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EXPERIMENTAL EVALUATION OF THE EFFECTIVENESS OF WEIGHTING REGIMES IN REDUCING SEABIRD BY-CATCH IN THE LONGLINE TOOTHFISH FISHERY AROUND SOUTH GEORGIA

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Abstract

A series of experiments was carried out in February 1999 at South Georgia (Subarea 48.3) to examine the effects of different weighting regimes on the incidental mortality of birds caught on longlines fishing for toothfish (*Dissostichus* spp.). Three regimes were examined, with weights of 4.25, 8.5 and 12.75 kg attached at 40 m intervals on a Spanish-rigged longline. There was a significant reduction in bird mortality when 8.5 kg was used compared to 4.25 kg, but no further significant reduction when 12.75 kg was used. Therefore to minimise seabird by-catch, line-weighting regimes of at least 8.5 kg at 40 m intervals should be used. Results suggested that seabird by-catch on lines using effective weighting regimes may be even further reduced where all lines being set in the vicinity use effective line-weighting regimes. The importance of a good design in experiments of this type is emphasised, because even though conditions may be held as constant as possible within experiments, the ability to separate treatment effects from other sources of variation (e.g. environmental factors) must be preserved.

Résumé

Une série d'expériences menées en février 1999 en Géorgie du Sud (sous-zone 48.3) a permis d'examiner les effets des divers régimes de lestage sur la mortalité accidentelle d'oiseaux accrochés aux palangres visant la légine (*Dissostichus* spp.). Trois régimes sont examinés, avec des lests de 4,25, 8,5 et 12,75 kg fixés à 40 m d'intervalle sur une palangre de type espagnol. La réduction de la mortalité des oiseaux est marquée lorsque l'on utilise des poids de 8,5 kg par rapport aux poids de 4,25 kg, mais on ne note pas de réduction significative si on les remplace par des poids de 12,75 kg. Ainsi, pour réduire au minimum la capture accidentelle d'oiseaux de mer, il semble nécessaire d'utiliser un régime de lestage d'au moins 8,5 kg tous les 40 m. Les résultats laissent entendre que la capture accidentelle d'oiseaux de mer sur les palangres utilisant des régimes de lestage efficaces pourrait encore être réduite si toutes les palangres posées dans les environs usaient de régimes de lestage efficaces. L'importance de la conception de ce type d'expériences est soulignée car, bien que les conditions puissent être maintenues pratiquement constantes pendant les expériences, la possibilité de séparer les effets des conditions dans lesquelles se déroulent les expériences, d'autres sources de variation (telles que des facteurs environnementaux) doit être préservée.

Резюме

В феврале 1999 г. у Южной Георгии (Подрайон 48.3) была проведена серия экспериментов по изучению влияния различных режимов затопления яруса на побочную смертность птиц, пойманных на ярусы при промысле клыкача (видов *Dissostichus*). Были изучены 3 режима, при которых на ярус испанской конфигурации с интервалом 40 м устанавливались грузила весом 4.25, 8.5 и 12.75 кг. Смертность птиц значительно сократилась при использовании грузил весом 8.5 кг по сравнению с 4.25 кг; использование грузил весом 12.75 кг не привело к дальнейшему существенному снижению смертности. Таким образом, чтобы минимизировать прилов морских птиц, надо использовать режим затопления яруса не менее 8.5 кг/40 м. Результаты говорят о том, что прилов морских птиц при ярусном промысле с эффективным режимом затопления ярусов может быть еще ниже, если на всех выставляемых поблизости ярусах также используется эффективный режим затопления. Подчеркивается важность хорошего планирования для экспериментов такого типа, т.к. хотя в самом эксперименте условия могут поддерживаться относительно постоянными, результаты эксперимента должны дифференцироваться от других источников изменчивости (например, факторов окружающей среды).

Resumen

En febrero de 1999 se llevaron a cabo una serie de experimentos en Georgia del Sur (Subárea 48.3) para examinar los efectos de diferentes regímenes de lastrado de la línea en la mortalidad incidental de las aves marinas capturadas en la pesquería de palangre de bacalao de profundidad (*Dissostichus* spp.). Se estudiaron tres regímenes, con lastres de 4,25, 8,5 y 12,75 kg cada 40 m en palangres de tipo español. La mortalidad de aves se redujo significativamente cuando se utilizaron lastres de 8,5 kg en comparación con los de 4,25 kg, pero no hubo mayor reducción al utilizar los lastres de 12,75 kg. Por lo tanto, se debe utilizar un regimen de lastrado de la línea que incorpore lastres de por lo menos 8,5 kg situados a intervalos de 40 m para reducir la captura incidental de aves marinas. Los resultados indican que la reducción de la captura incidental de aves marinas en líneas que utilizan un régimen de lastrado eficaz sería aún mayor si se adoptase el mismo sistema para todas las líneas caladas en la vecindad. Se subraya la importancia del diseño experimental en las pruebas de este tipo, porque aunque se trate en lo posible de mantener constantes las condiciones durante un experimento, se debe conservar la capacidad de separar los efectos del tratamiento de los efectos de otras fuentes de variabilidad (es decir, de los factores ambientales).

Keywords: longline, weighting regime, toothfish, seabirds, by-catch reduction, CCAMLR

INTRODUCTION

Longline fishing for toothfish (*Dissostichus* spp.) in the CCAMLR Convention Area started in 1989 and has since become one of the major finfish fisheries in Antarctic waters. Early reports from the fishery recorded high levels of incidental mortality of seabirds (particularly albatrosses and petrels) which, attracted to the bait, drowned after becoming caught on longline hooks during line setting. A CCAMLR conservation measure aimed at mitigating such incidental mortality has been in place since 1991 (CCAMLR, 1991). Since its inception, this measure has undergone several modifications; its latest version being Conservation Measure 29/XVI (CCAMLR, 1999). This measure requires the setting of longlines only at night, restrictions on offal dumping during setting, use of thawed bait only, use of a 'streamer' line which keeps birds away from the setting area, and a specified weighting regime to ensure that the line sinks rapidly. Combined with a general restriction on the fishery to winter months when seabirds are not abundant and when night setting is easiest, the incidental mortality of birds has declined from about 0.2 birds/thousand hooks in 1995 to less than 0.025 birds/thousand hooks in 1997 (SC-CAMLR, 1995 and 1998). Bird by-catch rates were undoubtedly much higher before the use of mitigation measures was required, and are now estimated to be 1–2 birds/thousand hooks (SC-CAMLR, 1998) for unregulated fishing vessels (those not fishing according to CCAMLR rules, and therefore not using mitigation measures).

Despite the success of such measures, birds are still being caught in fisheries regulated by CCAMLR. Further, there are operational difficulties with the current regime; operating fishing vessels in Antarctic or sub-Antarctic waters in the winter is inherently risky, and many operators would welcome a relaxation of the winter fishing restriction. Moreover, operators have found it difficult to fully comply with the line-weighting regime specified in Conservation Measure 29/XVI; for example a 10 km line would require about 3 tonnes of weight (usually stones or bricks) spaced at very short intervals. By contrast, in 1998 the weighting regime used by most vessels was about 5 kg at 40 m intervals (SC-CAMLR, 1998). The line-weighting regime required by the conservation measure (6 kg at 20 m intervals) was derived from a study of bird strikes in relation to weight size and spacing, and involved only a theoretical calculation of sink rates (Brothers, 1995 cited in Robertson, 2000). The CCAMLR line-weighting regime has not been tested experimentally, and it may not be the optimal one both for reducing bird mortality and for the fishery operation. Accordingly, CCAMLR has called for more experiments to determine optimal line-weighting regimes and sink rates for longlines in the Antarctic (SC-CAMLR, 1998). This paper reports the results of such experiments carried out at South Georgia in the 1998/99 austral summer.

METHODS

We conducted a series of experiments on line-weighting regimes between 1 and 17 February 1999, prior to the start of the fishing season. This research was carried out under the provisions of Conservation Measure 64/XII, which restricts research catches of toothfish to 50 tonnes. To increase the statistical power of the experiment, longlines were set during the day so that birds would be caught; however, all other provisions of Conservation Measure 29/XVI (including the use of a streamer line) were complied with. Fishing was carried out under strict adherence to a predefined experimental protocol. A total limit of 150 birds of all species, but no more than five wandering albatrosses (*Diomedea exulans*), was applied to ensure seabird mortality was not excessive.

Experiments were conducted on board the FV *Argos Helena* (UK), a 53 m vessel which has participated in the longline fishery around South Georgia for the past several years, and whose fishing operation is typical of many of the vessels in this fishery. The spacing of weights on the longline was at 40 m intervals, a typical spacing used in the fishery, and weights were stones (cobbles) of an average weight of 4.25 kg. Two experiments were conducted:

(i) a comparison of the use of one stone at each attachment site (termed 'control' in this experiment) against the use of two stones (termed 'treatment'); and

(ii) a comparison of the use of two stones at each attachment site (termed 'control' in this experiment) against the use of three stones (termed 'treatment').

The weight ratios for these regimes were 4.25 kg/40 m (4.25 kg at 40 m intervals), 8.5 kg/40 m and 12.75 kg/40 m.

Each experiment was conducted over a number of days when both longlines were set. In the first experiment one line had the one-stone setup (single weight) and the other had the two-stone setup (double weights). In the second experiment one line had the two-stone (double weights) and the other had the three-stone setup (triple weights). As far as possible, all setting conditions (sardine used for bait, setting speed, position and direction in relation to wind direction etc.) were held constant for all days and lines. The line was set with the swell astern of the vessel, which usually, but not always, coincided with the direction of the wind.

The setting times of the longlines were also held constant, at 0900 and 1100 h, but the setting time of lines with different weighting regimes was alternated each day within an experiment to eliminate the possibility of a bias arising from time of day.

The behaviour of birds during each set was monitored, and the number of birds killed was recorded when the line was hauled. During setting, observations were made from a position directly above the point where the lines were set from the stern of the vessel. Prior to line setting, the birds within a 500 x 500 m 'box' astern of the vessel were counted to give an idea of relative bird abundance in the vicinity of the vessel at the time of setting. However, birds outside this area are also likely to interact with the vessel during setting operations.

From early sets it was found that the high number of feeding attempts made it impossible to accurately record the outcome of each event.

Emphasis was therefore placed on species most vulnerable to capture by the longline gear: white-chinned petrel (*Procellaria aequinoctialis*) and black-browed albatross (*Diomedea melanophrys*). During setting, the total number of foraging attempts made by each of these species was counted using hand tally counters. A foraging attempt was regarded as any instance when a bird dived or ducked below the surface of the water. Birds were regarded as being at risk of becoming hooked during such feeding attempts.

At the end of setting, a second count of the birds astern of the vessel was made. Any birds seen to be hooked during setting were noted. On several occasions birds seen hooked at setting were not recovered during hauling.

As many hooks as possible were observed during line hauling. Stone weights were attached at regular intervals along the line, every 24 hooks (40 m). These sections were used as convenient sampling units, enabling the distribution of catch along the line to be recorded accurately.

Analysis of the bird catches was complicated by the presence of many sets with zero catches. Because the number of hooks set was constant throughout the experiment, and differences between the number of hooks observed on each set were minimal (Table 2), the Generalised Linear Models (GLMs) used in the data analysis utilised numbers of birds rather than bird by-catch rates as the response variable. A poisson model with square root link gave the best fit to the data, and residuals were evenly distributed on normal quantile plots. The number of effects that could be considered was, however, limited by the small number of data points. Response variables were either the number of birds or the number of black-browed albatrosses killed.

RESULTS

Experimental Results

No practical problems were experienced whilst fishing with double weights, and the captain of the *Argos Helena* thought that this option would be practical for commercial fishing. The captain was concerned, however, that triple weights might result in the line breaking whilst being hauled. As it turned out this was not a problem, but whether it would be for other vessels in other areas might depend on the seabed substratum and sea state.

Four longline sets were made before the start of the first experiment, to establish the setting regime and to trial an underwater setting device that proved ineffective. The results of these sets are not reported here. The total catch of toothfish in all sets was 42.6 tonnes, within the 50 tonne limit. A total of 88 birds was caught.

The position of sets is shown in Figure 1. The experiment was disrupted by the presence of orcas (*Orcinus orca*), and following this disruption, lines were set away from the experimental site north of South Georgia. Most of the experimental sets did, however, take place at the experimental site. During the setting of line number 13, the first line of the second experiment, the streamer line became entangled with the ground line. The tension created by the vessel's movement resulted in the streamer line snapping after a few seconds. The remains of the streamer line were quickly redeployed but approximately half its length had been lost. The lost section of the streamer line was recovered during hauling and reattached. All lines set, except numbers 13 and 14, were protected by an identical streamer line.

Tables 1, 2 and 3 present the observations and environmental conditions during setting, and observations during line hauling. A summary of the results is presented later in the paper (Table 4).

No empirical measurements of line sink rates were made. However, a rough indication of the sink rate could be judged by watching the rate at which the slack on the connecting line, between the ground and fishing lines, was taken up. It was clear from observations made with the naked eye that the sink rate of the hook line was greatly increased by the addition of weights. However, even with three weights attached, some baits remained close to the surface, particularly immediately before weights left the vessel.

The catch of seabirds was not distributed uniformly along the line. This was particularly clear in the data collected from control lines set with a single weight. Seabirds are naturally buoyant, and the first bird caught adds buoyancy to the line and consequently reduces the sink rate. Adjacent baits are thus kept at the surface longer, resulting in a greater chance of birds getting caught on the hooks adjacent to the hook which caught the first bird.

Whilst the line was being hauled, baited hooks were once again brought within reach of foraging seabirds. Although most birds are not killed when they become hooked during hauling, some of the

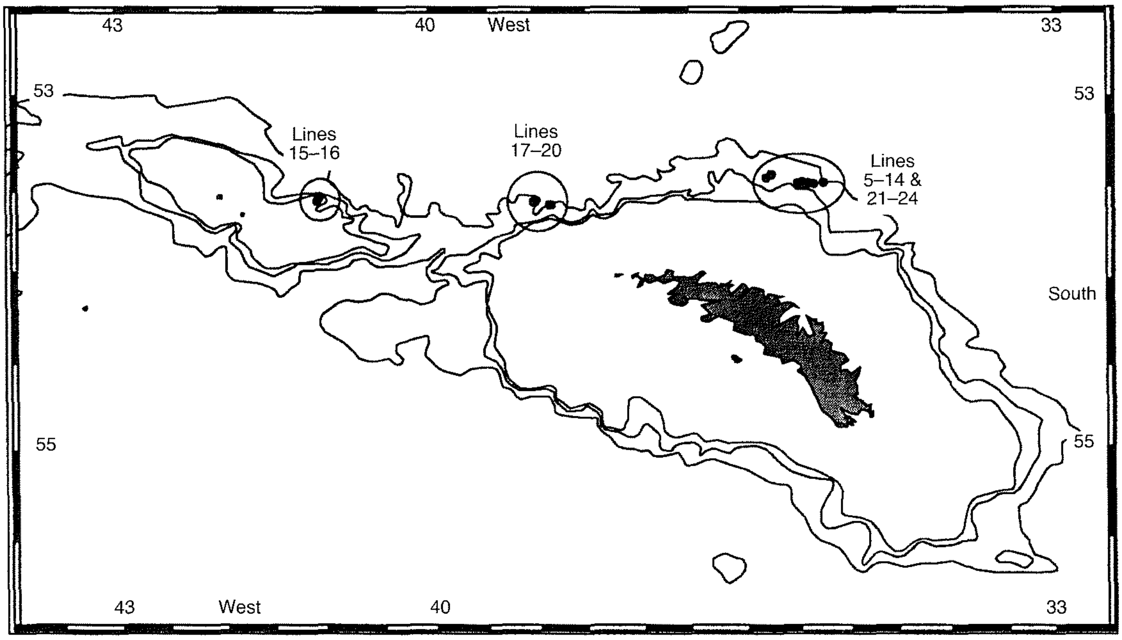

Figure 1: Start positions of longline sets (lines 5–12 were the first trial, lines 13–24 were the second trial; see Table 3). Bathymetric contours are: 500 m, 1 000 m and 2 000 m.

Table 1: Observations made during line setting. Experiment 1 (sets 5–12), experiment 2 (sets 13–24).

Set No.	Line Type	No. of Weights	Feeding Attempts		No. of Birds at Start of Setting		No. of Birds at End of Setting		No. of Birds Observed being Hooked	
			DIM	PRO	DIM	PRO	DIM	PRO	DIM	PRO
5	T	2	250	179	32	34	40	60	4	2
6	C	1	370	358	47	18	53	63	10	2
7	C	1	394	350	45	50	49	88	6	5
8	T	2	258	200	45	30	54	82	1	1
9	T	2	230	184	47	21	60	75	1	0
10	C	1	350	260	42	29	53	92	11	14
11	T	2	196	200	42	70	56	95	0	4
12	C	1	245	280	39	48	65	89	6	8
13	C	2			42	38			2	0
14	T	3							0	0
15	T	3	143		40	10	61		1	1
16	C	2	227		9	4	60		0	0
17	C	2	153		45	7	54		0	0
18	T	3	124		47	17	73		0	0
19	T	3	45		14	3	65		0	0
20	C	2	27		19	2	57		0	0
21	C	2	121	32	42	28	54	49	2	0
22	T	3	73	19	23	19	45	25	1	0
23	T	3	83	108	27	40	32	75	1	0
24	C	2	105	101	15	38	27	61	0	0

DIM = Black-browed albatross C = Control
PRO = White-chinned petrel T = Treatment

Table 2: Environmental conditions during setting operations.

Line No.	Set Direction (degrees)	Wind		Swell	
		Direction (degrees)	Speed (knots)	Direction (degrees)	Height (m)
5	270	270	9	45	3
6	270	240	13	70	3
7	90	310	25	310	5
8	90	300	30	300	5
9	90	275	14	270	1.5
10	90	270	30	270	2.5
11	90	315	26	270	2
12	90	270	26	270	2
13	90	270	8	270	1
14	90	270	8	270	1
15	90	225	18	225	1.5
16	90	270	19	270	2
17	90	225	14	225	1
18	90	225	14	225	1
19	90	315	8	270	2
20	90	315	9	270	2
21	135	315	18	315	3
22	135	315	18	315	3
23	135	315	18	315	3
24	135	315	18	315	3

Table 3: Observations made during hauling. Experiment 1 (sets 5–12), experiment 2 (sets 13–24).

Line No.	Date	Type	No. of Weights	Hooks		Seabird Mortality				Toothfish (kg green weight)
				Set	Observed	DIM	DIC	MAG	PRO	
5	05/02/99	T	2	3 960	3 600	4	0	0	2	1 795
6	05/02/99	C	1	3 960	2 856	10	0	0	2	2 396
7	06/02/99	C	1	3 960	3 684	6	0	0	5	2 856
8	06/02/99	T	2	3 960	3 480	1	0	0	1	1 361
9	07/02/99	T	2	3 960	3 552	1	0	0	0	2 147
10	07/02/99	C	1	3 960	3 624	11	0	0	14	2 027
11	08/02/99	T	2	3 960	3 576	0	0	0	4	2 197
12	08/02/99	C	1	3 960	3 780	6	0	1	8	1 936
13	09/02/99	C	2	3 960	3 768	2	0	0	0	1 941
14	09/02/99	T	3	3 960	3 624	0	0	0	0	2 220
15	11/02/99	T	3	3 960	3 792	1	1	0	1	195
16	11/02/99	C	2	3 960	3 576	0	0	0	0	2 437
17	12/02/99	C	2	3 960	3 792	0	0	0	0	2 141
18	12/02/99	T	3	3 960	3 720	0	0	0	0	2 820
19	14/02/99	T	3	3 960	3 785	0	0	0	0	1 731
20	14/02/99	C	2	3 960	3 790	0	0	0	0	2 103
21	15/02/99	C	2	3 960	3 576	2	0	0	0	1 733
22	15/02/99	T	3	3 960	3 720	1	0	0	0	1 181
23	16/02/99	T	3	3 960	3 552	1	0	0	0	1 964
24	16/02/99	C	2	3 960	3 552	0	0	0	0	1 186

DIM = Black-browed albatross
DIC = Grey-headed albatross
MAG = Southern giant petrel
PRO = White-chinned petrel

C = Control
T = Treatment

injuries sustained are likely to be deleterious to the long-term health of the bird concerned. In total, 13 birds (6 black-browed albatrosses, 5 northern giant petrels and 2 white-chinned petrels) were observed to be hooked during hauling, out of a total of 81 591 hooks observed (0.16 birds/thousand hooks hauled).

Environmental conditions greatly affected the way the vessel operated. The Spanish-system longlines cannot be set in strong crosswinds, as the ground and fishing lines are likely to become entangled. The strategy adopted by the captain of the *Argos Helena* was to set with the swell astern of the vessel. The direction of the swell usually corresponded with the wind direction, although the swell tends to lag behind after sudden wind changes. When hauling, the vessel faced into the wind. Lines were therefore frequently set and hauled in opposite directions.

Environmental conditions can influence seabird by-catch by affecting the performance of the streamer line. Although the streamer line used by the *Argos Helena* complied with CCAMLR regulations, it was only effective at deterring foraging seabirds when deployed directly above the fishing line. Crosswinds tend to bow the streamer line, which exposes the fishing line to seabirds. During conditions of heavy swell, with the line being set with the swell astern of the vessel, the streamer line was not affected by the swell, but the fishing line tended to be deflected by the wave action. Consequently, it would meander from side to side. This effect was exaggerated if the vessel yawed in heavy weather. These sorts of problems could be counteracted by the use of more than one streamer line.

Statistical Analysis

Experiment 1 (Sets 5 to 12)

Line weighting significantly affected the number of birds caught in the first experiment (Chi-squared anova on the GLM model, $p < 0.001$[1]). Day, setting order and environmental variables (wind strength and swell height) were not significant factors. The average number of birds present during setting was also a significant factor ($p < 0.05$).

The same relationships held when the number of black-browed albatrosses caught was the response variable. The number of black-browed albatrosses caught was dependent on the weighting regime and the number of black-browed albatrosses present during setting[2], but the latter was not very significant ($0.05 < p < 0.1$).

Experiment 2 (Sets 13 to 24)

In the second experiment, the weighting regime was not a significant factor influencing the number of birds caught. As before, environmental variables had no influence either. The only factor which was significant was the setting order of the two lines ($p < 0.05$). The number of birds present during setting was not significant. Twice during this experiment the vessel relocated to the west to avoid orcas (Figure 1), but area of fishing was not a significant factor in the GLM.

The first half of the second experiment was characterised by relatively low numbers of white-chinned petrels and zero feeding attempts by this species (Table 1). When the number of black-browed albatrosses caught was the response variable, the most significant factor was setting order ($0.05 < p < 0.1$). The number of black-browed albatrosses present during setting was also not significant.

Comparison of Experiments 1 and 2

Lines with double weights were used during both experiments; as the treatment in the first experiment and as the control in the second. A GLM was run to test for differences between the two sets of double-weight lines. The total number of birds caught on double-weight lines was significantly different between the two experiments ($p < 0.01$). The setting order (first or second in the day) was also significant ($p < 0.05$ in both cases). The number of birds present and environmental variables were not significant factors in this model.

However, it seems likely that this result was driven by the very low numbers of white-chinned petrels, and the total absence of feeding attempts by this species, during the first half of the second experiment. When the number of black-browed albatrosses alone was considered, the weighting regime in the second experiment was shown to have had no significant effect on the number of black-browed albatrosses caught.

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1 This and all subsequent quoted *p* values are for Chi-squared tests.
2 Calculated as the average of numbers present at the start and at the end of setting.

Table 4: Bird by-catch rates and numbers of feeding attempts in the two line-weighting experiments.

Experiment	1		2	
Number of weights	1	2	2	3
Hooks observed	13 941	14 208	22 054	22 193
Hooks set	15 840	15 860	23 760	23 760
Number of DIM caught	33	6	4	3
Number of DIC caught	0	0	0	1
Number of PRO caught	29	7	0	1
Total birds caught and killed	63	13	4	5
Albatross by-catch rate	2.37	0.42	0.18	0.18
Bird by-catch rate per hooks observed	4.52	0.91	0.18	0.23
Bird by-catch rate per hooks set	3.98	0.82	0.17	0.21
Average number of feeding attempts (DIM) per set	339.8	233.5	126.6	93.6

DIM = Black-browed albatross
DIC = Grey-headed albatross
PRO = White-chinned petrel

There was a suggestion in this latter model that wind speed (but not swell height) was inversely related to the number of birds caught ($0.05 < p < 0.1$). There was also a weak relationship between the number of black-browed albatrosses caught and the number of feeding attempts ($0.05 < p < 0.1$). Table 4 shows that even though there were similar numbers of black-browed albatrosses present during setting in experiments 1 and 2, the number of feeding attempts by this species was lower in the second experiment than in the first. A model with the number of feeding attempts as the response variable had both experiment and wind speed as significant factors ($p < 0.01$) (but not swell height or the number of black-browed albatrosses present). Examination of the data reveals that this positive correlation (an increase in the number of feeding attempts with wind speed) was only present in the second experiment (Figure 2). It does, nevertheless, seem possible that the combination of general weighting regime and wind speed has an effect on the number of feeding attempts made by black-browed albatrosses, and that this may (weakly) affect the number of birds caught.

Although there was no difference between the numbers of black-browed albatrosses present during setting between the first and second experiment, there was in the numbers of white-chinned petrels present. Putting numbers of white-chinned petrels as the response variable in a GLM of double-weight lines, both wind and experiment were significant factors ($p < 0.01$). However, plots of all the data on white-chinned petrels present reveal that this is not a simple relationship (Figure 3).

The final results are given in Table 4.

The above analysis suggests the following:

(i) There was a significant reduction in bird mortality when double weights were used on the line compared to single weights. However, there was no further significant reduction when triple weights were used. Double weights were equivalent to 8.5 kg at 40 m intervals (8.5 kg/40 m) and triple weights were equivalent to 12.75 kg/40 m. The CCAMLR-recommended weight regime is 6 kg at 20 m intervals.

(ii) The apparent improvement in the performance of double weights between the first and second experiments is most likely to be the result of a combination of factors. There was a lower number of feeding attempts by black-browed albatrosses, which may have been caused by lower wind speeds or lower general availability of bait. There were lower numbers of white-chinned petrels present in the second experiment, perhaps due to lower wind speeds.

(iii) There was some suggestion that the first line set of any day had a higher chance of catching black-browed albatrosses.

Seabird Vulnerability

From observations made during line setting it became clear that not all seabird species were equally likely to become hooked. The species composition of the flock associating with the vessel differed greatly between setting and hauling. Those species prevalent during setting, the black-browed albatross and white-chinned petrel, are more likely to become the victims of incidental mortality than are birds which are predominantly

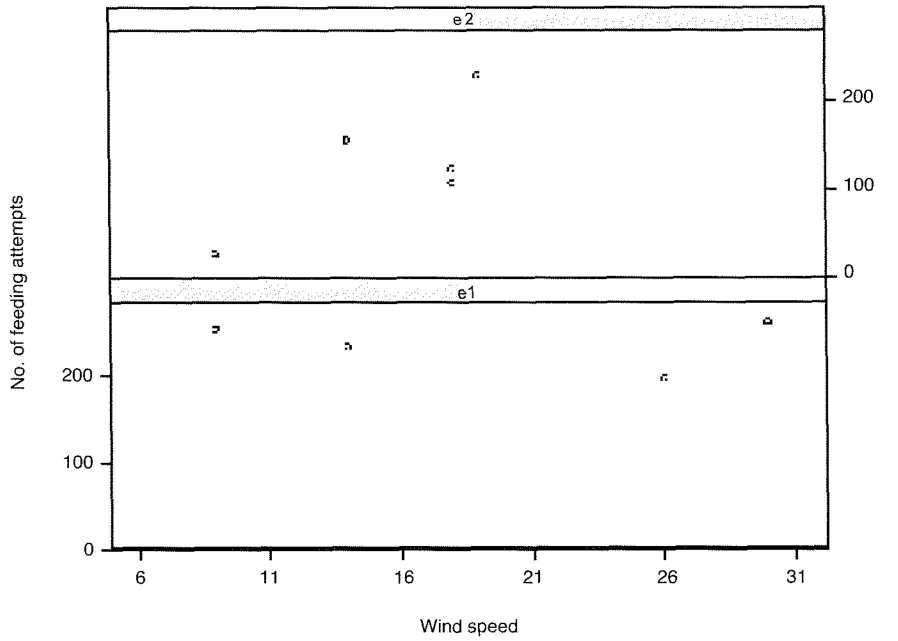

Figure 2: Number of feeding attempts by black-browed albatrosses in experiments 1 and 2 (e1, e2), plotted against wind speed.

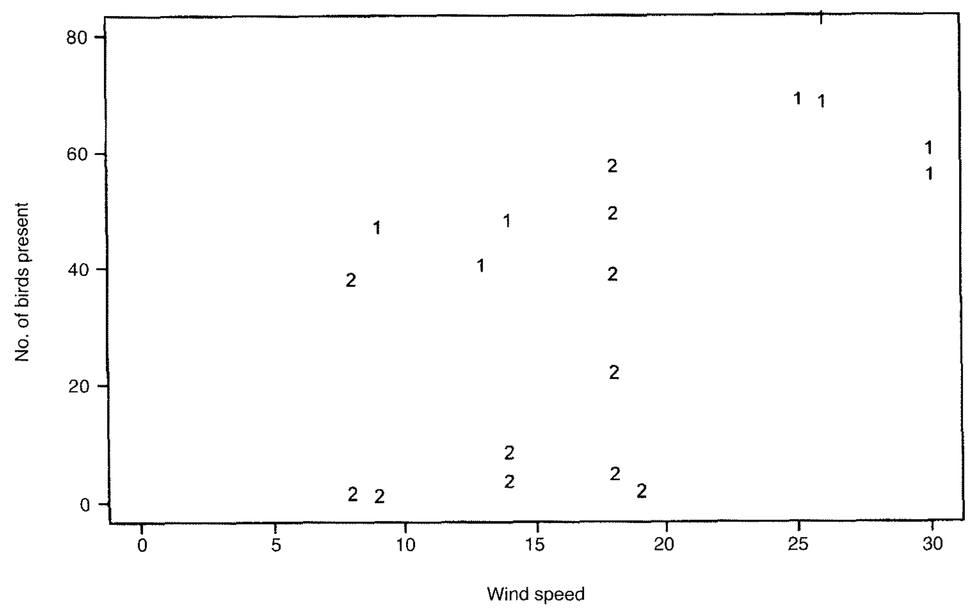

Figure 3: Relationship between numbers of white-chinned petrels present and wind speed, by experiment (1 or 2).

present at hauling, such as the southern and northern giant petrels (*Macronectes halli* and *M. giganteus*).

Black-browed albatrosses were consistently the most numerous species associated with the vessel during setting. They are very skilful fliers and adept at taking baits from hooks. Black-browed albatrosses approached the line from down wind (i.e. flying into the wind). This allowed them to gain lift from the wind and thus reduce their speed through the air. In this manner they can effectively hover above the line, searching for a bait to attack. Once a bait is located, they swoop down and settle heavily on the water surface and immediately dive below the surface, using their wings and feet for propulsion. They have been recorded to reach depths of up to 5 m in this manner (Prince et al., 1994). Alternatively, if baits are close to the surface, black-browed albatrosses descend to about a metre above the surface of the water, whence they make a clumsy attempt at plunge diving. The birds rarely fully submerge during these plunges.

Whilst foraging, black-browed albatrosses are very aggressive and they monopolise the area closest to the vessel. Their feeding attempts are relatively easy to observe. When a bird is hooked it will attempt to free itself with violent jerks of the head. It was noted that when only a single weight was deployed, black-browed albatrosses could resist the pull of the line for a considerable period, remaining on the surface until approximately 250 m astern of the vessel. Thus they effectively act as a float and retain the line close to the surface where other birds can become caught. This effect was greatly reduced when more weight was applied to the line. Albatrosses hooked on lines deployed with three weights were dragged below the surface within a few seconds. The streamer line deterred black-browed albatrosses from making feeding attempts but was only effective when set directly above the hook line.

White-chinned petrels were also conspicuous ship associates during setting. They generally foraged at a greater distance astern of the vessel than black-browed albatrosses. Their behaviour was not linked with wind direction to the same extent as the larger albatrosses. Their superior diving ability, reaching depths of up to 12 m (Huin, 1996), allows them to feed on baits that are unavailable to other species. This underwater feeding behaviour makes it very difficult to see if a bird actually takes a bait or becomes hooked. It is believed that those white-chinned petrels hooked are unable to return to the surface.

During the experiment, grey-headed albatrosses did not associate with the vessel in large numbers. Typically, one or two birds of this species were present during setting. They exhibit similar behaviour to black-browed albatrosses when approaching the line, however they are much better plunge divers. They would frequently plunge from two or three metres above the surface of the water and remain submerged for several seconds. Additionally, in contrast to black-browed albatrosses, they seemed to be undeterred by the streamer line and were observed flying through streamers. The differences in feeding behaviour may reflect the differences in diet between the two species. Grey-headed albatrosses take a high proportion of squid in their diet, whilst black-browed albatrosses are generalists taking a mixture of squid, fish and krill (Prince, 1980). The low number of grey-headed albatrosses caught during the course of this experiment was due to the low numbers associating with the vessel, but their behaviour makes them highly vulnerable to incidental mortality.

Although northern giant petrels were recorded in higher numbers than southern giant petrels throughout the course of the experiment, their behaviour and thus vulnerability to incidental mortality is similar. Giant petrels are regarded as scavengers and are not skilled at taking baits from longline hooks. Although giant petrels were the most numerous species during line hauling, when they scavenged offal and discards, their presence was not obvious during setting. The small number of feeding attempts observed was generally restricted to surface seizing and very few dives were observed. However, one southern giant petrel was caught, on line 12, a control line with a single weight per 40 m (Table 3). Giant petrels appeared to be at very low risk when lines were set with additional weight.

Wandering albatrosses were often in the vicinity of the vessel as lines were set, however no attempts at feeding on baited hooks were observed. From the observations made it appears that they are only potentially vulnerable when the line is maintained close to the surface, such as from the buoyant effect of hooked birds.

DISCUSSION

These trials have clearly shown the advantage of line-weighting regimes of at least 8.5 kg/40 m. Increasing the line-weighting regime to 8.5 kg/40 m had no deleterious effect on fishing operations but significantly reduced the by-catch of birds. Increasing the weight beyond this did not significantly reduce the number of birds killed. Although the line with hooks appeared to sink faster with triple weights attached, sections of line with the 40 m spacing between weights were still available to foraging seabirds. The possibility that changing to 20 m spacing might solve this problem should be investigated. Greater weight may have the additional benefit of counteracting the buoyancy effect of a hooked bird, which may otherwise temporarily increase the probability of other birds being caught. Another possible approach to reducing the threat to seabirds, which has yet to be investigated, is to set the line at a slower vessel speed, although this might cause problems with the line fouling the propeller.

When using double or triple weights, environmental factors became much more important than the line-weighting regime. Wind speed, in particular, appeared to affect the number of white-chinned petrels that were present around the line. Both wind speed and experiment were shown to have significant effects on the number of feeding attempts by black-browed albatrosses (more feeding attempts in higher wind speeds). This latter result suggests that in addition to wind, the decrease in the general availability of baits (because both line-weighting regimes were >8 kg/40 m) in the second experiment reduced the number of feeding attempts. This observation has important consequences because it implies that the bird by-catch rates from lines using 8.5 kg/40 m would be lower in a fleet of vessels all using 8.5 kg/40 m than in a fleet using a mixture of weighting regimes.

The cause of the effect of setting order (first or second in the day) is currently unknown. The duration of setting was almost exactly the same for each set (0.5 h).

It is noteworthy that the bird by-catch rates in Table 4 are similar under the second line-weighting regime to those found during daytime setting around South Georgia in the 1998 winter fishery (April to August). By-catch rates from the 8.5 kg/40 m weighting regime may well have been lower had the streamer line not broken on set 13, when two black-browed albatrosses were caught. Many more birds, especially black-browed albatrosses, are present around south Georgia in the February period than in winter. The fact that such low catch rates are achievable even when fishing during the day at a time of year when black-browed albatrosses and white-chinned petrels are most vulnerable, suggests that it may be possible to reduce seabird by-catch to acceptably low levels from longline fishing at any time around South Georgia.

CONCLUSIONS

(i) To minimise seabird by-catch, line-weighting regimes of at least 8.5 kg/40 m should be used. Line weightings greater than this (such as the 12.75 kg/40 m used here) have not been shown by this experiment to significantly reduce seabird by-catch over that with 8.5 kg/40 m.

(ii) Good weather conditions (e.g. low wind speed) favour reduced seabird by-catch through enhancing streamer-line efficiency. Crosswinds in particular reduce the efficiency of streamer lines, although a second streamer line may compensate in some conditions.

(iii) Seabird by-catch on lines using effective weighting regimes may be even further reduced where all lines being set in the vicinity use effective line-weighting regimes (as in our second experiment) than where some lines use ineffective regimes.

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