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Performance assessment of an underwater setting chute to mitigate seabird bycatch in the Hawaii pelagic longline tuna fishery

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Abstract

Mortality in longline fisheries is one of the most critical global threats to some seabird species. Underwater setting technology may offer an effective and commercially viable solution. The underwater setting chute for pelagic longline fisheries releases baited hooks underwater, out of sight and reach of diving seabirds. Results from a study in the Hawaii pelagic longline tuna fishery indicate that the underwater setting chute is the most effective technology tested to date to minimize seabird capture in this fishery. The chute eliminated seabird capture during this short-term trial. During control replicates, the capture rate was 4.24 captures per 1000 hooks and when normalized for albatross abundance, the rate was 0.114 captures per 1000 hooks per albatross. Expressed as contacts per 1000 hooks per albatross, the chute was 95% effective at reducing albatross contacts with fishing gear compared to a control.

The chute was practical for use and design and installation improvements are likely possible to make the chute more palatable for uptake by industry. The chute has the added benefit of increasing fishing efficiency. The cost for purchasing and installing the chute would be recouped after only a maximum of two fishing trips. Based on an assessment of bait retention and hook setting interval when using the chute versus setting conventionally, vessels would experience a gain in efficiency of between 14.7% and 29.6% when albatrosses are abundant. Economic incentives are essential to abate global seabird mortality in longline fisheries.

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1. Introduction

Of all the threats to seabirds, one of the most globally critical is mortality in longline fisheries [1–4]. 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 [3–5].

The four North Pacific albatrosses are all caught in longline fisheries. North Pacific albatrosses include the short-tailed (*Phoebastria albatrus*), black-footed (*Phoebastria nigripes*), Laysan (*P. immutabilis*), and waved albatross (*P. irrorata*); however, the waved albatross is largely restricted to the Galapagos Islands, waters off Northern Peru, and the ocean between these two areas [6–8].

The total population of the short-tailed albatross is approximately 1400 birds. Slowly recovering from near extinction in the early 1900s, the species has experienced an average population increase of over 7% annually largely due to efforts to improve nesting habitat. The short-tailed albatross is classified as Vulnerable in the 2002 IUCN Red List of Threatened Species [9,10].

The black-footed albatross, with a population of approximately 300,000, also is included on the 2002 IUCN Red List of Threatened Species as a Vulnerable species [9,10]. Based on monitoring data from three colonies in Hawaii where over 75% of the world population nests, black-footed albatross breeding pairs declined 9.6% from 1992 to 2001, a 1.1% annual decline [11].

The Laysan Albatross, the most abundant of North Pacific albatrosses, has a population of approximately 2.4 million birds, with an IUCN status of Lower Risk, Least Concern [9,10]. There has been a 30% decrease in Laysan albatross breeding pairs from 1992 to 2001, a 3.3% annual decline, at three monitored nesting colonies where 90% of the world's population nest. The number of Laysan breeding pairs increased 2% from 1992 to 1997, but decreased more than 31% between 1997 and 2001 [11]. Given the most recent data, BirdLife International is reviewing the status of this species (personal communication, April 2003, Dr. Deon Nel, BirdLife South Africa, and Dr. John Croxall, British Antarctic Survey).

These recent, short-term declines in breeding pairs of Laysan and black-footed albatrosses may result from numerous causes. For example, albatrosses may experience increased rates of skipped breeding years because of depleted food resources caused by El Niño and general warming of the oceans. This scenario would result in only a temporary decline in breeding pairs and no population declines. However, declines may be real and may be influenced by various sources of actual mortality. One of the most significant sources of this mortality is likely from interactions with longline vessels [12,13].

Available estimates of total albatross mortality in North Pacific pelagic longline fisheries, along with population modeling experiments on the black-footed albatross, highlight that mortality in longline fisheries may threaten the existence of black-footed albatrosses and poses a significant threat to Laysan and short-tailed albatrosses [12,14]. Population modeling experiments indicate that the world black-footed albatross population can withstand a loss of no more than 10,000

birds per year from all mortality sources and remain stable [14]. Mortality in pelagic longline fisheries alone may exceed this threshold [12,15,16]. Cousins et al. [15] uses quantitative data on seabird catch rates in Hawaii-based pelagic longline fisheries to roughly estimate that there are approximately 35,000 albatrosses caught per year in combined North Pacific pelagic longline fisheries. Another study estimates that combined North Pacific pelagic longline fisheries kill a total of 10,000 black-footed albatrosses and 8000 Laysan albatrosses per year [16]. Except for a portion of the US Alaska demersal longline fisheries, no estimates are available for albatross mortality in other North Pacific demersal longline fisheries [3,17]. Based on their lowest mortality estimates of 1.9% of the black-footed population killed per year in pelagic longline fisheries, Crowder and Myers [16] project that the black-footed albatross population will continue to decline over the next 20 years. Similar modeling experiments have yet to be conducted for the other three North Pacific albatrosses.

Hawaii pelagic longline fisheries have resulted in the annual mortality of approximately 3000 albatrosses, of which roughly half were Laysan albatrosses and half were black-footed albatrosses [18,19]. However, recent changes in regulations due to concerns over mortality of marine turtles, which closed the Hawaii swordfish fishery and places 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 [19].

Investigators conducted research on an underwater setting chute on a Hawaii longline tuna vessel in the hope of minimizing seabird mortality in the Hawaii longline tuna fishery, to proactively address the seabird bycatch problem in potential future Hawaii longline fishery sectors, and to identify an effective seabird avoidance method potentially exportable to other longline fisheries. The project goals were to determine if an underwater setting chute is effective at reducing the incidental capture of seabirds in the Hawaii longline tuna fishery, if the chute is practical for use, and how its use affects fishing efficiency.

Most longline vessels probably do not employ effective seabird avoidance methods despite the availability of effective and commercially viable mitigation methods [3]. Reasons for this may be low industry awareness of the availability of these 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 [3,13,20,21]; and lack of a strong economic incentive to change long-standing fishing practices. Recognizing this context, there is a need to maximize industry's sense of ownership for the use of effective seabird avoidance measures and provide industry with incentives for voluntary compliance [22]. The longline industry is expected to respond most strongly to economic incentives and disincentives. Seabird mitigation methods that can be demonstrated to substantially increase fishing efficiency have the highest chance of being accepted by industry. Conversely, if regulations requiring fisheries to minimize seabird mortality are consistently enforced and carry significant economic consequences for non-compliance, this can achieve broad industry compliance.

The ideal seabird avoidance method (or combination of methods) would (a) reduce seabird mortality to insignificant levels; (b) not cause increases in bycatch of other sensitive species; (c) require a minimal amount of alteration of traditional fishing practices and provide operational benefits; (d) be simple for crew to employ and not increase safety hazards to crew; (e) increase fishing efficiency; and (f) be feasibly enforced when limited resources for enforcement are available. The underwater setting chute was tested in the Hawaii tuna fleet because it promises to meet many of these criteria for a suitable seabird mitigation method, and because the chute may likewise be suitable for use in other longline fleets.

2. Underwater setting chute history

Over the past 15 years, national governments, regional organizations, and longline industries have developed and tested seabird avoidance methods in longline fisheries, including changes in fishing gear (e.g., altering gear weighting design, using a bait casting machine), fishing practices (e.g., thawing bait, removing hooks from discards, changing the location and time of discarding offal), fishing operations (e.g., night setting and establishing area and seasonal closures), and vessel layout (e.g., altering deck lighting) [3,23,24].

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 [25–27]. Research on the effectiveness of the Mustad underwater setting funnel has been conducted in demersal longline fisheries in South Africa, Alaska, and Norway [26–30]. 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.

In addition to this trial of the chute in the Hawaii pelagic longline fleet, there have also been trials of underwater setting devices in pelagic longline fisheries in New Zealand and Australia. The first underwater setting chute for pelagic longline vessels was developed in 1995 [31]. 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 2.85 m deeper than branch lines set by the conventional method of hand-throwing, indicating the chute's potential to reduce mortality of diving seabirds [32]. 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 [33]. Preliminary results 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.

3. Methodology

3.1. Chute installation

The chute, manufactured by Albi Save with a similar design as the chutes undergoing assessment in Australian [33], was installed over 4 days in February 2002, with two short at-sea trials. Figs. 1 and 2 show the chute used in the Hawaii trial. The design of the underwater setting chute illustrated in [31] is similar to that used in this trial.

3.2. Period

The *Katy Mary* left port on 21 February 2002 and returned on 9 March 2002. This period was selected to ensure abundance of albatross in nearby waters. When this research fishing trip was conducted, most breeding black-footed and Laysan albatrosses were in the beginning of their chick-rearing period when parents mix short and long foraging trips [34–36].

3.3. Location

The research fishing grounds were located between 50 and 200 nm off the Northwestern Hawaiian Islands. This location is occasionally but infrequently fished by the Hawaii tuna fleet, but grounds near these islands, where 99% of the world's Laysan albatrosses and 98% of the total population of black-footed albatrosses nest, were selected to ensure high albatross abundance. The fishing grounds for the



Fig. 1. The underwater setting chute delivers baited hooks while setting so that they first emerge underwater out of sight and reach by diving seabirds. The chute's slot enables external deployment of the main line, buoys, and radio beacons. The main line is set through a line setting machine, baited hooks are sent through the underwater setting chute (directly in front of the crewmember with the baited hook), and the branch line with the baited hook is clipped onto the main line moments after the baited hook is sent down the chute.



Fig. 2. The underwater setting chute is stored on deck against the bulwarks. The chute used in this trial is 9 m long and when deployed, 5.4 m of the chute's shaft is underwater.

Hawaii longline tuna fleet has primarily been south of 23°N latitude where few albatrosses forage. From 1994 to 2001, fewer than 14% of sets by the Hawaii longline tuna fleet were conducted north of 23°N (US National Marine Fisheries Service Honolulu Laboratory unpublished longline logbook data).

3.4. Treatments

The experimental treatment entailed setting on a Hawaii longline tuna vessel using an underwater setting chute in addition to normal tuna setting practices of using weighted branch lines and a main line shooter. When setting with the 9 m long underwater setting chute on the F.V. *Katy Mary*, 5.4 m of the chute's shaft is underwater.

The control treatment entailed setting on a Hawaii longline tuna vessel using a line setting machine and weighted branch lines as typically conducted by the Hawaii tuna fleet as described in US National Marine Fisheries Service [37]. Because there are almost no data on seabird interactions with a Hawaii longline tuna vessel fishing in

the location where the underwater setting chute was tested (only 186 sets and two albatross takes have been observed on Hawaii tuna sets north of 23°N latitude [19]), a control treatment was necessary.

3.5. *Replicates and research design*

For the main assessment to calculate seabird attempt, contact, and capture rates, one replicate consisted of one-sixth of a set, or setting 1 tote box of approximately 460 hooks. The research fishing trip consisted of six sets. The main assessment included 12 replicates for each of the experimental and control treatments obtained during four sets. There were 4966 hooks observed under the experimental treatment and 5077 hooks observed under the control treatment for the main assessment. Variability in environmental conditions and bird abundance between totes qualified each tote as an independent sample. Data from all six sets are used to calculate bait retention and hook setting intervals.

The order of setting between the control and experimental treatments for the main assessment was balanced so that setting with the chute occurred first in two sets and setting first with the control treatment occurred in two sets. The order of replicates was not randomized to enable the chute to affect bird abundance around the vessel. Three continuous replicates of a single treatment were followed by three continuous replicates of the second treatment for the four sets used for the main assessment. The assumption, based on experience with the chute in the Southern Hemisphere, was that continuous setting with the chute would result in decreased seabird abundance near the vessel and reduced searching behavior of albatrosses. If we had randomized the order of the experimental and control treatment replicates, this could have resulted in an artificially high abundance of seabirds around the boat during application of the experimental treatment. Seabirds would have remained interested in the vessel during replicates using the chute due to the visibility of baited hooks being set during preceding control replicates.

3.6. *Bird abundance*

Every 15 min a count of each seabird species within a 500-m × 500-m square area (within 250 m of port and starboard of the center of the vessel stern and within 500 m behind the vessel) astern of the vessel was recorded.

3.7. *Seabird attempts and contacts*

Observations of seabird unsuccessful attempts and contacts with gear near baited hooks were recorded. A seabird “contact” is defined as a seabird contacting the fishing gear near the hook. An unsuccessful seabird “attempt” is defined as a seabird attempting to contact bait either by plunging underwater or completely submerging and not coming into contact with the fishing gear near the hook.

Only one interaction per bait is recorded regardless of whether multiple birds attempt to contact or contact the bait or a single bird attempts to contact or contacts

a bait multiple times. For instance, if a bird's first attempt to contact a bait is unsuccessful and the bird makes a second attempt and successfully contacts the bait, only the contact is recorded. A bird sitting on the sea surface simply looking underwater is not considered an attempt; the bird must conduct a submerged or partially submerged body thrust to be considered an attempt.

3.8. *Capture and loss of caught birds before hauled aboard*

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 researcher categorized observations of birds caught during setting into three degrees of certainty. For instance, when a bird was seen caught, rough sea conditions or high bird abundance may have made it difficult to keep track of the potentially caught bird for long enough to verify the catch with the same confidence as other observations.

The number of dead seabirds hauled aboard was also recorded, enabling a comparison with the number of seabirds observed caught during setting. During hauling, observations of the numbers and species of birds present and seabird interactions with fishing gear were recorded.

3.9. *Bait retention*

To assess bait retention, for each haul of the experiment's 6 sets, 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 and branch lines that were delayed during hauling (potentially dragged unseen through prop turbulence astern) were not included in the bait retention count. No birds were caught on the hooks observed for this assessment, but if a bird had been caught on one of these hooks, it would have been counted as a lost bait.

3.10. *Hook setting interval*

Investigators used information recorded on the time of the start and end of the setting of each tote to estimate the hook setting interval for setting under control and experimental treatments. Only totes where the chute was not deployed or retracted were included in this analysis. This was done because the time to deploy and retract the chute would not be a factor under normal fishing operations.

3.11. *Captain and crew debriefing*

The principal investigator debriefed the captain and crew of the *Katy Mary* upon completion of the research fishing trip to assess whether the Hawaii longline industry

would support and comply with rules requiring use of the chute. The principal investigator attempted to determine fishers' perception of the underwater setting chute's (a) effectiveness at avoiding seabird interactions, (b) degree of effort to employ, and (c) effect on fishing efficiency.

The principal investigator collected information on the captain and crew's perceptions of the chute design and installation, safety hazards associated with use of the chute, change in bait retention and hook setting, intrusion on normal fishing operations, whether they would voluntarily choose to use the chute, whether they would prefer to use the chute versus seabird avoidance methods required by regulations, and the potential for Hawaii industry-wide acceptance of the chute.

4. Results from scientific experiment

A detailed project report [38] provides additional results and discussion not presented in this article, including (a) the effect of the chute on albatross abundance compared to a control; (b) the effect of order of treatment on bird abundance; (c) the correlation between albatross unsuccessful attempts to contact gear, contacts with gear, and captures; (d) hook sink rate, profile, and final depth; (e) the effect of swivel weight on incidence of bird capture; (f) necropsy analysis data on age, sex, and breeding condition of birds killed during the trial; (g) description of the Hawaii longline tuna and swordfish fleets' fishing gear and methods; and (h) incidence of branch line tangling.

4.1. Bird abundance and seabird interactions with gear

Summary statistics for seabird attempt, contact, and capture rates are reported in Table 1. Only counts of Laysan and black-footed albatrosses are included in the analysis for Table 1, which were the only species of seabirds observed to interact with fishing gear. No seabirds interacted with gear during hauling.

Expressed as contact rate per 1000 hooks, the chute was 98% effective at reducing albatross contacts with fishing gear near baited hooks compared to a control. Expressed as contact rate per 1000 hooks per albatross (normalized for albatross abundance), the chute was 95% effective at reducing albatross contacts compared to a control (Table 1).

Three black-footed albatrosses were caught and killed, and 22 Laysan albatrosses were caught and 21 were killed during the six sets based on the number of birds hauled aboard. The chute eliminated seabird capture; no birds were observed to be caught during setting with the chute nor were any albatrosses hauled aboard during chute treatment replicates.

Figs. 3–5 show that there is a highly significant linear correlation between albatross abundance and (a) attempts ($R = 0.61^{**}$), (b) contacts ($R = 0.73^{**}$), and (c) captures (using observed number of birds hauled aboard, $R = 0.53^{**}$). Further analysis could be conducted to determine the best fit for modeling the relationship between albatross abundance and interactions with gear.

Table 1
Summary statistics for combined albatross species' attempt, contact, and capture rates

Treatment	Abundance	Attempts/1000 hooks		Contacts/1000 hooks		Catch rate (set) ^a		Catch rate (haul)	
		Nominal ^b	Per bird ^b	Nominal	Per bird	Nominal	Per bird	Nominal	Per bird
Control	41.11	132.38	3.85	75.93	1.97	6.63	0.181	4.24	0.114
Chute	24.98	15.11	0.63	1.85	0.10	0	0	0	0
Effect ^c	–39%*	–89%**	–84%**	–98%**	–95%**	–100%**	–100%**	–100%**	–100%**

^a Using the perceived most reliable observation of birds caught during setting of 37 birds captured during sets 2–5.

^b “Nominal” means not normalized for albatross abundance, and “per bird” means normalized for albatross abundance.

^c A single* indicates the statistic is significant, where $p < 0.05$ and ** indicates that the statistic is highly significant, where $p < 0.01$.

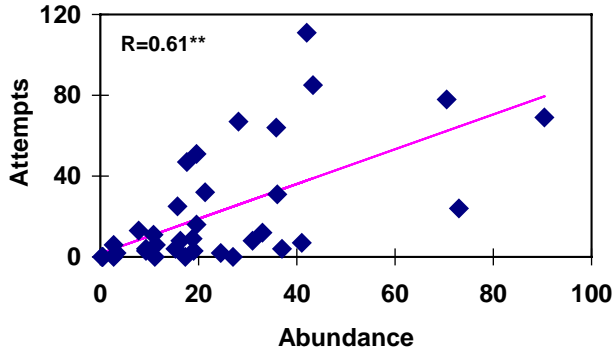


Fig. 3. Albatross abundance versus attempts (combined Laysan and black-footed albatrosses).

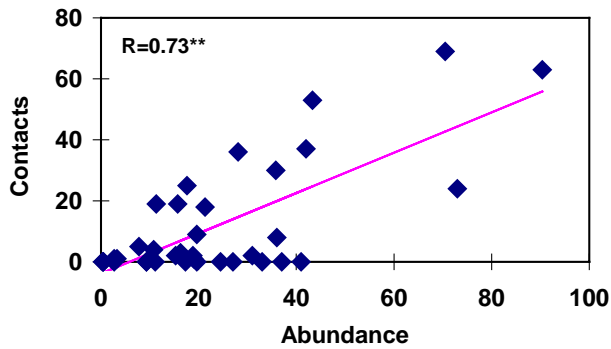


Fig. 4. Albatross abundance versus contacts (combined Laysan and black-footed albatrosses).

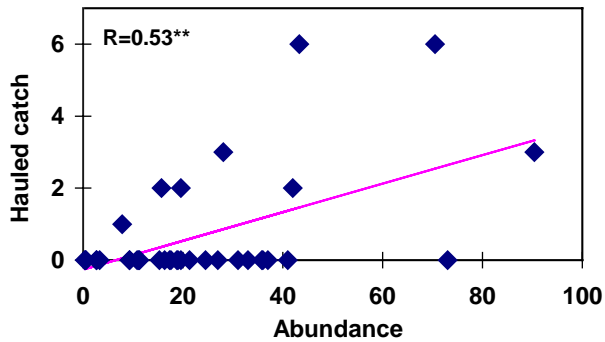


Fig. 5. Albatross abundance versus capture (using the number of birds observed hauled aboard, combined Laysan and black-footed albatrosses).

4.2. Loss of caught birds before hauled aboard

Thirty-four birds were observed caught during setting with the highest degree of confidence. An additional four birds were observed caught, but due to obstructions

these four birds were not observed long enough to verify capture with the same degree of certainty as the other 34 birds. Another two birds were observed that may have been caught, but confidence in these observations was less than for the other observations. Therefore, there are three degrees of certainty of observations of birds caught during setting, giving a range of between 26.5% and 37.5% of birds that fell off the gear prior to hauling, with the perceived most reliable estimate being 34% (where 13 of 38 birds fell from the gear prior to hauling).

The seabird catch rate for the control treatment using the perceived most reliable number of birds observed caught during setting is 6.63 captures per 1000 hooks. When adjusted for albatross abundance this rate is 0.181 captures per 1000 hooks per albatross. This is a slightly higher rate than when using the number of birds hauled aboard as the estimate for seabird capture (Table 1).

5. Results from commercial demonstration

5.1. Bait retention

Bait retention when setting with the chute and under control conditions is summarized in Table 2. When setting through the chute, 90.1% of bait was retained ($n = 700$), while when setting under control conditions, 69.5% of bait was retained ($n = 400$). Increased retention of bait when setting through the chute was statistically significant ($t = 3.6$, one tailed $*p < 0.012$).

5.2. Hook setting rates

Table 3 summarizes the hook setting intervals with and without the chute. The average hook setting rate for sets made with the chute was 8.14 s per hook ($n = 5$ sets, s.e. = 0.34 s). For combined control set sections, the average hook setting rate was 7.20 s per hook ($n = 6$ sets, s.e. = 0.18 s). The difference was statistically significant ($t = 2.60$, two tailed $p < 0.029$).

Table 2
Bait retention summary

	Baited hooks set through chute ($n = 700$)				Baited hooks set under control treatment ($n = 400$)	
Hooks observed retaining bait on haul	193	165	179	92	151	127
Hooks observed without bait on haul	7	35	21	8	49	73
Total hooks	200	200	200	100	200	200
Percent retained	96.5	82.5	89.5	92	75.5	63.5
Average percent retained	90.1				69.5	

Table 3
Hook setting rates under experimental and control treatments

Set number	Chute or control	Hooks set	Total seconds	Rate (seconds/hook)	Average rate for set
Set 1	Chute	473	3420	7.2	7.2
	Control	480	3840	8.0	7.4
	Control	468	3120	6.6	
	Control	466	3540	7.6	
Set 2	Chute	463	4200	9.1	9.1
	Control	469	3120	6.6	7.9
	Control	238	2160	9.1	
Set 3	Chute	234	1800	7.8	7.8
	Control	457	3240	7.1	6.9
	Control	458	3060	6.7	
	Control	222	1500	6.8	
Set 4	Chute	453	3600	7.9	7.9
	Control	475	3600	7.6	7.0
	Control	453	3000	6.6	
	Control	437	2940	6.7	
Set 5	Chute	408	3540	8.7	8.7
	Control	511	3720	7.3	
	Control	481	3300	6.9	7.3
	Control	409	3180	7.8	
Set 6	Control	437	3540	8.1	6.7
	Control	472	2460	5.2	
	Control	432	3000	6.9	
	Control	426	2880	6.8	
	Control	466	3060	6.6	

5.3. Chute change in CPUE

An estimated gain in fishing efficiency in terms of catch per unit of effort (CPUE) when setting with the chute versus the control with albatrosses present was calculated to be 29.6% based on 90.1% bait retention with the chute and 69.5% bait retention without the chute (Table 2).¹ Without albatrosses present, an additional 0.2% of the bait is retained with the chute, and an additional

¹The gain in fishing efficiency, or increased CPUE, when using the chute (29.6%) is calculated as the bait savings of 20.6% ($=90.1\%-69.5\%$) expressed as a fraction of the baits retained under control conditions ($20.6/69.5=0.296$). The assumption is made that with 29.6% more baits there will be a 29.6% increase in CPUE as compared to control conditions. For instance, a vessel setting 100 baited hooks would retain 20.6 more baits on their hooks if setting with a chute than if they set without a chute, which is a 29.6% increase in bait retention above the number of baits that they would have retained if setting without a chute (69.5 baits).

4.8% is retained without the chute, resulting in an estimated CPUE gain of 21.5% with the chute.² Based on average hook setting intervals, without the chute the *Katy Mary* would have averaged 5.6 h to set 2800 hooks. With the chute, the vessel would have only been able to set 2477 hooks in 5.6 h, an 11.5% reduction in fishing effort and catch per set. The remaining 323 hooks could be set through the chute in 44 min requiring an additional 6.5 miles of main line, with no reduction in fishing effort or catch per set. However, if a vessel was limited by time or by lack of main line this could result in a maximum of a 11.5% loss of fishing efficiency.

5.4. Captain and crew debriefing

Criticisms identified by the vessel captain and crew regarding use of the underwater setting chute included a slower hook setting rate with the chute compared to normal setting, the trough design and placement made it difficult to set branch lines, crew had difficulty sliding the chute across the rail, a safety hazard was created from a higher incidence of branch line tangles when crew prematurely grasped the main line in anticipation of clipping on branch lines, and the effort required to deploy and retract the chute was perceived as being inconvenient. The chute can be deployed by two crew and manually retrieved by three crew or two crew with mechanical assistance. Most of these concerns can be addressed through modifications to the design and installation of the chute, practice and attention by the crew to the timing of clipping branch lines onto the main line, and more crew experience using the chute to shorten the hook setting interval.

The captain and crew of the *Katy Mary* would voluntarily choose to use the chute when at fishing grounds where albatrosses occur because the crew perceived that the chute significantly increased bait retention when compared to normal setting operations, and the chute effectively avoids interactions with seabirds. The crew would prefer to use the chute instead of currently required blue-dyed bait.

The crew believes that the underwater setting chute would be as effective at avoiding seabird interactions and have the same requirements for altered fishing technique throughout the Hawaii longline tuna fleet as experienced on the *Katy Mary*. The *Katy Mary* has a fast hook setting interval relative to the rest of the Hawaii tuna fleet, therefore setting with the chute would require a smaller increase in the hook setting interval on other Hawaii tuna vessels. Also, the safety hazard from increased incidence of branch line tangles may not occur when setting with the chute on these other vessels. (The increased incidence of tangling when setting with the chute on the *Katy Mary* was found to be minimized when crew avoided prematurely grasping the main line.) It will require more thought to determine where to mount and store the chute on smaller vessels.

²The gain in efficiency or CPUE when setting with the chute with no albatrosses present (21.5%) is conservatively estimated as the bait savings (16% = 90.3%–74.3%) expressed as a fraction of the baits retained under control conditions (16/74.3 = 0.215).

Because the chute significantly increases bait retention compared to normal setting operations, this could create enough of an economic incentive for the majority of the fleet to use the chute at all fishing grounds.

6. Discussion

6.1. Normalizing seabird interaction rates for bird abundance

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. Normalizing seabird interaction rates for bird abundance allows for more accurate comparisons between results from multiple experiments. Figs. 3–5 show a highly significant linear correlation between albatross abundance and attempts, contacts, and captures, confirming the hypothesis that seabird interaction rates should be normalized for albatross abundance. To help explain the benefit of normalizing seabird interaction rates for bird abundance, consider one experiment in which an average of 25 albatrosses follow a vessel, and a separate experiment where 100 albatrosses follow a vessel, and both vessels are testing the same seabird avoidance method(s). Based on the results from this study, we expect about four times more captures per unit effort (e.g., per 1000 hooks) in the second experiment than in the first, 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 and sample sizes are sufficient. 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 four times lower than the capture rate of the second experiment. Therefore, normalizing seabird interaction rates for bird abundance is important to allow accurate comparisons between seabird interaction rates from different experiments.

Numerous confounding factors determine the degree of seabird mortality for a given fishery and a specific vessel, including fishing practices, fishing grounds, fishing effort, type and configuration of fishing gear, weather conditions such as wind speed and direction, seabird abundance, and the complex of seabird species present [3,23,39]. Bird abundance is possibly one of the largest confounding factors. However, as demonstrated in Section 6.2, even when seabird interaction rates are normalized for bird abundance, the combined effect of these additional numerous confounding factors can prevent useful comparisons between results of multiple experiments.

6.2. Seabird interactions with gear

Table 4 presents results of research on seabird mitigation methods tested in North Pacific pelagic longline fisheries. Because the majority of the body of literature on

Table 4
Albatross interaction rates for seabird avoidance methods tested in North Pacific pelagic longline fisheries

Study ^a and variable	Treatment								
	Control ^b	Underwater setting chute 9 m	Blue-dyed bait	Towed Buoy	Strategic discards	Streamer line	Night setting	Additional 60 g weight at bait	Night setting and blue-dyed bait
McNamara et al. [41] Hawaii longline swordfish gear									
Contact rate	32.8 ^c (265.7)		7.6 (61.6)	16.1 (130.4)	15.7 (124.7)	15.7 (127.2)			
Contact reduction (%)			77	51	53	52			
Capture rate	2.23 (18.0)		0.12 (17.5)	0.26 (6.8)	0.32 (2.3)	0.47 (6.6)	(0.60) ^d		
Capture reduction (%)			95	88	86	79	97 ^d		
Boggs [40] Hawaii longline swordfish gear									
Contact rate ^e	7.60 ^c (313.5)		0.43 (20.5)			1.82 (93.4)		0.61 (25.0)	
Contact reduction (%)			94			76		92	
Gilman et al. [38] Hawaii longline tuna gear—this study									
Contact rate	0.61 (75.93)	0.03 (1.85)							
Contact reduction (%)		95							

Capture rate	0.06 (4.24)	0.00 (0.00)	
Capture reduction (%)		100	
Boggs [42] Hawaii longline swordfish gear			
Contact rate	0.78 (27.1)		0.053 (4.8)
Contact reduction (%)			93
Capture rate	0.058 (2.0)		0.0013
			(0.11)
Capture reduction (%)			98
			100

Interaction rates are expressed normalized for seabird abundance (expressed as contacts or captures per 1000 hooks per bird) and without normalizing for bird abundance (expressed in parentheses as contacts or captures per 1000 hooks). Percent reductions are based on normalized rates unless noted otherwise.

^aResearch 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 [51]. 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.

^bControl treatments in McNamara et al. [41] and Boggs [40] entailed conventional Hawaii longline swordfish fishing operations.

^cThe different contact rates observed by Boggs [40] and McNamara et al. [41] may be explained by the use of different definitions of what constituted a seabird contact. McNamara et al. [41] 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 [40] 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.

^dThis rate is not normalized for albatross abundance because researchers could not estimate seabird abundance during night setting.

^eContact rates are averages of rates reported by Boggs [40] for Laysan and black-footed albatrosses.

seabird mitigation studies in longline fisheries has not normalized seabird interaction rates for bird abundance, [Table 4](#) includes seabird interaction rates both normalized and non-normalized for bird abundance.

Even when normalized for seabird abundance, the results reported in [Table 4](#) 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. [41] (2.23 captures/1000 hooks/bird) is over 38 times higher than the control treatment capture rate observed by Boggs [42]. And the Boggs [40] 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 [42]. This variability 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.

A seabird avoidance method, or combination of methods, that is appropriate for a fishery will consistently reduce seabird captures to close to zero despite 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.

6.3. *Loss of caught birds before hauled aboard*

A percentage of birds caught during setting fall off from hooks before being hauled aboard. 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 possibly are removed from hooks by sharks, currents, or other mechanical action during the line soak and haul.

There is an unknown degree of error with observations of caught seabirds during setting. Observed captures of seabirds during setting may be overestimates as there is an unknown degree of certainty that seabirds observed caught do not free themselves before the observation is obstructed. It is also possible that a larger number of seabirds are caught than are observed during setting, such as when large numbers of seabirds are following a vessel, obstructing view of all seabirds that are caught on hooks. For instance, during one replicate, the researcher observed two albatrosses captured during setting, while three albatrosses were hauled aboard, indicating that at least one more albatrosses was caught during this replicate than the researcher was able to observe during setting.

Seabird catch rates recorded on fishing vessels from observations of dead birds hauled aboard are conservative underestimates as there is unobserved discarding of incidentally caught seabirds by crew, and seabirds can fall from the hooks before hauling [14,39,43]. 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 hooked during setting were not hauled aboard [39]. Gales et al. [43] studied seabird mortality in the Japanese longline southern bluefin 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), which they would fail to observe during routine observations (when their primary task is to sample fish). Gales et al. [43] found that the seabird catch rate in Tasmania was 95% higher on hauls with observations of seabirds cut off by crew than on routine observations.

Albatrosses have also been observed dying on their nests due to hook wounds (e.g., Weimerskirch and Jouventin [44] observed wandering albatrosses likely injured from hooks discarded in offal from demersal longline fisheries). Longline vessels discarding hooks in offal and crew cutting free birds caught during hauling are two sources of these hooks [23]. Mortality of one albatross of a breeding pair is expected to result in chick starvation and mortality, and the remaining adult albatross partner will take several years before mating again [23,45]. Thus, actual seabird mortality rates caused directly and indirectly by longline fisheries are higher than reported [39].

6.4. *Bait retention*

Bait retention when setting through the chute was significantly higher ($*p < 0.012$) than when setting without the chute. Bait loss was 30.5% without the chute and only 9.9% with the chute, resulting in savings of 20.6% of bait when setting with the chute.

If we assume that every seabird contact results in the removal of bait from the hook, then we can estimate the proportion of the bait loss due to seabirds and the remaining proportion of bait loss due to mechanical action, loss to fish, and other non-seabird-related factors that cause the loss of baits from hooks. We can assume that setting with the chute does not alter factors that cause bait to be removed from hooks other than reducing seabird interactions and turbulence as a baited hook enters the water compared to control conditions because the chute only affects the gear's initial entry into the water. For instance, the amount of removal of baits from hooks by fish should not be affected by setting with or without the chute.

Seabird interactions with gear resulted in a maximum loss of 421 baits out of 8724 baited hooks (4.8%) set under control conditions, and the loss of 10 baits out of 6639 baited hooks (0.15%) set through the chute. Due to mechanical action and other non-seabird factors when setting through the chute, 9.8% of baits are lost (9.9%–0.15%) and 25.7% of baits are lost from mechanical action and other non-seabird factors when setting with conventional methods without a chute (30.5%–4.8%). Thus, increased bait retention when using the chute is primarily a result of the mechanical effect of reduced turbulence and not the chute's ability to prevent seabirds from stealing bait off hooks, although both effects have similar magnitudes.

In summary, there was a bait saving of 20.6% when setting through the chute versus setting with conventional methods. Eighty-four percent of this increased bait retention can be inferred to be a result of the chute's mechanical effectiveness of reducing physical stress on the bait as it enters the water, while only 16% of the increased bait retention is a result of reduced seabird interactions. This suggests that longline vessels would benefit from increased CPUE from setting with the chute both in areas with abundant albatrosses and at fishing grounds without albatrosses.

6.5. Hook setting rates

It took significantly longer to set using the chute than under control conditions. This is not expected to be a substantial problem for several reasons: (a) The hook setting interval using the chute is expected to improve gradually as crew gain experience using the chute over several trips; (b) most vessels have slower conventional hook setting intervals than the *Katy Mary*, and use of the chute is not expected to force the crew of these other vessels to reduce their normal slower hook setting interval; and (c) certain design features of the chute were noted to be impractical and once corrected could result in a faster hook setting interval. Furthermore, while the *Katy Mary* experienced a slower hook setting interval when using the chute versus setting under control conditions, the crew was able to set most or all of the hooks anyway, and the cause of ending sets was not usually running out of main line.

6.6. CPUE, revenue, and recouping chute costs

Combining the gain in efficiency using the chute due to reduced bait loss with and without birds with the possible loss in efficiency due to increased hook setting interval when setting with the chute results in a range of possible efficiency gains using the chute. Assuming vessels using a chute have enough time and main line to complete slower sets, or that vessels will not have to reduce their conventional hook setting interval when using the chute, the gain would be 29.6% with abundant albatrosses present and 21.5% without any albatrosses present. However, if slower setting with the chute reduces efficiency by 11.5%, then the net gain in efficiency would be 14.7% with abundant albatrosses present and 7.5% without any albatrosses present. The slower setting with the chute could reduce the number of branch lines deployed by a factor of 0.885 (i.e., a reduction of 11.5%) compared to the number of branch lines deployed under control conditions. With albatrosses present, bait retention with the chute increases efficiency by a factor of 1.295 (i.e., by 29.5%). These factors combined ($0.885 \times 1.296 = 1.147$) result in an efficiency (or CPUE) increase of 14.7%. Similarly, 11.5% smaller sets using the chute without albatrosses present result in an efficiency increase of only 7.5% ($0.885 \times 1.215 = 1.075$).

Based on the limited available information on bait loss and hook setting rates from this experiment, we translated this range of gains in efficiency into catch and dollar amounts per set, per trip, and per year for one vessel. Assuming a vessel

typically catches 2500 pounds and grosses \$5000 per set, makes 10 sets per trip, and makes 15 trips per year, the increased efficiency from using the chute could produce an additional 188–740 pounds or \$375–\$1,480 per set, an additional 1875–7400 pounds or \$3750–\$14,800 per trip, and an additional 28,125–111,000 pounds or \$56,250–\$222,000 per year, depending on whether all sets were made in areas with no albatrosses present and with high albatross abundance, respectively.

The cost for purchasing and installing the chute will be recouped after only a maximum of two fishing trips in the Hawaii longline tuna fleet. The chute used in this trial cost US \$4000 and freight from Hobart, Australia to Honolulu, Hawaii cost about US \$1000. There is some additional cost to install the chute and perhaps some cost for occasional maintenance.

6.7. *Enforceability*

If the chute were required in regulations, enforcement could be conducted via dockside inspections, at-sea boarding, and overflight surveillance. It may also be technically feasible to require vessels to install a hook counter on an underwater setting chute to monitor and enforce mandatory use, but this technology has yet to be tested. Given the large expanse of the Hawaii longline fleet's fishing grounds and the limited resources of US resource management agencies, enforcement of regulations requiring use of the chute would be limited. Thus, identifying economic incentives and other incentive instruments that are likely to maximize voluntary compliance is a priority, as well as maximizing onboard observer coverage of the fleet (e.g., see [22]). Compliance with required seabird avoidance measures is expected to increase with an increase in onboard observer coverage of the Hawaii longline fleet even though observers do not have enforcement responsibilities or authorization.

6.8. *Recommendations for management authorities*

Management authorities are encouraged to authorize use of the chute with adequate branch line weighting and a main line shooter as an alternative to other currently required seabird bycatch mitigation measures to enable requisite development of capacity and stakeholder support for use of the chute. Regulations should prohibit the discharge of offal and spent bait when setting with the chute to minimize bird abundance and searching behavior. The underwater setting chute is effective, in part, because it hides the fact that the vessel is setting baited hooks, with concomitant reductions in seabird abundance around the vessel and reduced seabird searching behavior. Discarding bait or offal during setting with the chute would counteract the chute's ability to prevent birds from gaining interest in actively searching in the area where gear is being set. It is also recommended that management authorities institutionalize an incentives program for use and additional performance assessment of the chute.

Fishery management authorities have already taken action to implement these recommendations by initiating the process to amend regulations to include the

underwater setting chute as an alternative seabird avoidance method in the Hawaii longline tuna fishery [46]. Additional performance assessment of the chute and other seabird avoidance methods is planned in the Hawaii longline tuna and swordfish fisheries in 2003 [47].

Making the chute an alternative seabird avoidance method in regulations will provide stakeholders with time to make this gear commercially available, develop the capacity for requisite training to install and use the chute, create incentives for vessels to voluntarily use the chute, and to continue performance assessment. The continued trials have the potential benefit of confirming the expectations that the chute will (a) perform consistently; (b) increase fishing efficiency; and (c) be sufficiently practical and convenient to employ, especially after design improvements are made and a more efficient system to deploy and retract the chute is created for vessels installing the chute for long-term use. The continued trials promise to increase industry familiarity and support for use of the chute.

7. Conclusions

Results from a short trial of an underwater setting chute in the Hawaii longline tuna fishery indicate that this gear is both effective at avoiding seabirds as well as practical and cost saving. The chute eliminated seabird capture during this trial and reduced seabird contacts by 95% compared to a control. Vessels would experience a gain in efficiency between 7.5% and 29.6% when setting with the chute over conventional setting practices, providing an essential economic incentive to industry to use this effective seabird mitigation method. Broad trials are needed to improve the chute's design and installation, determine if the chute will perform consistently, and develop industry support for its use.

The Hawaii longline fleet is a very small component of total longline fishing effort in the North Pacific, representing about 2.7% of the longline hooks deployed in the entire Pacific Ocean each year [15,16,48]. Closure of Hawaii longline fisheries by US government management authorities would likely result in redistribution of the fleet to other domestic and international bases where bycatch of sensitive species may continue [16]. Thus, substantially larger conservation benefits can be realized by working with the Hawaii longline industry to develop innovative bycatch solutions that can be mainstreamed regionally and globally.

If the US Government can identify effective and practicable seabird avoidance methods that may be suitable in foreign longline fleets, the US, as one of the world's largest swordfish market (the US consumes about 25% of global swordfish landings [49]), has the ability to significantly influence the management of foreign longline swordfish fisheries by influencing consumer demand through eco-labeling schemes and educational campaigns (e.g., see [22,50]).

Effective and commercially viable seabird avoidance methods have been available for the past decade; however, most longline fisheries are not using them. Most national fishery management authorities lack frameworks to manage interactions

between seabirds and longline vessels, and do not require employment of effective seabird avoidance methods [3,13,20,21]. Given this management context, there is a need to maximize industry's sense of ownership for the use of effective seabird avoidance measures and provide industry with incentives for voluntary compliance. Strong economic incentives are needed to change long-standing fishing practices to minimize seabird mortality. Bycatch mitigation methods that effectively avoid seabirds, substantially increase fishing efficiency, and are practical and convenient, have the highest chance of being accepted by industry.

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