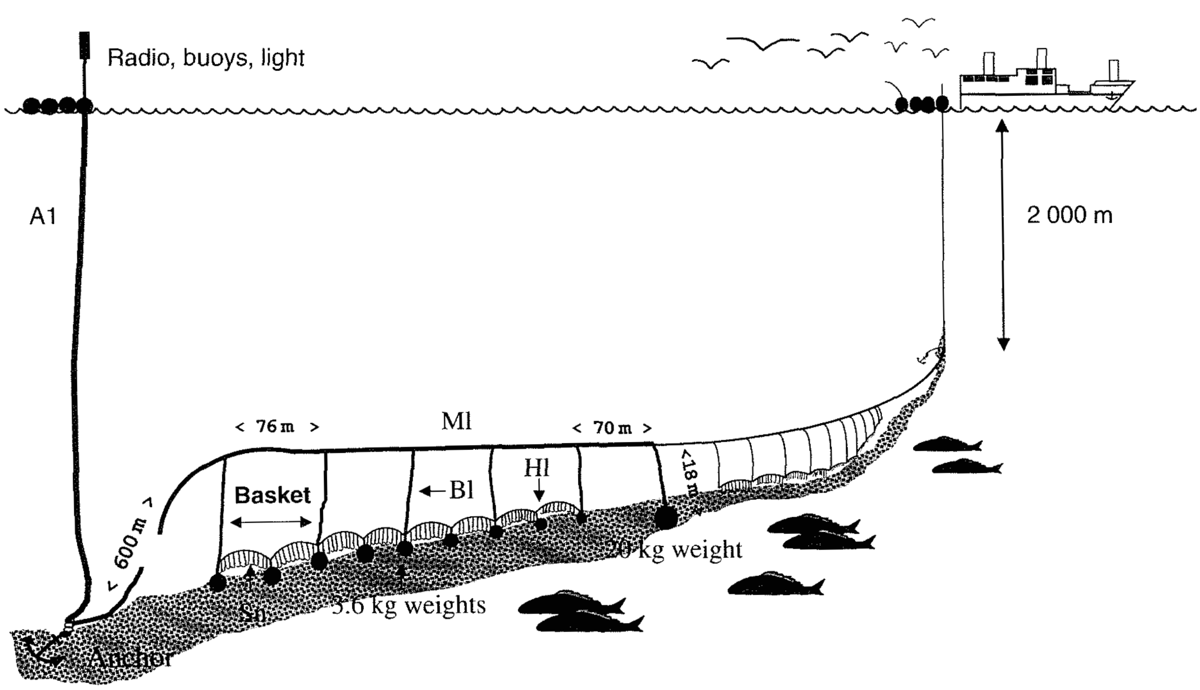

Figure 2: Longline configuration of the *In Sung 66* (Spanish system, double line) used for toothfish fishing. Anchor lines (A1), mother line (M1), branch lines (B1), hook line (H1) and snood lines (Sn) are 20, 18, 9, 5 and 2.5–3 mm in diameter respectively. Baited hooks are deployed in 'baskets', with each basket containing 76 m of hook line and 48 baited hooks.

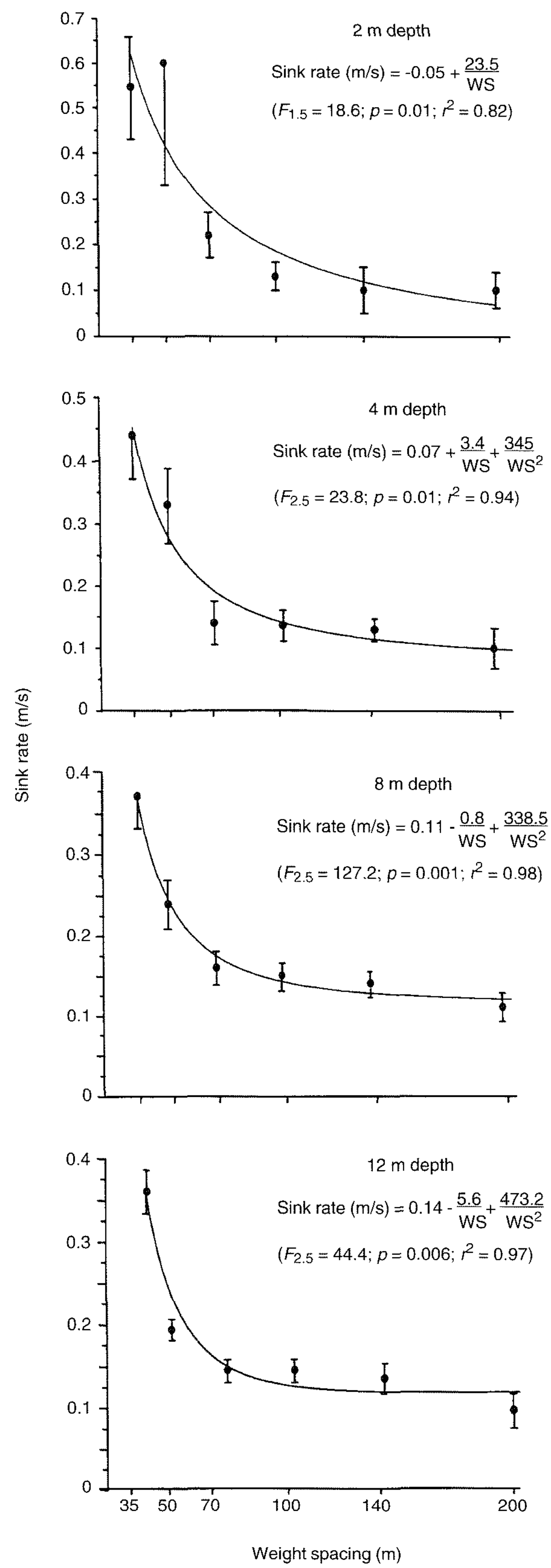

Figure 3: Longline sink rate to depths, shown as a function of weight spacing (WS in metres) on longline set by the *CFL Pioneer*. Results to 2 m depth are provisional (see text). Note differences in increments on 'y' axes. Closed circles indicate means ±1 standard deviation for three dive recorders deployed simultaneously on longlines.

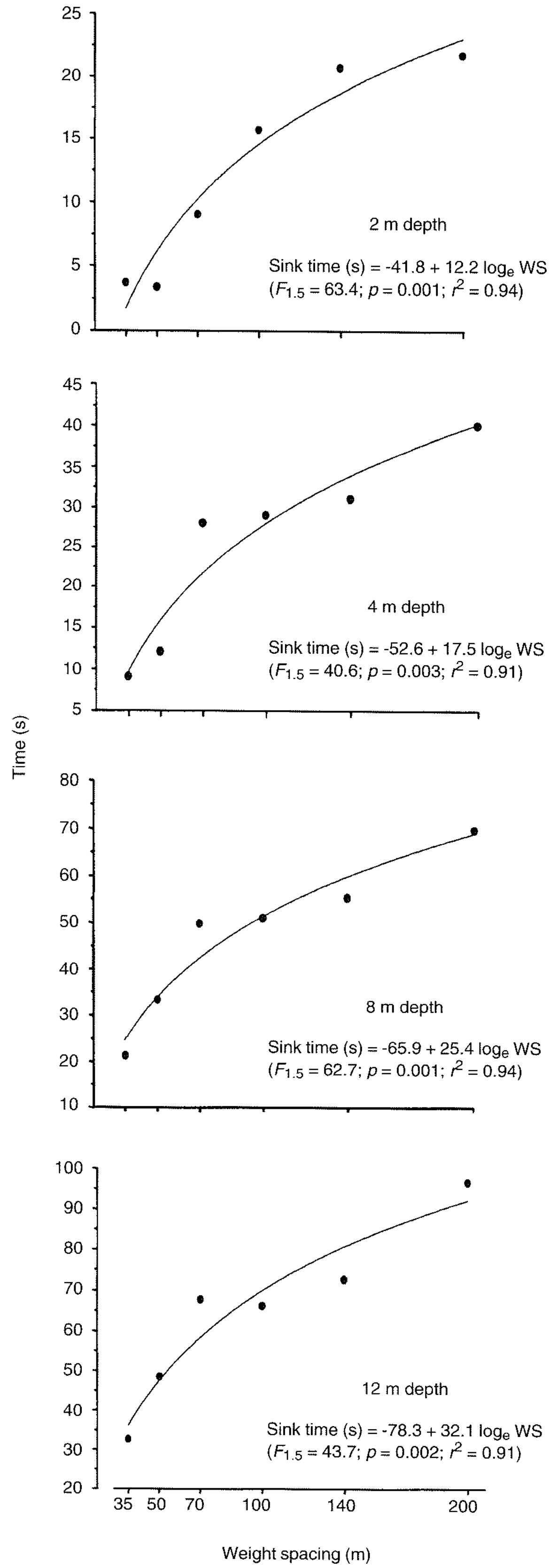

Figure 4: Longline sink time (seconds) to depth, shown as a function of weight spacing (WS in metres) on longline set by the *CFL Pioneer*. Results for 2 m depth are provisional (see text). Note variation in increments on 'y' axes. Closed circles represent means from three dive recorders.

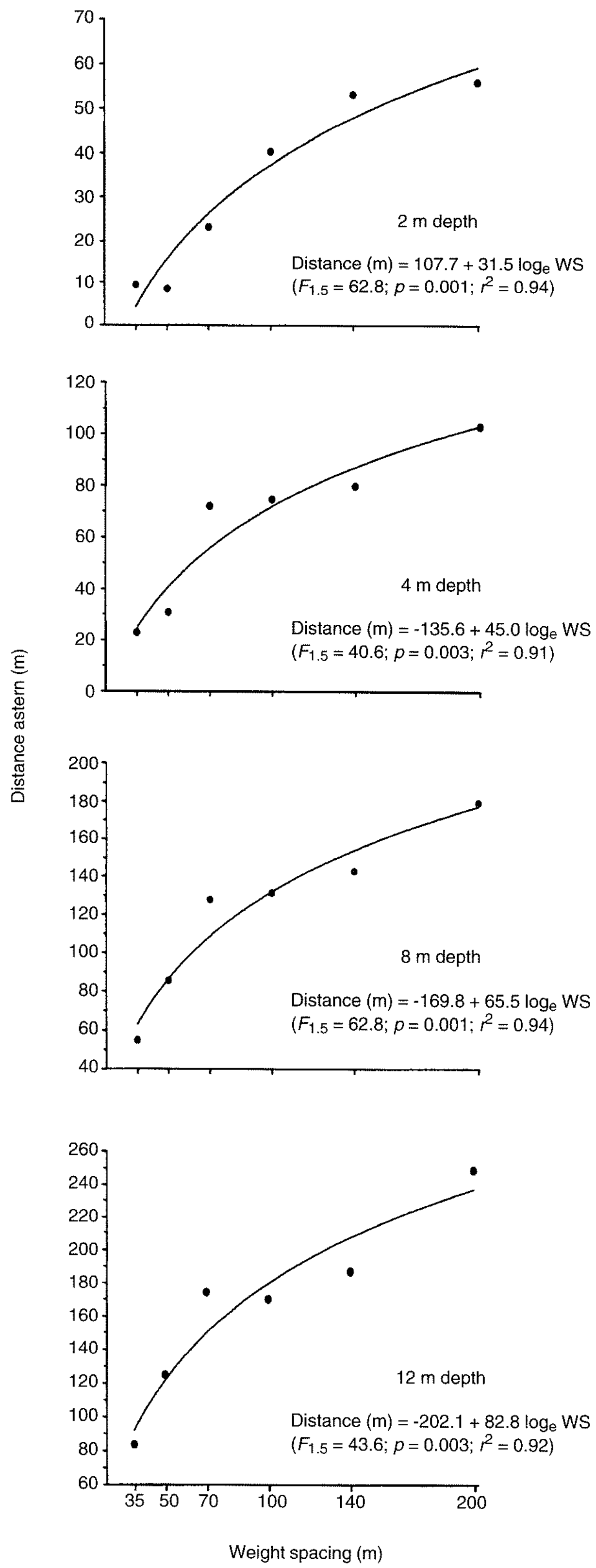

Figure 5: Longline distance astern from water entry point (15 m behind vessel) at depths, shown as a function of weight spacing (WS in metres) on longline set by the *CFL Pioneer*. Results for 2 m depth are provisional. Ship setting speed was 2.572 m/s (5 knots). Closed circles represent means from three dive recorders.

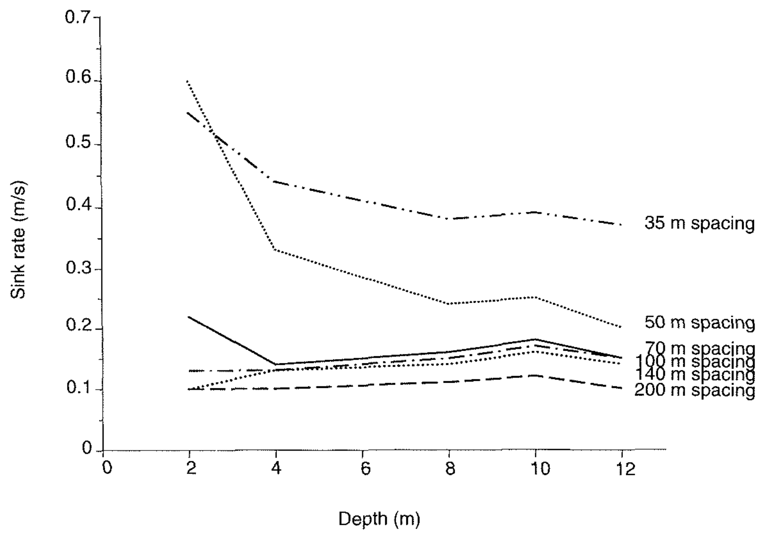

Figure 6: Sink rate to depth, shown as a function of weight spacing on longline. Estimates to 2 m depth may be spurious (see text). Linear interpolation between 4 m depth and 'y' axis indicates sink rates to 2 m depth of about 0.5 m/s and 0.4 m/s for 35 and 50 m weight spacings respectively. Sink rates to this depth for all other weight spacings were 0.1–0.15 m/s.

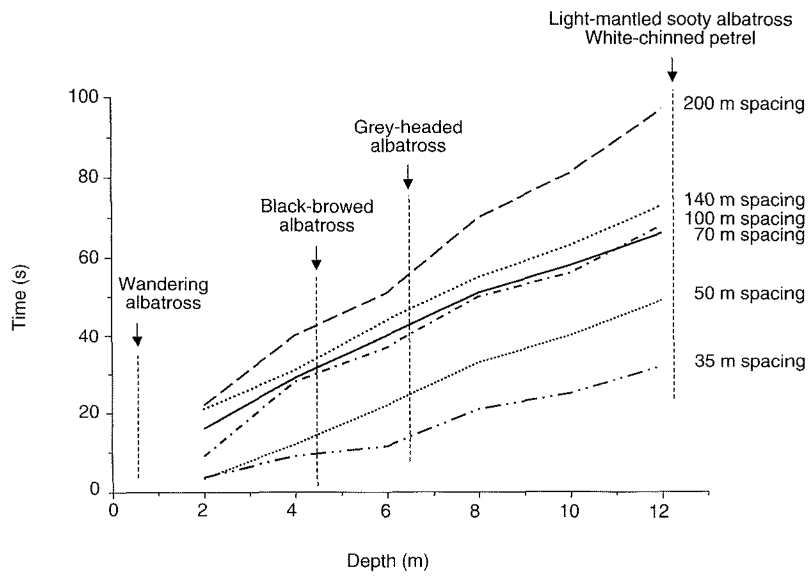

Figure 7: Time for longline to reach depths, shown as a function of weight spacing on longline. Maximum recorded diving depths of the grey-headed albatross, light-mantled sooty albatross and white-chinned petrel are indicated by dotted lines. For given weight spacings, cross reference of seabird diving depth and 'y' axis reveals time available for seabird strike to occur.

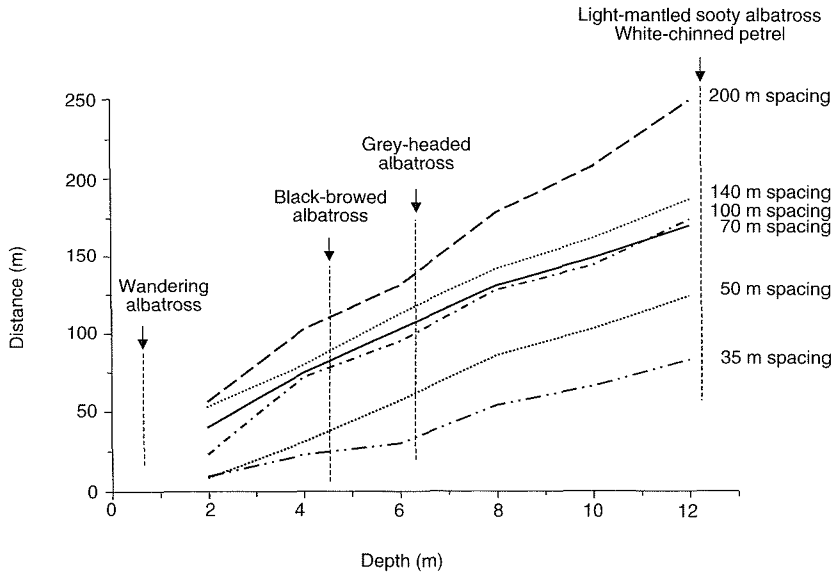

Figure 8: Distance astern at depths, shown as a function of weight spacing on longline. Maximum recorded diving depths of grey-headed albatrosses, light-mantled albatrosses and white-chinned petrels are indicated by dotted lines. For given weight spacings, cross reference of seabird diving depths and 'y' axis reveals distance behind the *CFL Pioneer* baited hooks are 'available' to birds.

Liste des figures

Список рисунков

Обратите внимание на различную шкалу для оси у. Кружками показано среднее ±1 стандартное отклонение для 3 одновременно задействованных на ярусе датчиков.

Рис. 4: Скорость погружения яруса (сек.) на заданную глубину в зависимости от расстояния между грузилами (м); судно *CFL Pioneer*. Результаты для 2 м предварительные (см. текст). Обратите внимание на различную шкалу для оси у. Кружками показано среднее по 3 датчикам.

Рис. 5: Расстояние, на котором ярус погружается на заданную глубину, от точки входа в воду (15 м за судном), в зависимости от расстояния между грузилами (м); судно *CFL Pioneer*. Результаты для 2 м предварительные. Скорость судна при постановке 2.572 м/сек. (5 узлов). Кружками показано среднее по 3 датчикам.

Рис. 6: Скорость погружения (по глубине) в зависимости от расстояния между грузилами. Оценки до глубины 2 м могут быть неправильными (см. текст). Линейная интерполяция между глубиной 4 м и осью у дает скорости погружения на глубину 2 м примерно 0.5 м/сек. и 0.4 м/сек. при интервалах между грузилами соответственно 35 и 50 м. Скорость погружения на эту глубину при всех других интервалах была 0.1–0.15 м/сек.

Рис. 7: Время погружения яруса на заданную глубину в зависимости от расстояния между грузилами. Пунктирные линии показывают максимальную зарегистрированную глубину ныряния сероголового и светлоспинного дымчатого альбатросов и белогорлого буревестника. Значение по оси у, соответствующее точке пересечения пунктирной линии и заданного расстояния между грузилами, показывает время, когда птица может схватить наживку.

Рис. 8: Расстояние за кормой по глубинам, в зависимости от расстояния между грузилами. Пунктирные линии показывают максимальную зарегистрированную глубину ныряния сероголового и светлоспинного дымчатого альбатросов и белогорлого буревестника. Значение по оси у, соответствующее точке пересечения пунктирной линии и заданного расстояния между грузилами, показывает расстояние за кормой *CFL Pioneer*, на котором птица может схватить наживленные крючки.

Lista de las figuras

Figura 1: Configuración de los palangres del *CFL Pioneer* (método automático Mustad (línea simple)) utilizados en la pesca de bacalaos de profundidad. El cable de anclaje (A1), la línea madre (M1) y las brazoladas (Sn) tienen 18, 11,5 y 3 mm de diámetro respectivamente.

Figura 2: Configuración de los palangres del *In Sung 66* (sistema español, línea doble) utilizado en la pesca de bacalaos de profundidad. El cable de anclaje (A1), la línea madre (M1), ramales (B1), línea con anzuelos (H1) y brazoladas (Sn) tienen 20, 18, 9, 5 y 2,5–3 mm de diámetro respectivamente. Los anzuelos cebados se calan en 'canastos', cada uno de los cuales posee una línea de 76 m de largo con 48 anzuelos con carnada.

Figura 3: Tasas de hundimiento de palangres por profundidad, en función de la distancia entre los pesos (WS en metros) en los palangres calados por el *CFL Pioneer*. Los resultados del hundimiento hasta los 2 m de profundidad son provisionales (ver texto). Nótense las diferencias en los incrementos en el eje de las ordenadas 'y'. Los círculos negros muestran el promedio ± una desviación estándar para tres registradores de buceo sumergidos simultáneamente en las líneas de palangre.

Figura 4: Tiempo de hundimiento del palangre (segundos) por la profundidad, en función de la distancia entre los pesos (WS en metros) en los palangres calados por el *CFL Pioneer*. Los resultados del hundimiento hasta los 2 m de profundidad son provisionales (ver texto). Nótense las diferencias en los incrementos en el eje de las ordenadas 'y'. Los círculos negros muestran el promedio de tres registradores de buceo.

Figura 5: Distancia desde la popa al punto de entrada del palangre en el agua (15 m detrás del barco) por la profundidad, en función de la distancia entre los pesos (WS en metros) en los palangres calados por el *CFL Pioneer*. Los resultados del hundimiento hasta los 2 m de profundidad son provisionales. La velocidad de calado del barco fue de 2,572 m/s (5 nudos). Los círculos negros muestran el promedio de tres registradores de buceo.

Figura 6: Tasa de hundimiento en función de la profundidad, según la distancia entre los pesos del palangre. Las estimaciones hasta los 2 m de profundidad pueden ser falsas (ver texto). La interpolación lineal entre los 4 m de profundidad y el eje 'y' indica tasas de hundimiento hasta los 2 m de profundidad cercanas a 0,5 m/s y 0,4 m/s para distancias de 35 y 50 m entre los pesos respectivamente. Las tasas de hundimiento a esta profundidad para las demás distancias entre pesos fueron de 0,1–0,15 m/s.

Figura 7: Tiempo de hundimiento del palangre hasta distintas profundidades según la distancia entre pesos del palangre. Las líneas punteadas indican las profundidades de buceo máximas registradas para el albatros de cabeza gris, el albatros oscuro de manto claro y el petrel de mentón blanco. Para una distancia determinada entre los pesos, la referencia cruzada entre la profundidad de buceo de las aves marinas y el eje 'y' muestra el tiempo que disponen las aves para apoderarse de la carnada.

Figura 8: Distancia desde popa en función de la profundidad, ilustrada en función de la distancia entre los pesos del palangre. Las líneas punteadas indican las profundidades de buceo máximas registradas para el albatros de cabeza gris, el albatros oscuro de manto claro y el petrel de mentón blanco. Para una distancia determinada entre los pesos, la referencia cruzada entre la profundidad de buceo de las aves marinas y el eje 'y' muestra la distancia desde el *CFL Pioneer* a la que los anzuelos cebados están 'disponibles' para las aves.

APPENDIX 1

LINE WEIGHT AND WEIGHTS ON THE LINE

FV *CFL PIONEER*

The mother line on the *CFL Pioneer* was a 11.5 mm Fiskevegn swiveline made from a mix of polypropylene and polyester, coated with tar to protect the line from abrasion on the seabed and to improve coiling ability. The specific weight of the line was 1.10 and the line weighed 12.65 kg/100 m including swivels (22.5 g in water) and tar (1.07 kg/100 m land weight). Hooks weighed 5.18 g and bait weighed 50 g.

The weight of the longline during the set has an important bearing on line sink rate and whether or not seabirds will be caught. The crew of the *CFL Pioneer* attached 6.5 kg weights to the line, initially at 140 m spacings (i.e. 12 weights/magazine) and later (following the capture of birds) at 70 m spacings every second set of 140 m spacings (i.e. 16 weights/magazine). In a standard set of eight magazines (10 800 hooks) with 12 weights/magazine, the *CFL Pioneer* deployed about 3 050 kg dry weight of gear. This comprised 728 kg of anchor lines, 1 640 kg of mother line and swivels, 55 kg of hooks and 624 kg of line weights. With 16 weights/magazine the fishing gear would weigh 3 254 kg, line weights being 26% of this total. During a haul from 2 000 m depth the dry weight of the gear being hauled would be about 390 kg; line weights would be 33% of this weight. To this must be added the pull on the mother line of the current, the effect of fouling on the seabed and the weight of the fish catch (dry weight may exceed 1 tonne). Breakages of the 2 000 kg breaking strain line were common.

FV *IN SUNG 66*

The lines used by the *In Sung 66* were polypropylene. The anchor line, mother line, branch line and hook line weighed 18.2, 14.77, 3.77 and 1.1 kg/100 m respectively. All lines were buoyant, having a specific gravity of 0.91. Swivels used to attach snoods to the hook line weighed 5.5 g and had a specific gravity of 7.1. Hooks weighed 6.3 g and had a specific weight of 7.8. With the complicated structure of the line, the number of weights on the hook line, the large weights on the mother line and the amount of rope involved, for the *In Sung 66* to shoot the same number of hooks (10 800) as in a standard set for the *CFL Pioneer*, about 5 430 kg dry weight of gear would be deployed, about 40% more than the *CFL Pioneer*. This would comprise 728 kg of anchor ropes, 2 390 kg of mother line, 146 kg of branch line, 178 kg of hook line, 68 kg of hooks, 59 kg of swivels, 200 kg of mother line weights and 1 440 kg of hook line weights. The dry weight of the non-rope components (weights, hooks and swivels) amounts to about 1 770 kg, or about 32% of total gear weight (about the same as for the *CFL Pioneer*). All ropes used by the *In Sung 66* were buoyant and would have floated without the attachment of weights (3.6 kg), which were placed 38 m apart on the hook line. During a haul from 2 000 m depth the dry weight of the line used by the *In Sung 66* would be about 540 kg, but the non-buoyant components would be only about 205 kg (about half that of the *CFL Pioneer*). The line weights would constitute about 90% of the weight of these non-buoyant components.