Longline sink rates of an autoline vessel, and notes on seabird interactions

SCIENCE FOR CONSERVATION 183

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Published by
Department of Conservation
P.O. Box 10-420
Wellington, New Zealand

Science for Conservation presents the results of investigations by DOC staff, and by contracted science providers outside the Department of Conservation. Publications in this series are internally and externally peer reviewed.

ISSN 1173-2946
ISBN 0-478-22154-1

This report was prepared for publication by DOC Science Publishing, Science & Research Unit; editing by Lynette Clelland and layout by Ian Mackenzie. Publication was approved by the Manager, Science & Research Unit, Science Technology and Information Services, Department of Conservation, Wellington.

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ABSTRACT

A series of longline sink-rate trials were conducted with and without weights, from an autoline fishing vessel working the New Zealand ling (*Genypterus blacodes*) longline fishery on the Chatham Rise, New Zealand during July and August 1998. The autoline equipment is designed to sink without weights, and non-weighted longline line sink data were collected first to provide baseline information. Further trials were conducted with weights added to the longline as in normal fishing operations. A robust attachment method for Time Depth Recorders was developed. A tori line was used at all times by the vessel, and the design was refined during the voyage. The aerial section of the tori line appeared to provide an effective deterrent to most seabirds. Statistical analyses of the data from the line sink rate trials indicate that the weighting regimes used (5 kg per 400 m) had no effect on line sink rate. However, direct observations at sea indicated that weights did have an effect on line sink for 20–40 m either side of the attached weights. Data on line sink rate and tori line coverage suggest that quicker line sink rates could help decrease the incidental mortality of seabirds during autoline fishing. Seabird incidental mortality rate for the voyage was 0.0093 seabirds per 1000 hooks set. Grey petrels (*Procellaria cinerea*) accounted for 90% of the observed incidental catch; of which 90% were foul hooked rather than having swallowed a baited hook. Fourteen species of large seabird and 5 species of small seabird were observed interacting with the vessel. The seabird community constantly changed in size, species composition, and relative proportion of each species present. A large proportion of the seabirds present at any one time were Cape pigeons (*Daption capense*). Seabird behaviour about the vessel varied with fishing activity. Four distinct community behaviours were noted: set behaviour, haul behaviour, steaming (no offal) behaviour, and steaming (offal) behaviour. A night vision scope was trialed and found to be of limited benefit because of ineffective range, and the mono-colour vision.

Keywords: longline, sink rates, seabirds, tori line, ling, *Genypterus blacodes*, albatross, petrels, bycatch, Chatham Rise, New Zealand

This paper may be cited as:

Smith, N.W.McL. 2001. Longline sink rates of an autoline vessel, and notes on seabird interactions. *Science for Conservation 183*. 32 p.

1. Introduction

Seabirds are known to interact with bottom autoline fishing vessels during all phases of fishing operations (Temple 1997; Palmer 1998). The effect of interactions can be benign, beneficial, or undesirable for both the seabirds and the vessel. Positive interactions include a food source for the seabirds (Thompson 1992; Sagar et al. 1999; James & Stahl 2000) and aesthetics for the crew, whilst negatives include incidental seabird mortality and lost fishing opportunity for the vessel. Observations of seabird interactions with a ling longline vessel were made during a 47-day voyage in winter 1998. Most of the voyage occurred on the Chatham Rise, approximately 200 nautical miles off the East Coast of central southern New Zealand (Fig. 1).

1.1 IMPORTANCE OF LINE SINK RATE AND SEABIRD BEHAVIOUR STUDIES

The time that seabirds are exposed to risk of capture on longlines during setting is crucial in both designing and determining the effectiveness of methods to mitigate incidental capture. Two types of information are needed to determine the duration of seabird access to longlines during setting. One is the diving and foraging behaviour of various species of seabird. This information allows the determination of desirable gear performance parameters for avoiding incidental seabird capture. The other information required is longline sink rate. This data allows us to determine the length of time that baited hooks remain accessible to seabirds. With analysis of both data sets we can determine the changes in gear performance that may be required to mitigate incidental seabird mortality.

The recent literature on seabirds suggests that albatrosses, such as light-mantled sooty albatross (*Phoebetria palpebrata*), black-browed albatross (*Thalassarche melanophrys*), and grey-headed albatross (*T. cauta*), dive regularly to depths of 5 m or more (Prince et al. 1994; Hedd et al. 1997). The petrel species, such as white-chinned petrel (*Procellaria aequinoctialis*) and sooty shearwater (*Puffinus griseus*) may regularly dive to 20 m and deeper (Huin 1994; Weimerskirch & Sagar 1996). However, observations at sea of the depths to which seabirds will go to reach baits is less well-documented, and usually qualitative.

Measuring line sink rate is a relatively new area of research, with projects in progress in the Japanese pelagic longline fishery (Satani & Uozumi 1998) and the New Zealand pelagic longline fishery (O'Toole & Molloy 2000). Projects underway in Australia are considering both the pelagic longline and bottom autoline fisheries (N. Brothers, Tasmanian Parks & Wildlife pers. comm.). Preliminary trials are also occurring in the toothfish fishery south of the Falkland Islands (G. Robertson, Australian Antarctic Division pers. comm.) and in the North Atlantic (Lokkeborg 1998). In fisheries such as bottom lining, where the snood[1] is short, the emphasis is on the sink rate of the main line, whereas in

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[1] Snood—the line that branches off the backbone (mainline) of a longline and has a hook at the terminal end (see detail on Fig. 3).

Figure 1. Map of New Zealand, showing location of the study area on the Chatham Rise.

fisheries such as pelagic tuna longlining (which uses very long snoods), more emphasis is placed on hook/snood sink rate.

Knowledge of line sink rate and the diving behaviour of seabirds also help us to assess the theoretical effectiveness of tori[2] lines. From the sink rate data we can determine if the longline has sunk below the maximum depth a seabird can dive, by the end of the aerial section of the tori line. Here, in theory, the longline should be inaccessible to the seabird. Vessel speed, the exact dimensions of the tori line, and knowledge of the effectiveness of the tori line on each species are also needed to make such assessments. In theory, faster line sink rates should decrease the probability of incidental seabird capture.

1.2 THE VESSEL, SETTING, AND HAULING

The trials were undertaken on a 37.5 m purpose-built autoliner. The vessel, fitted with Mustad[3] autoline equipment, and carrying a crew of 22, operated around the clock. Between 26 000 and 30 000 hooks are set per day at a setting speed of 6–6.5 knots. The target species during the voyage, and historically for the vessel, was ling (*Genypterus blacodes*)[4].

The longline is set from the stern, with the setting door offset to starboard. The setting door is approximately 2.5 m above sea level. The baiting machine, a Mustad Autobaiter Type D Mk II, is located directly forward of the setting door. Magazines[5] containing the longline connect directly to the autobaiter. During setting of the longline, the vessel steams at 6–6.5 knots along the desired course for placement of the longline allowing for any tidal or current drift. This course generally follows ocean floor topographic features and is independent of sea conditions in all but foul weather.

Line setting starts from the hauling room where a marker flag float and two 1 m diameter windy buoys are thrown overboard. These are attached to a downline, the length of which is determined by the depth being fished and local currents. At the end of the downline the line forks: one branch leading to a 40 kg grapnel on a short leader; the other branch (the shotline) runs along the outside of the vessel from the hauling room to the setting door at the stern. The shot line is approximately 100 m long and connects to the start of the first magazine of the longline (Fig. 2).

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[2] Tori line—or bird line, is a seabird-scaring device commonly used in longline fisheries (Brothers et al. 1999) towed behind the vessel, above the longline during setting. It is designed to keep seabirds away from the area where the danger from baited hooks, accessible to seabirds, is greatest.

[3] Mustad—a Norwegian company, is the principal manufacturer of autoline machinery and large system components for autolining. They are one of several manufacturers of actual lines, snoods, and hooks.

[4] Ling—A commercially valuable teleost with exports currently worth in excess of NZ$75 million per annum (www.seafood.co.nz).

[5] Magazine—the item of equipment, an extruded aluminum rack, used to store approximately equal length sections of a longline on an autoliner. Often used as a gross unit for measuring autoline longline length.

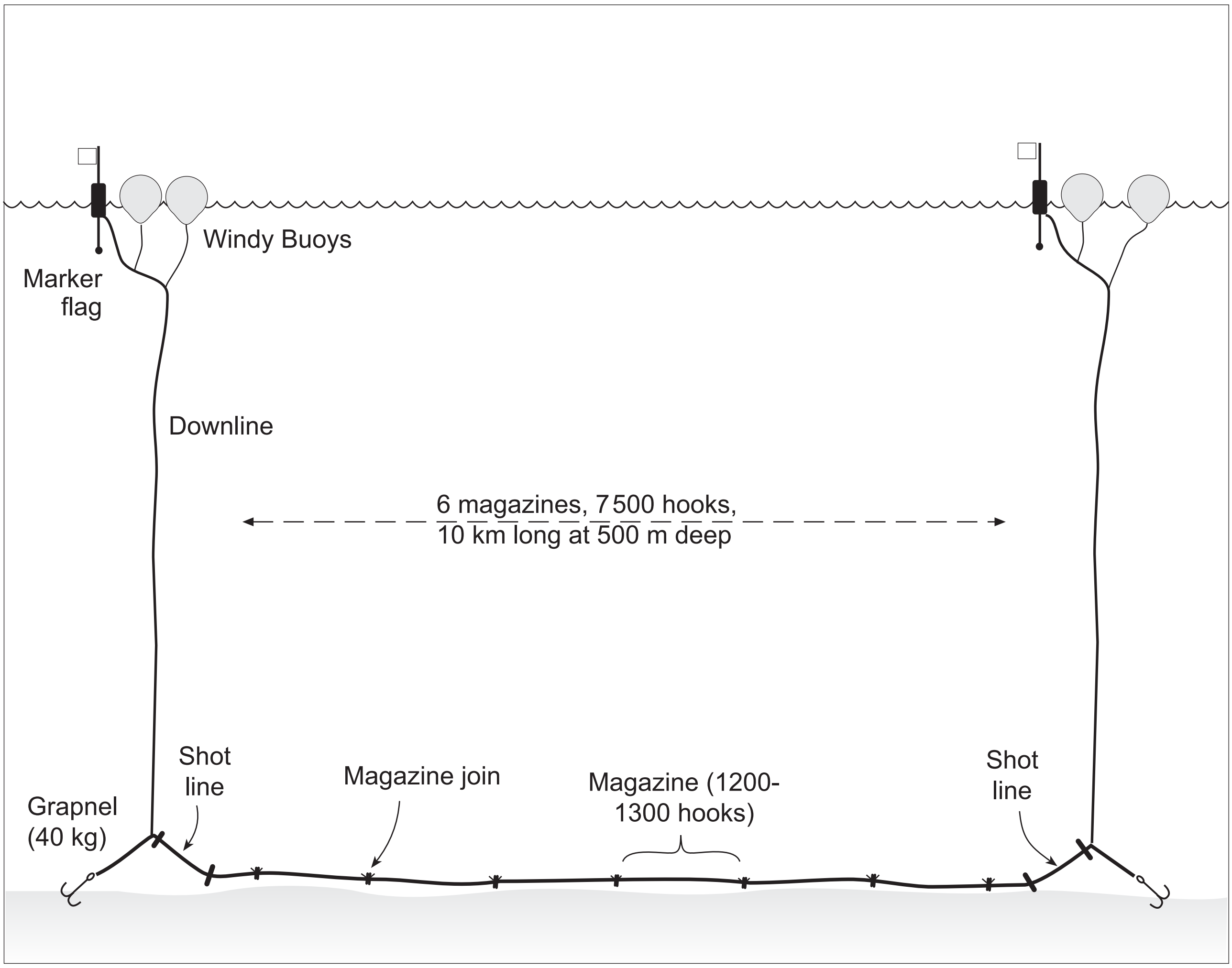

Figure 2. Diagram of a typical demersal longline.

The longline is pulled out of the vessel by a combination of the forward motion of the vessel and the drag created by the gear already in the water. Hooks pass through the baiting machine and are automatically baited as they leave the vessel. Magazines are joined in sequence to create the desired length of longline. The typical line on the observed voyage consisted of six magazines; approximately 7500 hooks, and was about 10 km long (Fig. 2).

Weights or floats may be attached to the longline at various intervals along the line during setting to improve the fishing ability of the line, or to mitigate incidental capture of seabirds. Weights and floats are placed in a metal chute above and to the starboard of the baiting machine. They are clipped to the backbone at the desired attachment point, and pulled out of the vessel as the longline feeds out.

The line is hauled from the same deck of the vessel as set from, but well forward on the starboard side. During hauling, the vessel steams at 1–2 knots and the longline is hauled as close to vertical from the seabed as possible. The gear is fed automatically back to the hook room at the stern of the vessel, where it is hung back on magazines and repaired by the crew for the next set.

1.3 FISHING GEAR DESCRIPTION

The longline used was 9 mm diameter tarred polyester backbone with snoods spaced every 1300 mm. Stoppers either side of an 18 mm gap create the snood attachment point (Fig. 3). A metal plate with an attached swivel is pressed around the mainline in this gap. This swivel and plate combination creates an attachment point for the snood that can swivel 360° around the mainline, as well as 360° about the swivel. The snood, constructed from light blue nylon braid (18 gauge), is 400 mm long. Mustad Ezibait 12/0 hooks were used throughout the voyage (Fig. 3).

The longline is supplied to the vessel in hanks (270 m of backbone) with parts of hanks being added to old longline magazines to replace damaged or lost sections, or, several hanks being combined to create a new magazine (1200–1300 hooks on 1560–1690 m of backbone). The longline is hung on magazines (24 onboard) in magazine racks in the hook room.

The 9 mm diameter tarred polyester backbone has a specific gravity of 1.4. One magazine of longline weighs approximately 157 kg dry, or 9.8 kg per 100 m (K. Schimanski, Sanford Ltd pers. comm.).

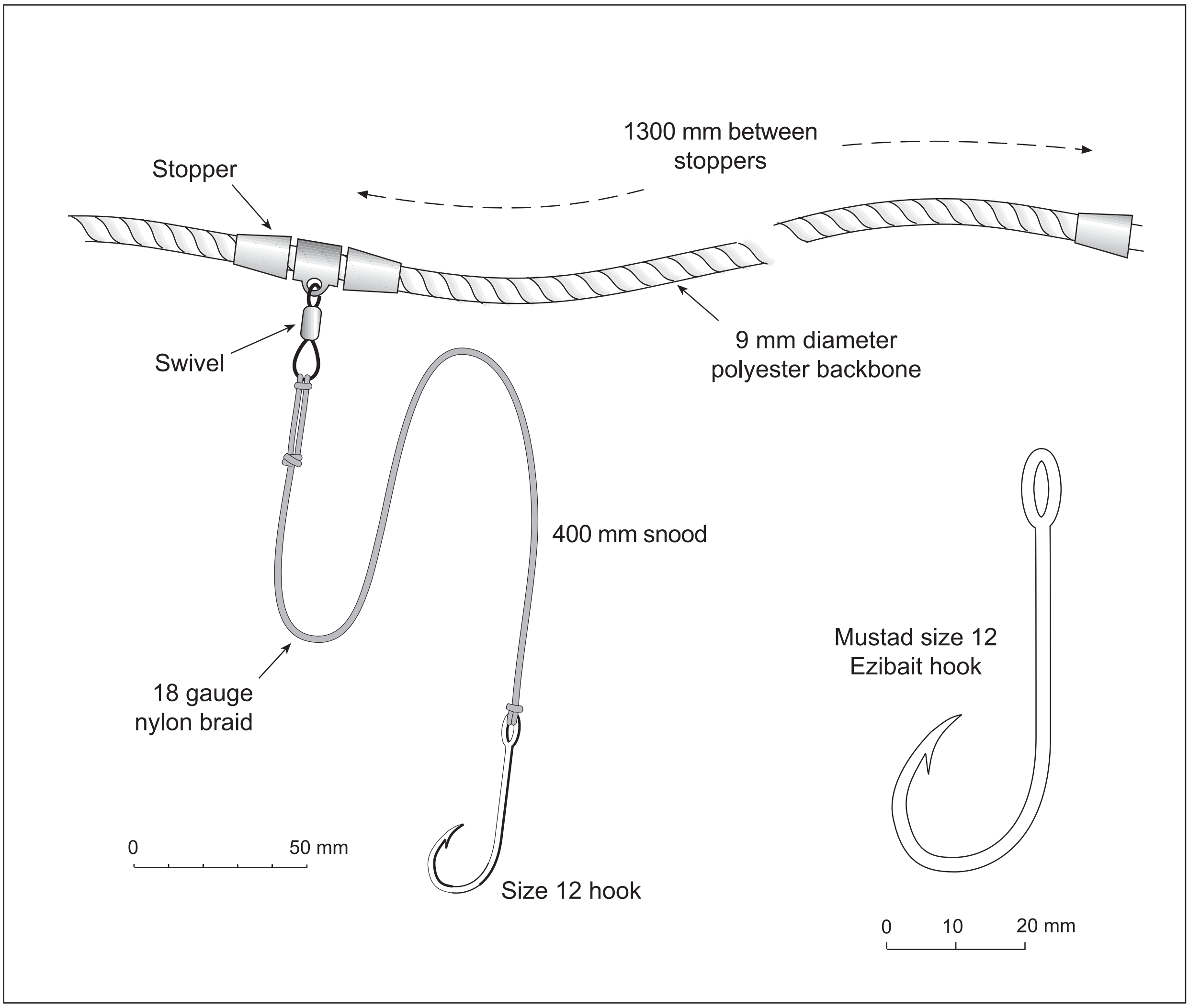

Figure 3. Detail of a section of autoline longline gear.

1.4 TORI LINE DESCRIPTION

The vessel used a tori line at all times during setting (Fig. 4). The line used during these observations was developed at an early stage of the voyage from the vessel's historic tori line design. It incorporated the CCAMLR recommendations, as detailed in the appendix to CCAMLR Conservation Measure 29/XVI (CCAMLR 1997). Further modifications were also made to improve performance, based on observations made by the Captain of the vessel and the author during the voyage.

The tori line was suspended from a point 7 m above the water (CCAMLR recommends a 4.5 m minimum). The vessel used an attachment system that allowed the tori line to be set directly above the longline in any weather condition (Fig. 4C and 4D). The position of the tori line was usually altered to starboard by letting extra line off the drum or sometimes by shortening the bridle. The tori line used a 6 mm nylon rope backbone (CCAMLR

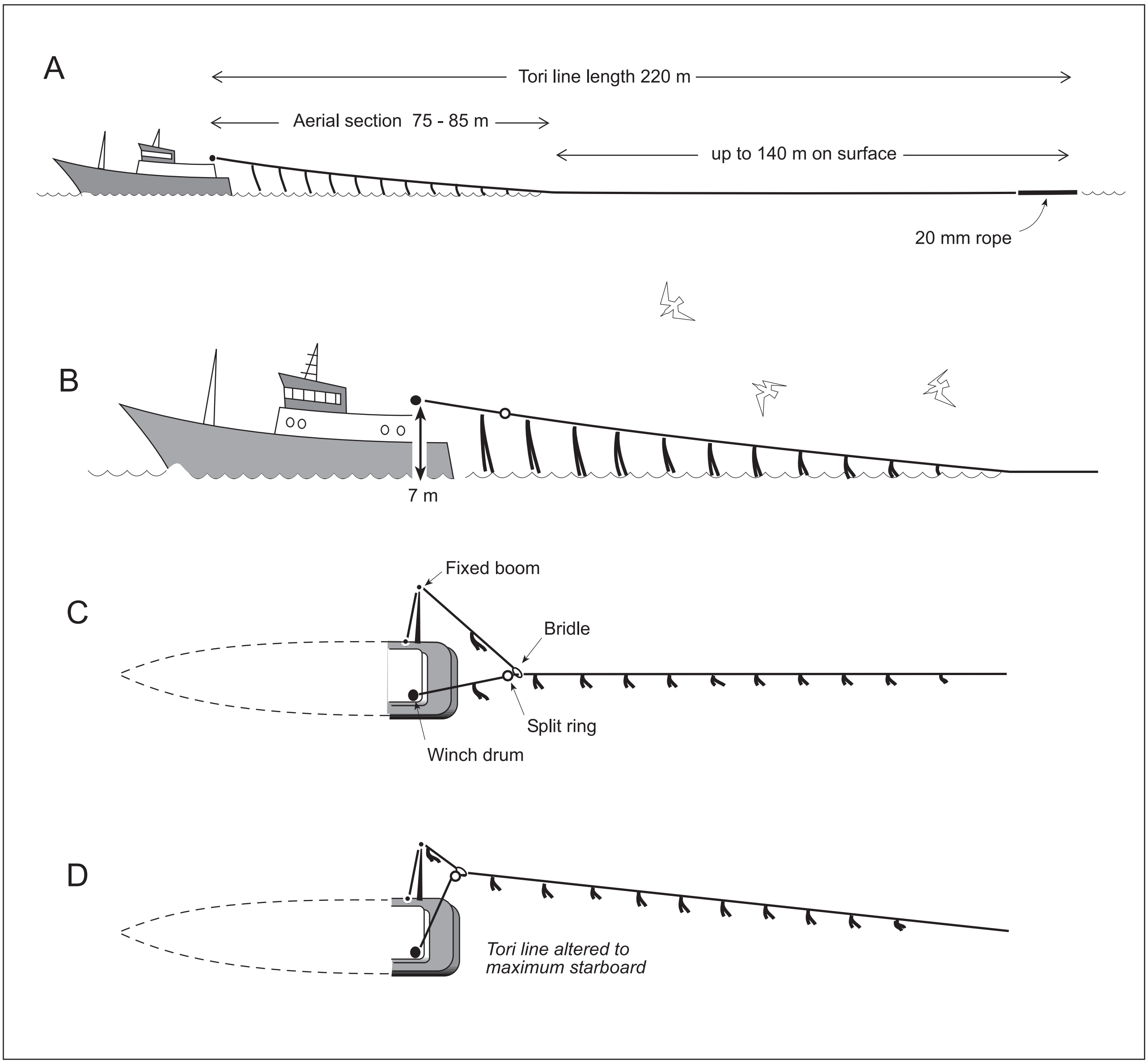

Figure 4. Tori line as used during a voyage. A—fully deployed; B—aerial section with streamers; C—plan view of stern attachment; D—altered to maximum starboard.

recommendation is 3 mm), 220 m long in total (CCAMLR minimum 150 m), with an aerial section of 75–85 m (Fig. 4B).

Eleven paired removable red streamers were attached in the aerial section of the tori line (CCAMLR recommends five paired streamers). The streamers varied in length from 4 m to 0.3 m and all just touched the water. The streamers were constructed from 3 mm sekiyama[6] with 5 mm red polyurethane tubing slipped over the top (Fig. 5). The tori line had a 2 m-long section of 20 mm rope attached at the terminal end to create extra line tension (see Fig. 4A).

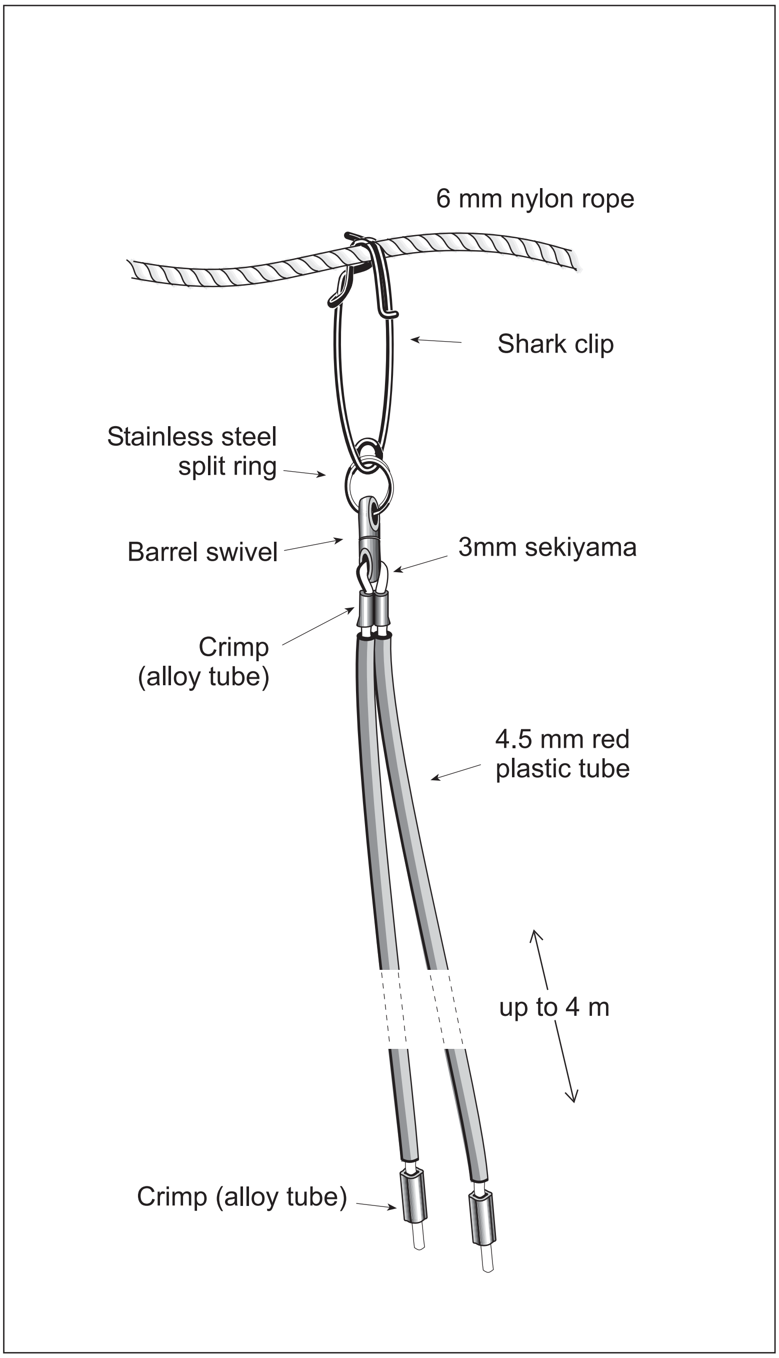

Figure 5. The details of a tori line streamer, as used during the voyage.

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[6] Sekiyama—a multi braid nylon line used extensively in the Japanese pelagic longline fleet.

2. Methods

Because the vessel's fishing pattern was dependent on the fishing environment (weather, moon phase, exploration, bottom structure), the planning of structured trials with replication was difficult.

2.1 TIME DEPTH RECORDERS

Time Depth Recorders[7] (TDRs), archival data logging devices, were used to measure line sink in these trials. The TDRs used operate to 1000 m, weigh 12 g in water, and measure 95 mm long, 17 mm deep, and 24 mm wide. The TDR has a depth sensor, a temperature sensor and light intensity cell. Two external contacts create a circuit when the TDR is immersed in seawater. An external socket, with Teflon plug, allows rapid download of archived data to a personal computer (PC) in hexadecimal format.

2.2 LINE WEIGHTING TRIAL

The loss of a Time Depth Recorder (TDR) early in the voyage resulted in changing the TDR attachment method from a sharkclip attachment (as was used for streamers in Fig. 5) to that described below.

The three TDRs used during the rest of the trials were cable tied, whipped (with a thin nylon cord) and then taped (with insulation tape) to a 500 mm length of 8 mm rope for the duration of the voyage. An eye splice at one end of this rope allowed rapid attachment to the longline. The open end of the rope was passed around the longline and back through the eye for deployment (Fig. 6).

Prior to the voyage, all TDRs were checked for accuracy of depth recording, time keeping, and performance for extended periods at low temperatures. Calibration tests in Wellington Harbour checked TDR recorded and logged depth against known depth as measured physically by weighted rope. TDRs were refrigerated in water for 24 hours to assess performance in cold water. During both tests the internal TDR clock was checked against a digital watch for accuracy to one-second intervals.

Before deployment at sea, each TDR was activated (memory cleared and set to data logging mode) using the manufacturer-supplied software. After activation, the TDR was placed in a bucket of ambient-temperature seawater (obtained from deck hoses taking water directly from the surrounding ocean) to soak until deployment. This soak period lasted at least 30 minutes and allowed the temperature-sensitive TDR depth sensors to settle and record a steady depth, the 'zero depth equivalent'.

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[7] Mk7 Model Time Depth Recorders—purchased from Wildlife Computers, Redmond, WA, USA.

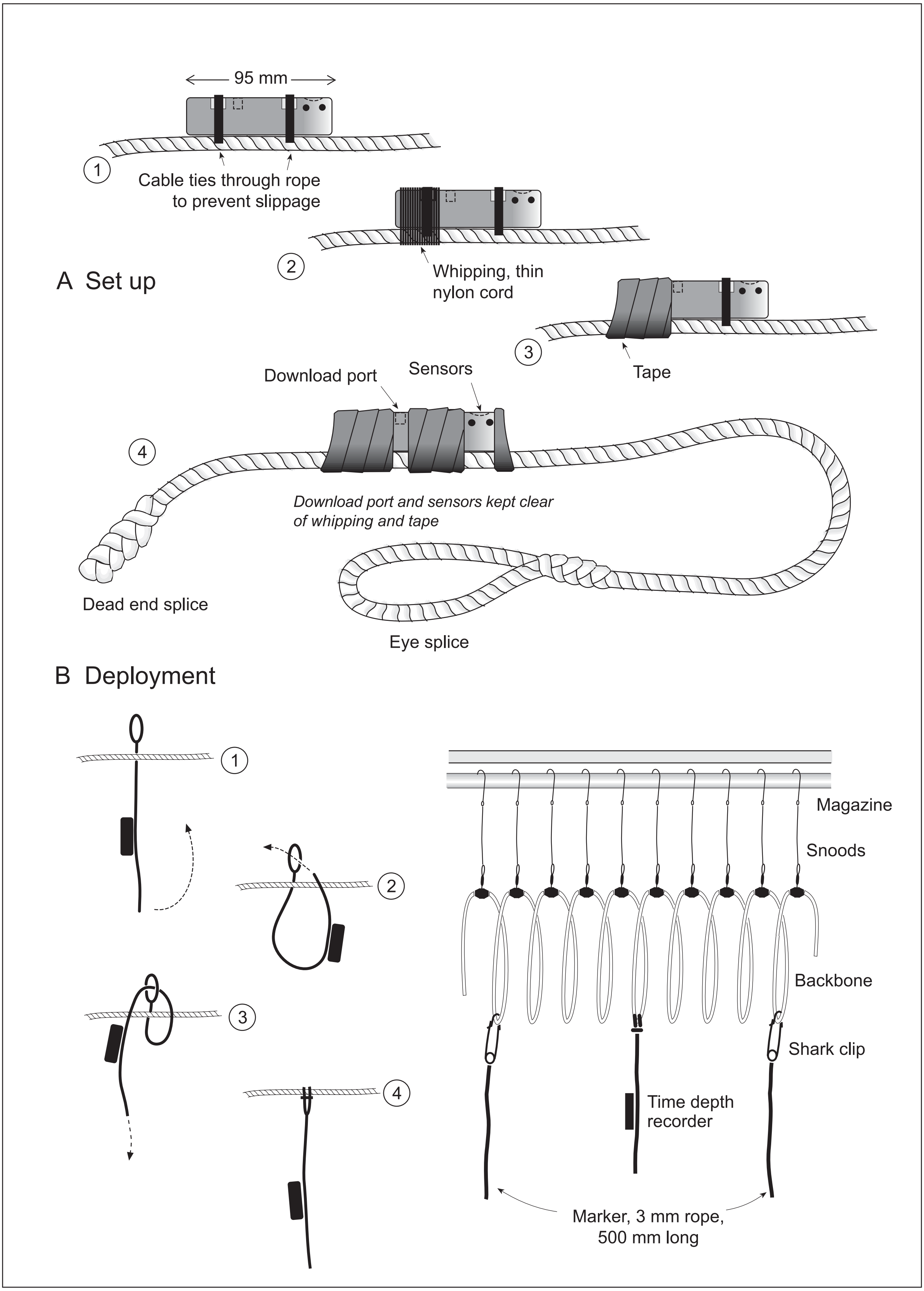


Figure 6. Time Depth Recorder: A—as set up; and B—as deployed on the longline.

The TDR was removed from the bucket and held by the free 'tail' (Fig. 6) by the author or a crewmember for the 15–30 seconds immediately before leaving the vessel. The TDR did not cause entanglement when pulled through the autobaiter, as it had no hook attached. A rope marker was attached to the line 5–10 hooks either side of the TDR to remind crew of the approach of a TDR during hauling (Fig. 6). Dual markers were necessary because the vessel hauled the line from either end. Time of TDR entry to the water was recorded.

After the TDR was retrieved from the hauled line the logged data were downloaded onto a PC hard drive with a back-up copy made on floppy disc.

2.3 SAMPLING POSITIONS ON THE LINE

As different parts of the longline may sink at different rates, the line was divided into five representative sampling positions (Fig. 7). The first sampling position was near the first hooks (S), the second near the first magazine join (S+), the third in the middle of the line (M), the fourth at the last magazine join (E–), and the fifth

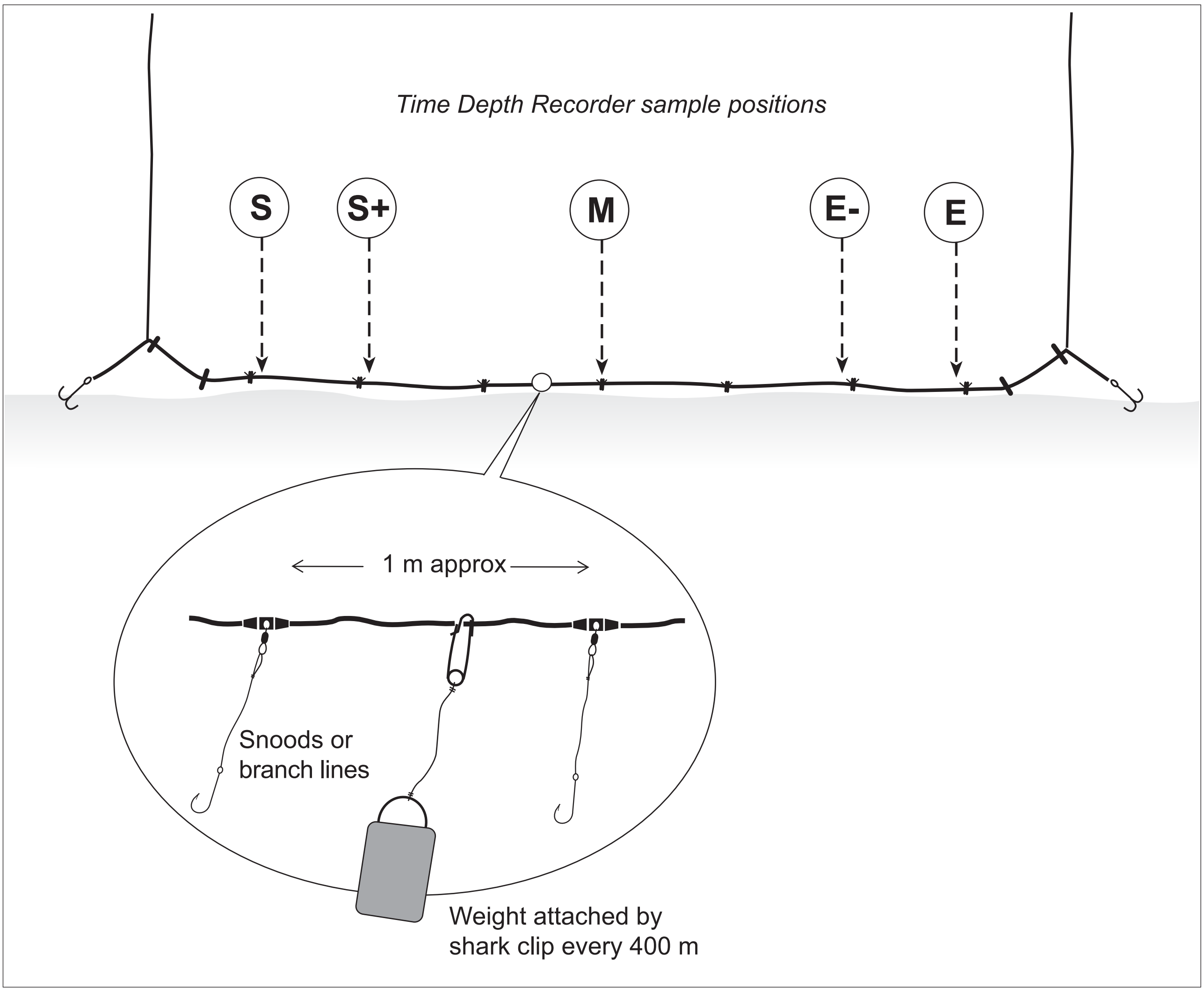


Figure 7. Sampling positions on the longline.

near the last hooks on the line (E). The sample points were approximately 1600–3200 m apart. The sample positions were chosen to help develop a model of how this type of longline sinks. With only three TDRs available and five sample positions on the line, sample positions of the TDRs for each set were selected randomly. To ensure random equal coverage of all sample positions on the longline, a pre-calculated matrix detailing the sequence of TDR attachment at each sample point was developed using random tables from Snedecor & Cochran (1967).

2.4 UNWEIGHTED LINE TRIALS

During the unweighted line trials no extra weight, other than the grapnel at each end of the line and the integral weight of the line (9.8 kg per 100 m for this gear) was used. This represented most normal fishing effort. Eleven replicates at each of the five sample positions were undertaken in this phase of the trials.

2.5 WEIGHTED LINE TRIALS

The spacing between weights and the quantity of weights used for the trials were determined by the vessel's standard operating practice. Weighting the line was used to fish with the longline hard on the bottom, or as an attempt to mitigate seabird incidental mortality (as determined by discussions with the Captain and crew of the vessel).

Four mild steel weights per magazine, approximately 400 m apart, were attached by a sharkclip to the longline for the weighted line trials (Fig. 7). Three replicates at each of the five sample positions were undertaken with 2.5 kg weights, and three or six replicates with 5 kg weights. TDRs were always placed at the greatest possible distance from an added weight (200 m at mid-line sample positions and 400 m at start and end of line sample positions).

2.6 DATA GROOMING

Data logged by the TDRs were downloaded after every set. As the depth sensor in the TDR is sensitive to temperature, data grooming involved determining the sea level zero depth equivalent for each TDR every time it was used. This was achieved by calibrating the readings obtained during deployment with readings taken during the pre-deployment soak, thus determining a correction factor for sea level. Once a correction factor was established, the first three minutes of continuous data were selected based on the timed start of the deployment, sea level corrected (with the deployment specific correction factor) and converted to produce a standard computer format line sink profile.

2.7 LINE SINK RATE

Sink rate was determined from the surface to a specified depth (usually 5 m, 10 m, 15 m, or 20 m). Line sink rate was determined by dividing depth (metres) by time to depth (seconds), to give a sink rate in metres per second. Means and associated measures of variance were calculated for the time the longline took to reach 5 m, 10 m, 15 m, and 20 m when unweighted, and when weighted with 2.5 kg weights and 5 kg weights. This was done for each of the five sample positions along the line.

A three-way analysis of variance (trial, position on line, depth) was undertaken using S-Plus©. The analysis was used to test for any change in sink rate caused by the addition of weights to the longline, differing sink rates along the line and differing sink rates at different depths.

2.8 TORI LINE EFFECTIVENESS

The length of aerial tori line coverage of the longline was determined by two methods. At sea, the time taken for a piece of paper to travel from the stern of the vessel to the point where the tori line contacted the water was recorded. These timed trials were conducted throughout the voyage in a wide variety of weather conditions. Distance covered was calculated by multiplying time taken by velocity. The tori line was also measured on dry land at the end of the voyage to verify the data collected at sea.

2.9 SEABIRD OBSERVATIONS

During the voyage, at least 6 hours per day were spent recording the species and numbers of seabirds present and making qualitative notes on seabird behaviours. Counts and behavioural notes were made during both the haul and the set, and whilst the vessel was steaming between fishing grounds.

During sets, seabirds were counted in a theoretical box 250 m either side of the vessel and 500 m astern, an area of 0.25 km^2. The area was delimited by comparison of observed distances to the known length of the tori line. The taxonomy used for albatross follows the suggestion of Robertson & Nunn (1998), with the taxonomy for other seabirds following that given in Onley & Bartle (1999). Video footage was also shot throughout the voyage to provide a reference for the behaviour modes observed.

2.10 NIGHT VISION SCOPE

A night vision scope was trialed early in the voyage for utility in observing setting operations during darkness. Seabird counts were made and attempts to identify species undertaken. Comparative counts were made with the naked eye and on a few occasions with a large searchlight.

3. Results

Pre-voyage equipment trials, at sea experiments and observations were conducted from early July through mid August 1998. Most fishing during the observed voyage occurred on the eastern end of the Chatham Rise (see Fig. 1). A six-magazine set usually took 40–45 minutes to complete, whilst hauling the same length line took 4.5–5 hours. From 75% to 90% of hooks were successfully baited by the autobaiter during setting. Lines were soaked for periods of a few hours through to 36 hours.

3.1 TIME DEPTH RECORDERS

Onshore, prior to the voyage, the TDRs measured depth to within 0.5 m of physically measured depth intervals down to 12 m, functioned normally in cold water for periods of over 24 hours, and kept time within 1 second of a digital watch, set and checked against a time signal. New Zealand National Radio, 567 kHz, broadcasts a time signal hourly.

During the voyage 114 records from TDRs were obtained (see Fig. 8 for typical profiles). Of these, 19 records were not used in the line trial analyses because either floats were added, irregular weighting regimes were applied, or there were extreme variations in the number of magazines used for the set.

Line jerk (caused by hooks jamming in the autobaiter) also caused the line sink to arrest temporarily at times, as seen in Fig. 8B at approximately 7 m depth.

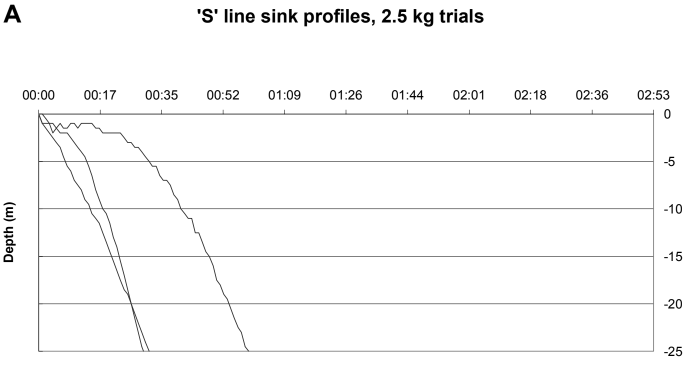
3.2 UNWEIGHTED LINE TRIALS

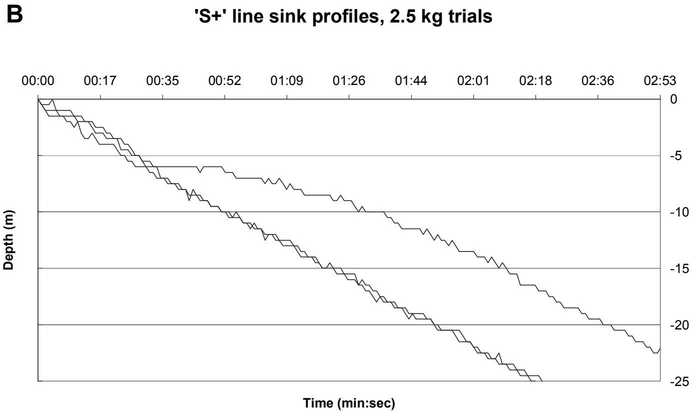
Eleven TDR deployments for each of the five sample positions were completed with unweighted longlines (55 deployments). The mean sink rate varied between 0.15 and 0.19 m/s in the middle of the line (S+, M, E–); between 0.29 and 0.48 m/s at the start of the line (S); and, between 0.18 and 0.22 m/s at the end of the line (E). Mean sink rates for the line at 5 m, 10 m, 15 m, and 20 m depths at each of the five sampling position are given in Table 1.

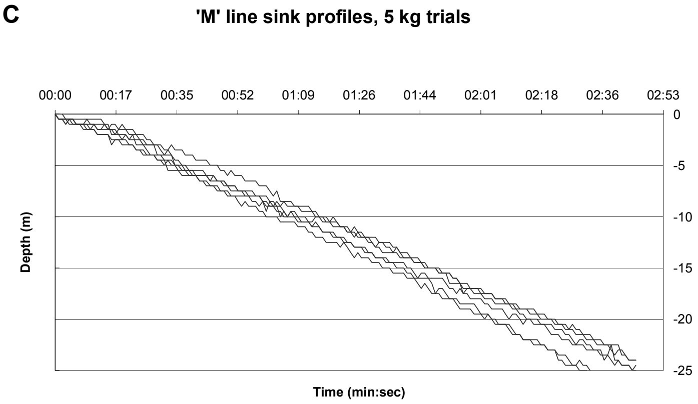
3.3 WEIGHTED LINE TRIALS (2.5 kg)

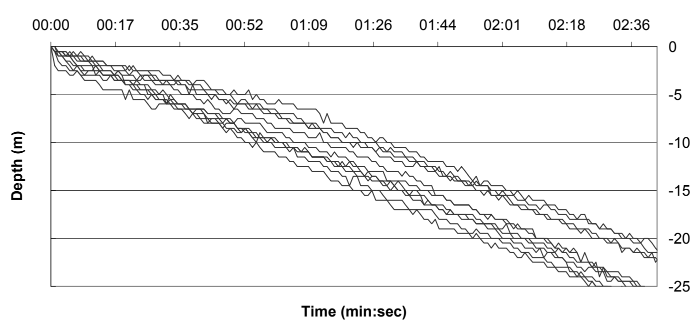
Three deployments were completed for each of the five sample positions with 2.5 kg weights (15 deployments). The mean sink rate varied between 0.14 and 0.20 m/s in the middle of the line (S+, M, E–); between 0.38 and 0.64 m/s at the start of the line (S); and, between 0.20 and 0.36 m/s at the end of the line (E). The variance measure (Standard Error (s.e.)) for the S and E means is considerably larger than through the middle (S+, M, E–) of the line (Table 1).

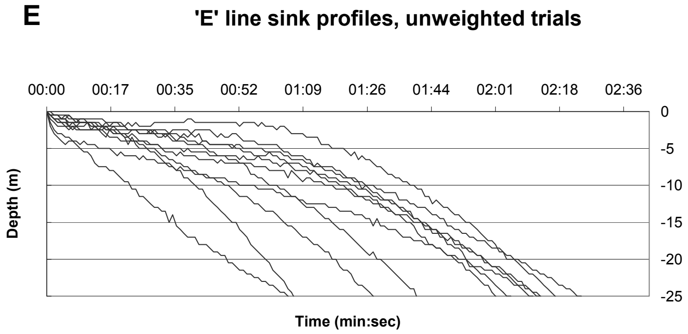
Figure 8. Some typical longline sink profiles: A—'S' line sink profiles (2.5 kg trials); B—'S+' line sink profiles (2.5 kg trials); C—'M' line sink profiles (5 kg trials); D—'E-' line sink profiles (unweighted trials); E—'E' line sink profiles (unweighted trials).











3.4 WEIGHTED LINE TRIALS (5 kg)

Three deployments were obtained for the 'S' sample position, six each for the 'S+', 'M', and 'E–' sample positions and four for 'E' with 5 kg weighted longlines (25 deployments). The mean sink rate varied between 0.15 and 0.18 m/s in the middle of the line (S+, M, E–); between 0.50 and 0.88 m/s at the start of the line (S); and, between 0.16 and 0.28 m/s at the end of the line (E). The variance measure (s.e.) for the S and E means is considerably larger than through the middle (S+, M, E–) of the line (Table 1).

Visual observations of the line directly behind the vessel during setting indicated rapid sink rate adjacent to weights. However, this effect appeared to be very localised, with line set after a weight returning to a slower sink rate within 40 m of the weight. This observation was made regularly during weighting trials.

3.5 SINK RATE ANALYSES

Weights were used as both categorical and continuous variables in a three-way analysis of variance (trial, position on line, and depth).

The line sink rate varied between sampling positions (Fig. 8) and a significant interaction between position on the longline and sink rate was noted (ANOVA: $F_{4,\,360}=150.8$, $p<0.001$). Most variation in sink rate occurred in measurements to 5 m depth at all sample positions (Fig. 8) with a significant interaction between depth and sink rate (ANOVA: $F_{1,\,360}=931.3$, $p<0.001$).

No difference in line sink rate between the three trials was detected by this analysis.

3.6 EFFECTIVENESS OF THE TORI LINE

Setting was on average undertaken at a speed of 6.5 knots. As one nautical mile is 1852 m long, and assuming no tide as was most often the case, the vessel maintained an average over ground speed of 3.34 m/s during setting[8]. The aerial section of the vessel's tori line was observed to give a mean coverage of 26 seconds (s.e. = 0.73, n = 25) through a variety of weather conditions. At average setting speed this converts to 86 m behind the vessel[9].

For both unweighted and weighted lines the first two sample positions (S & S+) reached a depth of close to 5 m at the end of the aerial section of the tori line. The line at the other sample positions has not reached 5 m by this time. In some cases the lines are as shallow as 2 m at the end of the aerial section of the tori line (Fig. 9).

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[8] $\{1852 \text{ m} \times 6.5\} / \{60 \text{ min} \times 60 \text{ sec}\} = 3.34$ m/sec

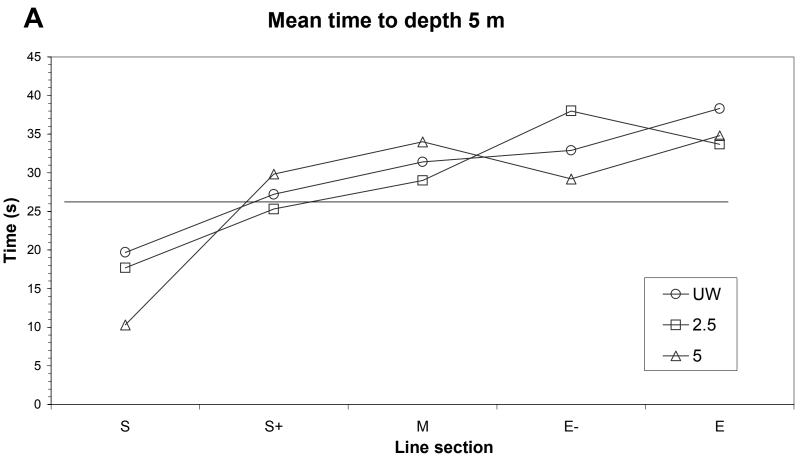
[9] $3.34 \text{ m/sec} \times 26 \text{ sec} = 86.84$ m

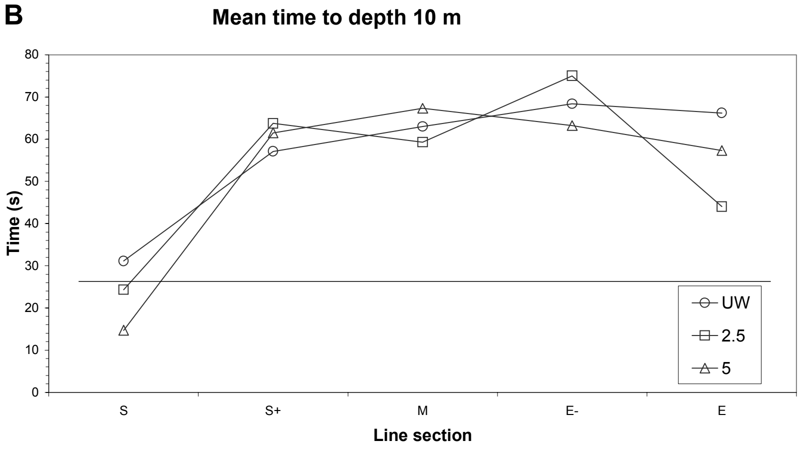
TABLE 1. MEAN SINK RATE IN METRES PER SECOND, WITH SE AND ***n***, TO SELECTED DEPTHS FOR THE THREE TRIALS.

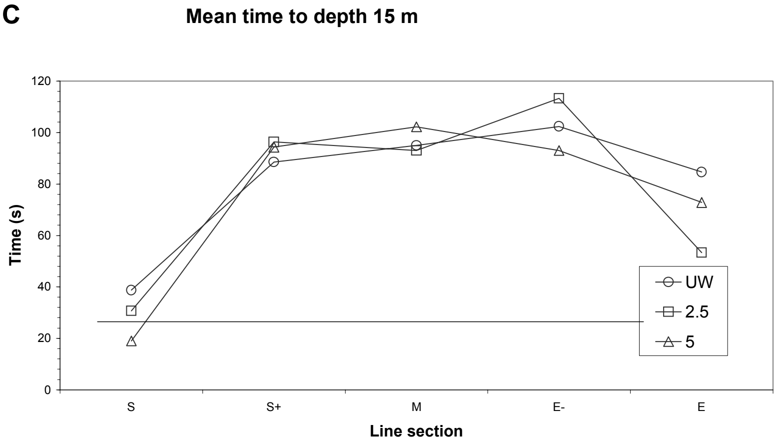
DEPTH	TRIAL		SAMPLE POSITION ON LONGLINE*				
			S	S+	M	E−	E
@ 5 m	Unweighted	mean	0.29	0.19	0.17	0.16	0.19
		SE	0.03	0.01	0.01	0.01	0.04
		n	11	11	11	11	11
	2.5 kg weights	mean	0.38	0.20	0.18	0.15	0.20
		SE	0.13	0.01	0.03	0.04	0.08
		n	3	3	3	3	3
	5 kg weights	mean	0.50	0.17	0.15	0.18	0.16
		SE	0.06	0.01	0.01	0.01	0.04
		n	3	6	6	6	4
@ 10 m	Unweighted	mean	0.35	0.18	0.16	0.15	0.18
		SE	0.03	0.01	0.01	0.01	0.03
		n	11	11	11	11	11
	2.5 kg weights	mean	0.49	0.17	0.17	0.15	0.26
		SE	0.12	0.03	0.02	0.04	0.08
		n	3	3	3	3	3
	5 kg weights	mean	0.70	0.17	0.15	0.16	0.21
		SE	0.07	0.01	0.01	0.01	0.06
		n	3	6	6	6	4
@ 15 m	Unweighted	mean	0.42	0.17	0.16	0.15	0.20
		SE	0.03	0.00	0.01	0.01	0.03
		n	11	11	11	11	11
	2.5 kg weights	mean	0.56	0.16	0.16	0.14	0.31
		SE	0.12	0.02	0.01	0.02	0.07
		n	3	3	3	3	3
	5 kg weights	mean	0.81	0.16	0.15	0.17	0.24
		SE	0.08	0.01	0.00	0.01	0.06
		n	3	6	6	6	4
@ 20 m	Unweighted	mean	0.48	0.17	0.16	0.15	0.22
		SE	0.04	0.00	0.00	0.00	0.02
		n	11	11	11	11	11
	2.5 kg weights	mean	0.64	0.16	0.16	0.14	0.36
		SE	0.13	0.02	0.01	0.02	0.08
		n	3	3	3	3	3
	5 kg weights	mean	0.88	0.16	0.15	0.17	0.28
		SE	0.07	0.01	0.00	0.01	0.07
		n	3	6	6	6	4

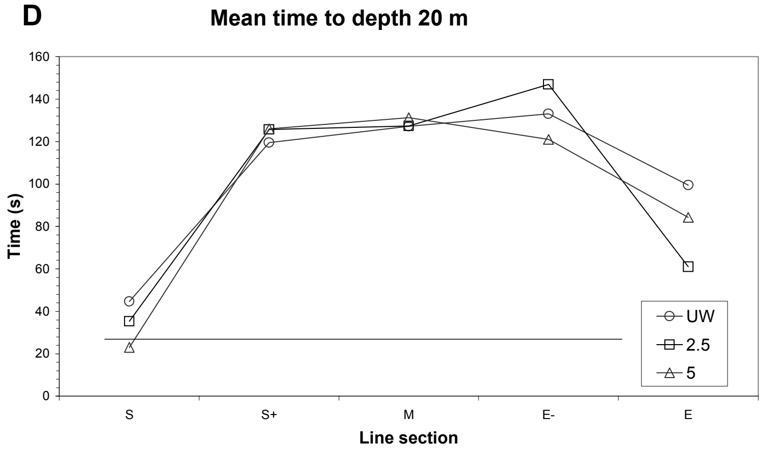
* These sample positions on the longline are shown diagrammatically on Fig. 7.

Figure 9. Mean time in seconds for the longline to reach: A—5 m; B—10 m; C—15 m; and D—20 m depth at the various sampling positions (S, S+, M, E-, E). The plot lines represent the various weighting regimes (unweighted, 2.5 kg, and 5 kg), and contrast with the mean time the longline is protected from seabirds by the aerial section of the tori line (shaded).









Assuming a diving depth of at least 10 m for some species present, the aerial section of the tori line only provided coverage of the longline at the start of the longline and then only to approximately 10 m depth (Fig. 9). At times, the line was at depths less than 10 m for over 170 m beyond the aerial coverage of the tori line[10] (Fig. 9B).

The tori line was observed in a variety of configurations in most weather states. Collecting useful numeric data on the effectiveness of tori lines was found to be problematic. The aerial section of the tori line appeared to keep all species, except for Cape pigeons (*Daption capense*) away from the longline. Cape pigeons were observed flying between tori line streamers daily. The aerial section of the tori line appears to provide coverage from seabirds attempting to dive for baits, thus 'protecting' the longline and thus the seabirds. The tori line appeared to have most effect on the larger seabird species, especially *Diomedia* spp. albatrosses.

3.7 SEABIRD SPECIES OBSERVED: FREQUENCY, AND QUANTITY

Seabirds were observed about the vessel every day during the voyage. The numbers present, at least in sight from the vessel, ranged from one to over 1000. The larger numbers were associated with fishing activity later in the voyage. Differences in the proportions of species present were noted between the haul and set behaviour modes, however these data are not reported here. The species observed during the voyage and some general observations on the species from this voyage are noted below.

- **Royal albatross** (*Diomedia epomophora*) and Sanford's albatross (*D. sanfordi*) were observed throughout the voyage; their presence was intermittent with up to 75 present at times.
- **Antipodean albatross** (*D. antipodensis)* and Gibson's albatross *(D. gibsoni*), both sub-adult and adult, were observed. One large very white wanderer presumed to be a snowy albatross (*D. chionoptera*) was observed about the vessel for a day. Wanderers were seen in moderate numbers throughout the voyage, if present at least two were seen and the most observed at any time was 30.
- **One seabird** presumed to be an Antipodean albatross, and later confirmed as a female Antipodean wandering albatross at least 16 years old, at the time foraging for a four-month-old chick (K. Walker, DOC pers. comm.) was observed with a blue left leg tag #375 on 10 August at 178°W 44°S.
- **A light-mantled sooty albatross** (*Phoebetria palpebrata*) was seen on two separate occasions, both times for a very short duration (minutes as opposed to hours).
- **Chatham albatross** (*T. eremita*) were seen in moderate numbers throughout the voyage, with the number of birds present ranging up to 100 on four days, more often between 10 and 40. Several sub-adults were observed—a new

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[10] 78 s — 26 s = 52 s: 52 × 3.34 = 173.7 m

record for New Zealand waters (distinguished by bill colour and confirmed from photographs, C.J.R. Robertson, DOC pers. comm.).

- **Salvin's albatross** (*T. salvini*) were seen in moderate numbers throughout the voyage with the number of birds present ranging up to 100, but more often between 20 and 60.
- **White-capped albatross** (*T. cauta*) were seen in moderate numbers throughout the voyage with the number of birds present ranging up to 120, but more often between 20 and 60.
- **Black-browed albatross** (*T. melanophrys*) and Campbell albatross (*T. impavida*) were both observed during the voyage, however only a few Campbell albatross were distinguished. Black-browed albatross were present throughout the voyage with the number of birds present ranging up to 200, but more often between 60 and 100.
- **Southern Buller's albatross** (*T. bulleri*) were only seen occasionally during the voyage. The maximum number observed was 10. The occurrence of southern Buller's appeared cyclical rather than associated with peaks in other seabird activity.
- **Giant petrels**, both northern (*Maconectes halli*) and southern (*M. giganteus*) species, were observed throughout the voyage. A white phase southern giant petrel was observed over a period of three days late in the voyage. The number of giant petrels present ranged between 40 and 200 daily, with a maximum count in excess of 300 late in the voyage.
- **Cape pigeons** (*Daption capense*) were the most numerically abundant species present at most times during the voyage. Numbers observed ranged from 20–300 regularly, with peak estimates in excess of 500.
- **Grey petrels** (*Procellaria cinerea*) were present during most of the voyage with the number of birds appearing to steadily increase through the voyage, 10–50 grey petrels were regularly observed with maximum counts of approximately 150 noted late in the voyage.
- **Sooty shearwaters** (*Puffinus griseus*) were occasional visitors with ten the maximum number observed throughout the voyage.
- **Westland petrels** (*P. westlandica*) were observed infrequently in the later half of the voyage with a maximum count of 10.
- **One brown skua** (*Catharacta maccormicki*) readily distinguished by size, flight, and colour was observed at the peak of seabird activity in the first week of August.

Note that other small petrels (storm petrels and diving petrels) were observed, but are not detailed here. Seabird numbers peaked around the 7 August just prior to the full moon on 8 August; coincidentally at the same time fish catches peaked for the voyage.

3.8 SEABIRD INCIDENTAL MORTALITY

During the voyage, 12 incidental seabird mortalities representing 3 species were recorded: 10 grey petrels, a Chatham albatross, and a Cape pigeon. Captures occurred throughout August with only one multiple capture event of two grey petrels on one line recorded.

The Cape pigeon was caught on the haul. One grey petrel was drowned by entanglement with the tori line during setting. The remaining 10 seabirds were captured during setting and drowned. All grey petrels captured were males (C.J.R. Robertson, DOC pers. comm.). All but one of the grey petrels captured was foul-hooked, the last having taken a baited hook.

With 1 069 867 hooks set for these 10 captures, the incidental mortality rate was 0.0093 seabirds per 1000 hooks set.

3.9 SEABIRD BEHAVIOUR

Behaviour patterns noted during the haul were clearly distinct from those noted during the set. Two other important behaviour modes were also observed, the behaviours observed when steaming between grounds with no offal discharge, and, behaviours observed steaming between grounds with offal being discharged.

3.9.1 Haul behaviour

The vessel was moving at a speed of 0.5–1.5 knots during the haul, so it was possible for most of seabirds present to swim alongside or close astern the vessel. This resulted in most seabirds in the area being on the water during the haul, rather than in flight. Flight was generally only used as a means of regaining contact with the vessel after drifting some way behind, for getting to prime feeding locations such as fresh offal rapidly, and as an escape mechanism from some real or perceived threat. Most seabirds were concentrated to starboard (the same side as the offal chute) and astern. Large aggregations of seabirds about fish accidentally lost off the line were common.

3.9.2 Set behaviour

The vessel was moving at speeds of 5.0–6.5 knots during the set, so it was not possible for most seabirds to stay in contact with the vessel by swimming. Flying and plunge diving were most common. Numbers during the set varied from 10 to over 1000. Seabird activity tended to reduce over the period of a set, or series of sets, unless offal was dumped. Any seabirds diving for loose bait or baited hooks did so behind the aerial protection afforded by the tori line (see Fig 4). Many seabirds landed on the water behind the tori line to feed on any offal that was discarded during setting.

3.9.3 Steaming (no offal) behaviour

With the vessel moving at speeds of up to 12 knots when steaming, the only way for seabirds to stay with the vessel was by flying. Flight patterns observed were: use of pressure waves created by the vessel, use of tail winds stronger than the vessels forward speed, active flight, dynamic soaring, and combinations of these methods. The longer the duration of the steam between fishing grounds, the lower the number of seabirds present. Those seabirds that were present also tended to range considerably further away from the vessel than during any other behaviour mode.

3.9.4 Steaming (offal) behaviour

Again, with the vessel moving at speeds of up to 12 knots when steaming, the only method for seabirds to stay with the vessel was by flying. Flight patterns observed were as described above. However, the moment offal was dumped, sea birds immediately dropped onto the water adjacent the offal in numbers ranging from 50 to 200. These seabirds would still be feeding on the offal as they disappeared out of sight from the vessel. During these steaming periods with offal being dumped, seabirds tended to stay very close to the vessel, predominantly on the starboard side, within sight of the offal chute.

3.9.5 Grey petrel behaviour

Of special note was the behaviour of grey petrels (*Procellaria cinerea*) during setting (based partially on observations made during hauling). During hauling, grey petrels were often observed swimming on the surface of the water, repeatedly and regularly putting their heads underwater and searching. This was followed by a dive when potential food was observed. In clear water, grey petrels were observed to dive to depths estimated to be at least 6 m[11] and seize bits of offal, discarded baits, and discarded small fish. The birds subsequently returned to the surface with the food item and ate it. No attempt to swallow the bait underwater was observed. Larger seabirds, *Diomedia* spp. and *Thalassarche* spp., would often pounce on grey petrels as they returned to the surface and steal the prey item. During setting, grey petrels were regularly observed landing on the surface just behind the aerial section of the tori line, looking underwater and then diving. This behaviour was often noted to occur in the loose bait trail[12] rather than in the vicinity of the longline being set. From time to time, the loose bait trail and the longline would overlap. All the grey petrel behaviours described were observed at all times of the day and night. None of the other species present during the voyage were observed regularly diving after baits.

Chatham albatross (*Thalassarche eremita*) were on a few occasions (less than 10 for the entire voyage) observed to plunge dive in the vicinity of the longline, aft of the aerial section of the tori line.

3.10 NIGHT VISION SCOPE

The night vision scope allowed more accurate counts of seabirds near the boat, but did not allow counts as accurate as those collected during daylight due to restricted range of vision (approx. 50–75 m, based on trials ashore prior to the voyage).

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[11] A piece of string, marked at 1 m intervals, was dropped over the side with a marker on end until the marker disappeared from view. This depth was 7 m.

[12] The autobaiter cuts a bait for each hook, however, not all hooks get baited. The unused baits formed a trail of loose bait behind the vessel during setting. Some baits are flicked off hooks after passing through the autobaiter. These also contribute to the loose bait trail. The loose bait trail did not always track the longline.

The lack of colour differentiation (all vision through the scope is shades of green) meant the scope offered little help in identifying seabirds at night. Some size differentiation was possible, allowing seabirds to be split at the petrel/small albatross/large albatross level. The lack of magnification meant that an assessment of the actual quantity of seabirds present was not feasible. This was highlighted by use of the vessel's spotlight, which, when directed astern and turned on for a brief period, illuminated more than double the number of seabirds recorded with the night vision scope[13].

4. Discussion

The observations reported here provide initial information on the nature and extent of the interaction between seabirds and the ling longline fishery. The fishing strategy altered daily to take account of weather and sea conditions, and production requirements. Accordingly, structured empirical trials were difficult to undertake whilst present on the vessel in an observation-only capacity.

This type of vessel operates around the clock, with most time spent hauling longlines rather than setting. The vessel sets approximately 28 000 hooks per day, as compared to the 2 500–3 000 hooks set per day in the pelagic longline fishery for tuna (Murray et. al. 1993). This is important when comparing and extrapolating incidental seabird catch rate figures, and in the design of mitigation research.

Time Depth Recorders provide a means of assessing line sink rate. Experience gained in these trials suggests that careful data recording and instrument calibration is required for the TDRs to record useful data. TDRs are particularly sensitive to sudden changes in water temperature, for example when deployed. Accordingly, TDRs should be handled carefully and soaked in ambient-temperature seawater for at least 30 minutes prior to deployment.

The initial attachment using a sharkclip was easy and quick, however the sharkclip was a weak link in this method, as indicated by the loss of a TDR early in the voyage. The subsequent reliance on the inherent strength and simplicity of the rope loop meant that no further TDRs were lost during the voyage. The use of markers either side of the TDR was helpful for the crew, and also freed the observer to undertake other duties rather than needing to watch constantly for returning TDRs.

A number of environmental and equipment variables affect line sink rate, as indicated by mean sink rates of from 0.14 to 0.88 m/s being recorded during the trials. Further, the greatest variation in sink rate occurred in measurements to 5 m depth indicating that variables such as propeller wash and turbulence, and vessel movement caused by swell, may also affect line sink rate.

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[13] Special thanks to Captain Schimanski for making this observation, and repeating the trial for the author to observe.

Identifying the variables that are most influential will be necessary to design a line-weighting regime that will achieve faster line sink rates. Variables that affect the flow of the line from the vessel such as jamming of the baiting machine and swell height are likely to be important.

The analyses undertaken show that the five sample positions had differing sink rates. On the basis of the raw numbers (Table 1) and plots (Fig. 8), the sample position chosen at the start (S) of the longline appears to have caused most of this variation. Given the proximity of the 40 kg grapnel to this sample position, it is likely this part of the line sank more rapidly than other parts of the line. The sink rate for the rest of an unweighted line was not sufficient to take the baited line to a depth beyond that easily dived by some of the albatrosses and petrels present.

Line sink rate was not accelerated at the sample points by the line weighting regimes trialed (maximum this trial, an additional 5 kg per 400 m). On the basis of observations made during the voyage it is likely that the addition of weights at much closer intervals is needed to accelerate line sink rate significantly. Observations suggest the interval is likely to be about 40 m.

The implication for the mitigation of incidental capture of seabirds is that any target line sink rate (or alternative measures of longline performance) must err heavily on the precautionary side of the relevant data to allow for day-to-day variations in the environment and the longline being used. Further, when measuring line sink rate using TDRs the TDR must be placed at the greatest possible distance from any attached weight to record the minimum line sink rate.

The TDR results also provide information for fishers on gear performance. This report covers only the first few minutes of data recorded for each set, as this is the period of interaction with seabirds. Data on the time taken for various parts of the longline to reach the seafloor were of considerable interest to the fishers and may allow more effective fishing over certain bottom types in future.

The analyses allow the development of a theoretical model of how a line of this type sinks (Fig. 10). The initial line sink is rapid and influenced by the grapnel (Fig. 10A). Once the gear anchors on the bottom the profile of the gear becomes flattened through the set as the drag of kilometres of partially sunk gear take over from the drag of the grapnel in pulling the line from the vessel (Fig. 10B–D). Finally, the last portion of the line again sinks rapidly under the influence of the second grapnel (Fig. 10E).

The results from the various line sink trials combined with data on the tori line aerial section allows determination of the depth to which the longline is protected by the tori line. The results also indicate that if seabirds able to dive deeper than 2–5 m are present, incidental seabird mortality is unlikely to be prevented by the use of a tori line alone. However, setting without a tori line would increase the opportunity for incidental seabird mortality considerably.

To decrease the exposure of the longline at seabird-foraging depths, one option is to reduce the vessel's setting speed. Although achieving the goal of extra depth at a reduced distance behind the vessel, this strategy has several inherent problems. The reduction in speed is likely to reduce the length of the aerial section of the tori line (due to reduced drag on the in-water section). Further,

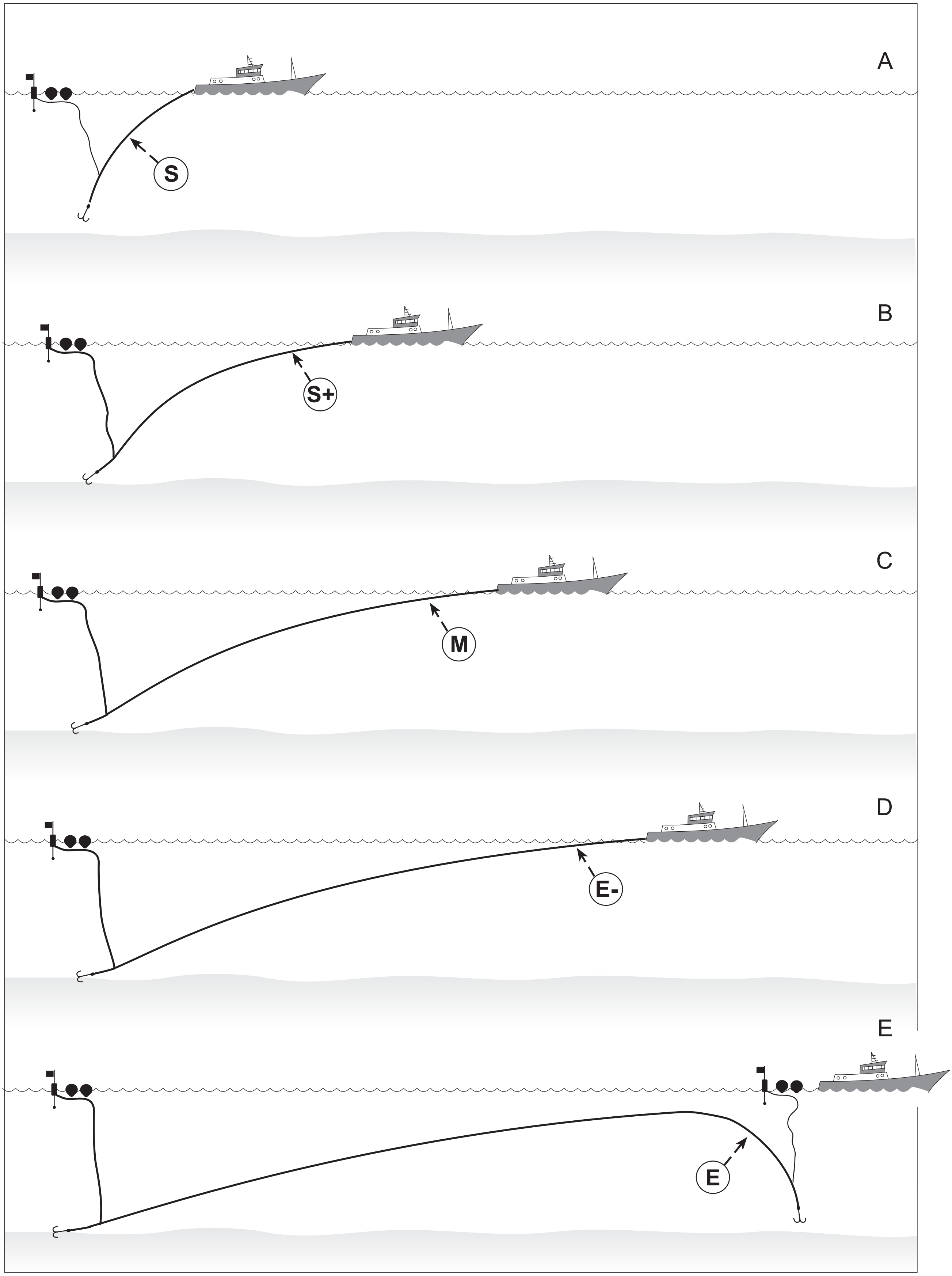

Figure 10. Theoretical model of how an unweighted autoline longline sinks. A—initially the line sinks rapidly, influenced by the grapnel weight; B—grapnel anchors on the seabed; C—profile of the line begins to flatten, from the combination of gear-drag and anchoring, against the pull of the vessel; D—profile continues to flatten, as gear-drag increases and the line continues to be pulled from the vessel; E—the last portion again sinks rapidly, influenced by the second grapnel.

the vessel is likely to incur an operational cost in lost time and loss of autobaiter function (K. Schimanski, Sanford Ltd pers. comm.).

An item of equipment which may help achieve the goal of allowing the line to sink to greater depths before the end of the tori line is a lineshooter (Brothers et. al. 1999). A lineshooter pulls the longline from the vessel, rather than the drag of the gear in the water and the forward motion of the vessel pulling the line from the vessel. This allows for a constant feed of slack line into the water avoiding line jerks caused by jams in machinery and swell (Lokkeborg 1998). This should allow the line to sink more rapidly.

Observations made during this study suggest that vessel activity in general is of interest to seabirds. When offal is discharged into the water this interest intensifies. Withholding offal during parts of the fishing operation only intensifies competition for that food when it is later released. The location and timing of release may lessen the chance of interaction with baited hooks, but not the number of seabirds present about the vessel. Therefore, once baited hooks enter the water the chances of incidental capture remains. As most seabirds use both visual and olfactory clues in foraging (Nevitt 1999), withholding offal altogether may provide the only solution to persistent seabird activity about the fishing vessel. The persistence of seabirds in following the vessel between fishing grounds suggests some learning that the vessel is a source of food and worthwhile following for extended periods of time.

During setting, most seabirds spent time searching rather than actively chasing baited hooks. One exception was grey petrels diving for loose baits. As most grey petrels captured were foul hooked, it suggests that they were captured whilst diving after loose baits rather than attempting to swallow baited hooks. In this case, the colour of the snood, bait, and line may be able to be altered to warn grey petrels away as Procellariformes are known to have colour vision (Harper 1979).

The loose bait trail (created during the set by unhooked baits and off cuts from the baiting machine) is an operational issue that could be remedied to mitigate the chance of seabird capture behind the vessel. Unfortunately, a practical way of doing this was not identified during this voyage.

The plunge diving displayed by Chatham albatross and shallow depth of some lines beyond the aerial section of the tori line (less than 3 m) readily explains the recorded incidental capture of this species. The other species present during this voyage appeared to be more interested in feeding on offal than the baited longline, and are not likely to be particularly prone to incidental capture in this fishery. The one Cape pigeon capture is explained by sheer numbers present ‘crowding’ airspace to the extent that this bird could not avoid being foul hooked.

The use for a night vision scope appears limited in this type of study unless they can be developed with multi-colour vision and considerably greater range.

Observations made during this voyage support previous comments about foraging behaviour of some of the species observed. Chatham albatross do feed as sub-adults within the New Zealand EEZ, with previous records only from South American waters (C.J.R. Robertson, DOC pers. comm.). Black-browed albatross actively forage in numbers on the Chatham Rise during winter (Waugh 1998).

5. Summary

The interactions between seabirds and this ling vessel were complex and dynamic. Line sink rate with standard gear leaves the longline vulnerable to seabirds. A weighting regime to increase line sink rate and decrease this vulnerability would likely need to be greater than 5 kg per 40 m of gear. The use of a tori line provides an effective means of reducing the probability of incidental seabird capture for some species. Grey petrels and Chatham albatross in particular are still vulnerable to capture in this fishery, given the behaviours they display. Many avenues remain for research into line sink rate and the behaviour of seabirds, which may help mitigate incidental seabird mortality. To be effective, mitigation research will need to consider both the individual species and the particular fishery.

6. Acknowledgements

This project was funded by New Zealand fishers through the Department of Conservation's Conservation Services Levy, investigation no. 3007. The assistance given by Andrew France (Ministry of Fisheries Scientific Observer Programme) and the Captain, crew, and onshore management of the vessel both at sea and ashore was greatly appreciated. Chris Edkins transformed my rough sketches into professional illustrations. Shelton Harley and Ian West provided thoughtful statistical advice. The document, in various stages, has benefited from very useful comments provided by Janice Molloy, Suze Baird, Jacqui Burgess, Camilla Cox, Rachel Garthwaite, Crispin Keith, and Ian Wilkinson. Jaap Jasperese deserves a special mention for editorial perseverance.

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