PERFORMANCE ASSESSMENT OF UNDERWATER SETTING CHUTES, SIDE SETTING, AND BLUE-DYED BAIT TO MINIMIZE SEABIRD MORTALITY IN HAWAII LONGLINE TUNA AND SWORDFISH FISHERIES

Final Report

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Summary

Mortality in longline fisheries is the most critical global threat to some seabird species. Research and a commercial demonstration were conducted on three methods designed to avoid seabird capture in the Hawaii pelagic longline swordfish and tuna fisheries. An assessment is made of each method's effectiveness at avoiding seabird interactions, practicality and convenience, effect on fishing efficiency, cost to employ, and enforceability when limited resources for enforcement are available.

A number of seabird avoidance methods have the capacity to nearly eliminate bird captures when employed effectively. However, to resolve the global problem of seabird mortality in longline fisheries, there is a need to identify and mainstream methods that not only have the capacity to minimize bird interactions, but are also practical and convenient, and provide crew with incentives to employ them consistently and effectively.

A seabird avoidance method called side setting, which entails setting gear from the side of the vessel, with other gear design the same as conventional approaches when setting from the stern, showed the highest promise of the tested seabird mitigation treatments. The hypothesis is that when side setting, baited hooks will be set close to the side of the vessel hull where seabirds will be unable or unwilling to attempt to pursue them, and by the time the stern passes the hooks, hooks will be too deep for seabirds to see or reach them. Side setting had the lowest mean seabird contact and capture rates of the seabird avoidance treatments tested when used with both Hawaii longline tuna and swordfish gear. Side setting provides a large operational benefit for certain types of vessels, and was perceived to be practicable for use by crew. The incentive for broad industry uptake and voluntary compliance is realistic, reducing the necessity for significant resources for compliance enforcement. Side setting requires a nominal amount of initial expense to employ. After the initial conversion to side setting is made, there is no additional effort required to implement the bird avoidance method. Side setting resulted in high fishing efficiency relative to the other treatments, based on bait retention and hook setting rates. Assessment of the feasibility of adjusting the gear to side set from various deck positions, the location of deployment of baited hooks from various side setting positions, sink rates of a range of types of baited hooks, and aspects of vessel conversion to side setting, indicates that side setting would be both feasible and effective at reducing seabird interactions on a wide range of longline vessel deck designs.

Two lengths of an underwater setting chute, a device that is designed to release baited hooks underwater, out of sight and reach of diving seabirds, were relatively effective at reducing bird interactions but performed inconsistently and were inconvenient due to a manufacturing flaw and design problems. Design and manufacturing improvements are needed and are likely feasible. Consideration could then be made to make the chute commercially available and possibly integrate the chute into deck hulls of the next generation of longline vessels. Two chutes, one 9m long and one 6.5m long, which deployed baited hooks 5.4m and 2.9m underwater, respectively, were used in this trial. The 9m chute had the second lowest mean seabird interaction rates when used with swordfish gear, and the 6.5m chute had the second lowest mean seabird interaction rates when used with tuna gear. However, the results from this comparative performance is affected by the technical problems encountered with the chutes in this trial, and does not reflect the chute's potential. The underwater setting chute is relatively expensive, costing U.S.$5,000 for the hardware. The chute is not commercially available for pelagic longline fisheries. Use of the underwater setting chute may be effectively enforced if combined with relevant technology such as hook counters. The chute is not yet suitable for broad commercial use, but holds high promise to minimize seabird mortality to acceptable levels in longline fisheries.

A third seabird avoidance method entails completely thawing and dying bait dark blue to attempt to reduce seabirds' ability to see the baits by reducing the bait's contrast with the sea surface. Blue-dyed bait was generally less effective at avoiding bird interactions than side setting and the underwater chute, was impractical and inconvenient for crew, and may not be employed consistently by different crew. Blue-dyed bait resulted in a relatively low fishing efficiency based on bait retention and hook setting rates. Blue-dyed bait is a relatively inexpensive seabird avoidance method, costing about U.S.$14 per set. Blue-dyed bait does not facilitate effective enforcement. Most of the practicality, convenience, and enforceability problems could be addressed if pre-blue-dyed bait were commercially available. Currently this seabird avoidance method holds less promise of tested methods to minimize seabird mortality to acceptable levels in longline fisheries.

Seabird Interaction Rates
Mean seabird contact and capture rates and bootstrapped (n = 1000) 95% nonparametric confidence intervals for combined seabird species are listed below for each experimental treatment. A "contact" is when a seabird comes into contact with gear near baited hooks. Reported capture rates are based on a count of the number of seabirds hauled aboard, and not the number of seabirds observed caught during setting. Treatments are listed from most effective (lowest mean contact or capture rate) to least effective. Treatments with significantly higher rates, based on non-overlapping 95% confidence intervals, are listed in parentheses next to each rate. For example, side setting used with tuna gear had a mean seabird contact rate of 0.01 contacts/1000 hooks/bird with a 95% confidence interval of 0.00 – 0.01, and this contact rate was significantly lower than contact rates of the three other experimental treatments.

<u>Tuna Gear Seabird Contact Rates</u>
Side setting 0.01 (0.00 – 0.01) contacts/1000 hooks/bird (6.5m chute, 9m chute, blue-dyed bait)
6.5m chute 0.20 (0.07 – 0.36) contacts/1000 hooks/bird (blue-dyed bait)
9m chute 0.28 (0.07 – 0.55) contacts/1000 hooks/bird
Blue-dyed bait 0.61 (0.43 – 0.78) contacts/1000 hooks/bird

<u>Tuna Gear Seabird Capture Rates</u>
Side setting 0.00 (0.00 – 0.01) captures/1000 hooks/bird (blue-dyed bait, 9m chute)
6.5m chute 0.01 (0.00 – 0.03) captures/1000 hooks/bird
Blue-dyed bait 0.03 (0.01 – 0.06) captures/1000 hooks/bird
9m chute 0.05 (0.01 – 0.11) captures/1000 hooks/bird

<u>Swordfish Gear Seabird Contact Rates</u>
Side setting 0.08 (0.01 – 0.20) contacts/1000 hooks/bird (9m chute, blue-dyed bait)
9m chute 0.30 (0.22 – 0.38) contacts/1000 hooks/bird (blue-dyed bait)
Blue-dyed bait 2.37 (1.79 – 2.97) contacts/1000 hooks/bird

<u>Swordfish Gear Seabird Capture Rates</u>
Side setting 0.01 (0.00 – 0.03) captures/1000 hooks/bird (blue-dyed bait)
9m chute 0.03 (0.00 – 0.07) captures/1000 hooks/bird
Blue-dyed bait 0.08 (0.03 – 0.13) captures/1000 hooks/bird

Differences between the capture rates for the 9m chute from a 2002 trial conducted in the Hawaii longline tuna fishery (0.00 captures/1000 hooks/bird) and for the 9m chute from this experiment (0.05 captures/1000 hooks/bird) also using Hawaii longline tuna gear were significant. This inconsistency in effectiveness is believed to be due to design flaws with the chute used in this trial.

Due to the rarity of occurrence of seabird contacts and captures, some confidence interval estimates of uncertainty for contact and capture rates may be inaccurate, especially in cases where there were relatively few observed contacts or captures.

Black-footed albatrosses were generally more effectively prevented from interacting with fishing gear than Laysan albatrosses. This may be a reflection of black-footed albatrosses being generally less capable of interacting with gear than Laysan albatrosses.

Bait Retention, Hook Setting Rate, Fish CPUE, and Fishing Efficiency
A seabird avoidance treatment's effect on fishing efficiency is the result of the treatment's ability to avoid having bait taken by seabirds, the incidence of loss of bait due to the mechanical process of setting baited hooks, the hook setting rate, and any additional probability effect the treatment may have on the catch per unit of effort of commercial fish species.

In the Hawaii longline tuna fishery, where the average conventional hook setting rate is 8 seconds per hook (based on the total time to deploy gear and not the vessel's buzzer time rate), the two underwater setting chutes would cause a delay in deploying branch lines, and could reduce the number of hooks deployed per set by 12.5% for the 9m long underwater chute and 28.8% for the 6.5m underwater setting chute if the vessel runs out of time or gear to complete the set at the slower hook setting rate. For treatments used with tuna gear, based on non-overlapping nonparametric 95% confidence intervals derived from percentile method bootstrapping at n=1000, the two lengths of underwater chute had significantly slower average hook setting rates than both side setting and blue-dyed bait. The average hook setting rates of blue-dyed bait and side setting when employed with tuna gear were not significantly different and the high end of their 95% confidence intervals were below the 8s/hook average hook setting rate of the Hawaii tuna fleet. None of the three seabird avoidance treatments used in this trial with swordfish gear would cause a delay in the conventional hook setting rate of the Hawaii longline swordfish fleet (12 s/hook).

Based on available information, when combining the effects of bait retention and hook setting rates on fishing efficiency for seabird avoidance treatments employed using swordfish gear, side setting would have the highest fishing efficiency and would produce a gain in efficiency of 7.8% over fishing with blue-dyed bait, and setting with the 9m underwater setting chute would produce a gain in efficiency of 2.5% over fishing with blue-dyed bait.

Based on available information, when combining the effects of bait retention and hook setting rates on fishing efficiency for treatments used with tuna gear, the 9m chute had the highest fishing efficiency and would produce a gain in efficiency of 55.9% over fishing with the 6.5m chute, side setting would have the second highest fishing efficiency and would produce a gain in efficiency of 52.7% over fishing with the 6.5m chute, blue dyed bait would have the third highest fishing efficiency and would produce a gain in efficiency of 45.2% over fishing with the 6.5m chute, and the 6.5m chute would have the lowest fishing efficiency

Based on overlapping bootstrapped (n=1000) 95% nonparametric confidence intervals, there was no significant difference between target and total commercial fish CPUE for experimental treatments. This result was expected because factors other than changing experimental treatments can have a far greater effect on commercial fish CPUE than the treatment itself when relying on a small sample size.

Loss of Caught Seabirds before Hauled Aboard

Forty six birds were observed caught during setting, and 33 caught birds were hauled aboard. Twenty eight percent (13) fewer birds were hauled aboard than were observed caught during setting. Assessments of the number of seabirds caught in a longline fishery that are based on a count of the number of seabirds recovered during the haul are underestimates.

Normalizing Seabird Interaction Rates for Seabird Abundance – Call for Standardization

Methods for quantifying and reporting seabird interactions with longline vessels should be standardized to facilitate more meaningful comparisons of results from different experiments. Normalizing seabird interaction rates for bird abundance is consistent with the accepted understanding of animal abundance and the capture process. Of all the confounding factors that likely affect the level of bird interactions with longline gear per unit of effort, including weather conditions, seabird species complex, and differences in gear and fishing practices, seabird abundance has been documented to be highly significant. Normalizing seabird interaction rates for bird abundance increases the accuracy of comparisons between results from multiple experiments. This has not been the norm for this body of literature.

Conclusions and Management Recommendations

Side setting combined with adequate line weighting holds significant promise for minimizing seabird mortality in longline fisheries. The Hawaii longline industry should be encouraged to conduct a broad, industry-wide trial of side setting to confirm expectations of the method's consistency and feasibility of being performed on a wide range of vessel designs. The Hawaii longline tuna and swordfish fleets are encouraged to employ side setting in combination with 60g swivels within 0.5 fathom (about 1m) of the hook, a bird-scaring curtain, and side setting as far forward as feasible. Less than three months after completing the research, six Hawaii longline vessels have voluntarily converted their vessels to side set, indicating that the industry has high expectations for achieving operational benefits from side setting, and that the industry is committed to determine the full extent of the mitigation method's potential. A formal incentive program should be instituted to encourage a larger proportion of the fleet to change their longstanding vessel design to voluntarily try side setting. Results from this broad trial would guide management authorities for appropriate amendments to relevant regulations.

Design faults with the underwater setting chute should be rectified and further evaluation conducted to a point where the technology is either made commercially available or discarded entirely in preference for more acceptable and effective mitigation methods.

Blue-dyed bait is not acceptable to industry given that pre-dyed bait is not commercially available, and holds less promise than other more convenient seabird avoidance methods at minimizing seabird mortality to close to zero, perhaps due to inconsistent effectiveness from variable environmental conditions and crew deployment of baited hooks. Attention should be focused on more promising methods. Blue-dyed bait used in combination with other mitigation methods such as side setting, underwater chute, or night setting, could improve bird avoidance, but again, without being commercially available, blue-dyed bait is unlikely to be employed.

To successfully abate the problem of seabird mortality in global longline fisheries, there is a need to mainstream seabird avoidance best practices for longline fisheries. Side setting, when combined with adequate line weighting, holds much promise to reduce seabird mortality in both pelagic and demersal longline fisheries worldwide. In the absence of substantial encouragement, most vessels are expected to refrain from voluntarily converting to side setting because stern setting has proven itself to be an effective and efficient method over the past 30 years. As a result, there will be an initial hurdle to overcome to convince vessels to try the new setting position. Commercial demonstrations need to be conducted on a variety of vessel lengths and designs to determine if bait loss off hooks and line tangling or cutting such as from contact with propellers are problematic. For fishing grounds and seasons where proficient deep-diving seabird species interact with longline vessels, it is likely that employment of a combination of side setting, adequate line weighting, and night-setting will be effective and necessary. Additional assessment should be conducted to confirm this hypothesis. Such evaluation and demonstrations must precede widespread advocacy for pelagic and demersal longline fleets to side set.

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1. Introduction

This report presents the result of an assessment of the performance of three methods to avoid seabird capture when employed in the Hawaii pelagic longline tuna and swordfish fisheries. An assessment is made of each method's effectiveness at avoiding seabird interactions, practicability, effect on fishing efficiency, cost to employ, and enforceability given limited resources for enforcement capability.

The most globally critical threat to some seabird species is mortality in longline fisheries (Brothers et al., 1999; Gilman, 2001a; Gilman and Freifeld, 2003). Birds are hooked or entangled primarily while fishing gear is being set and are dragged underwater and drown as the gear sinks. Hundreds of thousands of seabirds, including tens of thousands of albatrosses, are caught annually in longline fisheries worldwide (Brothers, 1991; Gilman, 2001a and b; CCAMLR, 2002). According to IUCN (The World Conservation Union), of the 61 species of seabirds affected by longline fisheries, 25 are threatened with extinction, including 17 species of albatrosses, and there is compelling evidence that longline mortality is a significant component in the declines of many of these species (Gales, 1998; Brothers et al., 1999).

Available estimates for total albatross mortality in North Pacific pelagic longline fisheries, along with population modeling experiments on the black-footed albatross, highlight the concern that mortality in longline fisheries threatens the existence of black-footed albatrosses and may pose a significant threat to the other North Pacific albatross species (Cousins and Cooper, 2000; Cousins et al., 2001; Gilman and Freifeld, 2003; Lewison and Crowder, In Press). North Pacific albatrosses include the short-tailed (*Phoebastria albatrus*), black-footed (*Phoebastria nigripes*) and Laysan (*P. immutabilis*). A fourth member of this genus, the waved albatross (*P. irrorata*), ranges north of the equator around the Galapagos Islands and surrounding waters where it may be caught in pelagic longline fisheries off northern Peru (Anderson et al., 1998; Jahncke et al., 2001; Anderson et al., 2003).

Hawaii pelagic longline fisheries, whose fishing grounds are in the North Pacific, have resulted in the annual mortality of approximately 3,000 albatrosses (U.S. National Marine Fisheries Service, 2001c; U.S. Fish and Wildlife Service, 2002). However, recent changes in regulations due to concerns over mortality of marine turtles, which closed the Hawaii swordfish fishery and placed restrictions on the tuna fleet, have significantly changed the Hawaii fleet's effort, spatial distribution of effort, and amount and composition of albatross bycatch. As a result of these changes to the Hawaii longline fleet, the annual seabird mortality in the Hawaii longline fishery is currently estimated to be an order of magnitude lower than previous levels (U.S. Fish and Wildlife Service, 2002). The Hawaii longline swordfish fishery may be authorized to resume in the near future. In an effort to minimize seabird mortality in the Hawaii pelagic longline tuna and swordfish fisheries, and potentially to identify seabird avoidance methods that are exportable to other longline fleets, a research experiment and commercial demonstration was conducted in the Hawaii longline tuna and swordfish fleets.

Numerous seabird avoidance mitigation methods have been suggested and implemented to reduce the incidental mortality of seabirds in longline fisheries (Brothers, 1995; Brothers et al., 1999). This paper reports results from trials in the Hawaii pelagic longline tuna and swordfish fisheries using four seabird avoidance experimental treatments: two lengths of underwater setting chutes, side setting, and blue-dyed bait. Goals of the project were to identify a seabird avoidance method that (a) is one of the most effective at consistently minimizing seabird mortality to close to zero under all variable conditions encountered by the fleet, (b) does not cause increases in bycatch of other sensitive species, (c) is practical for use by crew in the Hawaii pelagic longline fisheries with possible increases in fishing efficiency and operational benefits, (d) facilitates enforcement when limited resources for enforcement are available, and (e) may be equally effective and practicable for use in other longline fleets. The seabird avoidance methods selected for this trial were thought to hold promise to meet many of these criteria for a suitable seabird avoidance method.

An additional project goal was to determine if use of a shorter, more industry-friendly, 6.5m long underwater setting chute would compromise the chute's ability to reduce seabird captures compared to a longer 9m long chute shown to be extremely effective at avoiding bird captures compared to a control in a 2002 Hawaii trial (Gilman et al., In Review and 2002a). A shorter and lighter chute is expected to be easier for crew to deploy and does not affect vessel handling as much as a longer chute. The assumption is that the more practical the chute is to use by crew, the higher industry compliance with and support for use of the underwater setting chute will be.

Most longline vessels probably do not employ effective seabird avoidance methods despite the availability of effective methods that also increase fishing efficiency (Brothers et al., 1999). Reasons for this may be low industry awareness of the availability, effectiveness, and practicability of these seabird avoidance methods; few national fishery management authorities have frameworks to manage interactions between seabirds and longline vessels and do not require employment of effective seabird avoidance methods (Brothers et al., 1999; BirdLife International, 2003; FAO, 2003; Gilman and Freifeld, 2003); and lack of a strong economic incentive for industry to change long-standing fishing practices. Recognizing this context, there is a need to maximize industry's sense of ownership for using effective seabird avoidance measures and provide industry with incentives for voluntary compliance. The longline industry responds most strongly to economic incentives and disincentives (Gilman et al., 2002b). Seabird mitigation methods that can be demonstrated to significantly increase fishing efficiency and have operational benefits have the highest chance of being accepted by industry. Additionally, if regulations requiring the use of seabird avoidance methods are consistently and effectively enforced and carry significant economic consequences for noncompliance, this will likely result in broad industry compliance.

1.1. History of underwater setting chute, side setting, and blue-dyed bait

Over the past 15 years, national governments, regional organizations, and longline industries have developed and tested seabird mitigation methods in longline fisheries, which can be divided into six categories of methods to:

(a) Alter fishing practices to avoid peak areas and periods of bird foraging (e.g., night setting, area and seasonal closures);
(b) Reduce the detection of baited hooks by birds (e.g., underwater setting devices, blue-dyed bait, shielded lights);
(c) Limit bird access to baited hooks (e.g., side setting, thawed bait, addition of more weight closer to hooks, bait-casting machines);
(d) Deter birds from taking baited hooks (e.g., bird-scaring line with streamers, acoustic deterrents, water cannon, towed buoy);
(e) Reduce the attractiveness of baited hooks to birds (e.g., artificial lures, artificial smell); and
(f) Reduce injury to hooked birds (e.g., circle hooks, improved bird handling) (Brothers, 1995; Brothers et al., 1999).

Some U.S. Atlantic fishermen began experimenting with various colored baits in the mid-1970s in an attempt to increase catch per unit effort (CPUE) (Mcnamara et al., 1999). Blue-dyed bait has been assessed for effectiveness as a seabird avoidance method in Hawaii and Japan’s pelagic longline fisheries, and research has been initiated in Brazil (McNamara et al., 1999; Boggs, 2001; Gilman et al., 2002b; Minami and Kiyota, 2002). The hypothesis is that dyed bait is more difficult for birds to detect because it reduces the contrast between the bait color and sea color. The bait is thawed, separated, and soaked in a mixture of blue food coloring additive and sea water in an attempt to make the bait the same hue as the sea surface. Regulations for the Hawaii longline tuna fishery require vessels fishing north of 23 N to use completely thawed bait dyed blue to an intensity level specified by a color quality control card issued by the fishery management authority (U.S. National Marine Fisheries Service, 2002b). Boggs (2001) tested the effectiveness of blue-dyed squid bait in the Hawaii pelagic longline swordfish fishery, dying the squid in a concentrate made from 0.45kg of Virginia Dare FD&C Blue No. 1 powder dissolved in 7.2L of water. Three 50kg batches of partially thawed bait were soaked for 15-20 minutes each in 1.0L of the concentrated dye added to 18L of water. The dyed bait was often re-frozen and later used partially thawed (Boggs, 2001). McNamara et al. (1999) soaked bait for 15 to 30 minutes in sea water with dissolved blue dye to make the bait the same dark blue color of the ocean surface. Minami and Kiyota (2002) compared the seabird capture rates of blue-dyed and non-blue-dyed bait in the Japanese pelagic longline tuna fishery at fishing grounds in the western North Pacific. Section 4.3. presents the results from these previous assessments of blue-dyed bait.

Side setting entails setting from the side of the vessel, with other gear design the same as conventional approaches when setting from the stern (Brothers, 1996). No research has been previously conducted on side setting’s effectiveness as a seabird avoidance method in longline fisheries. The hypothesis is that when side setting, baited hooks will be set close to the side of the vessel hull where seabirds will be unable or unwilling to attempt to pursue the hooks, and by the time the stern passes the hooks, the hooks will have sunk to a depth where seabirds cannot locate them or cannot dive to the depth needed to reach them. Side setting is used on three vessels in Australia routinely (without a main line shooter) because the space at the stern of the vessel forces them to. There is no empirical information on the effectiveness of this method of setting as a bird-avoidance technique.

At least five studies on the effectiveness of a Mustad underwater setting funnel (also called a lining tube) in demersal longline fisheries have been conducted. The Mustad funnel is currently the only commercially available underwater setting device. It is a large metal chute attached to the stern, which delivers the line into the water up to 2 m below the surface (Mustad and Son, No Date; Melvin, et al., 2001; Ryan and Watkins, 2002). Research on the effectiveness of the Mustad underwater setting funnel has been conducted in demersal longline fisheries in South Africa, Alaska, and Norway (Lokkeborg, 1998 and 2001; Dunn and Steel, 2001; Melvin et al., 2001; Ryan and Watkins, 2002). Results from these studies found the funnel's performance to be inconsistent at reducing seabird capture. The line periodically would jump out of the slot running along the side of the tube, and the line could not be returned to the tube for the remainder of the set. And during high seas and when the vessel was front heavy, the bottom of the funnel was lifted out of the water during setting, making baited hooks available to seabirds.

There have also been trials of underwater setting devices in pelagic longline fisheries in New Zealand, United States (Hawaii), and Australia. The first underwater setting chute for pelagic longline vessels was developed in 1995 (Molloy et al., 1999). Results from research on an underwater setting chute in a New Zealand pelagic longline fishery showed that at 100 m astern of the vessel, the chute set branch lines an average of 2.85m deeper than branch lines set by the conventional method of hand-throwing, indicating the chute's potential to reduce mortality of diving seabirds (O'Toole and Molloy, 2000).

A short-term trial of an underwater setting chute in the Hawaii pelagic longline tuna fishery found that the chute eliminated seabird captures (the chute capture rate was 0.00 captures/1000 hooks/bird, 0.00-0.00 bootstrapped (n=1000) 95% nonparametric CI), was 95% effective at reducing seabird contacts with fishing gear compared to a control, and increased fishing efficiency 14.7% to 29.6% when albatrosses are abundant (results from this study are summarized in Section 4.4 and Appendix I) (Gilman et al., In Review and 2002a).

Australia has also been conducting research on an underwater setting chute and capsule in a pelagic longline fishery, and additional industry-wide testing of the chute in pelagic longline fisheries is underway (Brothers et al., 2000). Preliminary results of the broad performance assessment of the chute in Australia's pelagic longline fleet are discouraging, likely due to the seabird species complex found in Australian waters, the weighting design of Australian fishing gear, and the use of live bait. The chute trial in Australia has exceeded a target seabird catch rate of 0.05 captures per 1000 hooks. The trial is being continued to attempt to identify the cause of the higher-than-desired bird catch rate, and decide on the future direction of the chute in Australian longline fisheries (personal communication, Ingrid Holliday, Australian Fisheries Management Authority, 22 April 2002).

2. Study area, period, and methodology

Two research fishing trips were conducted on the Hawaii-based pelagic longline vessel, F.V. *Katy Mary* at grounds south of Laysan Island, an island part of the Northwestern Hawaiian Islands (Figure 1). This study area was selected to ensure sufficient albatross abundance to demonstrate statistically significant differences between seabird avoidance treatments' effectiveness at avoiding seabird interactions. Ninety-eight percent of the world's population of black-footed albatross and 99% of the world's population of Laysan albatrosses nest in the Northwestern Hawaiian Islands. The Hawaii longline tuna fleet's effort occasionally includes these fishing grounds (e.g., eight additional Hawaii-based longline tuna vessels were at these fishing grounds during the period of the two research fishing trips) (U.S. National Marine Fisheries Service, 2001a). The fishing grounds of the currently suspended Hawaii longline fleet targeting swordfish and mixed swordfish and tuna would also include these fishing grounds (U.S. National Marine Fisheries Service, 2001a).

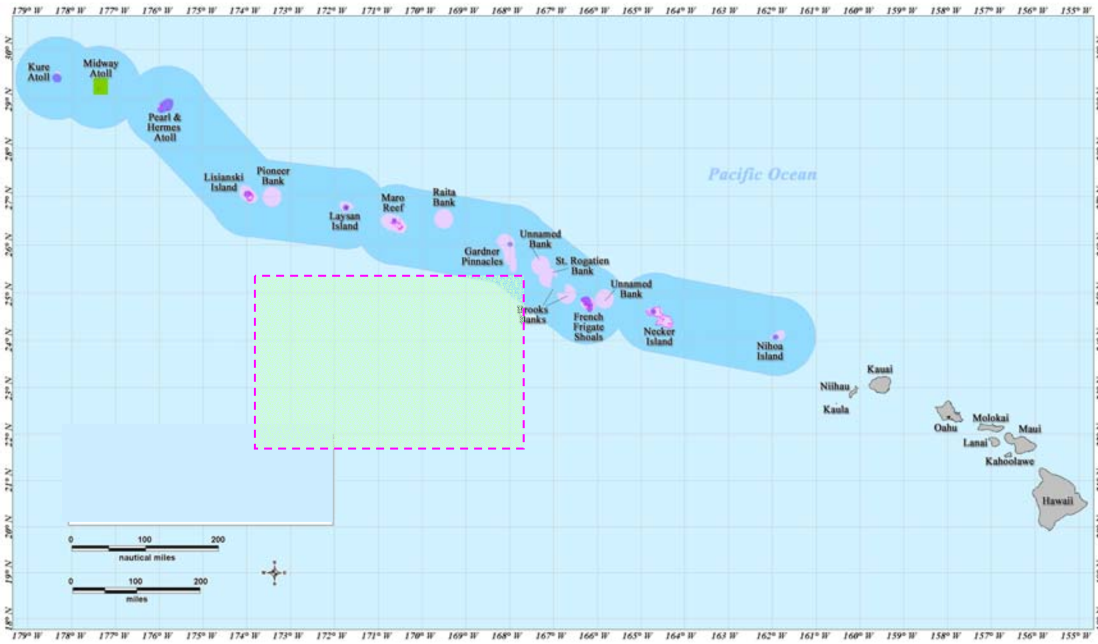


Fig. 1. Location of the study area adjacent to the Hawaiian Islands. The study area for the two research fishing trips was south of Laysan Island, Northwestern Hawaiian Islands, in the area between 21 41' N and 25 08' N, 173 58' W and 167 43' W, roughly the area within the rectangle.

The two fishing trips were conducted between 1 April and 17 May 2003. Breeding Laysan and black-footed albatrosses are in the latter half of their chick-rearing period during this period (Niethammer et al., 1992; Hyrenbach et al., 2002; U.S. Fish and Wildlife Service, 2002).

Table 1 provides a summary of the dates of the two research fishing trips, and the order of replicates by tote (also called snood bins, line boxes, or hook boxes) for each set. Four seabird avoidance experimental treatments were employed using Hawaii pelagic longline tuna and swordfish gear.

Table 1
Summary of research activities

Trip 1						
		Treatment and fishing method per tote[a]				
Set	Date 2003	A	B	C	D	E
1	6 April	B sword	9 sword	S sword	S sword	S tuna
2	7 April	S sword	9 sword	B sword	9 sword	9 tuna
3	8 April	9 sword	B sword	9 sword	S sword	S tuna
4	9 April	S sword	S tuna	B sword	B tuna	B tuna
5	10 April	B sword	B tuna	S sword	S tuna	S tuna
6	11 April	S tuna	S sword	S tuna	B tuna	B sword
7	12 April	B tuna	B sword	B tuna	S sword	S tuna
8	13 April	S tuna	S sword	S tuna	B sword	B tuna
9	14 April	B tuna	B sword	B tuna	S sword	S tuna
10	15 April	B sword	B tuna	S tuna	S sword	S tuna
11	16 April	S tuna	S sword	S tuna	B sword	B tuna
12	17 April	S tuna	S tuna	S tuna	S tuna	S tuna

Trip 2						
Set	Date 2003	Treatments per tote (all sets use tuna gear)[a]				
		A	B	C	D	E
1	1 May	B	9	6.5	S	6.5

2	2 May	B	6.5	9	B	9
3	3 May	6.5	S	B	S	9
4	4 May	9	Ss	6.5	S	B
5	5 May	9	B	S	S	6.5
6	6 May	6.5	S	B	S	[b]
7	7 May	6.5	9	B	S	B
8	9 May	S	B	9	6.5	S
9	10 May	9	6.5	S	B	S
10	11 May	S	S	S	B	S
11	13 May	S	B	S	S	S

[a] 6.5 = 6.5m long underwater setting chute (deploys baited hooks 2.9m underwater)
9 = 9m long underwater setting chute (deploys baited hooks 5.4m underwater)
B = Blue-dyed bait
S = side setting
“tuna” = tuna fishing gear
“sword” = swordfish fishing gear
[b] Only 4 totes deployed in this set

2.1. Experimental treatments

Four seabird avoidance experimental treatments were included in the experimental design. Two of the treatments were setting branch lines through a 9m long and 6.5m long underwater setting chute. The design of the underwater setting chute illustrated in Molloy et al. (1999) is a similar design to that used in this trial. When setting with the 9m chute on the F.V. *Katy Mary*, 5.4m of the chute’s shaft is underwater. When setting with the 6.5m chute on the F.V. *Katy Mary*, 2.9m of the chute’s shaft is underwater.

A third treatment was side setting. Side setting entails setting from the side of the vessel, with other gear design the same as conventional approaches when setting from the stern. Figures 2 and 3 show the F.V. *Katy Mary’s* deck layout when side setting. Baited hooks are thrown forward as close to the side of the vessel’s hull as possible to maximize protection of the baits from seabirds. Branch lines are clipped onto the main line as the thrown baited hook passes the main line shooter to prevent line tension from reducing the bait sink rate. A bird curtain was used when side setting, at positions identified in Figures 2 and 3, to increase the effectiveness of this mitigation method by preventing birds from establishing a flight path along the side of the boat where baited hooks are being deployed. Figure 4 shows an illustration of the design of a bird curtain pole, streamers, and mounting bracket.

The fourth treatment was blue-dyed bait. The bait was completely thawed and dyed blue by soaking it in a large tub with dissolved Virginia Dare FD&C Blue No. 1 powder for 1-4 hours to achieve darkness in compliance with regulations (U.S. National Marine Fisheries Service, 2002b). This experimental treatment differs from historical conventional fishing methods in two ways: the bait is blue and is more thawed during the process of dyeing.

Setting occurred only during daylight to enable observations of seabird interactions with fishing gear. Both tuna and swordfish gear used 60g swivels attached within 1m of the hook. If the swordfish sector of the Hawaii longline fishery is authorized to resume, then the Hawaii Longline Association members have agreed to adopt this weighting design to minimize seabird interactions with swordfish gear. All experimental treatments used a main line shooter.

Two previous studies have tested the effectiveness of blue-dyed bait against a control in the Hawaii longline swordfish fishery (McNamara et al., 1999; Boggs, 2001). One previous study has tested the effectiveness of an underwater setting chute with 5.4m of the shaft deployed underwater against a control in the Hawaii longline tuna fishery (Gilman et al., In Review and 2002a). Inclusion of these two “benchmark” treatments in this trial enables a comparison of the results from this study on the effectiveness of three seabird avoidance methods untested previously in the Hawaii fisheries with the effectiveness of seabird avoidance methods studied in previous experiments in the Hawaii fisheries.

If the Hawaii swordfish sector were not currently closed due to concerns over sea turtle mortality, regulations would require swordfish vessels to avoid bird capture by using blue-dyed and thawed bait, strategic offal discharge, and night setting (U.S. Fish and Wildlife Service, 2002). We decided not to include this combination of measures as a treatment in this experiment because we prioritized selecting an experimental treatment that has undergone previous assessment to determine its effectiveness at reducing seabird interactions compared to a control so that it can be used as a benchmark. Furthermore, because it is not possible to observe seabird contacts with gear during night setting, using a treatment that includes night setting would have required using seabird mortality observed as the number of birds hauled aboard as the central observation for the experiment. This would have required a larger number of seabirds to be killed and more replicates than was required for the experimental design employed in this trial to observe statistically significant differences between the treatments.

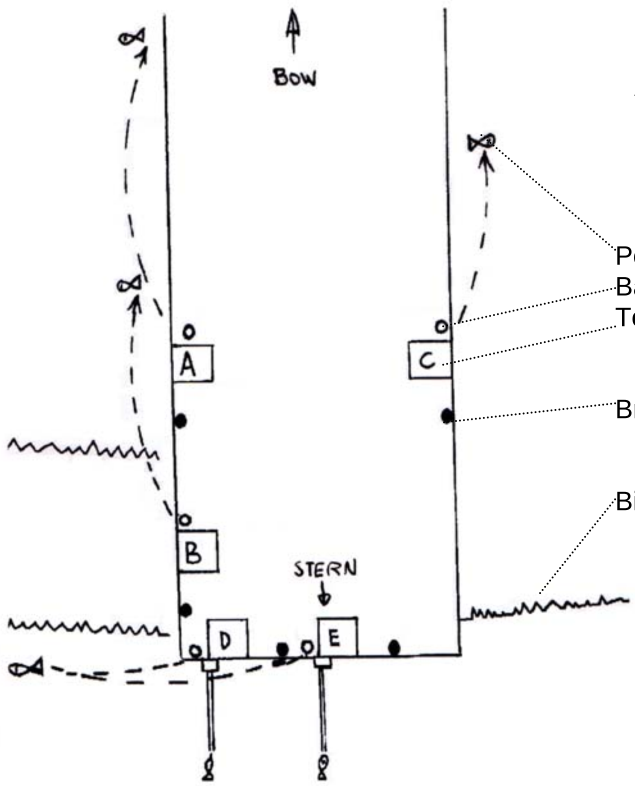
We also decided not to include a control of setting during the daytime with no seabird avoidance methods because (a) of concern over the large number of albatrosses that would be killed; (b) the central goal of this experiment is to determine which of the seabird avoidance methods works the best, and not how well each method works compared to a control treatment of not using any seabird avoidance method, which is not an option in the Hawaii longline fishery; and (c) use of previously tested experimental treatments provides a suitable benchmark.

The gear used by the *Katy Mary* for tuna and swordfish sets differed in five ways. The *Katy Mary* used 0.6m long wire leaders for the bottom section (from the swivel to the hook) of branch lines in tuna sets, and used 0.9m long, 2.3mm diameter, 500lb monofilament for swordfish sets. The *Katy Mary* used 8/0J hooks for swordfish sets, and open gap #7J hooks for tuna sets. The *Katy Mary* used spent green Pacific Lightsticks in swordfish gear, attached with an elastic band to the upper part of the branch line near the swivel. Lightsticks were not used in tuna gear. There were 19 hooks between buoys in swordfish gear, and 28 hooks between buoys in tuna gear. Bait used in tuna gear was a mixture of about 50% sardines (*Sardinops sagax*) and 50% Pacific saury (also called sanma) (*Cololabis saira*). Fifteen of the 19 baited hooks (79%) set between buoys in swordfish gear was squid, and the remaining 4 hooks (21%) was a mixture of sardines and saury. Gilman et al. (2002a) provides a general description of the Hawaii longline fleet's and the *Katy Mary's* fishing gear and methods.

The gear used for "swordfish" fishing in this experiment was designed to be in compliance with regulations governing the Hawaii longline fleet designed to avoid turtle takes (U.S. National Marine Fisheries Service, 2002a). The gear was designed to simulate swordfish gear in the first few meters from when the baited hook enters the water so that interactions with seabirds could be assessed to critique the effectiveness of seabird avoidance treatments at avoiding bird interactions. However, the gear was set deep as in the longline tuna fishery and not shallow as in the conventional swordfish fleet to remain in compliance with regulations. We accomplished this by using a main line shooter, setting 19 branch lines between buoys, using deep float lines greater than 20m long (the length of float line as used in the tuna fleet), using long branch lines as conventionally employed in the swordfish fleet, and using spent lightsticks (the light sticks did not emit light). The deepest point between two floats was designed to be deeper than 100m as required by regulations to protect sea turtles. In the past, Hawaii longline swordfish vessels would set the main line manually and not use a main line shooter, would set 4 to 6 hooks between buoys, would begin setting in the evening, would use lightsticks that emit light, and would place weighted swivels 5 to 7m from the hook (about mid way on the branch line) (Gilman et al., 2002a).

Setting with a main line shooter to set the line slack (as in the deep-set tuna fishery) with swordfish-style branch lines did not likely result in a different sink profile for baited hooks over the first few meters from the sea surface than occurred in conventional setting by the swordfish fleet where the main line was set taught. The sink rate of the baited hooks at the end of the 15m-long branch lines used in the swordfish gear are not expected to be affected by the more slowly sinking main line until the baited hook is several meters underwater, below the diving range of North Pacific albatross species. We expect baited hooks to sink more rapidly than the main line, as reported in Brothers and Reid (In Review). Thus, the main line will have a slowing influence on the hook sink rate but only after the branch line has almost reached its full extent, in this case, of 15m, which is well below the observed diving depths of Laysan and black-footed albatrosses.

As a result of the closure of the swordfish sector of the Hawaii longline fleet, all Hawaii-based longline vessels now have main line shooters installed to target tuna. If the swordfish fishery is authorized to resume in Hawaii, the Hawaii Longline Association expects that most longline swordfish vessels will continue to use the main line shooter voluntarily because there are advantages to using the main line shooter. Now that the Hawaii-based vessels have purchased and installed the shooters, they are expected to continue to use them even if they switch back to targeting swordfish.



Key

A	Side set port forward position
B	Side set port aft position
C	Side set starboard side position
D& E	Stern set position for blue-dyed bait and underwater chute

Position to where baits are thrown
Bait thrower
Tote

Branch line clipper and main line shooter

Bird curtain

Fig. 2. Plan view of deck layout indicating the various positions from where side setting was carried out. For position A, baits were thrown 15 m forward from the stern, the bait thrower was located 8m from the stern, the branch line clipper and main line shooter was 5.8m from the stern, and the bird curtain was 4.9m from the stern. For position B, baits were thrown 9m forward from the stern, the bait thrower was located 3.55m from the stern, the branch line clipper and main line shooter was 1.25m from the stern, and the bird curtain was 1.75m from the stern. For position C, baits were thrown 11m forward from the stern, the bait thrower was located 8m from the stern, the branch line clipper and main line shooter was 5.8m from the stern, and the bird curtain was 0m from the stern.

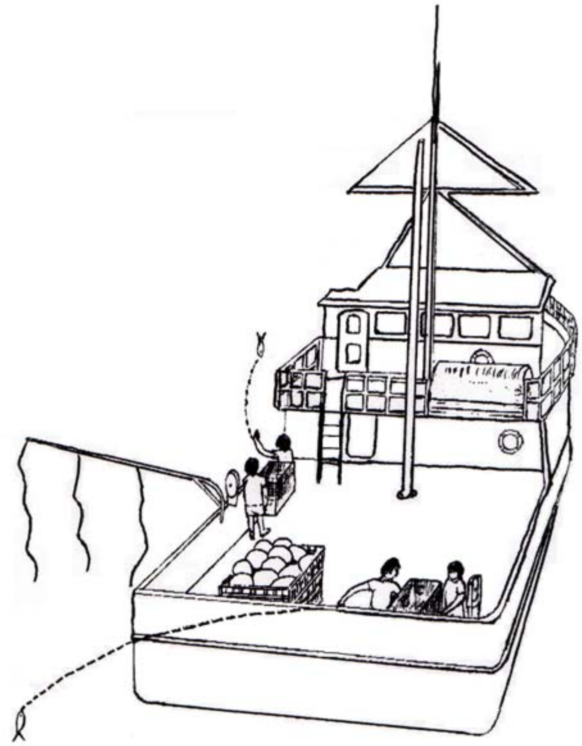


Fig. 3. Illustration showing one port side setting position with bird curtain (position A in Figure 2) and position of conventional stern setting (position E in Figure 2).

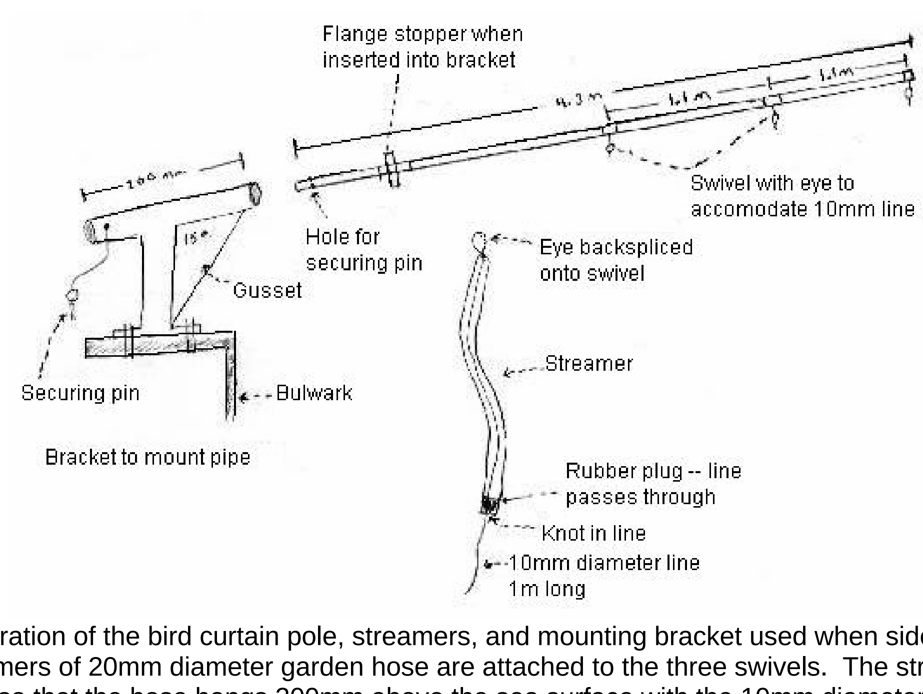


Fig. 4. Illustration of the bird curtain pole, streamers, and mounting bracket used when side setting. Three streamers of 20mm diameter garden hose are attached to the three swivels. The streamer length is designed so that the hose hangs 200mm above the sea surface with the 10mm diameter line protruding about 1m from the end of the hose to drag along the sea surface.

2.2. Replicates and research design

The experimental design included two research fishing trips. The order of treatments for the two fishing trips is summarized in Table 1. The experiment was designed to observe seabird contacts with gear near baited hooks as the central observation for comparing the effectiveness between the experimental treatments. Gilman et al. (In Review and 2002a) demonstrated a highly significant linear correlation between seabird contacts with gear and seabird captures, thus justifying employing contacts as the central observation for assessment to avoid higher seabird mortality that would have results if seabird captures were used as the central observation, and to minimize the length of the research trips to acquire enough data for sufficient statistical power. Figure 5 presents a linear regression between the seabird contact and capture rates from the control treatment replicates of Gilman et al. (In Review and 2002a), where the probability value ($p<0.05$) from the F-test indicates that there is a significant fit between the data to the linear regression model. Additional analysis could be conducted to determine the best fit for modeling this relationship, which may be non-linear.

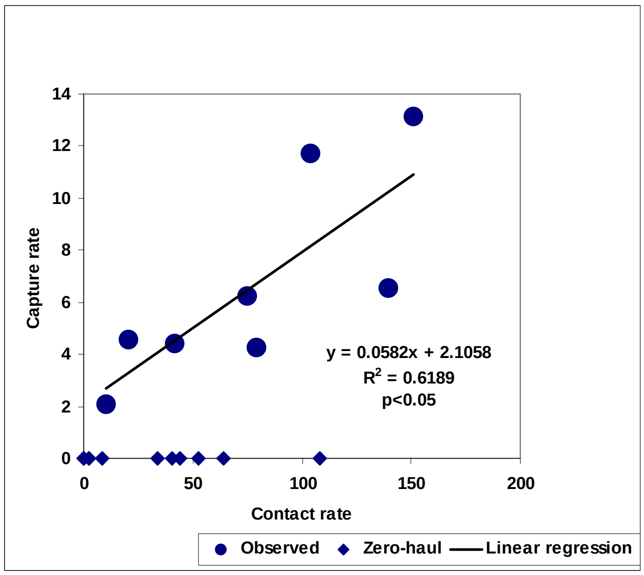


Fig. 5. Correlation between seabird contact and capture rates (contacts or captures/1000 hooks/bird) using control treatment data set from Gilman et al. (In Review and 2002a). The capture rate uses the number of birds hauled aboard and not the number of birds observed caught during setting.

One replicate consisted of setting 1 tote. However, if two or more consecutive totes employed the same treatment, these were combined and treated as a single replicate to avoid pseudo-replication. Blue-dyed bait is used as a pseudo control treatment. The 9m chute provides a benchmark treatment for tuna gear, and blue-dyed bait provides a benchmark for swordfish gear. Except for the final set of the first trip, all sets included blue-dyed bait for a minimum of one replicate, and an attempt was made to use the other experimental treatments an equal number of times before and after this pseudo-control treatment (Table 1).

2.3. Side setting position

Side setting was conducted from three different positions in order to assess whether the fishing method can be feasibly and effectively employed on vessels with deck designs that force them to side set a shorter distance from the stern than is possible on the F.V. *Katy Mary*, and vessels that can side set only from their port or starboard side (Figures 2 and 3). Data is analyzed to determine if there was a significant difference in the effectiveness of seabird avoidance between the three different side setting positions. For the analysis of the difference between the four experimental treatments, all of the side setting data from the three different positions is combined and treated as a single experimental treatment.

2.4. Bird abundance and its relationship to bird capture

Every 15 minutes throughout each set a count of each albatross species within a 500m by 500m square area (within 250m of port and starboard of the center of the vessel stern and within 500m behind the vessel) astern of the vessel was recorded. This information is needed to normalize seabird interaction rates for albatross abundance. While other seabird species on rare occasions are observed to be captured in Hawaii longline fisheries, Laysan and black-footed albatrosses have been the only seabird species observed to frequently interact with and be captured by Hawaii longline vessels (McNamara et al., 1999; Boggs, 2001 and 2003; Gilman et al., 2002a; U.S. Fish and Wildlife Service, 2002).

It is important to normalize seabird interaction rates for seabird abundance. This approach of analysis is consistent with the accepted understanding of animal abundance and the capture process (e.g., Ricker, 1958; Seber, 1973) derived from an early study on rats (Leslie and Davis, 1939). Gilman et al. (In Review and 2002a) demonstrated a highly significant linear correlation between albatross abundance and seabird interaction rates, confirming the hypothesis that seabird interaction rates should be normalized for albatross abundance. This is discussed in more detail in Section 4.1.

2.5. Contacts

Observations of seabird contacts with gear near baited hooks were recorded during setting. A seabird "contact" is defined as a seabird contacting the fishing gear near the hook. Only one interaction per bait is recorded regardless of whether multiple birds contact the bait or a single bird contacts a bait multiple times. The researcher also made observations of any seabird contacts during hauling.

2.6. Captures

The researcher observed seabird interactions with fishing gear during setting to record capture incidences and the species of seabirds caught. A bird capture event during setting was recorded if a bird struggled persistently with outstretched, flapping wings and was finally lost to view astern as it maintained the same position of attachment to a hook. The number of dead seabirds hauled aboard was also recorded, enabling a comparison with the number of seabirds observed caught during setting. The researcher also made observations of any seabird captures during hauling.

2.7. Bait retention

To assess differences in bait retention by experimental treatment, for each haul, the first several hundred hooks were checked for the presence or absence of baits. If a fish was caught on one of these hooks, this hook was counted as retaining its bait. Branch lines with tangles or delayed during hauling (potentially dragged unseen through prop turbulence astern) were not included in the bait retention count.

Because squid bait is thought to be retained on hooks significantly better than fish bait, the researcher observed bait retention on hooks containing only squid bait for swordfish gear, and observed bait retention on hooks containing only fish bait (mixed sardines and saury) for tuna gear. Because saury was observed to be more likely to be retained on hooks through the soak than sardines, the researcher attempted to only observe bait retention for sections of gear that had equal proportions of saury and sardines on tuna gear.

2.8. Hook setting interval

The researcher used information recorded on the time of the start and end of the setting of each tote to estimate the average hook setting interval for setting under each experimental treatment. The hook setting rate we are referring to is based on the total time to deploy gear and not the vessel's buzzer time rate. For instance, a vessel may set their buzzer timer to go off every 7 seconds, informing crew to set a hook every 7 seconds, however, the researcher recorded the actual numbers of hooks set in the time to deploy the fishing gear to measure the vessel's precise hook setting rate.

2.9. Fish CPUE

The number of commercial species of fish caught and the number of hooks set was recorded for each replicate.

3. Results

3.1. Bird abundance, contacts, and captures

A summary of albatross average abundance, total contacts, total captures observed during setting, and the total number of birds hauled aboard during replicates of each experimental treatment are recorded in Table 2. A table of summary statistics of the mean and 95% confidence interval for contact and capture rates by fishing gear method and by experimental treatment is included in Appendix I. This summary statistics table also provides information on the statistical difference between treatments based on overlapping or non-overlapping 95% confidence intervals. Figures 6-13 present the mean contact rates, mean capture rates (using the number of birds hauled aboard to estimate captures), and nonparametric 95% confidence intervals derived from percentile method bootstrapping at n=1000 for the two fishing methods for each treatment. This is a standard resampling technique to address variability when the parametric assumptions cannot be met, i.e., the underlying distributions are poorly known due to small sample size or other considerations such as skewed data and outliers (Efron and Tibshirani, 1986). This approach is particularly useful to determine empirical confidence intervals that can be asymmetrical, where the error interval above the point estimate differs from the error interval below the point estimate, i.e., the error specification is flexible and there is no assumption of symmetric error about the point estimate. The contact and capture rate ratios were bootstrapped across replicates, and not the raw values that went into the numerator and denominator of the ratios.

Due to the rarity of occurrence of seabird contacts and captures, some confidence interval estimates of uncertainty for contact and capture rates are likely to be inaccurate, especially in cases where there were no observed contacts or captures and the reported confidence interval is 0.00 – 0.00. To produce accurate results using percentile method bootstrapping, ten replications per treatment are needed when the event is common (pers. comm., Marti McCracken, U.S. National Marine Fisheries Service, August 2003). However, when the event is not common, as is the case with seabird contacts and captures in this trial, more replications are needed. For instance, for the side setting treatment used with tuna gear, there were 32 replications but no observed contacts by black-footed albatrosses. We cannot conclude that side setting used with tuna gear will eliminate black-footed albatross contacts, as there remains uncertainty in the result of zero contacts.

Seabird contact and capture rates are calculated for each experimental treatment and are reported with the following units:

$$\frac{\text{contacts or captures}}{(1000 \text{ hooks}) \times (\text{bird})}$$

A sample calculation for the bird contact rate for blue-dyed bait used with swordfish gear is provided to demonstrate how the units in reported contact and capture rates are derived. There were 253 observed contacts, 3,896 hooks were observed set, and the mean combined Laysan and black-footed albatross abundance during this treatment's replications was 27.8 (Table 2). The mean contact rate is manually calculated and units reported as follows:

$$\frac{(253 \text{ contacts}) \times (1000 \text{ hooks})}{(3896 \text{ hooks}) \times (1000 \text{ hooks}) \times (27.8 \text{ birds})} = 2.3 \text{ contacts/1000 hooks/bird}$$

The bootstrapping method uses replications to calculate a mean and confidence intervals, while this sample rate calculation aggregates all of the data, and the two calculation methods result in slightly different mean rates.

While all seabird species were recorded by the researcher, only albatross species were used for the estimate of bird abundance. Based on previous experiments in the Hawaii longline fishery, albatross species were anticipated to be the only species of seabirds that would be captured in fishing gear (McNamara et al., 1999; Boggs, 2001; Gilman et al., In Review and 2002a). Despite very few shearwaters being present during any count period, one short-tailed shearwater (*Puffinus tenuirostris*) and one sooty shearwater (*P. griseus*) were caught and hauled aboard during the two research fishing trips, discussed in Section 4.9.

At the end of the third set of the first research fishing trip, the 9m chute fractured and bent at the main pipe welding joint. This prevented further use in this trip, resulting in a smaller sample size than planned. Design problems were experienced with both chutes during the second trip, discussed in detail in Section 4.2.

Contact and capture rates and bootstrapped (n = 1000) 95% nonparametric confidence intervals are also reported for the 9m chute experimental treatment and control treatment used with Hawaii longline tuna gear from Gilman et al. (In Review and 2002a). There is a strong set of assumptions for comparing the results from Gilman et al. (In Review and 2002a) with results from this trial. The Gilman et al. (In Review and 2002a) research was conducted on the same fishing vessel; used the same 9m chute; was conducted at the same general fishing grounds; used the same general longline tuna fishing gear; and used the same captain, senior crew, and onboard researcher as used in this trial, but was conducted a bit over a year prior to the current trial. The control treatment entailed setting on a Hawaii longline tuna vessel using a line setting machine and weighted branch lines as is typically conducted by the Hawaii tuna fleet.

Table 2
Summary of average albatross abundance, total seabird contacts, total seabird captures on the set, and total seabirds hauled aboard, by experimental treatment.

			Mean albatross abundance[a]		Total contacts		Total birds caught during set		Total birds hauled aboard[a]			
Treatment	**N**	**Hooks**	**LA**	**BF**	**LA**	**BF**	**LA**	**BF**	**LA**	**BF**	**STS**	**SS**
Blue-dyed bait sword gear	11	3896	19.5	8.3	223	30	15	6	6	1	0	0
Blue-dyed bait tuna gear	23	11754	27.4	7.0	265	15	19	3	12	0	1	1
Side set swordfish gear	11	4322	17.1	8.4	8	0	1	0	1	0	0	0
Side set tuna gear	32	20133	21.4	5.7	3	0	0	0	1	0	0	0
9m chute swordfish gear	5	1805	7.4	8.4	8	1	0	1	0	1	0	0
9m chute tuna gear	10	4092	22.5	6.7	42	0	0	0	7	0	0	0
6.5m chute tuna gear	10	4263	24.4	6.4	24	0	1	0	2	0	0	0

[a] LA = Laysan albatross; BF = black-footed albatross, STS = short-tailed shearwater, SS = sooty shearwater. Species identifications for the two shearwaters are pending confirmation by the U.S. Fish and Wildlife Service.

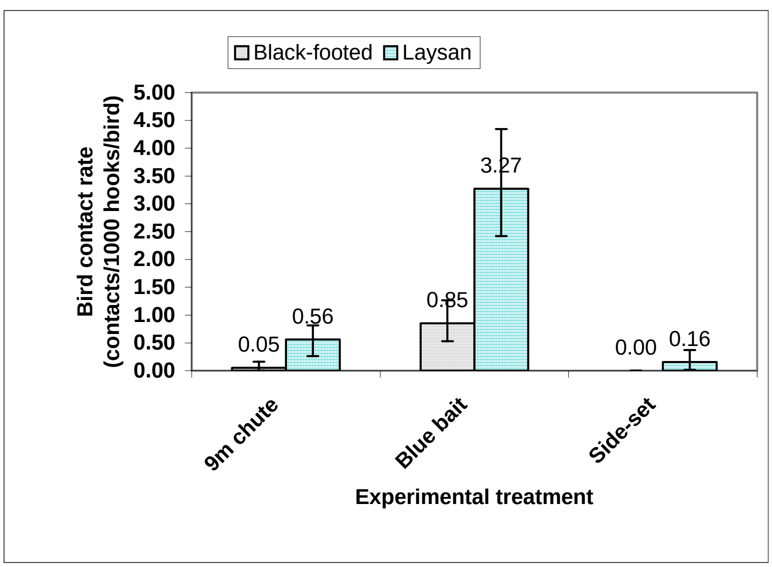


Fig. 6. Laysan and black-footed albatross contact rates (contacts/1000 hooks/bird) for experimental treatments used with swordfish gear. Error bars are boostrapped (n = 1000) 95% nonparametric confidence intervals.

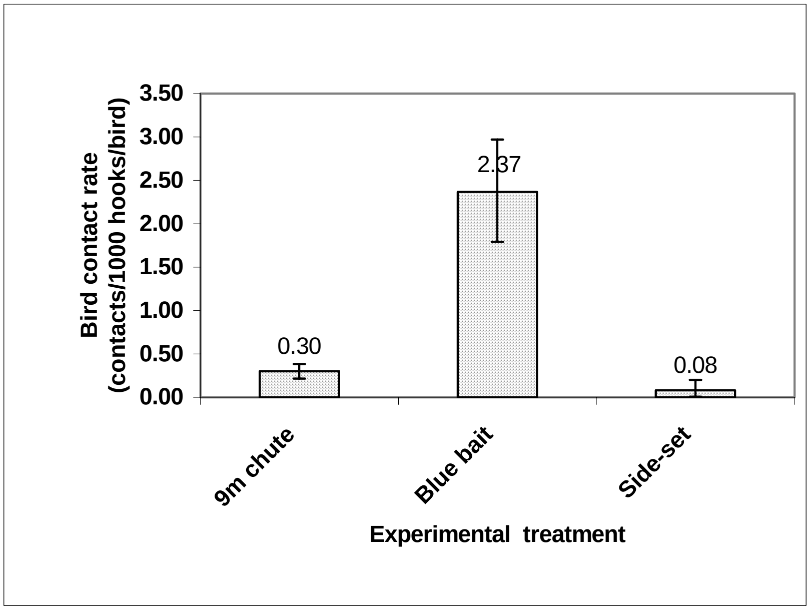


Fig. 7. Contact rates (contacts/1000 hooks/bird) for experimental treatments used with swordfish gear for combined Laysan and black-footed albatrosses. Error bars are boostrapped (n = 1000) 95% nonparametric confidence intervals.

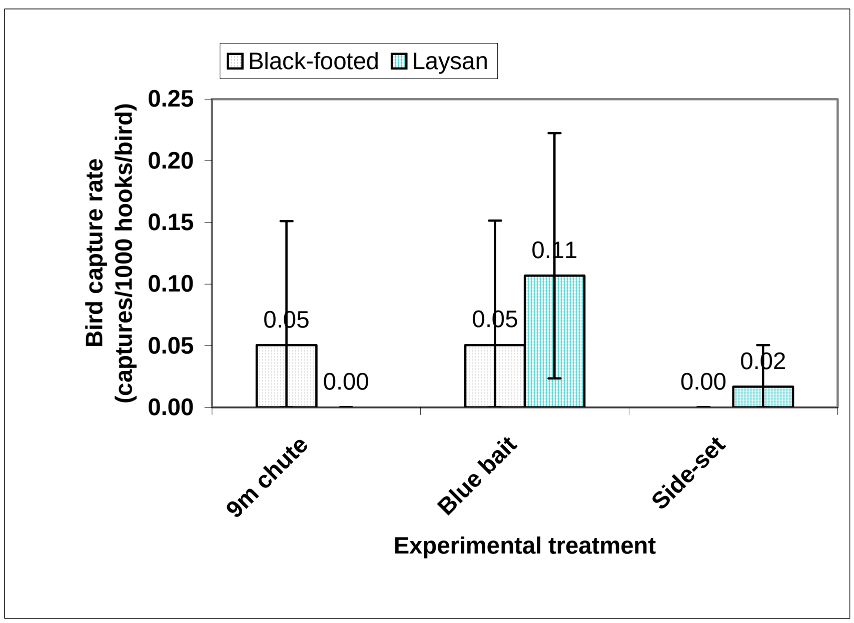


Fig. 8. Laysan and black-footed albatross capture rates (captures/1000 hooks/bird) for experimental treatments used with swordfish gear. Captures are based on the number of birds hauled aboard and not the number of birds observed captured during the set. Error bars are boostrapped (n = 1000) 95% nonparametric confidence intervals.

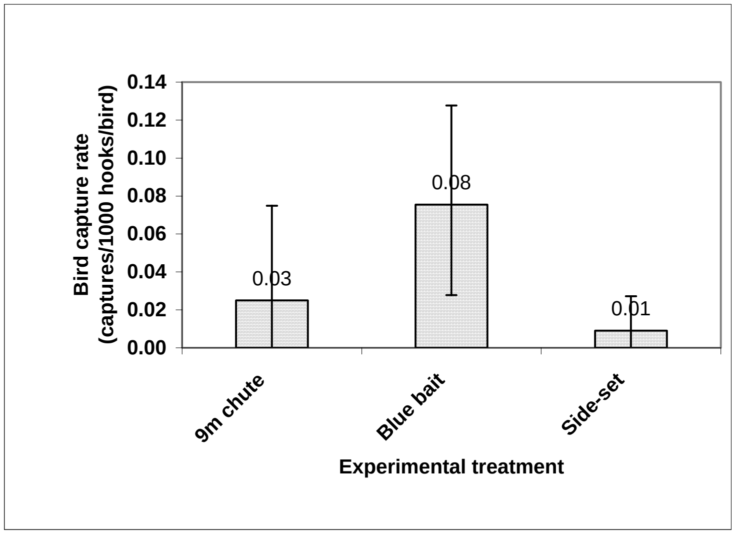


Fig. 9. Capture rates (captures/1000 hooks/bird) for experimental treatments used with swordfish gear for combined Laysan and black-footed albatrosses. Captures are based on the number of birds hauled aboard and not the number of birds observed captured during the set. Error bars are boostrapped (n = 1000) 95% nonparametric confidence intervals.

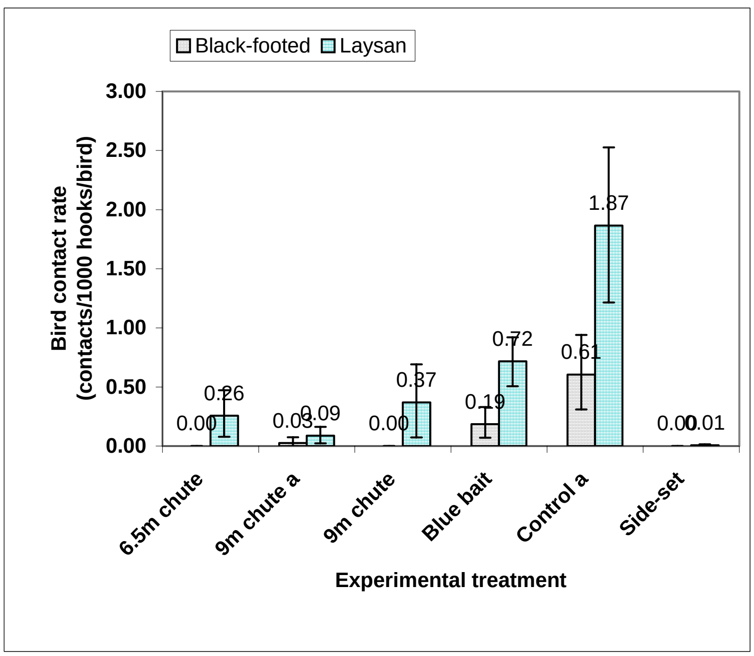


Fig. 10. Laysan and black-footed albatross contact rates (contacts/1000 hooks/bird) for experimental treatments used with tuna gear. The experimental treatments labeled “9m chute a” and “control a” are the seabird contact rates for the 9m underwater setting chute treatment and control treatment used with Hawaii tuna gear from Gilman et al. (In Review and 2002a) for Laysan and black-footed albatross species. Error bars are boostrapped (n = 1000) 95% nonparametric confidence intervals.

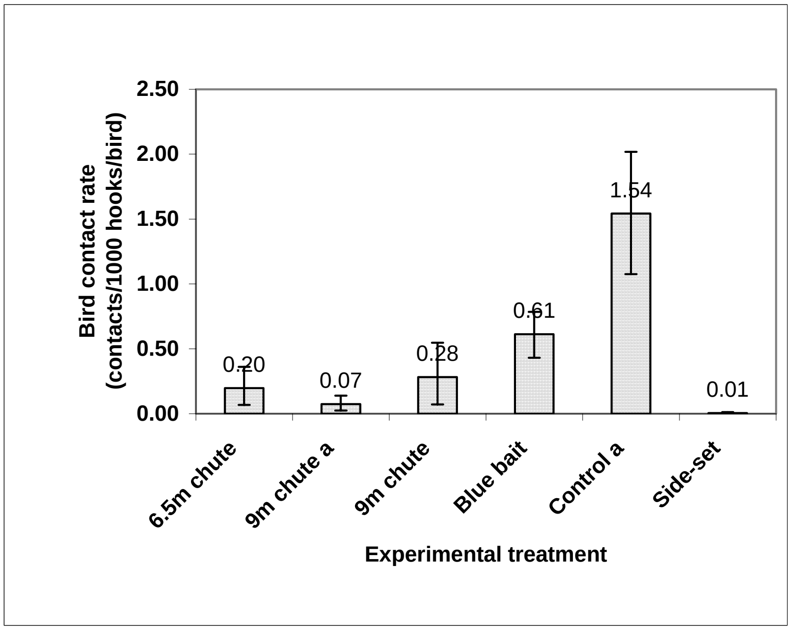


Fig. 11. Contact rates (contacts/1000 hooks/bird) for experimental treatments used with tuna gear for combined Laysan and black-footed albatross species. The experimental treatments labeled "9m chute a" and "control a" are the seabird contact rates for the 9m underwater setting chute treatment and control treatment used with Hawaii tuna gear from Gilman et al. (In Review and 2002a) for combined Laysan and black-footed albatross species. Error bars are boostrapped (n = 1000) 95% nonparametric confidence intervals.

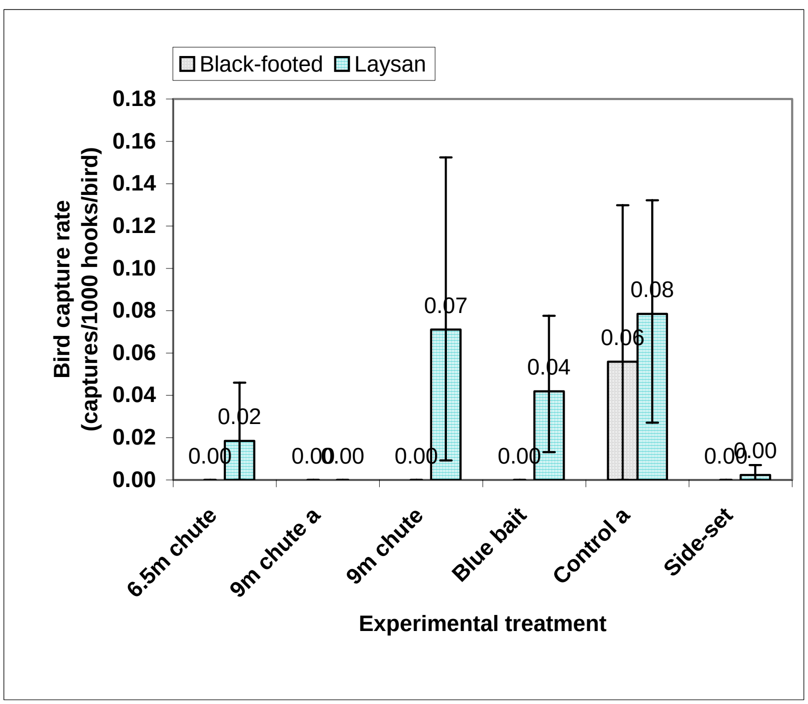


Fig. 12. Laysan and black-footed albatross capture rates (captures/1000 hooks/bird) of experimental treatments used with tuna gear. The experimental treatments labeled "9m chute a" and "control a" are the seabird capture rates for the 9m underwater setting chute treatment and control treatment used with

Hawaii tuna gear from Gilman et al. (In Review and 2002a) for Laysan and black-footed albatross species. Error bars are boostrapped (n = 1000) 95% nonparametric confidence intervals.

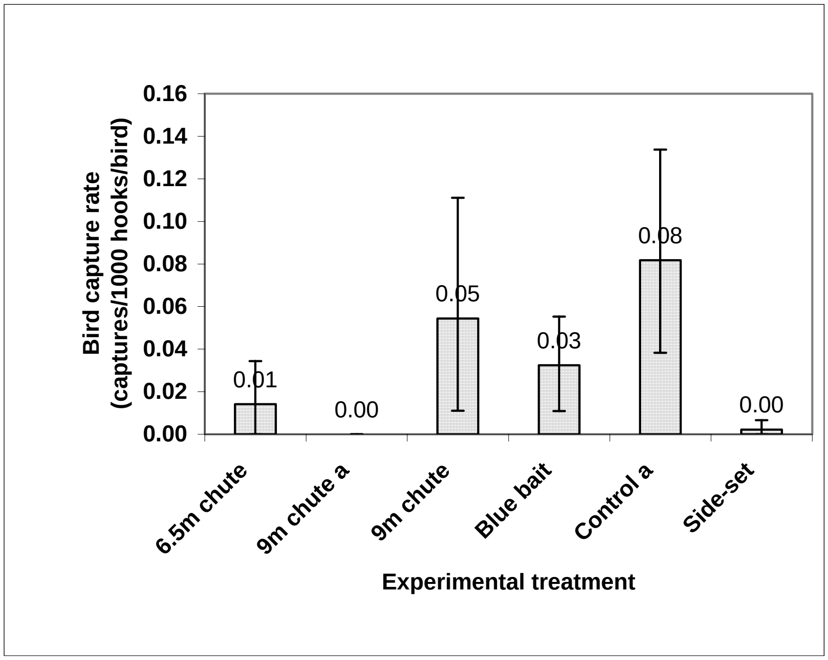


Fig. 13. Capture rates (captures/1000 hooks/bird) of experimental treatments used with tuna gear for combined Laysan and black-footed albatross species. The experimental treatments labeled "9m chute a" and "control a" are the seabird capture rates for the 9m underwater setting chute treatment and control treatment used with Hawaii tuna gear from Gilman et al. (In Review and 2002a) for combined Laysan and black-footed albatross species. Error bars are boostrapped (n = 1000) 95% nonparametric confidence intervals.

Section 4.3 summarizes the mean seabird contact and capture rates from this experiment and allows a comparison with interaction rates reported from other seabird avoidance method research conducted in the North Pacific.

3.2. Effect of order of treatments

The effect of order of experimental treatments was examined to see if there was a tendency for results (seabird abundance, contact rate, and capture rate) to differ when different treatments preceded others (Table 3). Because contact and capture rates are normalized for seabird abundance, any effect of order of treatments on bird abundance is addressed. However, the order of treatment may also affect bird behavior, such as searching instead of roaming, with concomitant effect on the incidence of bird contacts and captures. Table 3 shows that, based on overlapping 95% confidence intervals, there was no effect of order on albatross abundance or seabird interaction rates (contacts and captures/1000 hooks/bird), when the side setting treatment used with tuna gear preceded the blue-dyed bait treatment (a pseudo-control treatment for this experiment, because it resulted in the highest bird interaction rates) versus when the side setting treatment followed replicates using treatments other than blue-dyed bait.

Table 3
Effect of order on albatross abundance and seabird contact and capture rates (contacts and captures/1000 hooks/bird) when replicates of the side setting treatment used with tuna gear immediately followed replicates using the blue-dyed bait treatment, versus when the side setting treatment used with tuna gear immediately followed replicates using treatments other than blue-dyed bait. Nonparametric 95% confidence intervals are derived from percentile method bootstrapping at n=1000. The capture rate uses the number of birds hauled aboard and not the number of birds observed captured during setting.

Variable	After blue bait mean (95% CI)	Not after blue bait mean (95% CI)
Laysan abundance	23.40 (14.58 - 31.40)	20.78 (16.75 - 25.03)
Black-footed abundance	4.69 (3.70 - 5.58)	6.05 (4.83 - 7.48)
Contact rate	0.000 (0.00 - 0.00)	0.007 (0.00 - 0.02)
Capture rate	0.009 (0.00 - 0.03)	0.000 (0.00 - 0.00)

3.3. Side setting position

All side setting with swordfish gear was conducted from the port forward position (position A in Figure 2). Side setting was conducted from three different positions using tuna gear. Table 4 provides summary statistics for the difference in seabird interaction rates for these three different side setting positions. Based on overlapping bootstrapped (n=1000) 95% nonparametric confidence intervals, there were no statistically significant differences between contact and capture rates for the three different side setting positions, however there was a small sample size.

There were no incidences of gear being fouled in the propeller while side setting from any of the three setting positions. On a few occasions, the researcher had the vessel turn hard starboard and hard port in an attempt to determine of this would foul the gear during side setting, and found that it did not.

Table 4
Summary statistics for combined albatross species' contact and capture rates from three side setting positions using tuna gear. Capture rates are based on the number of birds hauled aboard. Nonparametric 95% confidence intervals are derived from percentile method bootstrapping at n=1000.

Treatment	N[a]	Contact rate (seabird contacts/1000 hooks/bird) mean (95% CI)
Port-forward	16	0.005 (0.000 - 0.016)
Port-stern	11	0.007 (0.000 - 0.017)
Starboard	6	0.000 (0.000 - 0.000)

Treatment	N[a]	Capture rate (seabird captures/1000 hooks/bird) mean (95% CI)
Port-forward	16	0.000 (0.000 - 0.000)
Port-stern	11	0.006 (0.000 - 0.019)
Starboard	6	0.000 (0.000 - 0.000)

[a] Number of side setting replicates conducted from each setting position.

3.4. Seabird interactions during hauling

No seabird contacts or captures were observed during any of the hauls during the two research fishing trips.

3.5. Loss of caught birds before haul

Table 2 provides data on the number of birds observed caught during setting and the number of birds hauled aboard. Forty six birds were observed caught during setting and 33 caught birds were hauled aboard. 28% (13) fewer birds were hauled aboard than were observed being caught during setting.

3.6. Bait retention

Bait retention when setting with each experimental treatment is summarized in Table 5. The sample size was too small to calculate confidence intervals for all but two of the treatments. Based on overlapping bootstrapped (n=1000) 95% nonparametric confidence intervals, there was no statistically significant difference in mean percent bait retention of blue-dyed bait and side setting with tuna gear.

Table 5
Bait retention summary (nonparametric 95% confidence intervals are derived from percentile method bootstrapping at n=1000)

Treatment	N[a]	Number of hooks observed[b]	Mean percent hooks retaining bait (95% CI)
Swordfish gear			
Side set	1	100	97.0
9m chute	1	104	92.3
Blue-dyed bait	1	112	90.2
Tuna gear			
9m chute	2	222	94.3
6.5m chute	2	320	74.3
Blue-dyed bait	5	992	76.8 (69.46 - 82.26)
Side set	12	2268	80.4 (77.02 - 83.65)

[a] Number of sections of gear checked for bait retention during hauling.
[b] Only sections of gear containing squid bait were assessed for bait retention/loss for swordfish gear, and only sections of gear containing fish bait (mixed sardine and saury) were assessed for tuna gear.

3.7. Hook setting rates

Table 6 summarizes the mean hook setting rates for each experimental treatment, and Figure 14 shows the mean hook setting rates for each treatment. Each tote is used as one replicate for statistical analysis.

For treatments used with swordfish gear, the blue-dyed bait and side setting treatments' mean hook setting rates were not significantly different from each other based on overlapping 95% confidence intervals. The mean hook setting rate for the 9m underwater setting chute was significantly slower than the blue-dyed bait mean hook setting rate, but was not significantly different from the side setting mean hook setting rate.

For treatments used with tuna gear, the two lengths of underwater chute had significantly slower mean hook setting rates than both side setting and blue-dyed bait. The mean hook setting rates of the two chutes were not significantly different. The mean hook setting rates of blue-dyed bait and side setting were not significantly different.

The mean hook setting interval for swordfish gear is slower than for tuna gear for each treatment.

Table 6
Mean hook setting rates summary for each experimental treatment (nonparametric 95% confidence intervals are derived from percentile method bootstrapping at n=1000)

Treatment	N[a]	Mean hook setting rate (seconds/hook) (95% CI)
Swordfish gear		
Blue-dyed bait	11	9.0 (8.39 – 9.69)
Side set	12	9.4 (9.02 – 9.85)
9m chute	5	10.5 (9.71 – 11.17)
Tuna gear		
Blue-dyed bait	24	6.9 (6.38 – 7.36)
Side set	42	7.2 (6.69 – 7.73)
9m chute	10	9.0 (7.85 – 10.49)
6.5m chute	10	10.3 (8.95 – 12.15)

[a] Number of replicates of each experimental treatment.

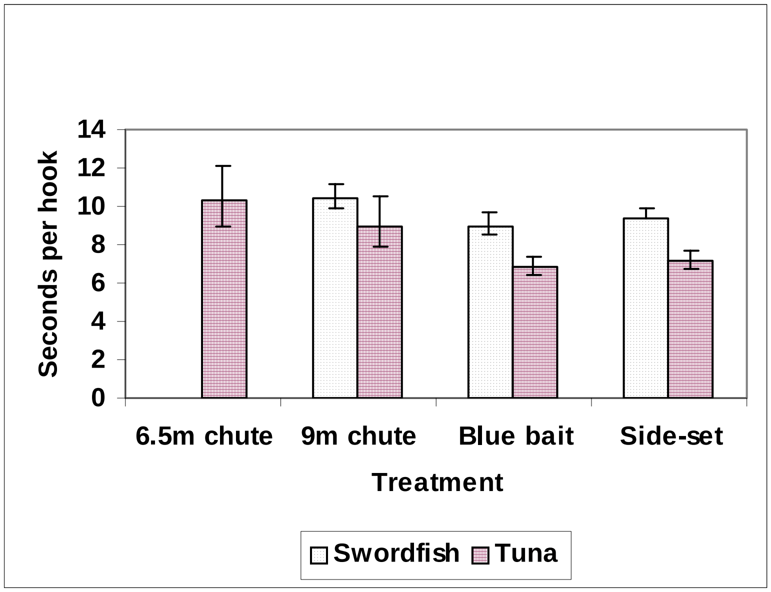


Fig. 14. Mean hook setting rate for each experimental treatment. Error bars are bootstrapped (n=1000) 95% nonparametric confidence intervals.

3.8. Fish CPUE

The mean CPUE for total and target commercial fish species for combined replicates for each experimental treatment for the second research fishing trip are calculated to determine if there is a significant difference in mean CPUE by experimental treatment. Both retained and discarded commercial fish are included to determine CPUE because the practice of discarding commercial fish is not a random event. For instance, spearfish caught during the first few days of a fishing trip are discarded because they do not keep on ice for a long period, but are retained when caught later in the trip. Thus, the CPUE assessment provides information on the fish catch performance potential of each treatment.

Data on fish catch and CPUE by replicate was collected for the first trip but is not included in this analysis for two reasons. Most of the first trip's replicates were conducted using the simulated swordfish gear, which was set deep to remain in compliance with regulations protecting marine turtles, and was not characteristic of conventional fishing methods. The commercial fish CPUE from the first trip for replicates conducted using both swordfish and tuna gear was extremely low.

Commercial fish species caught during the second fishing trip were big eye tuna, yellow fin tuna, albacore tuna, striped marlin, blue marlin, skip jack tuna, broad billed swordfish, opah, pomfret, dolphin fish, mako shark, wahoo, spearfish, and escolar (oil fish). Target commercial fish species are big eye tuna, yellow fin tuna, albacore tuna, and broad billed swordfish.

Figures 15 and 16 show that, based on overlapping bootstrapped (n=1000) 95% nonparametric confidence intervals, there was no statistically significant difference between CPUE for target commercial fish species nor between the CPUE for total commercial fish species for the four experimental treatments employed with tuna gear.

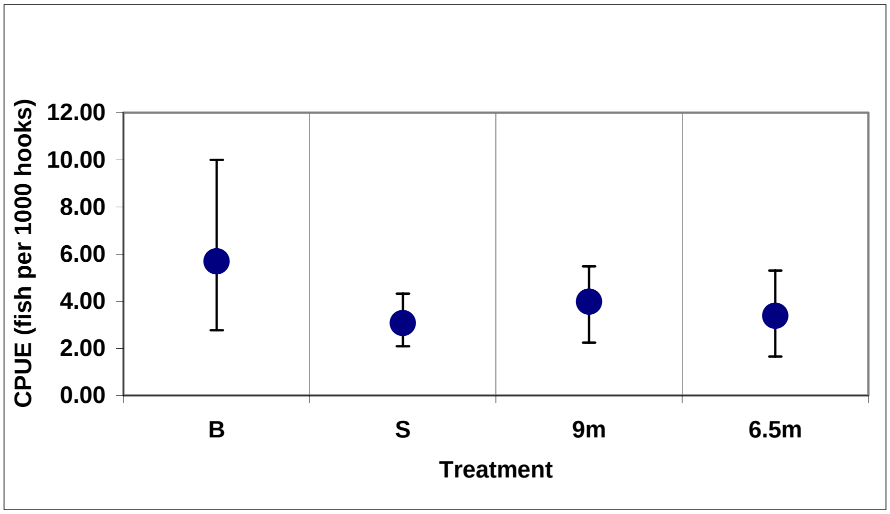


Fig. 15. CPUE for target commercial fish species for the four experimental treatments employed in the second research fishing trip, which employed longline tuna gear. Error bars are bootstrapped (n=1000) 95% nonparametric confidence intervals. B = blue-dyed bait, S = side set, 9m = 9m underwater setting chute, and 6.5m = 6.5m underwater setting chute.

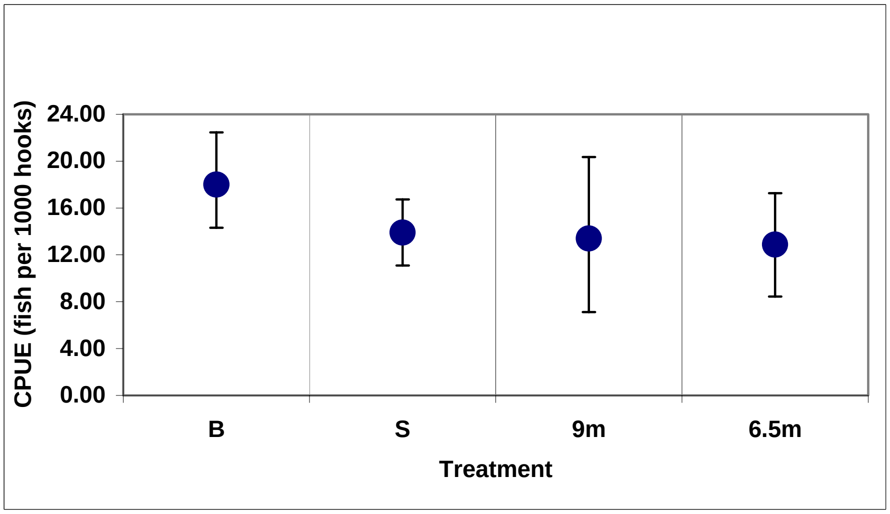


Fig. 16. CPUE for total commercial fish species for the four experimental treatments employed in the second research fishing trip, which employed longline tuna gear. Error bars are bootstrapped (n=1000) 95% nonparametric confidence intervals. B = blue-dyed bait, S = side set, 9m = 9m underwater setting chute, and 6.5m = 6.5m underwater setting chute.

4. Discussion

4.1. Contacts, captures, and normalizing rates for bird abundance

Based on mean seabird contact and capture rates, side setting was the most effect treatment tested in this trial when used with both Hawaii longline tuna and swordfish gear (Section 3.1 and Appendix I). The second most effective seabird avoidance method was the 9m chute when used with swordfish gear (swordfish replicates were conducted during trip 1 prior to the 9m chute breaking and being poorly repaired during subsequent use with tuna gear during trip 2). The 6.5m chute was the second most effective seabird avoidance method when used with tuna gear. However, some of the mean bird interaction rates were not significantly different based on overlapping 95% confidence intervals.

Black-footed albatrosses may be more effectively prevented from interacting with fishing gear than Laysan albatrosses. However, this may be more a reflection of black-footed albatrosses being less capable of interacting with gear than Laysan albatrosses, as black-footed albatrosses had lower contact and capture rates than Laysan albatrosses even when no seabird avoidance methods are employed during the control treatment of Gilman et al. (In Review and 2002a) (Section 3.1). Black-footed albatrosses were observed to be less agile in flight and underwater than Laysan albatrosses, making the black-footed albatrosses less capable of accessing baited hooks, possibly explaining the lower black-foot contact and capture rates. Also, the black-footed albatross abundance being much lower than Laysan abundance may have contributed to the lower black-footed albatross interaction rates, as the more abundant Laysan albatrosses were able to out-compete the outnumbered black-footed albatrosses.

Methods for quantifying and reporting seabird interactions with longline vessels should be standardized to facilitate more meaningful comparisons of results from different experiments. Normalizing seabird interaction rates for bird abundance is an approach of analysis that is consistent with the accepted understanding of animal abundance and the capture process (e.g., Ricker, 1958; Seber, 1973). Of all the confounding factors that likely affect the level of bird interactions with longline gear per unit of effort, including weather conditions, seabird species complex, and differences in gear and fishing practices, seabird abundance is thought to be one of the most important. Gilman et al. (In Review and 2002a) demonstrated a highly significant linear correlation between albatross abundance and seabird interaction rates, confirming the hypothesis that seabird interaction rates should be normalized for seabird abundance. Normalizing seabird interaction rates for bird abundance is necessary to allow accurate comparisons between results from multiple experiments. This has not been the norm for this body of literature (e.g., Lokkeborg, 1998 and 2001; Brothers, et al., 2000; Dunn and Steel, 2001; Melvin et al., 2001; Ryan and Watkins, 2002).

To help explain the benefit of normalizing seabird interaction rates for bird abundance, consider the scenario where in one experiment there are an average of 15 albatrosses following a vessel, and in a separate experiment there are 150 albatrosses following a vessel, and both vessels are testing the same seabird avoidance method(s). Based on the results from Gilman et al. (2002a and In Review), we expect about ten times more captures per unit effort (e.g., per 1000 hooks) in the second experiment than in the first experiment, assuming all other potentially confounding factors (weather conditions, seabird species complex, different type of gear, different bait, etc.) are the same for the two experiments. If we did not normalize the capture rates from the two experiments by bird abundance, a comparison of the reported capture rates (presented as captures per 1000 hooks) would imply that the capture rate in the first experiment was ten times lower than the capture rate of the second experiment. Therefore, normalizing capture and contact rates for bird abundance is important to allow accurate comparisons between seabird interaction rates reported from multiple experiments. Normalizing seabird interaction rates for significant confounding factors, when possible, makes rates reported from multiple experiments more comparable.

4.2. Underwater setting chute performance and comparison of bird interactions with two different length chutes

At the end of the third set of the first research fishing trip, the 9m chute fractured and bent at the main pipe welding joint, preventing continued use of the chute during the remainder of the first trip. The cause of the fracture was likely a manufacturing fault. The 9m chute was inadequately repaired for the second research fishing trip. For the second trip, the 9m chute had a bend in the shaft at the point of repair, preventing insertion of the lead ballast into the shaft. Also, after the attempt to repair the 9m chute, there were several large protrusions of welding material and pitted areas inside the shaft, which may have caused hooks to periodically get caught. The 6.5m chute also had design problems. The 6.5m chute had a rough slot edge, with irregular serration along portions of the length of the slot, which may have caused baited hooks to get caught, and did cause a delay in the hooks' sinking, leading to increased line tension and increased access of baited hooks to birds. Also, the shape of the funnel edge of both the 9m and 6.5m chutes caused delays in branch line departure, causing baited hooks to occasionally either jam inside the shaft or creating tension on the branch line, which caused baited hooks to re-surface astern and increased access to birds. The 6.5m chute was not available for use during the first research fishing trip before the 9m chute broke.

Unfortunately, the engineering deficiencies experienced with the two chutes prevent a meaningful comparison of the two different length chutes' effectiveness at reducing seabird interactions, and prevent a meaningful comparison of the chutes' effectiveness to the other experimental treatments. The 6.5m chute had a lower mean seabird contact and capture rate than the 9m chute when used with tuna gear, but there was no statistically significant difference based on overlapping 95% confidence intervals. The 9m chute would produce a gain in fishing efficiency of 52.7% over fishing with the 6.5m chute when used with tuna gear, based on available information when combining the effects of bait retention and hook setting rates on fishing efficiency (Section 4.10). If both chutes were used without design flaws, we would expect the 9m chute to deploy baited hooks consistently deeper than the 6.5m chute, resulting in the same or lower seabird contact and capture rates than the 6.5m chute. If both chutes were used without design flaws, both lengths of chutes would likely produce the same hook setting rates and similar bait retention rates, with similar fishing efficiencies.

There is concern that, even if all the chute's engineering deficiencies were fixed, it may be an insurmountable problem to avoid having gear getting occasionally tangled around the chute for vessels that set their main line slack, such as in the Hawaii longline tuna fleet. This is discussed in detail in Section 4.5.3.

4.3. Summary of seabird avoidance method research in North Pacific pelagic longline fisheries

Table 7 summarizes the results of all research conducted on seabird avoidance methods in North Pacific pelagic longline fisheries.

Table 7
Albatross interaction rates for seabird avoidance methods tested in North Pacific Ocean pelagic longline swordfish and tuna fisheries. Interaction rates are expressed as contacts or captures per 1000 hooks per bird (the rates are normalized for seabird abundance) unless noted otherwise.

		Treatment									
Study[a] and variable	**Control[b]**	**Underwater setting chute 9m**	**Blue-dyed bait**	**Towed Buoy**	**Strategic Discards**	**Streamer line**	**Night setting**	**Additional 60g weight at bait**	**Night setting & blue-dyed bait**	**Side setting**	**Underwater setting chute 6.5m**
McNamara et al. (1999) Hawaii longline swordfish gear											
Contact rate	32.8[c]		7.6	16.1	15.7	15.7					
Contact reduction			77%	51%	53%	52%					
Capture rate	2.23		0.12	0.26	0.32	0.47	0.60[e]				
Capture reduction			95%	88%	86%	79%	97%[e]				
Boggs (2001) Hawaii longline swordfish gear											
Contact rate[d]	7.60[c]		0.43			1.82		0.61			
Contact reduction			94%			76%		92%			
Gilman et al. (In Review and 2002a) Hawaii longline tuna gear											
Contact rate	0.61	0.03									
Contact reduction		95%									
Capture rate	0.06	0.00									
Capture reduction		100%									
Boggs (2003)[f] Hawaii longline swordfish gear											
Contact rate	0.78						0.053		0.01		
Contact reduction							93%		99%		
Capture rate	0.058						0.0013		0.00		
Capture reduction							98%		100%		
This study, Hawaii longline swordfish gear											
Contact rate		0.30	2.37							0.08	
Capture rate		0.03	0.08							0.01	
This study Hawaii longline tuna gear											
Contact rate		0.28	0.61							0.01	0.20
Contact reduction[g]		82%	60%							99%	87%
Capture rate		0.05	0.03							0.00	0.01

Capture reduction[g]	38%	63%							100%	88%

[a] Research has also been conducted by the Japan Fisheries Research Agency on the effectiveness of blue-dyed bait on reducing seabird interactions in Japan's longline tuna fishery in the western North Pacific Ocean (Minami and Kiyota, 2002). Results were not published in a format that provides seabird interaction rates expressed as contact or capture per number of hooks or normalized rates for seabird abundance.

[b] Control treatments in McNamara et al. (1999) and Boggs (2001) entailed conventional swordfish fishing operations. Control treatment in Gilman et al. (In Review and 2002a) entailed conventional tuna fishing operations.

[c] The different contact rates observed by Boggs (2001) and McNamara et al. (1999) may be explained by the use of different definitions of what constituted a seabird contact. McNamara et al. (1999) counted the total number of times a seabird came into contact with gear near the hook, even if the same bird contacted the gear multiple times, while Boggs (2001) defined a contact where only one contact per bait was recorded as a contact regardless of whether a single bird contacted a bait multiple times.

[d] Contact rates are averages of rates reported by Boggs (2001) for Laysan and black-footed albatrosses.

[e] This rate is not normalized for albatross abundance. McNamara et al. (1999) could not estimate seabird abundance during night setting. McNamara et al.'s (1999) control capture rate when not normalized for albatross abundance was 18.0 captures per 1000 hooks. Night setting reduced this control capture rate by 97%.

[f] Preliminary results, unpublished data.

[g] The contact and capture reductions use the control treatment contact and capture rates of Gilman et al. (In Review and 2002a). Little weight should be given to these reductions from the previous year's control treatment bird interaction rates, as the control rates from a different year may not be applicable to the current study for reasons discussed below.

Even when normalized for seabird abundance, the results reported in Table 7 show a high degree of variability in treatment contact and capture rates from one year and one experiment to the next. For instance, the control treatment capture rate in the Hawaii longline swordfish fishery from McNamara et al. (1999) (2.23 captures/1000 hooks/bird) is over 38 times higher than the control treatment capture rate observed by Boggs (2003). And the Boggs (2001) control treatment contact rate in the Hawaii longline swordfish fishery (7.60 contacts/1000 hooks/bird) is over 9 times higher than the control contact rate observed by Boggs (2003). This variability of bird interaction rates normalized for bird abundance by the same treatment may be a result of numerous confounding factors. Such factors might include weather, season, bird behavior, bird species complex, fishing practices (e.g., time of day when setting, use of deck lighting at night, offal discharge practices, type and condition of bait, amount and location of weights, length of branch lines, size of hooks, crew practices for deploying branch lines), location of fishing grounds, and consistency in observer's methods (Brothers, 1991; Brothers, 1995; Environment Australia, 1998; Brothers *et al.*, 1999; Gilman, 2001a and 2001b). Or, in the case of the 9m underwater setting chute, which was observed to have a contact rate over nine times higher in this study than in Gilman et al. (In Review and 2002a), the variability in bird interaction rates is likely due to engineering inconsistencies. A seabird avoidance method, or combination of methods, that is appropriate for a fishery will perform relatively consistently towards reducing seabird captures to close to zero despite the existence of these numerous sources of variability – performance, measured as minimizing contact and capture rates, will not vary significantly when used on different vessels, in different years, with varying bird behavior and species complex, varying weather conditions, etc.

4.4. Loss of caught birds before haul

The observation that fewer caught seabirds are hauled aboard than are observed caught during setting indicates that assessments made using onboard observer data of seabird capture in longline fisheries, based on a count of the number of birds hauled aboard, are underestimates.

In this experiment, crew did not attempt to dislodge or discard caught seabirds during hauling, and no live birds were caught on the lines as they were being hauled. Thus, the seabirds observed caught during the set by the researcher but not hauled aboard can be interpreted as seabirds falling from hooks due to fish predation, current, or other mechanical action during the line soak and haul. Results from this study indicated that 28% fewer birds were hauled aboard than were observed being caught during setting, which is consistent with Gilman et al. (In Review and 2002a) (34%), and Brothers (1991) (27%).

It is possible that observed captures of seabirds during setting are overestimates, as there is an unknown degree of certainty that seabirds observed caught do not free themselves before the observation is obstructed. And it is also possible that a larger number of seabirds are caught than observed during setting, such as when large numbers of seabirds are following a vessel or when large waves obstruct view of all seabirds that are caught on hooks. For instance, data in Table 2 shows that on several occasions the researcher observed fewer birds being captured during the set than were hauled aboard.

Seabird catch rates recorded on fishing vessels from observations of dead birds hauled aboard are conservative underestimates because not all seabirds that are caught are hauled aboard, as there is unobserved discarding of incidentally caught seabirds by crew, and seabirds can fall from the hooks before hauling, considered by some to be significant biases (Brothers, 1991; Gales et al., 1998; Gilman et al., In Review). In one study, counts of albatrosses observed caught during line setting on Japanese longline tuna vessels fishing off Tasmania, Australia in 1988 showed that an estimated 27% of those observed hooked during setting were not hauled aboard (Brothers, 1991). Gales *et al*. (1998) studied seabird mortality in the Japanese southern bluefin longline tuna fishery within the Australian Fishing Zone from 1988 to 1995. As part of this study, in 1995 around Tasmania, observers dedicated to watching hauling to quantify seabird catch rates assessed the numbers of discards (seabirds hooked but not hauled aboard due to crew flicking or cutting them off the line while along side the vessel, perhaps done to mask the extent of seabird catch), which they would fail to observe during routine observations when their primary task is to sample fish. Gales *et al*. (1998) found that the seabird catch rate in Tasmania in 1995 was 95% higher on hauls with observations of seabirds cut off by crew than on routine observations, which is not a relevant factor for this trial.

4.5. Seabird avoidance method treatment practicability and enforceability

Debriefing of the captain and crew after completion of the two research fishing trips highlighted positive and negative aspects of each seabird avoidance method. Discussion focused on how each method required alterations from conventional fishing methods, the degree of difficulty to employ the method effectively, the cost to employ the seabird avoidance method, the method's effect on fishing efficiency, and the enforceability of each method.

4.5.1. Blue-dyed bait

Pros

- Some crew members perceive that, relative to conventional fishing with non-dyed bait, blue-dyed bait is effective at avoiding bird capture when bird abundance is low;
- Because the bait is thawed more so than with the other seabird avoidance methods (assuming the bait is not pre-dyed), birds are able to more easily remove the bait from the hook than if the bait were partially frozen. This likely decreases the incidence of birds fighting over the bait, which is when most bird hookings occur;
- It may be feasible to make pre-dyed bait commercially available, which would make enforcement of rules requiring possession of blue-dyed bait feasible via dockside inspections.

Cons

- To dye bait to a suitable darkness requires that the bait be completely thawed. However, the crew prefer squid and fish bait to be slightly frozen because (a) this increases bait retention on hooks during the soak, (b) fish bait tends to fall apart when baiting the hook through the fish head if the bait is completely thawed, and (c) crew want the option to preserve bait quality in case the set is cut short, allowing the baits to be returned to the freezer (pre-dyed bait could resolve this concern);

- Blue-dyed bait is inconsistently effective due to differences in where crew throw bait when setting. Some crew throw blue-dyed bait short over the white water of the turbulent propeller wash, where the bait may be highly visible to seabirds from above. Other crew throw the dyed bait very wide to the port side, providing birds with easier access to the baited hook. Some crew might throw the blue-dyed bait immediately to the side of the propeller wash, minimizing birds' access and visibility;
- It is not possible to get fish bait to the regulatory-required darkness. Fish scales come off the fish bait when handled by crew, removing the blue-dye;
- The skipper makes snap decisions on whether or not to set, not always allowing enough time for crew to properly dye bait (pre-dyed bait could resolve this concern);
- There is the perception that blue-dyed bait is not effective enough at decreasing seabird interactions, reducing the incentive for crew to employ the method as required by regulations. Crew perceive that blue-dyed bait was only slightly better than conventional fishing with undyed bait, and perceive that blue-dyed bait is inconsistently effective depending on weather, light, sea surface color and other variable environmental conditions, in addition to the inconsistency due to variability in where different crew deploy baited hooks. Blue-dyed bait effectiveness appears to be partially dependent on light intensity and direction in relation to a bird's flight path, where dull light conditions result in the blue-dyed bait being visible to birds, and bright light conditions with glare off the sea surface assists with concealing the dyed bait;
- Dyeing bait requires that crew spend significant extra time preparing the bait in lieu of personal time, such as sleeping (pre-dyed bait could resolve this concern);
- Blue-dyed bait is messy, dying the crew's hands and clothes, and the deck (pre-dyed bait might resolve this concern);
- Blue-dye costs about U.S.$14 per set in the Hawaii longline fleet. This cost could be sufficiently high to pose an economic disincentive for some vessels. There is no perceived increase in fishing efficiency from using blue-dyed bait;
- Blue-dyed bait does not facilitate enforcement in Hawaii longline fisheries. Vessels without onboard observer can place a bucket of blue dye on deck in case there is surveillance by overflights, and the majority of the fleet is believed not to attempt to effectively comply with regulations requiring the use of blue-dyed bait.

Overall, blue-dyed bait is impracticable and inconvenient for crew, is perceived by crew to be insufficient at minimizing bird mortality, is relatively inexpensive, is not used consistently by crew, is not perceived to increase target fish CPUE, and does not facilitate effective enforcement to ensure it is being employed effectively. Several of the inconveniences and enforceability problems could be addressed if pre-blue-dyed bait were commercially available. Blue-dyed bait used in combination with other mitigation methods could improve bird avoidance, but again, without being commercially available, blue-dyed bait is unlikely to be employed.

4.5.2. Side setting

Pros

- Side setting provides significant operational benefits, especially for vessels with an aft wheelhouse and main work deck forward of the vessel's wheelhouse. (a) Side setting allows for better supervision of fishing operations by the vessel captain from his work station on the bridge, providing safety and efficiency advantages. (b) Instead of having two separate work areas as is necessary when line setting is carried out from the vessel stern, at the stern for line setting and at midship for line hauling, side setting permits a vessel to have a single work area. When side setting, all of the gear can be stored at a single area, allowing for the area where the gear is stored to be condensed, which could be a significant benefit for smaller vessels. Side setting would provide significantly more deck room on all vessels, even those with a forward wheelhouse. (c) Vessels conventionally setting from the stern will move totes, line buoys, and radio beacons between the mid-ship hauling position and the stern setting position when stern setting. They also will move large quantities of bait from the forward storage freezer to the stern for line setting. Some of these vessels have very narrow passageways along the starboard side of the vessel where they have to move the gear back and forth between each set and haul, forcing some vessels to use narrow and small bins. Some vessels have a conveyer belt system down the port side to transport fishing gear from the line haul work area to the aft line setting work area. Crew would no longer have to move the gear from setting to hauling positions when side setting, and a significant amount of valuable deck space would be freed up now that the vessel no longer has to accommodate an aft line setting position;

- Emergency maneuvering on occasions when a main line jams during setting will be more effective when line setting is carried out from midship on the starboard side;
- Can be feasibly employed on all vessels in the Hawaii longline fleet. The crew perceive that, after a trial of side setting from various positions on the F.V. *Katy Mary*, that with some initial thought, all are practical;
- May increase fishing efficiency. Some crew of the F.V. *Katy Mary* found they could increase their hook setting rate when side setting compared to conventional setting. The increased retention of bait by avoiding bird interactions will increase target fish CPUE;
- There is no cost associated with side setting after any initial expense of adjusting the vessel deck design and fabricating or purchasing a bird curtain;
- Crew perceive that there are fewer gear tangles when side setting compared to conventional stern setting;
- Crew perceive that side setting is very effective at avoiding bird interactions, noting that seabirds stopped searching for baits and would start roaming when they were side setting, thus providing an incentive for crew to employ this method;
- Side setting can be feasibly enforced in the Hawaii longline fleet. Regulations can include language to prevent vessels from locating a main line shooter at the vessel stern, such as by prohibiting a facility to stern-mount a main line shooter.

Cons

- Some cost and effort is required to alter a vessel's deck design for side setting. Also, a bird curtain is estimated to cost U.S.$50;
- Some nominal effort is required to change industry's longstanding practices of stern setting, however, crew perceive that it requires very little time to adjust to the new setting location, and there is no short or long-term decrease in efficiency. For instance, crew need to become proficient at throwing bait parallel alongside the boat, and the crew need to either install a small hauler off the stern or park the boat sideways to haul when breaking lines;
- The crew member clipping branch lines has an increased risk of injury from hooks when there are tote tangles, because of the direction branch lines go off of the vessel, as compared to conventional stern setting;
- There may be occasional inconvenience and discomfort for crew when side setting in heavy weather when it cannot be avoided to have the swell come onto the side where setting is occurring. This will be a more noticeable problem on smaller vessels;
- Required use of a bird curtain as a complementary practice when side setting does not facilitate effective enforcement. It is not known how much the bird curtain contributed to the side setting method's effectiveness in this study. The expectation that side setting will be only slightly less effective when conducted without use of a bird curtain could be wrong.

Overall, side setting is practical and operationally beneficial for crew for several reasons, is perceived by crew to be effective at avoiding seabird capture, is inexpensive, is expected to be employed consistently, may increase fishing efficiency, and facilitates effective enforcement. For these reasons, side setting is expected to result in lower seabird mortality than the use of blue-dyed bait or the underwater setting chute.

4.5.3. Underwater setting chute

Pros

- Crew perceive that the underwater setting chute significantly reduces seabird interactions;

- The hook setting interval is easier for crew—the interval is slower than the conventional hook setting interval;
- Crew find setting with the chute to be less messy than conventional setting, as bait does not splatter and hit the crew when setting bait through the chute;
- May increase fishing efficiency due to increased bait retention from avoiding bird interactions and mechanical effectiveness. But these factors will be offset to a degree by the slower hook setting rate in the tuna longline fishery;
- Required use of the underwater setting chute might be feasibly enforced in the Hawaii longline fleet if vessels are required to install a hook counter to monitor use. But this technology has yet to be tested.

Cons

- Slows the hook setting rate in the tuna longline fishery compared to conventional setting, potentially reducing fishing efficiency. The hook setting rate with the chute is expected to be suitable for the swordfish fishery where the conventional hook set interval is slower;
- Crew perceive the chute to be unwieldy to use. A more efficient system to deploy and retract the chute is needed and could be designed and installed if a vessel were to install a chute for permanent use and not just for a short-term period. If crew were forced to use the chute, they could probably make it work, but they would prefer to use other more convenient seabird avoidance methods;
- Performance of the chute will be inconsistent depending on crew diligence to timing of clipping branch lines to the main line;
- The chute costs about U.S.$5,000, and there is some additional cost associated with installation, which can be a significant economic disincentive for some vessels;
- The chute for pelagic longline fisheries is not commercially available;
- The chute's engineering and design is still in the development stages and requires more research. A number of engineering problems need to be resolved before the chute could be used broadly;
- There is concern that, even if all the chute's engineering deficiencies were fixed, it may be an insurmountable problem to avoid having gear getting occasionally tangled around the chute for vessels that set their main line slack, such as in the Hawaii longline tuna fleet. In current Australian trials of the chute, vessel operators increase the main line tension to avoid having the main line get tangled on the chute. The increased main line tension likely causes the gear to be set more shallow, which may increase seabird access to baited hooks, especially when deep-diving seabirds are present, and may increase the rate of incidental capture of sea turtles. Sea turtle tracking indicates that sea turtles spend a majority of their time at depths less than 40m (Polovina et al., 2002). Also, observer data from the Hawaii longline fleet shows that a higher proportion of loggerhead and leatherback turtles are taken on the branch line closest to floats than on other deeper branch lines (Kleiber and Boggs, 2000);
- When there is a large swell, use of the chute causes fouled hooks and gear tangles. When tangles cause hooks to come up prong first, this creates a safety hazard for crew during hauling. The two causes of the increased incidence of gear tangles when using the chute, timing of crew clipping branch lines to the main line and bin tangles, both are avoidable, but may be frequent with new and inattentive crew;
- The chute requires a lot of deck space to stow, which may be a significant problem on smaller vessels.

Overall, the underwater setting chute is inconvenient for use by crew, is relatively expensive, performs inconsistently due to design problems, is expected to increase fishing efficiency, and may facilitate effective enforcement. The chute in its current degree of development is not expected to be acceptable and broadly used by longline industries. However, the inconveniences and design problems with the chute likely can be corrected with additional research and design improvements. An effort should be made to rectify the chute's design faults, and if this is successful, then the chute should be made commercially available. For instance, the next generation of longline vessels could integrate a chute into their hulls.

4.6. Vessel conversion to side setting

4.6.1. Side setting position

There were no statistically significant differences between contact and capture rates for the three different side setting positions, however there was a small sample size. There were no incidences of gear being fouled in the propeller while side setting from any of the three setting positions. This component of the trial demonstrated that it was possible to adjust the gear to side set from various deck positions without any apparent compromise to the effectiveness of the method at avoiding seabird interactions, indicating that it is most likely a feasible seabird avoidance method on a variety of vessel deck designs.

Several aspects of a vessel's layout need to be considered when planning to convert to side setting, including the feasibility of setting from the port versus starboard side; new position for the main line shooter; and location for buoy, radio beacon, and branch line tote storage. A central principle is that the further forward the setting position is from the vessel stern, the more effective this method will be at avoiding seabird interactions and thus reducing the loss of bait to birds. Also, the further forward the setting position, the easier it is to contend with tote tangles and inadvertently badly thrown baits.

Side setting from the port side is operationally more convenient than setting from the starboard side for several reasons:

(a) A fixed position main line shooter will not interfere with line hauling at the conventional starboard position when setting from the port side;
(b) It is a more natural throwing motion for right-handed crew to set from the port side than from the starboard side. When setting from the port side, crew use the conventional motion of swinging the bait outward and to the right using their right hand. When setting from the starboard side, crew throw the bait underhand and to the right using their right hand. As a result, crew will likely be able to throw the bait further forward when setting from the port side versus the starboard side; and
(c) Main line shooters have motors on their left-hand side, which makes it more convenient to clip branch lines to the main line when port-side setting than from the starboard side.

A vessel's first choice of positioning the main line shooter for side setting is on the port side as far forward as possible. However, a vessel layout may make it impossible to set from the port side, or may make it possible to set further forward from the starboard side than from the port side. Considering the conventional choice of setting direction in relation to the wind and sea direction, which puts the wind and sea onto the port-stern corner, setting from the starboard side has the potential to reduce birds' ability to take advantage of wind direction to access baited hooks.

A small number of vessels may have limited options on both the port and starboard sides to mount main line shooters for side setting from a position far forward from the stern. In these cases, the vessel needs a minimum of 0.5m from the stern corner to allow space to mount a bird curtain aft of the main line shooter.

4.6.2. Main line shooter hinges and hydraulics

The main line shooter can be a permanent fixture for side setting. However, the shooter base can be installed on a hinge plate for installation on either port or starboard sides to protect the shooter when the vessel is docked. Also, when setting from the starboard side, since a starboard shooter may have to be mounted within the line hauling work area, the shooter base can be hinged to allow the shooter to be folded inward and down for stowage to create a clear work area during hauling. Also, for starboard side installation of the main line shooter, quick-connect hydraulic hoses can be installed on the shooter to allow the crew to move the shooter out of the way when hauling.

4.6.3. Timing of clipping branch lines to main line

Observations of line setting characteristics suggest bait throwing can be coordinated with the timing of clipping the branch line onto the main line to maximize the bait sink rate. By clipping the branch line to the main line as the thrown baited hook is about to pass the main line shooter enables the sinking of the bait to occur without reduction in sink rate caused by line tension.

4.6.4. Line pullers

Hydraulic or electric line pullers may need to be installed for side setting to replace the function of the previously stern-mounted main line shooter used to recover the main line when the line breaks during hauling.

4.6.5. Right side line shooter motor and mounting plate

When setting from the starboard side, a main line shooter motor and mounting plate that accommodate right side mounting will be more convenient than the conventional main line shooter motors and mounting plates made for left-side mounting.

4.7. Side setting and bait depth at stern

Table 8 records the sink rates of alternative bait types. This information can be used to estimate the depth various baited hooks will be when passing the stern of the vessel when deployed from different side setting positions, when the vessel is travelling at different speeds during setting.

Table 8
Bait sink rates for alternative bait types, measured to 5m with a 60g swivel within 0.5m of the hook

Bait type	Average bait weight (grams)	N	Sink rate (seconds/meter)
Thawed sardine (with 120g swivel instead of 60g)	100	20	0.85
Thawed sardine	100	25	0.97
Frozen sardine	100	25	1.00
Frozen squid (no lightstick, hook through tail)	185	35	1.25
Thawed squid (no lightstick, hook through tail)	185	20	1.28
Thawed squid (with lightstick, hook through tail)	185	20	1.33
Frozen squid (no lightstick, hook through body side)	185	25	1.41

This sink rate experiment shows that fish bait sinks faster than squid, lightsticks slow the sink rate, and placing the hook in a squid's tail, which is the conventional practice by the F.V. *Katy Mary's* crew, results in a faster sink rate than placing the hook through the side of the squid. Doubling the weight by 100% from 60g to 120g only resulted in a slight increase in bait sink rate with the weight located within 0.5m of the hook, implying that use of a 60g swivel close to the hook is likely sufficient when side setting to avoid bird interactions. Also, this indicates that if a bait is set conventionally without employment of a seabird avoidance method, that increasing line weighting above 60g when located near the hook will not significantly reduce the availability of the baited hook to birds that access baited hooks only during the moment when the baited hook hits the sea surface.

From a side setting position where baits are thrown 15m forward from the stern (the forward port position used during this trial, Figure 2), and a vessel travelling at 7.5kt (3.9m/s) during setting (this is the setting speed used by the *Katy Mary*), the stern will pass a baited hook in 3.8 seconds. Given these conditions, the range of bait assessed in Table 8 will be between 2.7 and 4.5m underwater when they are passed by the vessel stern. This is shallower than the 9m long underwater setting chute deploys baited hooks (5.4m), and in the range that the 6.5m chute deploys baited hooks (2.9m).

From a side setting position where baits are thrown 9m forward from the stern (the least forward port position used during this trial, Figure 2), and a 7.5kt setting speed, the stern will pass baited hooks in about 2.3 seconds. Given these conditions, baits will be between 1.6 and 2.7m underwater when they are passed by the vessel stern. This is shallower than the depths to which both the 9m and 6.5m underwater setting chutes deploy baited hooks.

This exercise demonstrates how the bait throwing position distance forward from the stern, vessel setting speed, amount and location of weight on the branch line, bait condition, and bait type can be assessed to predict the depth that baited hooks will be underwater when they are passed by the vessel stern. If more precise data could be collected, it would be possible to create a graph showing how the baited hook depth when at the stern will change given different vessel setting speeds, side setting position forward, and bait sink rates. This assessment is useful when considering how to design a vessel to convert to side setting to maximize the depth of baited hooks when at the vessel stern.

The sink rates for this exercise were collected from a stationary vessel. Brothers and Reid (In Review) report that baited hooks will sink 22% more slowly when setting from the stern of the vessel during actual fishing operations with the vessel moving than when the vessel is stationary. The slower hook sink rate from a moving vessel is thought to be due to propeller turbulence. However, the sink rate of baited hooks when side setting is not believed to be affected by propeller turbulence. Thus, the measurements in Table 8 are expected to be accurate for actual fishing operations despite the measurements having been taken from a stationary vessel.

4.8. Side setting and risk to birds from bait loss from hooks during setting

When side setting, on rare occasions a fish bait will fall from a hook during throwing. Squid bait seldom falls off hooks when thrown. When a side set fish bait falls from the hook, it will float astern over an area where diving birds can become entangled in the main and branch lines. Of the two seabirds confirmed caught on the haul when side setting, one was tangled in the line and not hooked. It may be possible to adjust the timing of clipping branch lines to the main line to reduce the risk of birds become tangled in the gear. Or it may be possible to replace the existing light swivel on the clip (used to attach the branch line to the main line) with a 20g swivel to provide a slight increase in the branch line sink rate. Also, as there appears to be only a nominal decrease in side-set fish bait sink rate when the bait is frozen (Section 4.7), advocating the use of frozen fish bait when side setting might make the bait more buoyant if it falls from the hook, thus reducing the risk of birds diving deep pursuing the bait to become entangled in the gear. A 60g swivel appears to be sufficient to counteract the buoyancy of frozen bait. The more forward the position for side setting, the more time the gear will have to sink before reaching the stern, and the less frequent such interactions will occur where birds get entangled in gear while pursuing an unhooked bait.

4.9. Shearwater interactions – deep-diving seabirds

One short-tailed shearwater and one sooty shearwater were hauled aboard during the experiment (Table 2) (species identifications are pending confirmation by the U.S. Fish and Wildlife Service). There were no observations of contacts or captures of shearwater species during setting. There were many observations of shearwaters diving underwater for baits, but it was difficult to keep accurate interaction records during setting because these species of birds remain submerged for up to 40 seconds, by which time the observer would lose their position astern of the vessel. Albatrosses where observed to occasionally wait at the position where a shearwater dove underwater, but this did not occur very frequently, and there were no observations of shearwaters bringing baited hooks back to the sea surface where they would be available to albatrosses.

Data from the Hawaii longline observer program and seabird avoidance research projects in Hawaii longline fisheries indicate that capture of shearwaters is an extremely rare event, records indicate that shearwater interactions with all North Pacific pelagic longline fisheries is infrequent, and there are no reported observations of the Hawaii fleet of shearwaters bringing baited hooks to the surface making them available to albatrosses and other large seabirds (Brothers et al., 1999; McNamara et al., 1999; Boggs, 2001 and 2003; Gilman et al., 2002a; U.S. National Marine Fisheries Service, 2001a, 2001b, and 2001c; U.S. Fish and Wildlife Service, 2002). This is however a significant problem in Southern Hemisphere longline fisheries where species of deep-diving shearwaters and petrels interact with longline vessels (Brothers et al., 2000; Uhlman, 2003). For instance, the deep-diving flesh-footed shearwater (*Puffinus carneipes*), one of the two most often caught species in the Australian Fishing Zone, can reach baits to a depth of 20m (66 feet), bringing baited hooks to the surface where they might lose the baited hook to larger albatrosses, petrels, and skua species, if these other species are present, or get caught on the baited hook themselves. In areas and seasons where proficient deep-diving seabirds are problematic, the effectiveness of side setting with adequate line weighting (such as 60g within 1m of the hook) has yet to be assessed. It is likely that employment of a combination of side setting, adequate line weighting, and night-setting will be effective and necessary to minimize interactions with proficient deep-diving seabird species.

4.10. Bait retention, hook setting rate, fish CPUE, and fishing efficiency

A seabird avoidance method's effect on fishing efficiency is the result of the treatment's ability to avoid having bait be taken by seabirds, the incidence of loss of bait due to the mechanical process of setting baited hooks, the hook setting rate, and any additional effect the treatment may have on the incidence of commercial fish species getting caught on baited hooks.

The composition of fish bait used by crew is somewhat random making it possible to end up with varying proportions of bait types on different sections of line. The three types of bait used by the F.V. *Katy Mary*, squid, sardine, and saury (sanma), are retained on hooks to different degrees. We were able to partly address this confounding factor by comparing bait retention only for sections of gear containing squid bait for swordfish gear, and only comparing bait retention for sections of gear containing fish bait for tuna gear. Because the sample size for the analysis of bait retention by experimental treatment is extremely small, the results could be influenced by the undocumented fish bait composition on sections of gear assessed for different treatments used with tuna gear. Furthermore, the condition of bait, such as the degree of being frozen/thawed, also is thought to significantly affect retention on hooks, and this confounding factor may have also influenced the results of the bait retention analysis. There was a large enough sample size to conclude that there is no significant difference in bait retention between blue-dyed bait and side setting when used with tuna gear.

There was no significant difference in commercial fish CPUE between the treatments employed during the second fishing trip employing tuna gear, suggesting perhaps that the operational differences observed with these methods (e.g., different rates of bait loss, different hook setting rates, gear tangling) did not significantly affect fishing efficiency. With this extremely small sample size (11 sets of one fishing trip), factors other than changing treatments can have a far greater effect on commercial fish CPUE than the treatment itself. Pelagic fish have a patchy distribution over the 30 miles that a longline stretches. And random events such as a whale hitting the line can cause significant loss of caught fish on one section of line set under one of the experimental treatments. These and other factors can bias CPUE comparisons by treatment when relying on a small sample size. The results from the assessment of differences in hook setting rates and bait retention by treatment provide a better prediction of differences in fishing efficiency for each treatment over the long term.

Minami and Kiyota (2002) found that catch rates of tunas with and without blue-dyed bait were not significantly different. The CPUE assessment in this experiment showed that the total and target commercial fish CPUE for the blue-dyed bait experimental treatment was highest of the four experimental treatments, however the difference between the blue-dyed bait CPUE and the CPUE for the other three treatments was not significantly different based on overlapping 95% confidence intervals.

In the Hawaii longline swordfish fishery, the typical hook setting interval is 12 seconds per hook (based on the total time to deploy gear and not the vessel's buzzer time rate) (Gilman et al., 2002a). Thus, none of the three seabird avoidance methods used in this trial with swordfish gear would cause a delay in the conventional hook setting rate. If we assume that there is no additional significant difference in each treatment's effect on the probability of a commercial fish species being caught on a baited hook, when there are abundant albatrosses present, the difference in bait retention would be the only factor influencing fishing efficiency in the swordfish fleet. We also assume that the simulated swordfish gear employed in this trial, which was set at an unconventional depth, affected the bait retention observations equally across treatments. Based on the limited available information, for treatments employed using swordfish gear, side setting would have the highest fishing efficiency and would produce a gain in efficiency of 7.8% over fishing with blue-dyed bait, and setting with the 9m underwater setting chute would produce a gain in efficiency of 2.5% over fishing with blue-dyed bait.

In the Hawaii longline tuna fishery, where the average conventional hook setting rate is 8 seconds per hook (also based on the total time to deploy gear and not the vessel's buzzer time rate) (Gilman et al., 2002a), both lengths of underwater setting chute would cause a delay in deploying branch lines, and could reduce the number of hooks deployed per set if the vessel runs out of time or gear. Again we assume that there is no additional difference in each treatment's effect on the probability of commercial fish species getting caught on baited hooks. When there are abundant albatrosses present, we use the average hook setting rate of the Hawaii longline tuna fleet of 8s/hook as a baseline, and assume that the slower hook setting rates of the two lengths of chutes above 8s/hook would cause vessels to have to set fewer hooks because they do not have the time or extra gear to complete the slower sets. When we combine the effects of bait retention and hook setting rates on fishing efficiency of treatments used with tuna gear, the 9m chute would have the highest fishing efficiency and would produce a gain in efficiency of 55.9% over fishing with the 6.5m chute, side setting would have the second highest fishing efficiency and would produce a gain in efficiency of 52.7% over fishing with the 6.5m chute, blue dyed bait would have the third highest fishing efficiency and would produce a gain in efficiency of 45.2% over fishing with the 6.5m chute, and the 6.5m chute would have the worst fishing efficiency.[1]

4.11. Safety hazard

Crew are at risk of injury during hauling if a hook is attached to a clip, another hook, or the main line; or when a branch line is twisted around the main line, especially near the end of the haul when the crew is tired and less attentive. For instance, if a hook were attached to a clip on the main line where there was a knot in the main line (where a break in the main line had been mended), this could result in serious injury to the hand of the crew handling the main line.

Due to problems experienced with branch lines being delayed as a result of the edge of the 6.5m chute's funnel edge (Section 4.2), the main line shooter had to be positioned close to the chute to enable the crew member clipping the branch lines to the main line to be close enough to the chute to correct bait jams in the chute. As a result of having the main line shooter and chute so close, the main line would occasionally wrap behind the chute, causing hooks to get caught on the main line and on each other.

5. Conclusions

Reducing seabird mortality in Hawaii pelagic longline fisheries alone will not significantly reduce the degree of this threat to North Pacific albatross populations. The Hawaii longline fleet is a very small component of total pelagic and demersal longline fishing effort in the North Pacific: the Hawaii longline fishery represents about 2.7% of the longline hooks deployed in the entire Pacific Ocean each year, U.S. pelagic longline fleets contributed 13-21% of hooks deployed during 1994-2000 within areas of occurrence of the Laysan and black-footed albatrosses, and only 10% of total catch of Pacific pelagic species (U.S. National Marine Fisheries Service, 1999; Cousins *et al*., 2001; Lewison and Crowder, In Press).

In 2001 the number of active pelagic longline vessels in the Western and Central Pacific Ocean from China was 104; from Japan (combined coastal, distant-water, and offshore fleets) was 1,386; from Korea was 176; from Taiwan (distant-water and offshore) was 1,797; and Hawaii was 90 (U.S. National Marine Fisheries Service, 2002c; Secretariat of the Pacific Community, 2002). Most of the catch and effort in terms of number of hooks set by pelagic longline vessels in the Western and Central Pacific region is by the large-vessel, distant-water fleets of Japan, Korea, and Taiwan (Hampton and Williams, 2003). Distant-water vessels from China have recently entered the fishery and there has been rapid development of a longline fishery in Vietnam (Hampton and Williams, 2003). The Hawaii pelagic longline fleet comprises roughly 3% of the total pelagic longline vessels operating in the Western and Central Pacific Ocean region, and roughly 5% of the total effort in terms of number of hooks set per year in this area (U.S. National Marine Fisheries Service, 2001c and 2002c; Secretariat of the Pacific Community, 2002).

To successfully abate the problem of albatross mortality in North Pacific and global longline fisheries, there is a need to mainstream seabird avoidance best practices for longline fisheries, starting with exporting best practices to the major longline fleets. Results from research and commercial demonstrations conducted in the Hawaii longline fleet might be exportable to the world's largest pelagic and demersal longline fisheries.

Side setting combined with adequate line weighting holds much promise to reduce seabird mortality in all pelagic and demersal longline fisheries. The same operational benefits identified with side setting on the smaller vessels in the Hawaii longline fleet would apply to the large distant water pelagic longline fleets from Asian nations. Side setting on these large 35-45m long distant water pelagic longline vessels may not require changes to conventional branch line weighting due to the ability to set from a position far forward of the stern, despite the relatively fast vessel setting speed (10.5 knots) and

[1] For instance, of the possible 100% of baited hooks that can be set, the slower setting with the 9m chute would reduce the number of branch lines deployed by 0.125 (12.5%). 94.3% of these remaining branch lines would retain their bait, resulting in 0.825 of the possible 100% of baited hooks that could be set to be set and retain baits. The 6.5m chute would result in 0.529 of the possible 100% of baited hooks that could be set to be set retaining baits. The 9m chute's 0.825 setting of baited hooks is an increase in efficiency by a factor of 1.559 (55.9%) of the 6.5m chute's 0.529 setting of baited hooks.

concomitant short time for baited hooks to sink before being passed by the vessel stern. Side setting would be equally practicable, convenient, and effective at avoiding bird interactions on demersal longline vessels as it promises to be for pelagic longline vessels. Side setting would provide even greater operational advantages for both Spanish-system and non-Spanish system demersal longline vessels than pelagic longline vessels, as demersal vessels have to transfer even larger quantities of line weights between the hauling and setting stations daily than do pelagic longline vessels.

Despite the expected practicality and operational benefits, longline industries are expected to have a low incentive to convert to side setting because stern setting has proven itself to be an effective and efficient method over the past 30 years. As a result, there will be an initial substantial hurdle to overcome to convince vessels to try the new setting position. Commercial demonstrations need to be conducted on a variety of vessel lengths and designs to determine if bait loss off hooks and line tangling or cutting such as from contact with propellers are problematic. For fishing grounds and seasons where proficient deep-diving seabird species interact with longline vessels, it is likely that employment of a combination of side setting, adequate line weighting, and night-setting will be effective and necessary. Additional assessment should be conducted to confirm these hypotheses. Such evaluation must precede widespread advocacy for pelagic and demersal longline fleets to side set.

Design faults with the underwater setting chute should be rectified and further evaluation conducted to a point where the technology is either made commercially available or discarded entirely in preference of more acceptable and effective mitigation methods.

Blue-dyed bait is not acceptable to industry given that pre-dyed bait is not commercially available, and holds less promise than other more convenient seabird avoidance methods at minimizing seabird mortality to close to zero, perhaps due to inconsistent effectiveness from variable environmental conditions and crew deployment of baited hooks. Attention should be focused on more promising methods. Blue-dyed bait used in combination with other mitigation methods such as side setting, the chute, or night setting, could increase bird avoidance, but again, without being commercially available, blue-dyed bait is unlikely to be used broadly.

6. Recommendations for Hawaii Fishery Management Authorities

Results from this study indicate that side setting combined with adequate line weighting holds significant promise for minimizing seabird mortality in the Hawaii pelagic longline tuna and swordfish fisheries. The Hawaii longline industry should be encouraged to conduct a broad, industry-wide trial of side setting. A formal incentive program should be instituted to encourage the fleet to change their longstanding vessel design to voluntarily try side setting. Less than three months after completing the research, six Hawaii longline vessels have voluntarily converted their vessels to side set, indicating that the industry has high expectations for achieving operational benefits from the change, and that the industry is committed to ascertain the full extent of the mitigation method's potential. Results from this broad trial would guide management authorities to amend relevant regulations.

Broad trials have the potential benefit of confirming the expectations that side setting will (a) be feasible to implement on all of the vessels in the Hawaii fleet; (b) perform consistently under variable conditions found at different fishing grounds, seasons, years, weather conditions, and various light conditions; (c) perform consistently under the suite of fishing methods and gear used by the fleet, including determining the effect of having a range of crew skill levels at consistently deploying baited hooks close to the vessel hull; (d) increase fishing efficiency by reducing the loss of bait to birds and possibly by decreasing the hook setting rate; (e) not require significant effort to reconfigure deck layout; and (f) not require significant changes to normal fishing practices. The broad trials promise to increase industry familiarity with this fishing method and develop support for fleet-wide use. Fishery management authorities can make use of the Hawaii longline onboard observer program during the side setting commercial demonstration to compare seabird interaction rates for vessels employing and not employing side setting when fishing in the same grounds and time period. Part of this continued performance assessment could be designed to compare the effectiveness of side setting with and without a bird-scaring curtain. Because required use of a bird curtain does not facilitate effective enforcement, it is of interest to know how well side setting works without being employed in combination with the curtain to determine the promise for side setting to minimize seabird bycatch in longline fisheries globally.

The Hawaii fleet should be encouraged to employ side setting as developed through this preliminary two-trip trial as follows:

- Use 60g swivels within 0.5 fathom (about 1m) of the hook;
- Use a bird-scaring curtain of the same design used for this trial; and
- Side set as far forward as possible.

Fishery management authorities, the Hawaii Longline Association, and other organizations will likely need to institute formal incentive instruments to provide inducements for industry to try side setting and change their longstanding fishing practices. Alternative formal incentive programs include rewards and compensation, free or subsidized distribution of equipment such as a bird-scaring curtain and other side setting hardware identified in Section 4.6, industry self-policing, and formal constraints (Gilman et al., 2002b).

If side setting eventually becomes a regulatory requirement for the Hawaii longline fleet, enforceability could be conducted by including restrictions to prevent vessels from moving the main line shooter to the vessel stern, such as by prohibiting a facility to stern-mount a main line shooter. This type of regulation would facilitate enforcement via quick dockside inspections. However, swordfish vessels, which traditionally have not used a main line shooter, could simply not use their shooter when at sea to avoid this strategy.

Management authorities could also develop measurable performance standards for side setting (and other seabird avoidance methods) such as by prescribing a minimum depth of baited hooks when they are at the vessel's stern, or specifying a maximum seabird capture rate per individual vessel. Such performance standards could be used to encourage the fishery to employ prescribed methods as effectively as possible and minimize seabird mortality to the maximum extent practicable. The performance standards would require a high percentage of onboard observer coverage to effectively monitor fleet-wide compliance.

The ultimate method to ensure broad use of side setting throughout major longline fleets will be spreading the word that this fishing method is commercially viable and operationally beneficial.

Two assessments of night setting in the Hawaii longline swordfish fishery found this method to reduce seabird captures by 97% and 98% compared to a control (Table 7) (McNamara et al., 1999; Boggs, 2003). In both of these studies, weights were located about midway along the branch line, 5-7 m from the hook. We can expect that, with implementation of the Hawaii Longline Association's agreed use of 60g swivels within 1m of the hook, in conjunction with night setting, to make seabird interactions extremely rare in the Hawaii longline swordfish fishery, if it is authorized to resume. Some of the Hawaii longline swordfish vessels would historically initiate setting at dusk, especially when fishing at northern latitudes during the summer when days are long. Seabirds actively forage at dusk. Enforcement of night setting through VMS, which is mandatory for vessels participating in the Hawaii longline fishery, may not be able to detect vessels initiating setting an hour or so before nightfall. The combination of side setting, 60g swivels within 1m of the hook, and night setting even when setting is initiated before nightfall, is expected to be extremely effective at minimizing seabird interactions in the Hawaii longline swordfish fleet, facilitate relatively effective enforcement, and be practical and convenient with possible operational benefits and increases in fishing efficiency.

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8. Authorizations

This research was authorized by the U.S. Fish and Wildlife Service and U.S. National Marine Fisheries Service under

(a) Endangered Species Act Section 10(a)(1)(A) permit No. TE04780502;
(b) Migratory Bird Treaty Act amendment to U.S. National Marine Fisheries Service PIAO MBTA Permit No. MB052060-2; and
(c) Magnuson-Stevens Fishery Conservation Management Act Letter of Acknowledgement No. 2003-04-01-1.

9. References

Anderson DJ, Huyvaert KP, Wood DR, Gillikin CL, Frost BJ, Mouritsen H. 2003. At-sea distribution of waved albatrosses and the Galapagos Marine Reserve. *Biological Conservation* 110:367-373.

Anderson, D., A. Schwandt, and H. Douglass. 1998. Foraging ranges of Waved Albatrosses in the eastern Tropical Pacific Ocean. pp. 180-185 In *Albatross Biology and Conservation*, Robertson G and Gales R (eds). Surrey Beatty and Sons: Chipping Norton, Australia. 300 pp.

BirdLife International. 2003. FAO's positive efforts to cut seabird deaths undermined by 14 'longline laggards.' Cambridge, UK: BirdLife International (3 pp.).

Boggs, C. H. 2001. Deterring albatrosses from contacting baits during swordfish longline sets. Pages 79-94 *In* E. Melvin and K. Parrish (eds.) *Seabird Bycatch: Trends, Roadblocks, and Solutions*. University of Alaska Sea Grant, AK-SG-01-01, Fairbanks, AK. 206 p.

Boggs, C.H. 2003. Annual Report on the Hawaii Longline Fishing Experiments to Reduce Sea Turtle Bycatch under ESA Section 10 Permit 1303. U.S. National Marine Fisheries Service Honolulu Laboratory, Honolulu, HI, USA. 22 pp.

Brothers, NP, and T. Reid. In Review. The effect of line weighting on the sink rate of pelagic tuna longline hooks, and its potential for minimising seabird mortalities.

Brothers NP. 1991. Albatross mortality and associated bait loss in the Japanese longline fishery in the southern ocean. *Biological Conservation* 55: 255-268.

Brothers NP. 1995. Catching fish not birds: A guide to improving your longline fishing efficiency. Australian Longline Version. Hobart, Australia: Australia Parks and Wildlife Service (70 pp.).

Brothers, NP. 1996. Longline Fishing Dollars and Sense (Pesca de Palagreros los Dolares y el Sentido Comun). Hobart , Australia: Australia Parks and Wildlife Service, 80 pp.

Brothers NP, Cooper J, and Lokkeborg S. 1999. *The Incidental Catch of Seabirds by Longline Fisheries: Worldwide Review and Technical Guidelines for Mitigation.* FAO Fisheries Circular No. 937. Food and Agriculture Organization of the United Nations: Rome. 100 pp.

Brothers N, Chaffey D, Reid T. 2000. AFMA research fund--final report. Performance assessment and performance improvement of two underwater line setting devices for avoidance of seabird interactions in pelagic lonline fisheries. ARF Project R2000/0469. Canberra: Australian Fisheries Management Authority and Environment Australia, 19 pp.

CCAMLR. 2002. Incidental mortality arising from longline fishing. Pp. 288-331 in *Report of the Twenty-first Meeting of the Scientific Committee of the Commission for the Conservation of Antarctic Marine Living Resources*. Hobart, Australia.

Cousins K. and Cooper J (eds). 2000. *The Population Biology of the Black-Footed Albatross in Relation to Mortality Caused by Longline Fishing*. Report of a workshop held in Honolulu, Hawaii, 8-10 October 1998 by the U.S. Western Pacific Regional Fishery Management Council. Honolulu, HI, USA.

Cousins, K., P. Dalzell, and E. Gilman. 2001 . Managing pelagic longline-albatross interactions in the North Pacific Ocean. *Marine Ornithology* 28(2): 159-174.

Dunn E, Steel C. 2001. The impact of longline fishing on seabirds in the North-East Atlantic: Recommendations for reducing mortality. Bedfordshire, UK: Royal Society for the Protection of Birds, Norwegian Ornithological Society, and Joint Nature Conservation Committee.

Efron, B and R. Tibshirani. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. *Statistical Science* 1(1):54-77.

Environment Australia. 1998. *Threat Abatement Plan for the Incidental Catch (or By-catch) of Seabirds During Oceanic Longline Fishing Operations*. National Parks and Wildlife Biodiversity Group: Canberra, Australia. 61 pp.

FAO. 2003. Implementation of the NPOA-Seabirds. Committee on Fisheries progress report from 24th session on implementation of the International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries. United Nations Food and Agriculture Organization Committee on Fisheries.

Gales R. 1998. Albatross populations: Status and threats. pp. 20-45 In *Albatross Biology and Conservation*, Robertson G and Gales R (eds). Surrey Beatty and Sons: Chipping Norton, Australia. 300 pp.

Gales, R., N. Brothers, and T. Reid. 1998. Seabird mortality in the Japanese tuna longline fishery around Australia, 1988-1995. *Biological Conservation* 86(1): 37-56.

Gilman, E. and H. Freifeld. 2003. Seabird Mortality in North Pacific Longline Fisheries. *Endangered Species Update* 20(2): 35-46.
Gilman, E.L. 2001a. Integrated management approach to address incidental mortality of seabirds in longline fisheries. *Aquatic Conservation: Marine and Freshwater Ecosystems*. 11(5): 391-414.
Gilman, E.L. 2001b. Keeping Albatross off the Hook in the North Pacific Ocean. *World BirdWatch*. 23(2): 14-16.
Gilman, E.L., C. Boggs, and N. Brothers. In Review. Performance assessment of an underwater setting chute to minimize seabird mortality in the Hawaii pelagic longline tuna fishery. Submitted to *Ocean and Coastal Management.*
Gilman, E., C. Boggs, N. Brothers, J. Ray, B. Woods, K. Ching, J. Cook, S. Martin, and D. Chaffey. 2002a. *Performance Assessment of an Underwater Setting Chute to Minimize Seabird Mortality in the Hawaii Pelagic Longline Tuna Fishery. Final Report*. Submitted to U.S. Fish and Wildlife Service in fulfillment of Endangered Species Act and Migratory Bird Treaty Act permit conditions. Honolulu, HI, USA. vi+51 pp.
Gilman, E., C. Carboneras, P. Gandini, G. Balogh, D. Leadbitter, and T. Neves. 2002b. *Incentive Instruments for Sustainable Bycatch of Sensitive Species in Longline Fisheries*. Proceedings of the Incentives Session, Second International Fishers' Forum, 19-22 November 2002. National Audubon Society: Honolulu, Hawaii, USA. 11 pp.
Hampton, J. and P. Williams. 2003. The Western and Central Pacific Tuna Fishery: 2001 Overview and Status of Stocks. Secretariat of the Pacific Community, Oceanic Fisheries Programme, Tuna Fisheries Assessment Report No. 4. Noumea, New Caledonia.
Hyrenbach, K., P. Fernandez, and D. Anderson. 2002. Oceanographic habitats of two sympatric North Pacific albatrosses during the breeding season. *Marine Ecology Progress Series* 223: 283-301.
Jahncke, J., E. Goya, and A. Guillen. 2001. Seabird by-catch in small-scale longline fisheries in Northern Peru. *Waterbirds* 24(1): 137-141.
Kleiber, P., and C. Boggs. 2000. Workshop on Reducing Sea Turtle Takes in Longline Fisheries. Miami, August 31-Septemebr 1, 1999. U.S. National Marine Fisheries Service Southwest Fisheries Science Center Administrative Report H-00-09. Honolulu Laboratory, Honolulu, HI, USA. 16 pp.
Leslie, P.H. and D.H.S. Davis. 1939. An attempt to determine the absolute number of rats on a given area. *Journal of Animal Ecology* 8:94-113.
Lewison, R., and L. Crowder. In Press. Estimating fishery bycatch and effects on a vulnerable seabird population. *Ecological Applications*.
Lokkeborg S. 1998. Seabird by-catch and bait loss in long-lining using different setting methods. *ICES Journal of Marine Science* (54):145-149.
Lokkeborg S. 2001. Reducing seabird bycatch in longline fisheries by means of bird scaring lines and underwater setting. In: Melvin E, Parrish K, editors. Seabird bycatch: Trends, roadblocks, and solutions. Report AK-SG-01-01. Fairbanks, AK, USA: University of Alaska Sea Grant.
McNamara B, Torre L, Kaaialii G. 1999. *Hawaii Longline Seabird Mortality Mitigation Project*. Western Pacific Regional Fishery Management Council: Honolulu, HI, USA. 93pp.
Melvin EF, Parrish JK, Dietrich KS, and Hamel OS. 2001. Solutions to seabird bycatch in Alaska's demersal longline fisheries, report WSG-AS 01-01. Seattle, WA, USA: Washington Sea Grant Program, University of Washington.
Minami H, Kiyota M. 2002. Effect of blue-dyed bait on reduction of incidental take of seabirds. Shizuoka, Japan: Ecologically Related Species Section, Pelagic Fish Resources Division, National Research Institute of Far Seas Fisheries, Fisheries Research Agency.
Molloy J, Walshe K, Barnes P, editors. 1999. Developmental stages of the underwater bait setting chute for pelagic longline fishery, Conservation Advisory Science Notes 246. Wellington, New Zealand: Department of Conservation.
Mustad and Son. No date. New product boosts catch for the longlining fleet: Mustad Autoline System, Gjovik, Norway: Mustad and Son.
Niethammer, K., J. Megyesi, and D. Hu. 1992. Incubation periods for 12 seabird species at French Frigate Shoals, Hawaii. *Colonial Waterbirds* 15(1): 124-127.
O'Toole D, Molloy J. 2000. Short communication. Preliminary performance assessment of an underwater line setting device for pelagic longline fishing. *New Zealand Journal of Marine and Freshwater Research* (34):455-461.

Polovina, J., E. Howell, D. Parker, and G. Balazs. 2002. Dive-depth distribution of loggerhead (Carretta carretta) and olive ridley (Lepidochelys olivacea) turtles in the central North Pacific: Might deep longline sets catch fewer turtles? Unpublished Manuscript. U.S. National Marine Fisheries Service, Honolulu Laboratory: Honolulu, HI, USA.

Ricker, W.E. 1958. *Handbook of Computations for Biological Statistics of Fish Populations*. Bulletin No. 119. Fisheries Research Board of Canada: Ottawa, Canada. 300 pp.

Ryan PG, Watkins BP. 2002. Reducing incidental mortality of seabirds with an underwater longline setting funnel. *Biological Conservation* (104):127-131.

Seber, G.A.F. 1973. *The Estimation of Animal Abundance and Related Parameters*. Hafner Press: New York, NY. 506 pp.

Secretariat of the Pacific Community. 2002. *Secretariat of the Pacific Community Tuna Fishery Yearbook 2001*. Oceanic Fisheries Programme: Noumea, New Caledonia.

Uhlman, S. Fisheries Bycatch Mortalities of Sooty Shearwaters (Puffinus griseus) and Short-tailed Shearwaters (P. tenuirostris). DOC Science Internal Series 92. Wellington: New Zealand Department of Commerce. 52 pp.

U.S. Fish and Wildlife Service. 2002. *Biological Opinion of the U.S. Fish and Wildlife Service for the Effects of the Hawaii-Based Domestic Longline Fleet on the Short-Tailed Albatross (Phoebastria albatrus)*. Revised 18 November 2002. Pacific Islands Ecoregion. Honolulu, HI, USA.

U.S. National Marine Fisheries Service. 1999. *Our Living Oceans. Report on the Status of U.S. Living Marine Resources, 1999*. U.S. Department of Commerce: Silver Spring, MD, USA.

U.S. National Marine Fisheries Service. 2001a. Endangered Species Act Section 7 Consultation Biological Opinion: Authorization of Pelagic Fisheries under the Fishery Management Plan for the Pelagic Fisheries of the Western Pacific Region.

U.S. National Marine Fisheries Service. 2001b. *Alaska Groundfish Fisheries Draft Programmatic Supplemental Environmental Impact Statement*. USDC NOAA, National Marine Fisheries Service Alaska Region, Juneau, Alaska, USA, and Seattle, Washington, USA.

U.S. National Marine Fisheries Service. 2001c. Final Environmental Impact Statement. Fishery Management Plan Pelagic Fisheries of the Western Pacific Region. National Marine Fisheries Service: Washington, D.C., USA.

U.S. National Marine Fisheries Service. 2002a. Final rule. Fisheries off West Coast States and in the Western Pacific; Western Pacific Pelagic Fisheries; Pelagic Longline Gear Restrictions, Seasonal Area Closure, and Other Sea Turtle Take Mitigation Measures. Federal Register Volume 67(113), 40232-8.

U.S. National Marine Fisheries Service. 2002b. Final rule. Fisheriess off West Coast States and in the Western Pacific; Pelagic Fisheries' Measures to Reduce the Incidental Catch of Seabirds in the Hawaii Pelagic Longline Fishery. Federal Register Volume 67(93), 34408-34413.

U.S. National Marine Fisheries Service. 2002c. Preliminary Longline Logbook Summary Report, April-June 2002. Honolulu Laboratory, Honolulu, HI, USA.

Appendix I. Summary statistics table of the mean and 95% confidence interval for contact and capture rates by fishing gear method and by experimental treatment, including the experimental and control treatments from Gilman et al. (In Review and 2002a). Nonparametric 95% confidence intervals are derived from percentile method bootstrapping at n=1000. Capture rates use the number of birds hauled aboard and not the number of birds observed captured during setting. Seabird interaction rates are expressed as contacts or captures per 1000 hooks per albatross. Due to the rarity of occurrence of seabird contacts and captures, some confidence interval estimates of uncertainty for contact and capture rates are likely to be inaccurate, especially in cases where there were no observed contacts or captures and the reported confidence interval is 0.00 – 0.00.

Swordfish gear BFAL contact rates[a]			Statistical Comparisons[b]		
Treatment	Mean (95% CI)		9m chute	Blue bait	Side-set
9m chute	0.05	(0.00 - 0.16)	-	*	n.s.
Blue bait	0.85	(0.53 - 1.27)	*	-	*
Side-set	0.00	(0.00 - 0.00)	n.s.	*	-

Swordfish gear BFAL capture rates			Statistical Comparisons		
Treatment	Mean (95% CI)		9m chute	Blue bait	Side-set
9m chute	0.05	(0.00 - 0.15)	-	n.s	n.s.
Blue bait	0.05	(0.00 - 0.15)	*	-	n.s.
Side-set	0.00	(0.00 - 0.00)	n.s.	n.s.	-

Swordfish gear LAAL contact rates[a]			Statistical Comparisons		
Treatment	Mean (95% CI)		9m chute	Blue bait	Side-set
9m chute	0.56	(0.26 - 0.81)	-	*	n.s.
Blue bait	3.27	(2.42 - 4.34)	*	-	*
Side-set	0.16	(0.02 - 0.37)	n.s.	*	-

Swordfish gear LAAL capture rates			Statistical Comparisons		
Treatment	Mean (95% CI)		9m chute	Blue bait	Side-set
9m chute	0.00	(0.00 - 0.00)	-	*	n.s.
Blue bait	0.11	(0.02 - 0.22)	*	-	n.s.
Side-set	0.02	(0.00 - 0.05)	n.s.	n.s.	-

Swordfish gear combined albatross species contact rates			Statistical Comparisons		
Treatment	Mean (95% CI)		9m chute	Blue bait	Side-set
9m chute	0.30	(0.22 - 0.38)	-	*	*

Blue bait	2.37	(1.79 - 2.97)	*	-	*
Side-set	0.08	(0.01 - 0.20)	*	*	-

Swordfish gear combined albatross species capture rates			Statistical Comparisons		
Treatment	Mean (95% CI)		9m chute	Blue bait	Side-set
9m chute	0.03	(0.00 - 0.07)	-	n.s.	n.s.
Blue bait	0.08	(0.03 - 0.13)	n.s.	-	*
Side-set	0.01	(0.00 - 0.03)	n.s.	*	-

Tuna gear BFAL contact rates			Statistical Comparisons					
Treatment	Mean (95% CI)		6.5m chute	9m chute (Gilman et al. 2002a)	9m chute	Blue bait	Control (Gilman et al. 2002a)	Side-set
6.5m chute	0.00	(0.00 - 0.00)	-	n.s.	n.s.	*	*	n.s.
9m chute (Gilman et al., 2002a)	0.03	(0.00 - 0.08)	n.s.	-	n.s.	n.s.	*	n.s.
9m chute	0.00	(0.00 - 0.00)	n.s.	n.s.	-	*	*	n.s.
Blue bait	0.19	(0.07 - 0.33)	*	n.s.	*	-	n.s.	*
Control (Gilman et al., 2002a)	0.61	(0.31 - 0.94)	*	*	*	n.s.	-	*
Side-set	0.00	(0.00 - 0.00)	n.s.	n.s.	n.s.	*	*	-

Tuna gear BFAL capture rates			Statistical Comparisons					
Treatment	Mean (95% CI)		6.5m chute	9m chute (Gilman et al. 2002a)	9m chute	Blue bait	Control (Gilman et al. 2002a)	Side-set
6.5m chute	0.00	(0.00 - 0.00)	-	n.s.	n.s.	n.s.	n.s.	n.s.
9m chute (Gilman et al., 2002a)	0.00	(0.00 - 0.00)	n.s.	-	n.s.	n.s.	n.s.	n.s.
9m chute	0.00	(0.00 - 0.00)	n.s.	n.s.	-	n.s.	n.s.	n.s.
Blue bait	0.00	(0.00 - 0.00)	n.s.	n.s.	n.s.	-	n.s.	n.s.
Control (Gilman et al., 2002a)	0.06	(0.00 - 0.13)	n.s.	n.s.	n.s.	n.s.	-	n.s.
Side-set	0.00	(0.00 - 0.00)	n.s.	n.s.	n.s.	n.s.	n.s.	-

Tuna gear LAAL contact rates	Statistical Comparisons

Treatment	Mean (95% CI)		6.5m chute	9m chute (Gilman et al. 2002a)	9m chute	Blue bait	Control (Gilman et al. 2002a)	Side-set
6.5m chute	0.26	(0.08 - 0.47)	-	n.s.	n.s.	*	*	*
9m chute (Gilman et al., 2002a)	0.09	(0.02 - 0.16)	n.s.	-	n.s.	*	*	*
9m chute	0.37	(0.07 - 0.69)	n.s.	n.s.	-	n.s.	*	*
Blue bait	0.72	(0.51 - 0.92)	*	*	n.s.	-	*	*
Control (Gilman et al., 2002a)	1.87	(1.22 - 2.53)	*	*	*	*	-	*
Side-set	0.01	(0.00 - 0.01)	*	*	*	*	*	-

Tuna gear LAAL capture rates			Statistical Comparisons					
Treatment	Mean (95% CI)		6.5m chute	9m chute (Gilman et al. 2002a)	9m chute	Blue bait	Control (Gilman et al. 2002a)	Side-set
6.5m chute	0.02	(0.00 - 0.05)	-	n.s.	n.s.	n.s.	n.s.	n.s.
9m chute (Gilman et al., 2002a)	0.00	(0.00 - 0.00)	n.s.	-	*	*	*	n.s.
9m chute	0.07	(0.01 - 0.15)	n.s.	*	-	n.s.	n.s.	*
Blue bait	0.04	(0.01 - 0.08)	n.s.	*	n.s.	-	n.s.	*
Control (Gilman et al., 2002a)	0.08	(0.03 - 0.13)	n.s.	*	n.s.	n.s.	-	*
Side-set	0.00	(0.00 - 0.01)	n.s.	n.s.	*	*	*	-

Tuna gear combined albatross species contact rates			Statistical Comparisons					
Treatment	Mean (95% CI)		6.5m chute	9m chute (Gilman et al. 2002a)	9m chute	Blue bait	Control (Gilman et al. 2002a)	Side-set
6.5m chute	0.20	(0.07 - 0.36)	-	n.s.	n.s.	*	*	*
9m chute (Gilman et al., 2002a)	0.07	(0.02 - 0.14)	n.s.	-	n.s.	*	*	*
9m chute	0.28	(0.07 - 0.55)	n.s.	n.s.	-	n.s.	*	*
Blue bait	0.61	(0.43 - 0.78)	*	*	n.s.	-	*	*
Control (Gilman et al., 2002a)	1.54	(1.07 - 2.02)	*	*	*	*	-	*
Side-set	0.01	(0.00 - 0.01)	*	*	*	*	*	-

Tuna gear combined albatross species capture rates			Statistical Comparisons					
Treatment	Mean (95% CI)		6.5m chute	9m chute (Gilman et al. 2002a)	9m chute	Blue bait	Control (Gilman et al. 2002a)	Side-set
6.5m chute	0.01	(0.00 - 0.03)	-	n.s.	n.s.	n.s.	*	n.s.
9m chute (Gilman et al., 2002a)	0.00	(0.00 - 0.00)	n.s.	-	*	*	*	n.s.
9m chute	0.05	(0.01 - 0.11)	n.s.	*	-	n.s.	n.s.	*
Blue bait	0.03	(0.01 - 0.06)	n.s.	*	n.s.	-	n.s.	*
Control (Gilman et al., 2002a)	0.08	(0.04 - 0.13)	*	*	n.s.	n.s.	-	*
Side-set	0.00	(0.00 - 0.01)	n.s.	n.s.	*	*	*	-

[a] LAAL = Laysan albatross, BFAL = black-footed albatross
[b] n.s.=not significantly different based on overlapping 95% confidence intervals
*=significantly different based on non-overlapping 95% confidence intervals
- =no test