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Deterring Albatrosses from Contacting Baits During Swordfish Longline Sets

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Abstract

The effectiveness of albatross deterrent techniques was examined during line setting operations in the Hawaii-based longline fishery for swordfish *(Xiphias gladius).* Methods tested were bird scaring streamer lines, weights added to baits, and camouflaging bait with food coloring. Observations were made on ca. 66 baited branch lines deployed on 96 occasions. Baits dyed blue and baits with added weight both reduced the number of contacts between baits and Black-footed (*Phoebastria nigripes)* and Laysan *(P. immutabilis)* Albatrosses by about 90%. Streamer lines reduced contacts between baits and albatrosses by about 70%.

Introduction

Longline-related mortality has been implicated as a major threat to albatross populations, and a worldwide effort is under way to mitigate this problem (Bergin 1997). Mortality caused by the Hawaii-based domestic longline fishery could impact North Pacific Black-footed *(Phoebastria nigripes)* and Laysan *(P. immutabilis)* Albatross populations nesting primarily in the Northwestern Hawaiian Islands (NWHI), although the relative importance of fishing mortality is difficult to determine (Gales 1997, Ludwig et al. 1997, Cousins and Cooper 2000). Of the two species the Black-footed Albatross is the most vulnerable because it has the smallest breeding population (ca. 120,000 birds) and is taken in larger numbers (1,600-2,000 birds annually) by the domestic fishery (Cousins and Cooper 2000). The foreign take of albatrosses is unknown. The domestic fishery largely overlaps the range of both species, fishing mostly from 15°-45°N and from 145°-180°W (He et al. 1997). Domestic effort reached about 15 million hooks in 1997, and foreign longline fleets probably deployed about twice that much effort in the same general area (Cousins and Cooper 2000).

This study tested deterrents to albatross feeding on baited branch lines during longline setting. Studies on Southern Hemisphere pelagic longline fisheries indicate that southern species of albatrosses are mostly hooked during daylight setting, and are drowned as the line sinks, whereas those caught during line hauling are usually alive, sometimes uninjured, and may be released (Brothers 1994, Brothers et al. 1999). In the region around the NWHI only 5-40% of domestic longline sets are made in daylight (He et al. 1997) and sets are most often made in the afternoon or evening using light sticks attached to the branch lines to increase the nighttime catch rate of swordfish (Bigelow et al. 1999). Commercial vessel encounters with albatrosses may be somewhat reduced by setting at night and because commercial longlining is prohibited within 50 nautical miles of the NWHI (Boggs and Ito 1993). To increase the rate of bird encounters over that of commercial vessels for this study the National Marine Fisheries Service (NMFS) used a research vessel to conduct tests in daylight sets near the NWHI breeding colonies while albatrosses were foraging locally to feed small chicks (Anderson and Fernandez 1998, as cited by Cousins and Cooper 2000). To prevent albatross mortality, hooks were replaced with net pins to hold the bait.

The purpose of the study was to test seabird deterrent methods in the central North Pacific fishing grounds prior to enacting new bird deterrent regulations for the domestic fishery. The methods tested were: (1) a bird scaring streamer line, (2) addition of weight to the bait, and (3) dyeing the bait blue with food coloring. A streamer line (Brothers 1991, 1994) trails over the area in which the bait sinks as the vessel moves ahead, scaring birds away, and interrupting their flight paths to the bait. Adding weight (Brothers et al. 1995) causes bait to sink quickly below the limited plunging depth of albatrosses. And blue food coloring may make bait blend into the water, or make it appear deeper.

Methods

Longline Gear

Tests were conducted February 7-28, 1999, aboard the R.V. *Townsend Cromwell* near and between Laysan Island and French Frigate Shoals, mimicking swordfish longline techniques in which the main line is set much closer to the surface than tuna longline (Boggs and Ito 1993, He et al. 1997, Bigelow et al. 1999). A 4 mm monofilament main line was set tight at 7 knots (vessel speed = line setting speed) with branch lines attached at 16 second intervals (57.6 m apart). A float and float line were attached after every four branch lines (230 m between float lines). Branch lines were 14.6 m of 2.1 mm monofilament with 60 g swivel weights located 3.7 m above the bait. Float lines were 9 m of 6.25 mm polypropylene rope.

Squid *(Illex* sp.) weighing about 200 g each was used as bait and pinned to the end of each branch line using 8.25 cm nickel plated brass net pins weighing 13 g, about the same weight as typical straight shank #8/0 Mustad hooks. The pins resembled safety pins, having no exposed point. Bait thawing varied as in the commercial fishery, and was recorded, but was not a controlled variable. Typically, partially thawed bait (ice crystals present, but not rigid) was used in the morning and fully thawed bait (limp) was used in the afternoon. Bait was often reused to save money and because freezer space for bait was limited.

Experimental Design

A set about 16 km long with about 270 branch lines was made each morning and again each afternoon. Sections of these sets were observed, averaging 18 minutes duration (3.8 km in main line length), with an average of 66 attached branch lines. Each observed set section provided a record of contact rates between birds and baits for each species of albatross. Timed sections were intended to be of equal length, in order to utilize a prepackaged quantity of bait. However, accidental overruns and shortages of baits per case caused variation in the length and number of branch lines in each section. Bird contacts with bait were expressed as rates per 100 branch lines to adjust for variation in the number of branch lines observed per record.

Timed set sections were observed for each of four treatments (control, streamer line, dyed bait, and weighted bait). Four set sections were observed each morning and four each afternoon. It was assumed that bird behavior might be affected by setting operations commencing with a control treatment because the absence of a deterrent might encourage continued attempts to take bait during subsequent treatments. And it was assumed that behavior might differ between morning and afternoon. So, either the first or the last of each four morning and afternoon set sections was a control section, with the remaining three set sections used for replicate observations of a deterrent treatment. Order was classified as (1) control first in the morning, (2) control last in the morning, (3) control first in the afternoon, and (4) control last in the afternoon. Each order was applied an equal number of times to each deterrent treatment in a random sequence and the effects of treatments and order were evaluated with two-way analysis of variance (ANOVA, Sokal and Rohlf 1981).

The observation of one control treatment for every three deterrent treatments resulted in an equal number of records per treatment. Except for observing three replicates in a row of one deterrent treatment, and choosing the last few deterrent treatments to complete a balanced design, the deterrent treatments were applied at random. More complete randomization would have necessitated changing between deterrents several times each morning and afternoon. Changes in bird abundance, observers, and environmental conditions (e.g., visibility) between set sections qualified each section as a separate observation. No pairwise comparison of control versus deterrent treatments was planned a priori. It was not anticipated which, if any, of the deterrents would be successful. Pairwise comparisons were made a posteriori using Fisher's least-significant-difference (LSD) test (Kendall and Stuart 1968).

Five experienced marine biologists and one NMFS longline fishery observer were trained by a U.S. Fish and Wildlife Service expert to identify local pelagic seabirds to genera and all North Pacific albatrosses to species. During each observed set section two of these observers called out bird contacts with bait, by species, while a recorder tallied the data. One observer scanned the entire area in which contacts occurred, extending 150 m behind the stern and 15 m to either side of the main line, and reported contacts between birds and baited branch lines. A second observer used binoculars to zoom in on suspected contact events to confirm reports of the first observer and to observe whether other birds contacted the same bait.

A contact was defined as an albatross grasping a bait in its beak while the bait was attached to a branch line. Contacts by birds contending for a bait already held by one bird were not counted unless it could be determined that the bait was taken away by another bird. A crowd of birds usually formed around the first bird contacting a bait, making it hard to determine if a bait was taken except when the successful contender was a different species than the first bird. Undoubtedly some contacts escaped observation. Difficulties and inaccuracies in the observations applied equally to all treatments.

At the end of each set section (every ca. 18 minutes) the observers and recorder were replaced by alternates to increase attentiveness. The resting observers estimated the number of birds of each species (or genera for species besides albatrosses) in the area extending 300 m behind and to either side of the stern at the start and end of each set section. The start and end estimates were averaged to provide an abundance estimate on each taxa for each observed section. The effects of treatments and order on bird abundance data were also analyzed using two way ANOVA.

Deterrent Techniques

The streamer line materials and construction followed the design described by Brothers (1994) except for some modifications similar to those suggested by Kalish and Tong (1993). The 150 m streamer line comprised a 10 m attachment section made of 6 mm yellow twisted polypropylene, a 40 m aerial streamer segment made of the same material with seven forked branch streamers, an 85 m × 3 mm red twisted nylon trailing segment with 8 small streamers on the first 40 m, and a 15 m × 12 mm yellow twisted polypropylene drogue segment. The streamer line was flown from a fiberglass pole mounted 4 m forward of the stern, extending 10 m above water and 2 m outboard. The streamer line was about 8 m high at the stern, and the ends of the first forked streamer dangled just above water, 10 m behind the stern, about 5 m directly aft of the bait entry point. Changing between the streamer line and control treatments took about two minutes, during which main line setting continued but no baited branch lines were attached and observation was halted.

This streamer line differed from Brothers (1994) design by (1) replacement of the 30 mm barrel swivel end weight with a drogue segment, (2) the use of thicker line (6.25 mm as opposed to 3 mm) for the large streamer segment, (3) the use of different forked branch streamers, and (4) the addition of small streamers on the trailing segment. The drogue substituted for the heavy end swivel to add drag and keep the streamer line taut, but it was thought to be less likely to tangle with the longline. In case of such tangling the thicker forward segment was intended to defer breakage to the thinner and more easily replaced trailing segment.

Forked branch streamers were made from single (rather than double) 4 mm braided nylon cord with the upper half covered with 5 mm inside diameter clear plastic tubing crimped to the middle of the streamer along with a 40 g weight. The forked end of the branch streamer was made with three 1 m × 25 mm pieces of red, orange, and green plastic ribbon threaded through a swivel crimped to the end of the nylon cord such that the two ends of each ribbon dangled 0.5 m down from the swivel. This design (Kalish and Tong 1993) was substituted for that of Brothers (1994) to help prevent the branch streamers from wrapping around the streamer line in high winds.

The first branch streamer was attached 10 m from the stern, and the next six were attached at 5 m intervals behind the first. The length of nylon cord was adjusted so that the ends of the plastic ribbon occasionally touched the water. Brothers (1994) design calls for three branch streamers 7 m apart (or more as needed) to cover the length of the streamer line above the water. If the first of these three streamers was 10-20 m aft of the stern, this would suggest that the third streamer was only 24-34 m behind the stern. So in the present study the aerial portion of the streamer line extended at least as far back (>40 m) as in the nominal design recommended for the Southern Hemisphere tuna longline fishery (Brothers 1994). The aerial portion of the streamer line extended back about as far as birds made contacts with bait, except for cases where birds contacted baits already held by another bird. However, Kalish and Tong (1993) noted that the portion of the streamer line trailing in the water did little to prevent birds from taking baits that might still be near the surface that far back. And this study followed their recommendation in adding 8 short (0.15 m) streamers made by weaving yellow plastic strapping tape (bait carton straps) through the trailing segment at 5 m intervals.

Bait was dyed using a concentrate made from 0.45 kg of Virginia Dare FD&C Blue No. 1 powder dissolved in 7.2 L of water. Three 50 kg batches of partially thawed bait were soaked for 15-20 minutes each in 1.0 L of the concentrated dye added to 18 L of water. Soaking in dye had the advantage of thoroughly thawing the bait. However, dyed bait was not always more thawed than other bait because dyed bait was often re-frozen and later used partially thawed.

All branch lines were weighted as in the commercial fishery. For weighted bait treatments, an additional 60 g swivel weight was pinned on along with the bait. The fishing equivalent would be a weighted hook or a weight within a few centimeters of the hook.

Results

Observations

Although many kinds of shearwaters, boobies, petrels, terns, and frigate birds were seen in the area, only Black-footed and Laysan Albatrosses ever made contact with the bait. No other species of albatross was seen in over 100 hours of observation. No injuries or mortalities were observed. Retrieval of branch lines with missing net pins was rare, indicating that few could have come off as birds interacted with the bait.

A total of 96 set sections from 24 sets were successfully completed, providing 24 observations of each treatment for each of the two albatross species (Table 1). There were six observations per species in each treatment-order combination. The number of contacts observed per set section ranged from zero in some set sections with deterrents to 43 Black-footed and 48 Laysan Albatross contacts in control set sections. The number of birds observed ranged from 5 to 125 for Black-footed Albatross and from 2 to 325 for Laysan Albatross (Table 1). Abundance was lowest in the dyed bait treatments (mean = 37.8 and 42.9, $n = 24$) and highest in the weighted bait treatments (mean = 61.0 and 68.7, $n = 24$) but there was no significant treatment effect on abundance (two-way ANOVA, $F = 1.2$ and 2.0, $P = 0.1$ and 0.3, d.f. = 3, for Black-footed and Laysan Albatrosses, respectively). Abundance was lowest when deterrent treatments preceded the control treatment in the morning (order 2 mean = 31.6 and 34.5, $n = 24$) and the effect of order was significant (two-way ANOVA, $F = 4.0$ and 4.3, $P = 0.01$ and 0.007, d.f. = 3, for Black-footed and Laysan Albatrosses, respectively). The presentation of deterrent treatments first in the morning seems to have discouraged birds from aggregating around the vessel until the first control treatment was conducted. After that, bird abundance was often high during deterrent treatments.

Contact Rates

Contact rates per 100 branch lines (Table 1) were highest for the control treatment and lowest during the dyed bait treatment (Fig. 1). Contact rates were significantly affected by the treatments (two-way ANOVA, $F > 34$, $P < 0.0005$, d.f. = 3) for both albatrosses, and by order ($F = 7.1$, $P < 0.0005$, d.f. = 3) and by the interaction between treatment and order ($F = 3.1$,

$P = 0.003$, d.f. = 3) for Black-footed Albatross. The significance of the order and interaction effects could lead one to question the treatment effect. Significant variation in the abundance of albatrosses by order probably contributed to the apparent effect of order on contact rates, suggesting that the results should be standardized for bird abundance. Furthermore, linear regressions of contact rates (per 100 branch lines) for the combined deterrent treatments on bird abundance indicated significant proportional effects of abundance on contact rates (R^2 = 14.5% and 10.4%, intercept = 0, slope = 0.087 and 0.060 contacts per bird per 100 branch lines, and 95% CI for slope = 0.022 and 0.018, $P < 0.0005$, $n = 72$, for Black-footed and Laysan Albatrosses, respectively). Therefore the contact data were re-analyzed as contact rates per bird per 100 branch lines for both species (Table 2).

Contact rates per bird (Fig. 2) were again highest for the control treatment (0.83 contacts per Black-footed Albatross per 100 branch lines, and 0.69 contacts per Laysan Albatross per 100 branch lines) and lowest during the dyed bait treatment (0.046 and 0.039 contacts per bird per 100 branch lines for Black-footed and Laysan Albatrosses, respectively). For both species the contact rate per bird was not significantly affected by order or by treatment-order interactions, but was significantly affected by the treatments (Table 2, two-way ANOVA, $F = 27.4$ and 36.9, $P < 0.0005$, d.f. = 3 for Black-footed and Laysan Albatrosses, respectively).

Pairwise comparisons conducted a posteriori using Fisher's LSD did not indicate that any of the deterrents was significantly better than any other ($P > 0.09$) although the dyed bait treatment came closest to being significantly better than the streamer line ($P = 0.094$ and 0.113 for Black-footed and Laysan Albatrosses, respectively). All of the deterrent treatments had significantly lower contact rates than the control treatment in a posteriori tests ($P < 0.0005$).

The effectiveness of the deterrents was calculated as the percent reduction in contact rates in comparison with control results (Fig. 3). In terms of the contact rate per 100 branch lines, the streamer line reduced contacts by 68% and 74%, dyed bait reduced contacts by 95% and 92%, and weighted bait reduced contacts by 91% and 92% for Black-footed and Laysan Albatrosses, respectively. Expressed as contact rate per bird per 100 branch lines, the effectiveness of the deterrents was slightly improved. The streamer line was 75% and 77% effective, the dye was 95% and 94% effective, and weights were 93% and 91% effective for Black-footed and Laysan Albatrosses, respectively.

Discussion

The Hawaii-based longline fishery includes a deep-set daytime tuna fishing component, a shallow-set nighttime swordfish fishing component, and components with mixed fishing strategies and mixed target species, including swordfish. The swordfish and mixed components are dominant

Table 1. Rates of albatross contacts with bait (per 100 hooks) in a two-way factorial experiment with four treatments and four orders.

Treatment				Black-footed Albatross		Laysan Albatross	
	Order	Date (February)	Branch lines (no.)	Abundance (no.)	Contacts (per 100 hooks)	Abundance (no.)	Contacts (per 100 hooks)
Control	1	11	71	23	16.9	39	28.2
	1	14	60	18	10.0	28	30.0
	1	16	64	41	28.1	43	34.4
	1	17	68	40	17.6	82	44.1
	1	18	67	82	13.4	162	53.7
	1	23	71	32	7.0	3	0.0
	2	8	71	75	26.8	57	35.2
	2	12	71	40	28.2	100	60.6
	2	13	71	32	46.5	32	8.5
	2	15	64	100	28.1	125	37.5
	2	20	67	40	44.8	7	9.0
	2	21	64	8	14.1	2	3.1
	3	8	75	100	44.0	75	28.0
	3	10	71	125	53.5	125	26.8
	3	11	75	26	12.0	46	64.0
	3	14	64	75	37.5	57	42.2
	3	15	64	50	32.8	50	59.4
	3	20	64	25	45.3	3	3.1
	4	7	64	40	32.8	40	26.6
	4	9	68	50	51.5	50	35.3
	4	13	45	57	64.4	32	15.6
	4	16	64	125	67.2	125	29.7
	4	17	64	125	48.4	75	46.9
	4	21	64	5	14.1	5	3.1
Streamer	1	16	64	100	7.8	75	6.3
	1	16	64	125	12.5	100	9.4
	1	16	64	125	10.9	125	21.9
	1	23	64	29	0.0	3	0.0
	1	23	64	17	0.0	2	0.0
	1	23	68	14	0.0	2	0.0
	2	15	68	16	0.0	23	7.4
	2	15	64	32	7.8	57	7.8
	2	15	64	57	7.8	100	3.1
	2	20	60	32	31.7	5	0.0
	2	20	68	32	10.3	7	1.5
	2	20	64	32	17.2	7	7.8
	3	11	68	40	11.8	75	16.2
	3	11	68	40	11.8	75	17.6
	3	11	67	32	11.9	75	23.9
	3	14	64	75	12.5	57	9.4
	3	14	64	75	10.9	57	7.8
	3	14	67	57	4.5	75	6.0
	4	9	68	21	5.9	21	1.5
	4	9	67	57	9.0	40	0.0
	4	9	71	40	7.0	40	2.8
	4	16	64	125	28.1	75	9.4
	4	16	64	125	14.1	100	15.6
	4	16	64	125	18.8	125	14.1

Table 1. (Continued.)

Treatment	Order	Date (February)	Branch lines (no.)	Black-footed Albatross		Laysan Albatross	
				Abundance (no.)	Contacts (per 100 hooks)	Abundance (no.)	Contacts (per 100 hooks)
Dyed bait	1	14	68	25	0.0	40	0.0
	1	14	60	18	0.0	50	0.0
	1	14	67	18	1.5	40	0.0
	1	17	64	57	1.6	100	0.0
	1	17	64	100	0.0	100	0.0
	1	17	64	71	0.0	75	0.0
	2	12	67	14	1.5	21	3.0
	2	12	71	32	12.7	57	16.9
	2	12	71	40	9.9	75	26.8
	2	21	64	7	0.0	1	0.0
	2	21	64	8	0.0	2	0.0
	2	21	64	8	0.0	3	0.0
	3	8	71	82	0.0	57	0.0
	3	8	71	40	0.0	40	0.0
	3	8	53	32	0.0	40	0.0
	3	15	64	75	4.7	75	7.8
	3	15	64	75	6.3	75	1.6
	3	15	64	57	4.7	75	1.6
	4	13	71	57	0.0	40	0.0
	4	13	71	40	0.0	32	0.0
	4	13	68	40	0.0	25	0.0
	4	21	64	6	0.0	4	0.0
	4	21	64	7	0.0	6	0.0
	4	21	67	5	0.0	5	0.0
Weight	1	11	71	40	1.4	57	2.8
	1	11	71	40	1.4	40	0.0
	1	11	67	32	0.0	32	1.5
	1	18	64	125	1.6	325	7.8
	1	18	64	125	1.6	250	4.7
	1	18	64	125	4.7	200	7.8
	2	8	71	14	4.2	14	1.4
	2	8	75	32	1.3	25	0.0
	2	8	68	57	0.0	32	0.0
	2	13	71	12	0.0	16	0.0
	2	13	71	21	2.8	32	0.0
	2	13	71	25	2.8	32	1.4
	3	10	75	100	2.7	100	0.0
	3	10	71	100	5.6	100	4.2
	3	10	64	100	1.6	100	0.0
	3	20	64	25	3.1	3	0.0
	3	20	64	25	0.0	3	1.6
	3	20	64	21	0.0	3	0.0
	4	7	71	25	1.4	20	0.0
	4	7	71	36	0.0	36	0.0
	4	7	71	40	2.8	40	2.8
	4	17	64	102	10.9	46	4.7
	4	17	64	125	10.9	75	3.1
	4	17	64	125	12.5	75	15.6

Order: 1 = control first in the a.m., 2 = control last in the a.m., 3 = control first in the p.m., 4 = control last in the p.m.). Each observation ($n = 96$) is from a timed section (ca. 18 min, 3.8 km) of longline set for which the number of branch lines and number of birds present are shown.

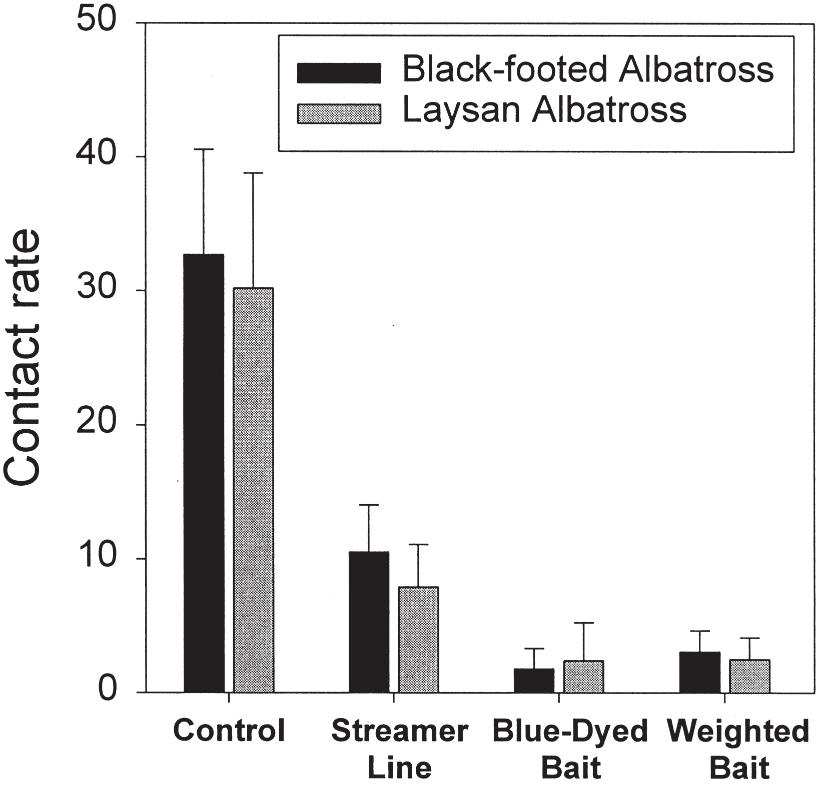

Figure 1. Mean contact rates (per 100 branch lines) between albatrosses and baited branch lines in observed sections of swordfish style longline sets subjected to four treatments (no deterrent = control, streamer line to ward off birds, bait dyed blue for camouflage, and bait weighted to sink faster). Each bar shows a mean and 95% CI for 24 observed set sections for each treatment and species of albatross. Sets were made in daylight near the Northwestern Hawaiian Islands in February 1999. Contacts were defined as birds grasping baits attached to branch lines.

Table 2. Table of means and two-way analysis of variance (ANOVA) on the contact rate (per bird per 100 branch lines) for two species of albatross.

		Treatment									
		Black-footed Albatross					Laysan Albatross				
Order		Control	Streamer	Dye	Weight	Total	Control	Streamer	Dye	Weight	Total
1	Average	0.47	0.044	0.018	0.022	0.14	0.58	0.059	0.000	0.030	0.17
	S.D.	0.24	0.049	0.033	0.016	0.22	0.37	0.072	0.000	0.019	0.30
2	Average	0.97	0.372	0.126	0.101	0.39	0.77	0.302	0.133	0.025	0.31
	S.D.	0.63	0.352	0.165	0.119	0.50	0.53	0.415	0.162	0.043	0.44
3	Average	0.73	0.227	0.038	0.038	0.26	0.86	0.193	0.024	0.111	0.30
	S.D.	0.56	0.113	0.042	0.049	0.39	0.49	0.084	0.041	0.252	0.43
4	Average	1.18	0.185	0.000	0.071	0.36	0.56	0.090	0.000	0.071	0.18
	S.D.	1.00	0.061	0.000	0.039	0.67	0.18	0.055	0.000	0.079	0.25
Total	Average	0.83	0.207	0.046	0.058		0.69	0.161	0.039	0.059	
	S.D.	0.67	0.213	0.095	0.070		0.41	0.224	0.096	0.130	

		Black-footed Albatross					Laysan Albatross				
ANOVA	Source	d.f.	MS	*F*	*P*-value	*F* crit	d.f.	MS	*F*	*P*-value	*F* crit
	Order	3	0.31	2.58	0.060	2.72	3	0.14	2.20	0.094	2.72
	Treatment	3	3.33	27.38	0.000	2.72	3	2.28	36.94	0.000	2.72
	Interaction	9	0.13	1.06	0.403	2.00	9	0.03	0.56	0.825	2.00
	Error	80	0.12				80	0.06			

The experimental design was composed of four treatments and four orders (1 = control first in the a.m., 2 = control last in the a.m., 3 = control first in the p.m., 4 = control last in the p.m.) with six observations in each cell. Each observation was from one timed section (ca. 18 min, 3.8 km) of longline set. S.D. = standard deviation, d.f. = degrees of freedom, MS = mean square, and *F* crit = the critical value of *F* at the 0.05 level.

in the northern fishing grounds (He et al. 1997), where most longline-related mortality takes place (Cousins and Cooper 2000). Although fishery opponents are highly critical of the current absence of seabird deterrent regulations, by setting primarily at night this fishery may already prevent 60% to 96% (Brothers et al. 1999) of potential longline mortality, and by using weighted branch lines this fishery may be preventing additional mortality (Brothers et al. 1998).

The time and location chosen for this study contributed greatly to its success. Strong season and area effects are typical of seabird fishery interactions (Brothers et al. 1999). The greatest localized foraging concentration of Black-footed Albatross occurs during the December-February incubation and hatching season near the largest colonies at Laysan Island and the Midway Islands, and the greatest incidence of seabird fishery interactions in the Hawaii fishery occurs just outside this area and northward (Cousins and Cooper 2000). Peak hatching occurs in early February, and for the first week to ten days after hatching the parent birds make relatively short foraging trips in contrast to the transoceanic foraging trips

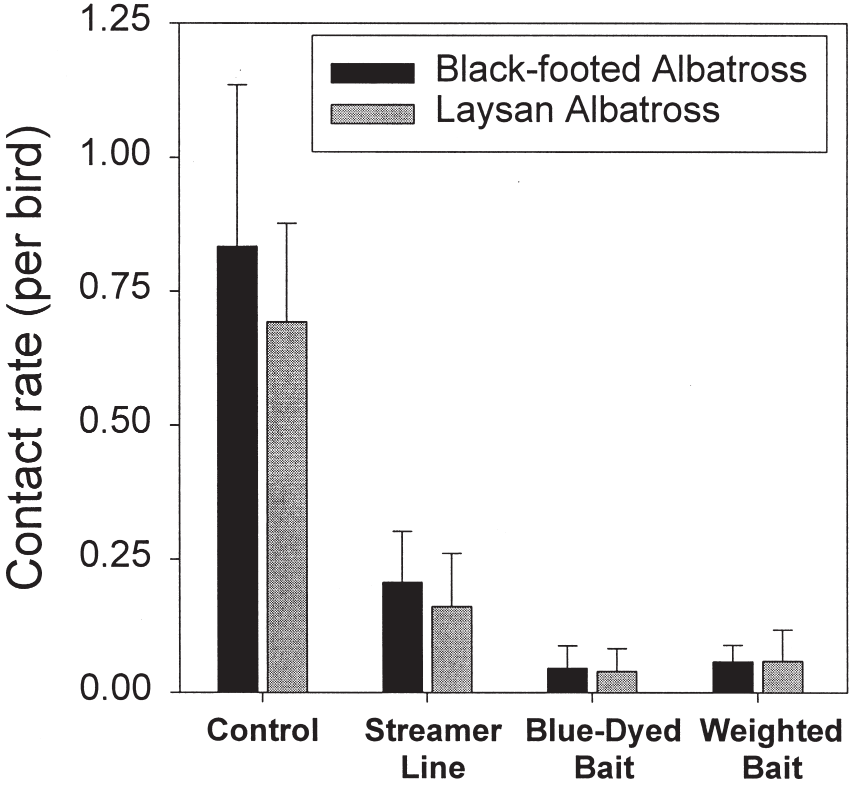

Figure 2. Mean contact rates per bird (per 100 branch lines) between albatrosses and baited branch lines in observed sections of swordfish style longline sets subjected to four treatments (control, streamer line, blue-dyed bait, and weighted bait). Each bar shows a mean and 95% CI for 24 observed set sections for each treatment and species of albatross.

that begin shortly afterward (Anderson and Fernandez 1998, as cited by Cousins and Cooper 2000).

Brothers (1991) stated that streamer lines were 69% effective in reducing bait stealing by Southern Hemisphere albatrosses in tuna longline fisheries. Other studies suggest albatross catch reductions of 31% to 71% using streamer lines in pelagic longline fisheries, but statistically significant results seem largely confined to studies of demersal longlines (Brothers et al. 1999). Weighted branch lines may reduce bird catches (Brothers et al. 1998) and experiments have demonstrated that adding weight does make even frozen bait sink faster (Brothers et al. 1995), but this study may be the first to demonstrate statistically significant results of this deterrent using pelagic longline fishing methods. Fishermen are at some risk of

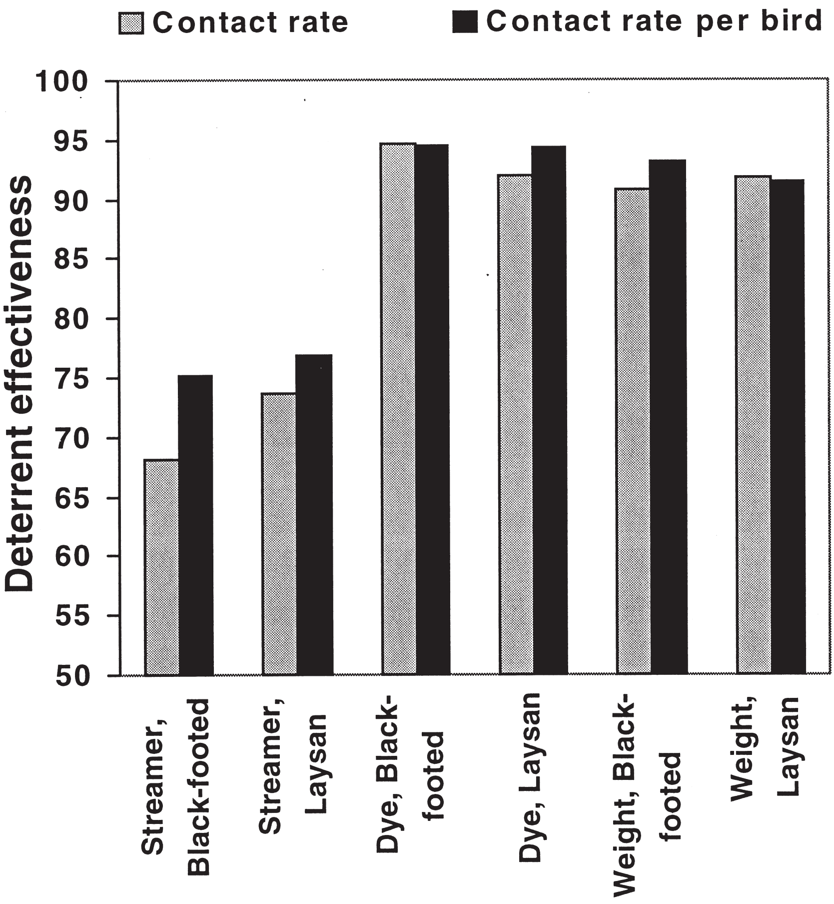

Figure 3. Deterrent effectiveness calculated in comparison with the control treatment as the percent reduction in the contact rate (contacts per 100 branch lines) or as the reduction in the contact rate per bird (contacts per bird per 100 branch lines) for three deterrent treatments and two species of albatrosses.

being hit by flying hooks that pop loose from fish as branch lines are hauled, and adding weight to the hooks might increase this danger.

The blue-dyed bait experimental results are original, although dyeing bait to increase the attractiveness to fish may have originated in the U.S. East Coast longline fishery for swordfish. The effectiveness of blue dye in reducing seabird scavenging of longline bait was first brought to the attention of the Western Pacific Regional Fishery Management Council (WPRFMC) by Hawaii fishermen. The cost of the food color used to dye the bait in this study was about $1.00 US per 100 squid.

Assuming that albatross mortality in real fishing operations is proportional to the number of times birds make contact with the bait, the deterrent effectiveness demonstrated by this study could be actualized as mortality reductions in the Hawaii-based swordfish fishery. However, implicit in this assumption is the idea that the behavior observed in this study is an accurate indicator of the risk of mortality. At the time this was written the WPRFMC was moving to include all three of the deterrent methods tested in the study in a list of alternative options to be required of Hawaii-based longline fishery participants. However, the efficacy of these measures will be hard to determine in the fishery because of the small sample sizes provided by very limited observer coverage (Cousins and Cooper 2000).

Actual hooking and mortality rates might be some unknown fractions of the contact rates measured in this study if there were a simple linear relationship between the bird behavior observed in the study (contacts) and hooking rates. The contact rate for Black-footed Albatross using the streamer deterrent, for the average number of birds in that treatment (59 birds) was 105 contacts per 1,000 branch lines. This was about 150 times higher than a seabird catch rate estimate of 0.71 birds per 1,000 hooks for the tuna longline fishery in Australia using streamer lines and monofilament longline gear (Brothers et al. 1999). The latter catch estimate was for a broad range of time and area, and the average number of birds present may have been much lower than in the present study.

Significant effects of the number of birds present on the number of bird mortalities on longline gear have not previously been documented, perhaps due to inaccurate or nonexistent bird counts (Brothers et al. 1999) or perhaps because rare events like hookings are not as simply related to bird density as are more common interactions like contact with baits. The number of albatross caught can also be affected by the number of birds of other species present. In the southern oceans many species besides albatrosses interact with the gear. Some seabirds are better divers than albatrosses and retrieve sinking bait that is subsequently taken away by albatrosses (Brothers 1991, Bergin 1997, Brothers et al. 1999). In the present study, behavioral observations demonstrated relationships between bird density and the number of bait contacts much more easily than a relationship between mortality and density could be demonstrated from analyses of fishery data. It could be inaccurate to project the effectiveness of the deterrents in this study as a measure of effectiveness in deterring fishing mortality at much lower densities.

Brothers et al. (1999) noted the difficulty of demonstrating significant effects of seabird deterrents using data from observers and commercial fishing operations and recommended the experimental approach followed in this paper. The results reported here clearly establish the effectiveness of the streamer line, blue-dyed bait, and added weight in reducing contact rates between albatrosses and longline baits in the type of longline fishing operations primarily responsible for seabird mortality in the Hawaii-based swordfish longline fishery. The results also suggest that other deterrents might be as effective or more effective than the streamer line, and in particular, that blue-dyed bait could be a highly effective, safe, cheap and convenient method for reducing albatross feeding on longline baits.

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Trends, Roadblocks, and Solutions

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