PERFORMANCE ASSESSMENT OF AN UNDERWATER SETTING CHUTE TO MINIMIZE SEABIRD MORTALITY IN THE HAWAII PELAGIC LONGLINE TUNA FISHERY

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SUMMARY

Mortality in longline fisheries is one of the most critical global threats to seabirds. Underwater setting technology may offer a practicable solution in some longline fisheries. Results from a research experiment and commercial demonstration of an underwater setting chute in the Hawaii pelagic longline tuna fishery indicate that the chute is effective at avoiding the incidental capture of seabirds and practicable for use by vessel crew. The chute demonstrated potential to significantly reduce seabird mortality and increase fishing efficiency, and required minimal effort to install and employ.

Chute Eliminated Seabird Captures and Reduced Contacts by 95%

When setting under control conditions, seabirds contacted 7.7% of baited hooks, a contact rate of 75.93 contacts per 1000 hooks. When normalized for the average number of albatrosses present, the contact rate is 1.97 contacts per 1000 hooks per albatross. Twenty-four seabirds were captured during control replicates, a catch rate of 4.24 captures per 1000 hooks. Normalized for albatross abundance, the seabird catch rate was 0.114 captures per 1000 hooks per albatross.

In contrast, when setting with the chute, seabirds contacted 0.2% of baited hooks set, a contact rate of 1.85 contacts per 1000 hooks. When normalized for albatross abundance, the rate is 0.10 contacts per 1000 hooks per albatross.[1] Expressed as contacts per 1000 hooks, the chute was 98% effective at reducing albatross contacts with fishing gear compared to a control. Expressed as contacts per 1000 hooks per albatross, the chute was 95% effective at reducing albatross contacts compared to a control. The chute eliminated seabird capture during this short-term trial.

Chute Reduced Birds' Interest in Vessel

The average number of albatrosses present when setting with the chute was significantly (*$p<0.05$) 39% lower than when setting under control conditions.

The effect of order of treatment was examined to see if there was a tendency for results to differ when control fishing was conducted first (which might attract more birds to both the control and chute replicates) as opposed to when the chute treatment was deployed first (which might discourage birds from interacting during both the chute and control fishing). Bird abundance was 24% lower during sets when chute replicates preceded control replicates than bird abundance during sets when control replicates were first, but the difference was not statistically significant ($p>0.24$).

Commercial Demonstration – Chute Generally Practicable, Increased Fishing Efficiency

The chute required nominal effort to install and use, and did not require substantive changes in fishing practices. The incidence of branch line tangles (a safety hazard during hauling) appeared to be higher for sections set through the chute, but the results were not statistically significant ($p>0.1$), perhaps due to low sample size ($n=5$). Tangling when setting with the chute was caused by crew prematurely grasping the mainline in anticipation of clipping the branch line to the mainline, and can be avoided.

Hook setting intervals when setting with the chute were significantly slower than the hook setting rate during control treatment replicates (*$p<0.029$). Because the vessel on which the trial took place has a faster hook setting rate than other vessels in the fleet, the hook setting interval when using the chute is not expected to require a reduced hook setting rate for the majority of vessels of the Hawaii longline fleet.

Bait retention when setting through the chute was significantly higher (*$p < 0.012$) than when setting without the chute. Bait loss was 30.5% when employing conventional setting methods versus 9.9% when setting with the chute, saving 20.6% of the bait when setting with the chute. Less than a quarter (about 16%) of the increased bait retention is attributed to the chute's ability to avoid seabird interactions, with over three quarters (about 84%) of the increased bait retention resulted from the chute's mechanical effectiveness of reducing physical stress on the bait as it enters the water. This suggests that longline vessels would benefit from increased catch per unit effort from setting with the chute at all fishing grounds, both at areas with abundant albatrosses and at grounds without albatrosses.

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[1] Eight of the ten observed seabird contacts when setting with the chute were observed to be the result of human errors, such as mistiming clipping a branch line to the mainline. The seabird contact rate is expected to be even lower than observed in this initial trial for a crew with more experience using the chute.

Based on increased bait retention, and assuming vessels either have enough time and mainline to complete slower sets using the chute, or that vessels will not have to reduce their conventional hook setting interval when using the chute, by setting with the chute, vessels would experience a gain in efficiency of 29.6% when abundant albatrosses are present, and a gain in efficiency of 21.5% without albatrosses present. However, if slower setting with the chute reduces efficiency (by a maximum of 11.5%), then the net gain in efficiency would be 14.7% with abundant albatrosses and 7.5% without albatrosses. Translating this range of gains in efficiency into rough catch and dollar amounts per year for one vessel, the increased efficiency from using the chute could produce an additional 28,125 – 111,000 pounds of fish or $56,250 - $222,000.

Some Seabirds Caught are not Hauled Aboard — Bycatch Assessments are Underestimates
Thirteen of 38 seabirds (34%) observed caught during setting were not hauled aboard.[2] Seabird catch rates based on the number of seabirds recovered during the haul are likely underestimates.

Highly Significant Correlation between Contacts and Captures -- Killing Birds During Research Can be Avoided
There was a highly significant linear correlation between contacts and captures using the observed number of birds hauled aboard (R = 0.84**), between contacts and the estimated number of captures observed during setting (R = 0.89**), and between attempts and captures using the observed number of birds hauled aboard (R = 0.76**). This implies that research on seabird deterrent methods could be designed so that bait is attached to gear with clips instead of hooks in order to minimize risks of injuring seabirds during research, where observations of attempts and contacts could be used to calculate capture rates under control and deterrent treatments. Further analysis could be conducted to determine the best fit for modeling the relationship between contacts and captures, and between attempts and captures.

Highly Significant Correlation between Seabird Abundance and Interactions with Fishing Gear
There was a highly significant linear correlation between albatross abundance and albatross unsuccessful attempts to contact gear (R = 0.61**), albatross contacts with gear (R = 0.73**), and captures (using the number of birds hauled aboard, R = 0.53**), justifying normalizing attempt, contact, and capture rates for albatross abundance. Normalizing capture, contact, and attempt rates for seabird abundance allows for more meaningful comparisons between seabird interaction rates observed in different experiments.

Conclusion and Management Recommendations
The chute is the most effective technology tested to date in the Hawaii longline fishery to minimize seabird capture, and preliminary results indicate that the chute has the added benefit of increasing fishing efficiency, even in the absence of albatrosses.

Short-term recommendations are made for management authorities to authorize use of the chute with adequate branch line weighting and a mainline shooter, where the discharge of offal and spent bait while setting with the chute is prohibited to minimize bird abundance and searching behavior, as an alternative seabird deterrent measure. It is further recommended that management authorities institutionalize an incentives program for use and additional performance assessment of the chute, facilitate making the chute commercially available, and develop the capacity for requisite training to install and use the chute. This will help develop broad industry support to use the chute, and if determined to be desirable, make future fleet-wide mandatory use of the chute possible.

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[2] There were three degrees of certainty for observations of birds caught during setting, giving the range of between 26.5% and 37.5% of birds caught during setting fall off the gear prior to being hauled aboard, with the perceived most reliable estimate being 34%.

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FIGURES AND TABLES

Citation

Gilman, E., C. Boggs, N. Brothers, J. Ray, B. Woods, K. Ching, J. Cook, S. Martin, and D. Chaffey. 2002. *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.

Limerick for the Crew of the F.V. *Katy Mary*

We avoided the birds, the chute didn't catch any,
Leaving bait for fish a plenty,
I only wish,
We caught more fish,
We saved the birds but made nary a penny.

AUTHORIZATIONS

This project was permitted under the following U.S. federal authorizations:

(a) U.S. Fish and Wildlife Service Permit No. TE047805-0, issued to Eric Gilman, National Audubon Society, 18 December 2001, amended 20 February 2002, under Section 10(a)(1)(A) of the U.S. Endangered Species Act;
(b) U.S. Fish and Wildlife Service Migratory Bird Permit Office Permit No. MB052060-0, issued to Lewis Van Fossen, U.S. National Marine Fisheries Service Hawaii Observer Program, 15 January 2002, under the U.S. Migratory Bird Treaty Act; and
(c) U.S. National Marine Fisheries Service Letter of Acknowledgement No. 2002-01-221, issued to Eric Gilman, National Audubon Society, 21 February 2002, under the U.S. Magnuson-Stevens Fishery Conservation and Management Act.

1. INTRODUCTION

Of the numerous threats facing albatrosses and some other petrels, including ingestion of plastics, organochlorine and heavy metal contamination, degradation of nesting habitat, predation by introduced species, disease and parasites, global climate change, and sea-level rise, scientists consider incidental bycatch in longline fisheries to be one of the most significant (Alexander, *et al*. 1997; Croxall, 1998; Croxall and Gales, 1998, Gales, 1998, Cousins and Cooper, 2000; Gilman, 2001a and b). Based on available estimates of total albatross mortality in North Pacific pelagic longline fisheries, and results of a population modeling experiment on the Black-footed Albatross, estimated bycatch rates justify the concern that mortality in longline fisheries most likely threatens the sustainability of Black-footed Albatrosses (*Phoebastria nigripes*) and poses a significant threat to Laysan (*P. immutabilis*) and Short-tailed Albatrosses (*P. albatrus*) (Cousins and Cooper, 2000; Gilman, 2001b).

Hawaii pelagic longline fisheries have resulted in the annual mortality of approximately 3,000 albatrosses. However, with the recent closure of the Hawaii swordfish longline fishery, 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, 2000). Investigators conducted research on an underwater setting chute on a Hawaii longline tuna vessel in the hope of being able to minimize 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 deterrent potentially exportable to other longline fisheries.

The project goals were to determine if an underwater setting chute is effective at avoiding and reducing the incidental capture of seabirds in the Hawaii longline tuna fishery and to determine if the chute is practicable for use. Objectives were to:

(a) Compare the seabird capture rate when setting with an underwater setting chute with the capture rate during normal setting procedures, and determine the chute’s effectiveness at reducing captures;
(b) Assess the difference in rates of seabird contacts and unsuccessful attempts to contact hooks when setting with an underwater setting chute versus a control, and determine the chute’s effectiveness at reducing contacts and attempts;
(c) Assess how use of a chute affects fishing efficiency based on the hook setting interval and bait retention when using the chute compared to a control;
(d) Determine the degree of effort required to install and use a chute;
(e) Assess if use of an underwater setting chute increases safety hazards;
(f) Assess whether operation of an underwater setting chute requires substantial intrusion on the normal operation of a Hawaii longline tuna vessel;
(g) Determine how use of a chute affects the sink profile and sink rate of hooks compared to a control;
(h) Assess differences in seabird abundance and behavior when setting with a chute compared to a control, and determine if the order of treatment affects seabird abundance;
(i) Determine the difference between the number of seabirds observed caught during setting versus the number of birds hauled aboard;
(j) Determine if there is a significant correlation between seabird abundance and attempts, contacts, and captures;
(k) Determine if there is a significant relationship between seabird attempts to contact hooks and captures, and between seabird contacts with hooks and captures;
(l) Observe seabird interactions with fishing gear during hauling;
(m) Observe if there was a significantly higher incidence of capture of seabirds on branch lines with lighter swivels than is expected by chance;
(n) Assess how the effectiveness of blue-dyed squid bait at reducing seabird interactions compared to a control was significantly different from results observed in other experiments; and
(o) Determine if there was a bias for age, sex, and breeding condition for the seabirds killed during the experiment.

2. PROBLEM STATEMENT

Of the myriad anthropogenic and natural threats to seabirds, one of the most critical global problems is incidental mortality in longline fisheries. Hesitance or failure by fishery managers and longline industries to adequately address this acute problem could result in the extinction of several albatross and petrel species within our lifetimes (Gilman, 2001a and b). One of the most critical conservation problems facing seabirds globally is the mortality caused by longline fisheries when albatrosses and petrels swallow baited hooks and drown (Croxall, 1998; Gales, 1998; Gilman, 2001a and b). Most species of seabirds forage by scavenging marine life found floating on the sea surface, making it a natural behavior to feed on discards from fishing vessels and swallow baited hooks (Brothers, 1995; Brothers *et al*., 1999). The birds get hooked or entangled when gear is being set and are dragged underwater and drown as the fishing gear sinks (Brothers *et al*., 1999). Birds may also be caught on baited hooks which have not caught fish and can get entangled in gear during the haul of the longline, typically during daytime hauls (Brothers, 1995; Alexander *et al*., 1997; Brothers *et al*., 1999). The ingestion of hooks discarded in offal by seabirds is another source of mortality. These direct sources of mortality also result in indirect mortality of chicks when one or both parents are killed.

Quantitative data on seabird bycatch are available only from a small number of fisheries (Brothers *et al*., 1999; Cousins *et al*., 2001; Gilman, 2001b; Gandini and Frere, In Prep.). Cousins *et al*., (2001) uses quantitative data on seabird catch rates in Hawaii-based pelagic longline fisheries to make a rough 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 8,000 Laysan Albatrosses per year (Crowder and Myers, 2001). The estimated total incidental catch of albatrosses in the Alaskan demersal longline fisheries (excluding the unobserved U.S. Pacific halibut fishery) from 1993 to 1999 was two Short-tailed Albatrosses, 908 Laysan Albatrosses, and 385 Black-footed Albatrosses per year (U.S. National Marine Fisheries Service 2001b). No estimates are available for albatross mortality in other North Pacific demersal longline fisheries (Brothers *et al*., 1999). On the order of tens of thousands of albatrosses and hundreds of thousands of seabirds are estimated to be caught annually in longline fisheries worldwide (Brothers, 1991; Anonymous, 1999; Thomas, 2000; Dunn and Steel, 2001; Gilman, 2001a and 2001b; Ryan *et al*., 2001; U.S. National Marine Fisheries Service 2001b; BirdLife International, 2002; Ryan and Watkins, 2002; Gandini and Frere, In Prep.).

Population modeling experiments indicate that, due in part to interactions with longline vessels, the current mortality rates of juvenile Black-footed Albatrosses likely exceed that required to maintain stable populations (Cousins and Cooper, 2000). Another conclusion from the modeling exercises is that Black-footed Albatross can withstand no more than a loss of 10,000 birds per year to all mortality sources (combined natural and anthropogenic sources) for the population to be stable (Cousins and Cooper, 2000). Gilman (2001b) explains that, based on available estimates of total albatross mortality in North Pacific pelagic longline fisheries, and results of this population modeling experiment on the Black-footed Albatross, estimated bycatch rates most likely justify the concern that mortality in longline fisheries most likely threatens the sustainability of Black-footed Albatrosses and poses a significant threat to Laysan and Short-tailed Albatrosses, which, as is expected of long-lived species with low reproductive rates, are particularly vulnerable to changes in survival rates (Tasker and Becker, 1992; Brothers, 1995). Crowder and Myers (2001) project that, based on their lowest mortality estimates of 1.9% of Black-footed populations being killed per year in combined pelagic longline fisheries, Black-footed Albatross population declines are likely over the next 20 years.

North Pacific albatrosses include the Short-tailed, Black-footed and Laysan Albatrosses (Figure 1). The total population of the Short-tailed Albatross is approximately 1,500 birds. Slowly recovering from near extinction in the 1940s, the species has experienced an average population increase of over 7% annually due in part to efforts to improve nesting habitat. The species is considered to be globally threatened with extinction. On 11 August 2002, the volcanic Torishima Island, the main nesting site for the Short-tailed Albatross, erupted. While the eruption took place during the non-breeding season, and currently there has not been significant degradation of nesting habitat, the volcano becoming active again could reverse or at least stall the recovery of the species (Hiroshi Hasegawa, personal communication, 13 August 2002, Toho University). The Short-tailed Albatross was reclassified from endangered to vulnerable in the 2000 IUCN Red List of Threatened Species (U.S. National Marine Fisheries Service, 2000 and 2001b; IUCN, 2000).

The Black-footed Albatross, with a population of approximately 300,000, is also included on the 2000 IUCN Red List of Threatened Species as a vulnerable species (IUCN, 2000). There has been a 9.6% decline in Black-footed Albatross breeding pairs from 1992 to 2001, a 1.1% annual decline, based on monitoring data of three nesting colonies where over 75% of the world population of this species nest (U.S. Fish and Wildlife Service, 2001).

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. IUCN did not assess the Laysan albatross' status for the 2000 IUCN Red List due to insufficient information and time (Caroline Pollock, personal communication, 31 October 2000, IUCN SSC Red List Programme). There has been a 30% decline 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) (U.S. Fish and Wildlife Service, 2001).

These recent, short-term declines in breeding pairs of the Laysan and Black-footed albatrosses could be the result of numerous causes, such as increased rates of skipped breeding, which might be due to depleted food resources caused by El Nino and general warming of the oceans, or the cause of the declines could be various sources of mortality, of which one of the more significant is hypothesized to be interactions with longline fisheries.

Figure 1. Laysan, Black-footed, and Short-tailed Albatrosses on Sand Island, Midway Atoll (photo by Eric Gilman).

The impact of anthropogenic-caused increases in mortality above natural levels is particularly significant in albatrosses. Seabirds are particularly sensitive to human impacts that affect adult mortality rates because seabirds live relatively long lives (albatrosses live into their 60s), have delayed maturity (seabirds do not start to breed until they are between 5 and 12 years old), and have relatively low reproductive rates (seabirds can raise only one chick every one or two years) (Tasker and Becker, 1992; Brothers, 1995). Egg incubation and chick rearing for several albatross species is conducted by both parents, so if one parent is killed on a longline hook, the chick will likely die of starvation (Brothers, 1995). Also, albatrosses typically stay with the same partner for life, so if one partner is killed, it may take several years for the remaining bird to find a new mate and resume breeding (Brothers, 1995). All of these characteristics mean that seabirds have difficulty recovering from the loss of a large number of individuals.

The estimated take rate of Laysan Albatross in combined Hawaii longline fisheries (longline vessels targeting swordfish, mixed sets targeting both tuna and swordfish, and vessels targeting tuna) ranged from 0.07 to 0.15 birds per 1,000 hooks from 1994 to 1998. The rates for Black-footed Albatross ranged from 0.07 to 0.17 birds per 1,000 hooks (U.S. Fish and Wildlife Service, 2000). The estimated annual take of Laysan Albatross by the Hawaii-based longline fishery ranged from 1,047 to 1,828 birds per year from 1994 to 1998 with 95% confidence limits on the estimated annual takes ranging from 569 to 2,984 birds (U.S. Fish and Wildlife Service, 2000). The corresponding estimated annual takes of Black-footed Albatross ranged from 1,568 to 1,994 birds per year with 95% confidence limits ranging from 1,158 to 2,102 birds (U.S. Fish and Wildlife Service, 2000). Stating this more crudely, the estimated total incidental catch of albatrosses in Hawaii pelagic longline fisheries from 1994 to 1998, based on data from very low (approximately 4%) onboard observer coverage, was zero short-tailed albatrosses, 1,831 Black-footed Albatrosses and 1,392 Laysan Albatrosses per year (U.S. National Marine Fisheries Service, 2000). However, recent changes in regulations, which closed the swordfish fishery and places restrictions on the tuna fleet, likely have significantly changed the Hawaii fleet's effort, spatial distribution of effort, and amount and composition of albatross bycatch.

These statistics on seabird bycatch in the Hawaii longline fleet are most likely underestimates. It is believed that seabird catch rates recorded on fishing vessels are conservative underestimates because not all seabirds that are caught are hauled aboard, as there is unobserved discarding of incidentally caught seabirds and seabirds can fall from the hooks before or during hauling, considered to be significant biases (Brothers, 1991; Gales *et al*., 1998; Cousins and Cooper, 2000). This is discussed in detail in Section 8.7.

The location of fishing grounds, time of setting, bait type, method of deploying gear, sink rates of baited hooks, use of lightsticks, time of day when setting and hauling, and potentially other differences between the Hawaii longline vessels targeting tuna, targeting swordfish, and targeting mixed swordfish and tuna result in significant differences in albatross take rates for these different set types in the Hawaii longline fishery (U.S. Fish and Wildlife Service, 2000; Cousins *et al*., 2001). There are many confounding factors that influence the degree of seabird entanglements and hookings in a longline fishery and for a specific vessel. Fishing practices (e.g. automated versus manual line hauling, method and depth of gear deployment, season and time of day when setting, use of deck lighting at night, offal discharge practices, type of bait, condition of bait when setting, and proper use of seabird deterrent measures, if any are employed), fishing location, fishing effort, type and configuration of fishing gear (e.g. gear sink rate, length of branch lines, size of hooks, number of hooks deployed per set, use of light sticks), weather conditions when setting, seabird abundance, and the complex of seabird species present influence the number of seabirds a specific vessel and fishery will catch (Brothers, 1991; Brothers, 1995; Bergin, 1997; Environment Australia, 1998; Brothers *et al*., 1999; Cousins *et al*., 2001, Gilman, 2001b). Bycatch rates of North Pacific albatrosses in swordfish longline fisheries are 30 to 60 times higher than in longline tuna fisheries (Cousins *et al*., 2001; Crowder and Myers, 2001).

Based on U.S. National Marine Fisheries Service observer records from 1994-1998, after observing 488 Hawaii longline swordfish sets, 370 birds were observed caught (0.758 birds caught per set). After observing 946 Hawaii longline mixed sets (when fishers target both tuna and swordfish), 472 birds were observed caught (0.499 birds caught per set). After observing 1,250 Hawaii longline tuna sets, 16 birds were observed caught (0.013 birds caught per set or approximately 0.0078 birds per 1,000 hooks) (U.S. Fish and Wildlife Service, 2000; Cousins *et al*., 2001). Based on logbook data, there were 8,929 tuna sets in the Hawaii longline fishery in 2000 (Ito and Machado, 2002). Using the estimate that 0.013 albatross are caught per Hawaii tuna set, a crude estimate of total albatross capture by the Hawaii tuna fleet in 2000 is 116 birds.

The Hawaii swordfish fishery was closed in 2001 due to concerns over bycatch of sea turtles (U.S. National Marine Fisheries Service, 2000, 2001a, 2002a). The Hawaii swordfish and mixed (vessels that made both swordfish and tuna sets) fishery had resulted in greater than 95% of the Hawaii longline fleets' annual seabird bycatch from 1994-1998 (U.S. Fish and Wildlife Service, 2000). The swordfish and mixed set fleets' fishing grounds overlapped with albatross foraging areas, while the tuna fleet's fishing grounds primarily do not overlap with albatrosses (U.S. Fish and Wildlife Service, 2000). The fishing grounds for the Hawaii longline tuna fleet has primarily been south of 23 degrees N. latitude where few albatrosses forage: from 1994 to 1998, over 85% of sets by the Hawaii longline tuna fleet were conducted south of 23 degrees N. latitude (U.S. Fish and Wildlife Service, 2000); in 2000, 90.4% of the Hawaii longline tuna fleet's sets were made south of 23 degrees N. latitude (853 sets or 9.6% of total tuna sets were made north of 23 degrees N. latitude) (U.S. National Marine Fisheries Service Honolulu Laboratory unpublished longline logbook data); and in 2001 91% of the Hawaii longline tuna fleet's sets were made south of 23 degrees N. latitude (1057 sets or 9.0% of total tuna sets were made north of 23 degrees N. latitude) (U.S. National Marine Fisheries Service Honolulu Laboratory unpublished longline logbook data). The vessels are not required to employ any seabird avoidance measures when fishing south of 23 degrees N. latitude (U.S. National Marine Fisheries Service, 2002a and 2002b). The Hawaii tuna fleet currently is believed to cause a relatively small amount of albatross mortality, and with fleetwide use of effective seabird avoidance techniques, the fleet can expect to kill even fewer birds. It is also hypothesized that the swordfish and mixed-set vessels may have had significantly slower hook sink rates over the first few meters than vessels targeting tuna, which would have made baited hooks available to seabirds longer than vessels targeting tuna, although there are no published data to confirm this.[3]

Results from this trial of the underwater setting chute may help minimize seabird mortality in the Hawaii longline tuna fleet, may have implications for potential new Hawaii longline fishery sectors, and might demonstrate the potential of the chute for use in other pelagic longline fisheries of the North Pacific Ocean. While it is evident that the risk of interaction between albatross and Hawaii longline vessels targeting tuna is much lower than it was for Hawaii vessels targeting swordfish and conducting mixed sets, now that the Hawaii swordfish longline fishery is closed, it behooves managers to avoid and minimize seabird mortality in the Hawaii longline tuna fleet to the maximum extent practicable. Researchers did not test the effectiveness of the chute on a Hawaii swordfish vessel because the results would currently have no application in the Hawaii longline fishery, and because such an experiment may not have received requisite federal authorizations. There is the remote possibility that the Hawaii longline tuna fishery will increase effort in northern areas where higher densities of seabirds occur, and the U.S. National Marine Fisheries Service Honolulu Laboratory is investigating the feasibility of a deep-set swordfish fishery using lightsticks and a line setting machine with setting conducted during the day (Laurs, 2001). The chute is expected to be effective at minimizing seabird mortality in these other potential fishery sectors as well (Section 8.21). Furthermore, the U.S. National Marine Fisheries Service is currently testing alternative sea turtle avoidance methods on Hawaii swordfish longline vessels (Laurs, 2001). If the U.S. National Marine Fisheries Service and partners are successful at finding measures to avoid turtle mortality in the Hawaii swordfish fishery, and if the Hawaii swordfish fishery is authorized to resume in the future, the underwater setting chute is likely to be as effective and practicable for the swordfish fleet as it would be for the tuna fleet to avoid seabird interactions (Section 8.21). In addition, the chute design assessed in Hawaii is expected to perform similarly on the pelagic longline vessels based out of the U.S. West coast, and perhaps in other non-US pelagic longline fleets that operate in the North Pacific Ocean (Section 8.21).

Recognizing the limited enforcement capabilities of U.S. Government management authorities over the Hawaii, Alaska, and U.S. West coast longline fleets, and the limited management and enforcement capabilities of some non-U.S. longline fleets that interact with albatrosses, 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 (Gilman *et al*., 2002). This means that a suitable seabird mitigation measure needs to be both effective at avoiding seabirds as well as practicable for use by vessel crew. The ideal seabird deterrent method (or combination of methods) would (a) have been demonstrated to avoid seabird interactions with fishing gear and eliminate seabird mortality for the entire fleet-wide range of fishing practices and gear designs, and under all weather conditions, seabird abundance and species assemblage, and other variable conditions encountered by the fleet; (b) not cause increases in bycatch of other sensitive species; (c) require a minimal amount of alteration of traditional fishing practices; (d) require nominal effort to employ and not pose a safety hazard 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 deterrent measure, and because the chute may likewise be suitable for use in other North Pacific longline fleets.

3. UNDERWATER SETTING CHUTE HISTORY

Over the past 15 years, national governments, regional organizations, and longline industries have developed and tested seabird deterrent methods, including changes in fishing gear (e.g. adding weights to the line and using a line-setting machine), fishing practices (e.g. thawing bait and avoiding setting baited hooks in ship wash and propeller turbulence), changes in fishing operations (e.g. night setting and establishing area and seasonal closures), and vessel layout (e.g. altering deck lighting) to reduce seabird bycatch in longline fisheries (Brothers, 1995; Bergin, 1997; Smith and Bentley, 1997; FAO, 1998; Brothers *et al*., 1999; McNamara *et al*., 1999; Molloy *et al*., 1999; Brothers *et al*., 2000; Keith, 2000;

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[3] The tuna fishery uses 38 to 80 g swivels within 20 to 90 cm from the hook, while the swordfish vessels placed 60 to 80g weights 5 to 7 m from the hook, which is expected to result in a slower sink rate of the baited hooks. But the Hawaii swordfish fleet used larger and heavier hooks than the tuna fleet, which would increase the swordfish baited hook sink rate.

Melvin, 2000; O'Toole and Molloy, 2000; Melvin *et al*., 2001; Anderson and McArdle, 2002; Minami and Kiyota, 2002; Robertson *et al*., 2002). Researchers in a number of countries are continuing to develop and test new seabird deterrent measures to avoid and minimize seabird mortality in longline fisheries.

In the North Pacific Ocean, in 1998, the U.S. Western Pacific Fishery Management Council sponsored research on the effectiveness of selected seabird deterrent measures in Hawaii-based longline fisheries (McNamara *et al*., 1999). The U.S. National Marine Fisheries Service conducted a separate research cruise to test the effectiveness of deterrent measures (Boggs, 2001) and also conducted a statistical analysis of observer data collected in Hawaii longline fisheries to infer the effects of night setting and area closures on seabird interactions (U.S. National Marine Fisheries Service, 2000). In 2001 the Washington Sea Grant Program completed a 2-year study on fishing vessels in the Alaska-based halibut and sablefish fishery and in the Pacific cod fishery to test selected seabird deterrent measures (Melvin, 2000; Melvin *et al*., 2001). Results from the Hawaii and Alaska research studies indicate that several mitigation measures reduce seabird bycatch rates in these fisheries by more than 90% (Melvin, 2000; U.S. National Marine Fisheries Service, 2000; Boggs, 2001; Melvin *et al*., 2001).

There have been at least five studies on the effectiveness of a Mustad underwater setting funnel (also called a lining tube) in demersal longline fisheries. The Mustad funnel is currently the only commercially available underwater setting device. The underwater setting funnel manufactured by Mustad is a large metal chute attached to the stern, which delivers the line into the water up to 2 meters below the surface (Mustad and Son, No Date; Melvin *et al*., 2001; Ryan and Watkins, 2002). Research has been conducted in South Africa on a Mustad underwater setting funnel in a demersal longline fishery for Patagonian toothfish (*Dissostichus eleginoides*) (Ryan and Watkins, 2002), in Alaska on a Mustad underwater setting funnel on a demersal longline vessel targetting cod (Melvin *et al*., 2001), and in Norway on a Mustad underwater setting funnel in a demersal longline fishery (Lokkeborg, 1998 and 2001; Dunn and Steel, 2001).

Melvin *et al*. (2001) found the funnel to be 79% effective at reducing seabird bycatch compared to a control, but the funnel was only effective at reducing the capture rate of Northern Fulmars (*Fulmarus glacialis*) and did not reduce the capture rate of deeper-diving Shearwaters (*Puffinis* spp.). Furthermore, Melvin *et al*. (2001) found the funnel's performance to be inconsistent, found the funnel to be inappropriate for some vessels in the fleet (the funnel can only be deployed from vessels that set from their lower decks), observed occasional operational problems (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 considered the funnel to be too expensive (about US$40,000) and did not recommend the funnel as a solution to seabird interactions in the Alaska fleet. Lokkeborg (1998 and 2001) found that the Mustad funnel reduced seabird capture by 72% and 93%, respectively in his two separate studies, relative to controls of no deterrent. However, Lokkeborg (1998 and 2001) found seabird capture rates to be variable between his two trials, and suggests that sea conditions, the loading of the vessel (if the ship was front-heavy, the bottom of the funnel and the longline was lifted out of the water during setting), and setting the gear in propeller turbulence resulted in variation in the funnel's setting depth and concomitant inconsistent effectiveness at reducing seabird capture. Ryan and Watkins (2002) found the Mustad funnel, used in conjunction with a bird-scaring line and line weighting, to result in a low seabird capture rate (0.022 birds captured per 1000 hooks). Ryan and Watkins (2002) also observed occasional problems with the line jumping out of the funnel slot and lifting of the bottom of the funnel and longline out of the water during large seas during setting. Dunn and Steel (2001) found that, during an at-sea trial in 1997, setting with a Mustad funnel resulted in a Northern Fulmar capture rate of 0.01 Fulmar captures per 1000 hooks, and setting with a streamer line resulted in 0.03 to 0.04 Fulmar captures per 1000 hooks. During a trial in 1998, Dunn and Steel (2001) observed that setting with a Mustad funnel in combination with a streamer line resulted in a Fulmar capture rate of 0.18 Fulmar captures per 1000 hooks, while there were no Fulmar captures when setting with only a streamer line, and concluded that in 1998 the funnel did not perform better than a streamer line in reducing seabird capture.

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 when Akroyd Walshe/Paul's Fishing Kites were contracted to design and build a prototype (Molloy *et al*., 1999). Results from research on an underwater setting chute in a New Zealand pelagic longline fishery showed that the chute has potential to reduce seabird mortality substantially with minimal intrusion on normal fishing operations (O'Toole and Molloy, 2000). The New Zealand chute, which delivers baits 4.2m below the surface, was tested on a longline tuna vessel in 1998 over a six-month period. Baited branch lines are normally hand-thrown. At 100m astern of the vessel, the chute set branch lines to a mean depth of 8.70m, while branch lines set by hand-throwing were at a mean depth of 5.85m at 100m astern of the vessel (O'Toole and Molloy, 2000).

Australia has also been conducting research on an underwater setting chute and capsule in a pelagic longline fishery (Brothers *et al*., 2000), and additional industry-wide testing of the chute in pelagic longline fisheries is currently underway. The Australian Fisheries Management Authority and Environment Australia have been conducting research on an underwater setting chute, using a modified design of the New Zealand chute, in their pelagic longline fishery (Brothers *et al*., 2000). An initial 6 month trial of the underwater setting chute and an underwater setting capsule on an Australian pelagic longline vessel in waters off Tasmania was completed in 2000, during which an assessment of bait retention, setting depth, line tangling, and effect on seabird interactions was made and modifications to the chute were made. Results indicate that the chute has the capacity to minimize seabird interactions during setting with low bait loss and tangles (Brothers *et al*., 2000). Research on the Australian pelagic longline industry-wide effectiveness of the chute has been initiated. It was intended that ten Australian pelagic longline vessels would be fitted with the chute to observe a chute seabird capture rate (personal communication, Anthony DeFries and Ingrid Holliday, Australian Fisheries Management Authority, January 2002). Section 8.21 discusses the preliminary status of the broad trial of the chute in Australia.

4. F.V. *KATY MARY* AND FLEETWIDE DESCRIPTIONS OF FISHING GEAR AND METHODS

The Honolulu-based F.V. *Katy Mary*, a 25.3 meter (83 foot) longline tuna vessel, steel hull, with foreword wheelhouse, was used to conduct the at-sea trial of the underwater setting chute (Figure 2).

Figure 2. The F.V. *Katy Mary*, a 25 m longline tuna vessel at its berth in Honolulu, was used to conduct the trial of the underwater setting chute.

4.1. *Katy Mary's* Fishing Gear and Method

The *Katy Mary's* mainline is approximately 56 km (35 miles) long of which 16 km (10 miles) is light-blue 3.6mm (0.14 inch) diameter nylon monofilament, and 40 km (25 miles) is dark blue 3.2mm (0.12 inch) diameter monofilament. Branch lines (also called snoods or gangions) are 2.0mm or 2.1mm diameter, and are 7.3 and 9.1 m (24 and 30 feet or 4 and 5 fathoms) long. The *Katy Mary* has approximately 2,800 branch lines (the total number of hooks and branch lines continually changes with each set as damaged branch lines are removed and new branch lines are made up and added to the gear). The *Katy Mary* uses six totes (also called snood bins, line boxes, or hook boxes), with approximately 467 branch lines per tote. Usually all of the hooks are deployed on each set. Typically, 30 hooks are set between buoys (called one basket), the branch lines are 13.5 fathoms (24.6m or 81 feet) apart, and buoys are 418.5 fathoms (765m or 2511 feet, about half a mile) apart. The distance from a buoy to the mainline is 20m (66 feet). Wire leaders on the branch lines are 45.7cm (18 inches) long, and the swivels (weights) are located relatively close, 45.7cm (18 inches) from the hook. Hooks are open gap #7 J. Most of the swivels at the wire leader are 60g, but a fraction of the leaders were found to have lighter, 38g swivels during the course of the experiment (these lighter swivels are intermixed throughout the branch lines and are gradually being removed and replaced by the heavier 60g swivels). Six radio beacons are placed throughout the set mainline to help locate the gear.

Branch lines are set out of a single tote and not out of two totes as occurs in some other longline fleets, such as is done by most of the vessels in the Australian pelagic longline tuna fishery, where crew alternate setting out of two totes. A branch line is set approximately every 7 seconds. A mainline shooter is used to set the mainline. The vessel speed during setting is 6 knots, with the mainline shooter set at 310 RPM. Gear is set and soaks during the daytime, and is hauled into the night. The *Katy Mary* has a captain and four crew.

When fishing North of 23 degrees North latitude, the *Katy Mary* uses a mixture of fish and squid for bait, where about 60% of the bait is saury (also called sanma), 30% is sardines, and 10% is squid. Bait is typically thawed before being set. Swim bladders are left intact (not punctured), not expected to be problematic for saury, potentially problematic for sardine, but not expected to significantly reduce the hook sink rate when 60g swivels are used. Lightsticks are not used when targeting tuna.

Compared to the rest of the Hawaii tuna pelagic longline fleet, described below, the *Katy Mary* is a relatively large vessel with high effort. For gear differences that would affect seabird interaction rates, the *Katy Mary's* swivel weight is about average, proximity of the weighted swivel to the hook is about average, and length of branch lines are shorter than the average of the Hawaii tuna fleet.

4.2. Hawaii Tuna and Swordfish Longline Fleet Description

4.2.1. Vessel Description (Weight and Length): All Hawaii longline vessels are less than 30.8m (101 feet) in length, where most of the medium and larger vessels between 17 and 30.8m (56 and 101 feet) long target swordfish, and the smaller vessels 17m (56 feet) or less in length target tuna (U.S. National Marine Fisheries Service, 2001a).

4.2.2. Fleet Size: Starting in 1994, the Hawaii-based longline fleet has been restricted to 164 transferable limited-entry Hawaii longline permits (U.S. National Marine Fisheries Service, 2001a). Of a possible 164 active vessels, there were an average of 110 active vessels between 1994 and 2001 (U.S. National Marine Fisheries Service, 2001a and 2002c). From 1994 to 1999, there was an average of 83 Hawaii longline vessels targeting tuna, an average of 40 vessels targeting swordfish, and an average of 49 vessels targeting a combination of tuna and swordfish (referred to as mixed trips) (one vessel can be counted as conducting both swordfish-specific targeted trips and mixed trips) (U.S. National Marine Fisheries Service, 2001a).

4.2.3. Gear and Fishing Method: The longline gear configurations and fishing methods are not consistent between Hawaii vessels. For instance, the color of main and branch lines, weight amount and location, type of buoys, vessel horsepower, trip length and fishing days, vary between vessels. Table 1 provides an overview of the fishing gear and fishing methods of the Hawaii tuna fleet, and the swordfish fleet before it was closed in 2001.

Table 1. Description of the fishing gear and methods of the Hawaii tuna and swordfish pelagic longline fleets. (U.S. National Marine Fisheries Service Honolulu Laboratory Unpublished Data; Boggs, 1992; Pacific Ocean Producers, 2000; Ito and Machado, 2001; U.S. National Marine Fisheries Service, 2001a and 2002c).

Fishing Gear and Method	Hawaii Tuna Fleet	Hawaii Swordfish Fleet[1]
Mainline material	Nylon monofilament[2]	Nylon monofilament
Mainline length	10 to 100 km, average of 54 km (6 to 65 miles, average of 34 miles)	30 to 100 km (19 to 62 miles)
Mainline deployment	Mainline shooter (to set mainline slack)	Manual (no shooter, to set mainline taught)
Number of branch lines per tote	425	425
Distance between buoys	800m (0.5 mile)	500m (0.3 mile)
Distance from buoy to mainline	22m (73 feet)	8m (26 feet)

(float line length)		
Average branch line length	13m (43 feet)	17m (56 feet)
Number of hooks between buoys	20 to 40 hooks, average of 27	4 to 6 hooks
Average maximum depth of hooks when set	234m (772 feet)	69m (228 feet)
Average maximum depth of mainline when set	221m (729 feet)	52m (172 feet)
Monofilament mainline sink rate	10m/minute (33 feet/minute)	4m/minute (6.6feet/minute)
Timing of set, soak, and haul	Gear is set in the morning, soaks during the day, and is hauled before dark.	Gear is set in the evening, soaks overnight, and is hauled the following morning.
Lightstick use	None	One lightstick every 1 to 5 hooks
Number of hooks per set	1,200 to 2,500 (in 2001, average of 1864 hooks per set)	700 to 1,000 (in 2001, average of 1082 hooks per set)
Hook setting interval	8 seconds per hook	12 seconds per hook
Radio beacons	6 per set	6 per set
Hook type	"J" shaped hook with adequate bend so that point is directed inside the eye, such as a 3.6 ring hook	"J" shaped hook without much bend so that the point is directed outside of the eye, such as a Mustad 7698-R9/0 or an Eagle Claw 9016
Weight size and location	38 to 80g, 20 to 90 cm from hook	60 to 80 g, 5 to 7m from hook
Bait type	Saury (also referred to as sanma)	Primarily use squid as bait but also use locally-caught scad, sardines, herring, and saury
Size of crew	Captain and 3 crew	Captain and 4 to 5 crew
Annual effort (number of hooks set per year)	13.4 million hooks per year (from 1994 to 2001)	4.0 million hooks per year (from 1994 to 2000)[3]
Vessel Monitoring System (VMS)	All limited entry Hawaii-based longline permit holders are required to participate in a Vessel Monitoring System program, used to enforce longline exclusion zones around the main and Northwestern Hawaiian Islands.	

[1] Hawaii pelagic longline vessels targeting swordfish and vessels targeting a combination of swordfish and tuna use the same gear and method.

[2] One vessel in the Hawaii tuna fleet uses an old-style of longline gear called basket gear or rope gear, made of a blend of nylon and Dacron, tarred and braided.

[3] Vessels targeting swordfish set an average of 1.4 million hooks per year, and vessels targeting a combination of swordfish and tuna (mixed sets) set an average of 2.6 million hooks per year from 1994 to 1999. In mid-2001, U.S. National Marine Fisheries Service regulations prohibiting shallow longline sets (to target swordfish) by Hawaii longline vessels came into effect. There were 453 swordfish and mixed sets (setting 0.49 million hooks) made in 2001 by the Hawaii longline fleet.

4.2.4. Fishing Season: The fishing season for the Hawaii tuna fishery is year-round. As a result of regulations promulgated in June 2001 to attempt to reduce sea turtle bycatch, the swordfish and mixed Hawaii longline fisheries are closed, the tuna fleet is prohibited from fishing in April and May in an area south of the Hawaiian Islands, and the regulations restrict permit holders from switching their vessel registration between California and Hawaii (U.S. National Marine Fisheries Service, 2001b). Prior to adopting the June 2001 regulations, the fishing season for Hawaii tuna, swordfish, and mixed longline fisheries was year-round. During the third calendar quarter, July through September, Hawaii longline fisheries had the lowest effort, when some fishers conducted maintenance, and between 15 to 30 vessels based themselves out of California and fished at grounds further east than could be reached from Hawaii (U.S. National Marine Fisheries Service, 2001a). As fishing improved to the west, these vessels would go back to basing themselves out of Hawaii (U.S. National Marine Fisheries Service, 2001a).

4.2.5. Fishing Grounds: In general, the Hawaii longline fleet fished beyond 25-50 nm from the Hawaiian Islands, fishing in the US EEZ adjacent to Hawaii and on the high seas out to more than 1,000 nm from port (U.S. National Marine Fisheries Service, 2001a). Fishing grounds vary seasonally and by target. Most effort is to the north and south of the Hawaiian Islands between latitudes 5 and 40 degrees N and longitudes 140 degrees W and 180 degrees (U.S. National Marine Fisheries Service, 2001a). For vessels targeting tuna, from January through March, effort is concentrated between latitudes 15 degrees N and 35 degrees N and longitudes 150 degrees W and 180 degrees. From April through June tuna fishing effort expands to the south and spreads further east and west to about longitudes 145 degrees W and 170 degrees E. Vessels targeting swordfish and mixed swordfish and tuna fished primarily in the area to the northeast of the Hawaiian Islands in the North Pacific Transition Zone (U.S. National Marine Fisheries Service, 2001a).

4.2.6. Total Average Catch Per Year of Target Species: Between 1994 and 1999, total landings of all species was an average of 24.4 million pounds per year (Ito and Machado, 1999; U.S. National Marine Fisheries Service, 2001a). Between 1994 and 1998 an average of 6.41 million pounds of swordfish, 2.34 million pounds of albacore tuna, 5.00 million pounds of bigeye tuna, and 1.80 million pounds of yellowfin tuna, were landed per year (U.S. National Marine Fisheries Service, 2001a). An average of 15.55 million pounds of target species were landed per year during this period.

4.2.7. Total Average Catch Per Year of Landed Finfish Incidental Catch: Between 1994 and 1998 an average of 2.22 million pounds of billfish species (blue marline, striped marline, and other billfish), excluding swordfish, were landed per year, and an average of 4.10 million pounds of shark species were landed per year (Ito and Machado, 1999; U.S. National Marine Fisheries Service, 2001a).

5. METHODOLOGY

5.1. Null Hypothesis

The experiment was designed to test a null hypothesis that setting with an underwater setting chute on a Hawaii longline tuna vessel would not be able to reduce seabird capture or contact rates by 90% compared to a control of setting under conventional practices (as defined in U.S. National Marine Fisheries Service, 2001a).

We were interested in determining if the chute is 90% or more effective at reducing seabird contacts with gear and captures when compared to a control, as research has demonstrated that other seabird deterrent methods can reduce seabird contacts and captures in the Hawaii longline fisheries by over 90% (McNamara *et al*., 1999; U.S. National Marine Fisheries Service, 2000; Boggs, 2001).

5.2. Chute Installation

Installation of the chute, manufactured by Albi Save with a similar design as the 10 chutes that Albi Save produced for the Australian Fisheries Management Authority (Brothers *et al*., 2000), took place over four days (18-21 February 2002), with two short at-sea trials. Figures 3 through 5 show photos of the chute used in the Hawaii trial. Installation procedures included (a) welding a carriage pipe directly to the stern of the vessel from the port stern corner to the center (designed so that the chute would operate from the center of the stern and be stowed on the port side of the vessel); (b) installing longer hydraulic hoses to enable researchers to be able to move the mainline shooter from its normal position, about halfway between the starboard-stern corner and the center of the stern, to the stern center, if needed during the trial (researchers ended up leaving the mainline shooter in its original position); (c) correcting the chute's trough shape to facilitate easier deployment of branch lines; (d) fixing the nylon runners to allow the chute to slide more freely through the V bracket; (e) fabricating stowage brackets and welding them onto the side of the deck along the port side; (f) repositioning the trough holes so that the water would no longer flow out of the trough and disturb crew during setting; (g) relocating the safety gate and water inlet to the port side of the chute trough; and (h) drilling pin holes in the carriage pipe and installing sleeves in the holes to locate the operating position of the chute. The activities described in c, d, f, and g were undertaken in order to correct faults with the original fabrication of the chute, which are design flaws that can be avoided in future manufacturing. Installation steps described in a and h are normal installation procedures, which will be necessary for installation of the chute on all vessels.

Figure 3. The underwater setting chute delivers baited hooks from the ship while setting so that they first emerge underwater out of sight and reach by diving seabirds. The chute has a slot to enable external deployment of the mainline, buoys, and radio beacons.

Figure 4. The underwater setting chute is stored on deck against the bulwarks. The chute is 9 meters long, and when deployed, 5.4 meters of the chute's shaft is underwater.

Figure 5. When setting, the mainline is set through a line setting machine (to the left), baited hooks are sent through the underwater setting chute (to the right of the crew), and the branch line with the baited hook is clipped onto the mainline moments after the baited hook is sent through the chute.

5.3. Period

The *Katy Mary* left port to conduct the at-sea trial of the chute on 21 February 2002 about 16:30 and returned to port on 9 March 2002 about 21:00. This period was selected to maximize abundance of albatross in nearby waters and to meet the availability of researchers. Setting occurred only during daylight to approximate normal fishing conditions, and to enable observations of seabird interactions.

5.4. Location

Table 2 includes information on the location of the *Katy Mary* at the start and end of each set. The six sets conducted during the trial were all located around the Northwestern Hawaiian Islands. Set 1 was located roughly 150 nautical miles North of Necker Island, where bird abundance was lower than desired (Section 6.2). The *Katy Mary* then sailed Northwest to about 150 nautical miles North of Maro Reef and Laysan Island where sets 2 and 3 were made. Bird abundance, and the number of albatross caught during control sets, was higher than desired during sets 2 and 3. In an attempt to find grounds with lower bird abundance, the *Katy Mary* sailed to a location about 60 nautical miles Southwest of Laysan Island and made sets 4 and 5. The final 6th set was made on route back to port, at a location about 45 nautical miles Southwest of French Frigate Shoals, where seabirds (and target fish) were in low numbers.

5.5. Seabird Deterrent Treatment

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 mainline shooter.

We used baited hooks (versus not using hooks as conducted by Boggs (2001)) to obtain information on the difference in capture rates of the chute versus the control and to enable collection of information for a commercial demonstration, which requires approximating normal fishing conditions. The experiment was designed to observe seabird contacts with gear near the hook as the central mechanism to test the null hypothesis instead of observing captures in order to minimize seabird injury and mortality, and to reduce the amount of time required to collect data. This design assumed a linear relationship between the number of times seabirds come into contact with baited hooks and the mortality of seabirds caused by hooking and entanglement in longline gear (Sections 6.9 and 8.18). Observations of seabird mortality by counting dead birds on the haul may have significant confounding factors, and could be even less of an accurate indication of seabird mortality caused by interactions between seabirds and longline gear than observing seabird contacts with baited hooks during the set. As explained in detail in Section 2, and to be discussed in Sections 5.14, 6.6, and 8.7, it is believed that seabird catch rates recorded on fishing vessels are conservative underestimates because not all seabirds that are caught are hauled aboard (Brothers, 1991; Cousins and Cooper, 2000).

5.6. Control Treatment

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, as described in U.S. National Marine Fisheries Service (2001a). Because there is 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 degrees North latitude (U.S. Fish and Wildlife Service, 2000), we needed a control to compare to the experimental treatment.

5.7. Replicates, Sample Size, and Summary of Research Activities

For observations of seabird contacts with baited hooks and seabird catch and mortality, one replicate consisted of one sixth of a set, or setting 1 tote box or approximately 460 hooks (approximately one hour). A summary of research activities conducted during each of the six sets conducted during the chute trial is presented in Table 2.

Only data from sets 2 through 5 are used to assess the difference in seabird attempts, contacts, captures, and changes in bird abundance when setting with the chute versus control conditions. During set 1, while familiarizing themselves with research operations, the vessel fished at grounds with relatively low albatross abundance, and the researcher and vessel crew used blue-dyed bait during both control and deterrent treatment replicates to minimize seabird interactions. This familiarization set was not included in the main analysis of the chute's effect on seabird interactions. During one control replicate and one seabird deterrent replicate in set 5, a portion of baits were dyed blue (Section 6.7). The use of blue dyed bait during these fractions of the two replicates probably had some effect on reducing seabird interactions. This ad-hoc modification was balanced (one control and one chute replicate on the same day). The use of blue dyed bait may have caused the results to indicate that the chute was slightly less effective by causing albatross interactions with gear to be reduced more under the control replicate than in the chute replicate. However, a comparison of the data from this pair of replicates (set 5 replicates C and D) indicates obvious effectiveness of the chute at avoiding seabird interactions even when blue bait is used (Sections 6.2 and 6.3). Data from this blue dyed bait portion of set 5 were left in the main data analysis of the chute's effect on seabird interactions. During set 6, bird abundance was extremely low or no birds were present, and the researcher repeated replicates of the control waiting for bird abundance to increase. Abundance did not reach a sufficient level for set 6 to be included in the main data analysis on the effect of the chute on bird abundance, attempts, contacts, and captures.

Data from all 6 sets are used to assess gear sink profile and sink rate; difference in bait retention; hook setting interval when setting under control conditions versus with the chute; and relationships between attempts, contacts, and captures. Assessments of the difference in capture of albatrosses by two different swivel weights and difference between birds observed caught while setting versus the number of dead birds hauled aboard used data only from sets 1 through 5 as there were no seabird captures during the 6th set.

The order of setting between the control and deterrent treatments was balanced (when using data from sets 2 through 5) but not randomized to enable the chute to affect bird abundance around the vessel. The assumption, based on experience with the chute in the Southern Hemisphere, is that continuous setting with the chute would result in decreased seabird abundance near the vessel and roaming behavior of albatrosses (versus searching for baits). If we randomized the order of the deterrent and control treatments, this could have resulted in artificially high abundance of seabirds around the boat during application of the deterrent treatment due to continued seabird interest in the vessel due to the visibility of baited hooks being set during the control replicates. The non-randomized approach may be a confounding factor. However, the value of the information from enabling observations of seabird abundance and behavior when the chute is operated continuously as compared to setting under control conditions is thought to outweigh the potential cost of having added a confounding factor. Setting was conducted with the chute first during sets 2 and 5, and setting was conducted under control conditions first during the other 4 sets.

Table 2. Summary of research activities conducted during the research trip's 6 sets.

Set #[1]	Date	Set Start Latitude	Set Start Longitude	Set End Latitude	Set End Longitude	Mainline Length Set	Research Activity
1	2/24/02	25 30’ N	163 15’ W	25 12’ N	163 46’ W	56 km (35 miles)	3 replicates of the control treatment followed by 3 replicates of the deterrent treatment
2	2/27/02	27 32’ N	170 6’ W	28 3’ N	169 55’ W	52 km (32 miles)	3 replicates of the deterrent treatment followed by 3 replicates of the control treatment
3	2/28/02	27 55’ N	170 49’ W	27 28’ N	171 4’ W	48 km (30 miles)	3 replicates of the control treatment followed by 3 replicates of the deterrent treatment
4	3/2/02	24 25’ N	172 46’ W	24 24’ N	173 32’ W	53 km (33 miles)	3 replicates of the control treatment followed by 3 replicates of the deterrent treatment
5	3/3/02	24 9’ N	172 43’ W	24 13’ N	173 23’ W	60 km (37 miles)	3 replicates of the deterrent treatment followed by 3 replicates of the control treatment
6	3/6/02	22 8’ N	167 0’ W	22 19’ N	167 37’ W	56 km (35 miles)	5 replicates of the control treatment followed by 1 replicate of the deterrent treatment

[1] For reasons explained in the text of Section 5.7, data from only sets 2 – 5 are used to assess the difference in seabird attempts, contacts, capture, and changes in bird abundance when setting with the chute versus control conditions. Data from all 6 sets are used to assess gear sink rate, difference in bait retention, and hook setting interval when setting under control conditions versus with the chute, and to observe seabird interactions on the haul. Assessments of the difference in capture of albatrosses by two different swivel weights and difference between birds observed caught while setting versus the number of dead birds hauled aboard used data from sets 1 through 5 as there were no seabird captures during the 6th set.

5.8. Time Depth Recorders

During the initial chute installation and modification stage, investigators attached time-depth recorders (TDRs) to branch lines to determine the setting depth, sink profile, and sink rate of hooks. During the first attempt, the TDRs were attached above the 60g swivels, which resulted in the gear tangling inside the chute, perhaps because the swivel was passing the TDR in the chute. Once the TDR was repositioned at the hook, the gear was deployed without tangling.

TDRs were deployed twelve times during the at-sea trial of the chute, during four of the 6 sets. All TDRs were set on 5 fathom-long branch lines, with 18" wire leaders, and 60g lead swivels. TDRs were attached at the hook and deployed without bait. TDRs were placed in different positions between buoys, but mostly midway between buoys (there were about 30 hooks per basket set between buoys).

5.9. Bird Abundance and Behavior

Every 15 minutes throughout the six sets a count of each seabird species within a 500m x 500m square area (within 250m to the port and starboard of the center of the vessel stern, and within 500m behind the vessel) astern of the vessel was recorded. Information on seabird behavior (e.g. roaming versus searching, and interactions between birds), treatment (deterrent versus control), and the timing of the start of a new tote (replicate) was also recorded. Observations of bird interactions were aided with use of Leitz 7x42B binoculars.

5.10. Seabird Contacts and Attempts to Contact Bait

Observations of seabird contacts and unsuccessful attempts to contact baited hooks were recorded. The researcher observed birds interacting with the longline gear through Leitz 7x42B binoculars. A seabird “contact” is defined as a seabird contacting the fishing gear near the hook (not near the clip or other part of the gear). An unsuccessful seabird “attempt” to contact a bait 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 attempt per bait is recorded as an attempt regardless of whether multiple birds attempt to contact the bait or a single bird attempts to contact 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 simply looking underwater from a position sitting on the sea surface is not considered an attempt; the bird must conduct a submerged or partially submerged body thrust to be considered an attempt.

5.11. Catch and Mortality

The researcher observed seabird interactions with fishing gear during setting to record incidences of the capture of seabirds 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 (Section 6.2). 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 through binoculars for long enough to verify the catch with the same confidence as other observations.

Observations were also made during hauling to record the capture of seabirds. The number of dead seabirds hauled aboard was recorded.

5.12. Necropsy

Necropsy analyses provided information on age, sex, and breeding condition for the albatrosses killed and hauled aboard during the experiment.

The salvaged birds are classified as belonging to one of three age categories based on the size and thickness of the bursa of Fabricius (Broughton, 1994). Broughton (1994) found that the size and thickness of the bursa of Fabricius declines with age in Laysan and Black-footed Albatrosses in a curvilinear fashion, where bursa size is calculated as the product of length and width of the flattened bursa. Laysan and Black-footed Albatrosses with fleshy bursas greater than 600 mm^2 are categorized as newly fledged (0.5 years old); birds with bursas between 500 and 75 mm^2 that are thin-walled or membranous are categorized as pre-breeders (1.5 – 4.5 years old); and birds with bursas less than 50 mm^2 are categorized as breeding-aged (older than 4.5 years) (Broughton, 1994).

Sex is determined by examining the gonads. Breeding condition is judged by observing the presence of absence of a brood patch.

5.13. Swivel Weight

When seabirds were hauled aboard, the researcher recorded the weight of the swivel on the branch line on which the bird was caught. A small fraction of the branch lines were constructed with lighter 38g swivels. The exact number of these branch lines with lighter swivels was recorded at the end of each set. A number of the lighter swivels were replaced with heavier 60g swivels after the third set.

5.14. Loss of Caught Birds Before Hauled Aboard

The number of seabirds observed caught during setting, as defined in Section 5.11, were compared with the count of the number of birds hauled aboard, reported in Section 6.6.

5.15. Seabird Interactions on the Haul

During hauling, observations were recorded of the numbers and species of birds present, and seabird interactions with fishing gear.

5.16. 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 were 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 were caught on one of these hooks, it would have been counted as a lost bait.

5.17. Hook Setting Interval

Investigators used information recorded on the time of the start and end of the setting of each tote, reported in Section 6.2, to estimate the hook setting interval for setting under control and deterrent treatments, reported in Section 7.2. Only totes where the time to deploy and retract the chute was not included in the time to set the tote 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 if the vessel crew were conducting the entire set with or without a chute.

5.18. Safety Hazard

During set 1, the investigator and crew noticed that the incidence of branch line tangles appeared to be higher during set sections made through the chute versus sections set under the control treatment. Branch line tangles are a safety hazard to crew during hauling (Sections 7.6 and 8.11.4). As a result, the incidence of these branch line tangles under control and deterrent treatments was recorded during hauling for sets 2-6.

During the trial, three potential causes of the increased number of branch line tangles when setting through the chute were identified as (a) the distance between branch lines was too short, which could be corrected by increasing the hook setting interval, (b) the chute angle in the water was too steep, which could be corrected by raising the chute lead weight to reduce the chute deployment angle, and (c) crew were prematurely grasping the mainline in anticipation of branch line clip-on, which could be corrected by focusing crew attention to avoid grasping the mainline too early. Each potential cause was investigated.

5.19. Captain and Crew Debriefing

The principal investigator debriefed Captain Jerry Ray, senior crew Barry Woods and Kuoki Ching, and crew Otto Dannis and Ronnie Lucios of the *Katy Mary* on 11 March 2002, to collect information on their perceptions of the chute design and installation, safety hazards associated with use of the chute, change in bait retention, intrusion on normal fishing operations, whether they would voluntarily choose to use the chute, whether they would prefer to use the chute versus seabird deterrents required by regulations, and the potential acceptance of the chute for industry-wide use in Hawaii.

6. RESULTS FROM SCIENTIFIC EXPERIMENT

6.1. Sink Profile, Rate, and Depth of Hooks

Table 3 summarizes results of the TDR deployment.

Table 3. Summary of Time Depth Recorder deployment and results.

Set	TDR	Hook #	Treatment	Sink Time to 5m (seconds)	Sink Time to 5m (outlier removed) (seconds)[2]	Max Depth (m)	Avg Depth (m)
1	229	6	Chute	4	4	161	114
1	215	11 deep[1]	Chute	8	8	206	131
1	129	16 deep	Chute	7	7	196	119
3	215	15 deep	Chute	9	9	190	176
6	129	20 deep	Chute	12	12	191	175
6	215	23	Chute	26[2]	--	139	129
			Mean	11	8	181	141
			Median	8.5	8	190.5	130

3	129	15 deep	Control	13	13	195	178
3	229	15 deep	Control	8	8	193	180
4	129	15 deep	Control	10	10	308	270
4	215	15 deep	Control	9	9	291	271
4	229	1	Control	6	6	71	60
6	229	25	Control	11	11	112	108
			Mean	9.5	9.5	195	178
			Median	9.5	9.5	194	179

[1] There were typically 30 hooks set between buoys. “Deep” set” TDRs are those set on hooks 11 through 20, mid-way between two buoys.

[2] The sink profile and rate of this TDR (Set 6, TDR 215) is an outlier, discussed below and in Section 8.1.

Figures 6 and 7 show the sink profiles of the 6 TDRs deployed through the chute, and the 6 TDRs deployed under control treatment. Figure 8 compares the average sink profiles of the 12 TDRs.

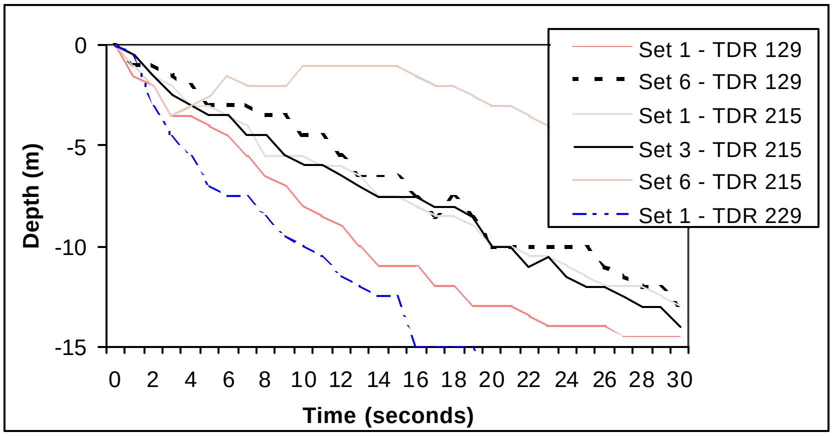

Figure 6. Sink profiles for TDRs set through the chute.

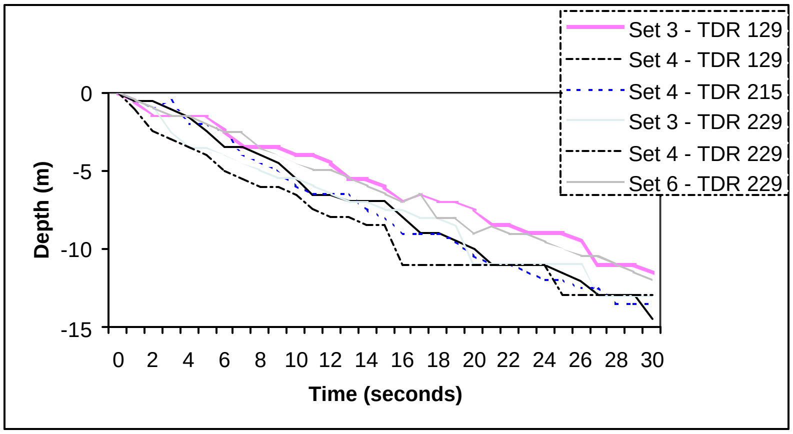

Figure 7. Sink profiles for TDRs set under the control treatment.

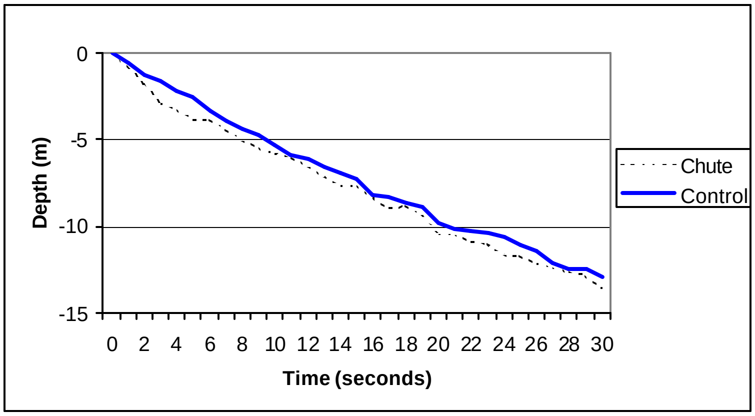

Figure 8. Average sink profiles for TDRs deployed under deterrent and control treatments.

Data for TDR 215 deployed in Set 6 through the chute show that the TDR sank to 3.5m in 3 seconds, rose to within 1m of the sea surface, began to sink again at 14 seconds, and finally reached 5m depth at 26 seconds (Table 3 and Figure 6). This is the only TDR of the 12 deployed that reversed its descent during the first 30 seconds of deployment (Figures 6 and 7). With this outlier removed for data analysis, the mean TDR sink rate set through the chute to a depth of 5m was faster than the mean sink rate for TDRs set under the control treatment, but the difference was not statistically significant ($p>0.37$, 2-tailed).

The difference between the average depth of setting of TDRs deployed under the chute versus control treatments was not statistically significant ($p>0.33$, 2-tailed).

There were usually 30 hooks per basket set between buoys. “Deep-set” TDRs are those set on hooks 11 through 20, mid-way between two buoys. Four TDRs were deployed through the chute on deep-set hooks, and four TDRs were deployed on deep-set hooks under control treatment (Table 3). The difference between the average depth of setting of TDRs deployed under the chute versus control treatments for just the deep-set hooks was also not statistically significant ($p>0.14$, 2-tailed).

6.2. Bird Abundance and Behavior, and Seabird Attempts and Contacts

Only counts of albatross species are included in Table 4, below, which were the only species of seabirds observed to interact with fishing gear. A list of all additional observed seabird species is in Section 8.13.

Based on qualitative observations, search intensity of seabirds following the vessel were perceived to decline when setting with the chute, as birds changed their behavior to roaming. At the onset of setting with the chute, seabirds would intermittently renew their interest in searching intensity for short periods. Searching intensity was perceived to generally remain constant or increase as bird abundance increased when setting under control conditions without the chute.

Observed albatross abundance; “attempts” and "contacts", defined in Section 5.10; captures observed during setting, defined in Section 5.11; and the number of birds hauled aboard are recorded in Table 4, and summary statistics are reported in Tables 5 and 6.

Table 4. Albatross abundance, attempts, contacts, captures on the set, and seabirds hauled aboard, under deterrent and control treatments. (LAAL = Laysan Albatross , BFAL = Black-footed Albatross).

Experimental Treatment											
Set No.	**No. of hooks**	**Start time**	**End time**	**Albatross abundance**[1]		**Attempts**		**Contacts**[2]		**Birds Seen Caught During Set**	**Birds Hauled Aboard**
				LAAL	**BFAL**	**LAAL**	**BFAL**	**LAAL**	**BFAL**		
Set 1	1202	10:46	13:36	7.2	2.7	7	0	0	0	0	0
Section D	475	10:46	11:58	5.3	5.8	0	0	0	0	0	0
Section E	473	11:58	12:55	7.3	2.0	3	0	0	0	0	0
Section F	254	12:55	13:36	9.0	0.3	4	0	0	0	0	0
Set 2	1166	9:15	12:14	15	4.5	12	3	3	1	0	0
Section A	469	9:15	10:26	10	5.3	1	3	1	1	0	0
Section B	463	10:26	11:36	15	3.8	9	0	2	0	0	0
Section C	234	11:36	12:14	20	4.5	2	0	0	0	0	0
Set 3	1127	11:40	14:36	35.0	2.0	22	1	0	0	0	0
Section D	479	11:40	12:45	31.0	2.0	11	1	0	0	0	0
Section E	234	12:45	13:15	38.7	2.3	7	0	0	0	0	0
Section F	414	13:15	14:36	35.2	1.8	4	0	0	0	0	0
Set 4	1402	10:29	13:30	12.8	4.7	7	4	4	0	0	0
Section D	474	10:29	11:26	10.8	6.5	0	0	0	0	0	0
Section E	453	11:26	12:26	12.3	4	6	2	3	0	0	0
Section F	475	12:26	13:30	15.4	3.6	1	2	1	0	0	0
Set 5	1271	8:05	11:05	18.5	7.4	20	4	2	0	0	0
Section A	437	8:05	9:10	15.0	4.6	15	1	0	0	0	0
Section B	408	9:10	10:09	21.0	10	5	3	2	0	0	0
Section C	426	10:09	11:05	19.5	7.5	0	0	0	0	0	0
Set 6	471	11:46	12:58	0.0	0.5	0	0	0	0	0	0
Section F	471	11:46	12:58	0.0	0.5	0	0	0	0	0	0
TOTAL	6639	15 hours 58 min		16.6 (mean)	4.0 (mean)	67	12	9	1	0	0

Control Treatment											
Set No.	**No. of hooks**	**Start time**	**End time**	**Albatross abundance**[1]		**Attempts**		**Contacts**		**Birds Seen Caught During Set**[3]	**Birds Hauled Aboard**
				LAAL	**BFAL**	**LAAL**	**BFAL**	**LAAL**	**BFAL**		
Set 1	1414	7:50	10:45	5.2	4.4	21	9	23	5	1	1
Section A	480	7:50	8:54	4.3	3.5	6	7	1	4	1	1
Section B	468	8:54	9:46	7.3	4	6	0	19	0	0	0
Section C	466	9:46	10:45	4	6.8	9	2	3	1	0	0
Set 2	1174	12:14	14:22	34.7	3.3	201	5	74	1	4 (+1)	2

Section D	467	12:14	13:06	38.0	4.0	107	4	36	1	2	2
Section E	469	13:06	13:58	33.5	2.3	64	0	30	0	2 (+1)	0
Section F	238	13:58	14:22	32.5	3.5	30	1	8	0	0	0
Set 3	1137	9:27	11:37	74.2	3.7	162	9	152	4	13 (+1)	9
Section A	457	9:27	10:21	67.0	3.5	70	8	68	1	8 (+1)	6
Section B	458	10:21	11:12	86.7	3.7	68	1	62	1	5	3
Section C	222	11:12	11:37	69.0	4.0	24	0	22	2	0	0
Set 4	1365	7:50	10:29	36.3	5.5	97	26	46	7	5	4
Section A	475	7:50	8:50	12.3	5.3	40	7	23	2	1	0
Section B	453	8:50	9:40	10.7	5.0	23	2	16	3	2	2
Section C	437	9:40	10:29	13.3	6.3	34	17	7	2	2	2
Set 5	1401	11:05	13:55	23.4	7.5	159	25	103	4	11 (+2)	9
Section D	511	11:05	12:07	31.0	12.3	71	14	52	1	8[4]	6
Section E	481	12:07	13:02	21.8	6.3	61	6	35	1	1 (+1)	3
Section F	409	13:02	13:55	17.3	4.0	27	5	16	2	2 (+1)	0
Set 6	2233	7:37	11:46	0.1	1.8	0	8	1	1	0	0
Section A	437	7:37	8:36	0.0	0.5	0	0	0	0	0	0
Section B	472	8:36	9:17	0.3	3.0	0	2	1	0	0	0
Section C	432	9:17	10:07	0.0	2.7	0	6	0	1	0	0
Section D	426	10:07	10:55	0.0	2.7	0	0	0	0	0	0
Section E	466	10:55	11:46	0.0	0.3	0	0	0	0	0	0
TOTAL	8724	17 hours 3 min		22.5 (mean)	4.2 (mean)	640	82	399	22	34 (+4) (5 BFAL, 33 LAAL)	25 (3 BFAL, 22 LAAL)

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[1] The mean number of albatrosses present for each section (tote or replicate) is calculated as the total number of albatrosses counted at 15 minute intervals during the set divided by the number of observations. The mean number of albatrosses present per set is calculated as the average of the means of albatross abundance for each section. The mean number of albatrosses present for the total combined 6 sets is calculated as the average of the albatross abundance for each section.

[2] Observations of the circumstances that may have resulted in the ten seabird contacts when setting with the chute are as follows: (1) Set 2 section A, tangle of branch lines in the tote (tangle in the line bin that was not corrected aboard before deploying the branch line through the chute) may have caused the BFAL contact. (2) Set 2 section A, delay clipping branch line to mainline may have caused the LAAL contact (delaying clipping the branch line to the mainline can cause bait to be pulled up towards the sea surface from the chute exit depth, making the bait accessible to seabirds). (3) Set 2 section B, delay clipping branch line to mainline may have caused the LAAL contact. (4) Set 2 section B, did not observe possible cause of second LAAL contact. (5) Set 4 section E, delay clipping branch line to mainline may have caused the LAAL contact. (6) Set 4 section E, heavy yaw to port causes chute to slide to the starboard, and baited hook may have entered prop turbulence on the starboard side of the prop and brought closer to the sea surface, possibly as a result of having raised the lead weight in the chute during the set 4 sections E and F. The lead weight in the chute was raised to the water level, about half way up, in an attempt to identify the cause of the high incidence of branch line tangling when setting with the chute (Section 7.6). As a result, the setting angle was less steep and the chute moved to the port and starboard with vessel yawing more so than when the lead weight was in its normal position at the bottom of the chute. This was perceived to reduce the depth of setting of baited hooks by about 1 meter, allowing the chute to increase movement with swells, and allowing hooks to be delivered from the chute in prop wash. This alteration of the placement of the weight in the chute may have enabled the LAAL contact. (7) Set 4, section E, did not observe possible cause of third LAAL contact. (8) Set 4, section F, vessel slides heavily to the port, causing chute to set to starboard, and baited hook may have entered prop turbulence and brought closer to the sea surface, making the LAAL

contact possible. (9) Set 5 section B, buoy line tangles with branch line and may have caused the LAAL contact. (10) Set 5 section B, tangle of branch lines in the tote may have caused the LAAL contact.

[3] For entries in the column, "Birds Seen Caught During Set," numbers and numbers in parentheses, such as 4 (+1), indicates that 4 birds were observed caught during the set, and an additional 1 bird was thought to be caught but with less 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 through binoculars for long enough to verify the catch with the same confidence as the other observations.

[4] An additional 2 seabirds were observed potentially caught during this section, however, due to obstructions, the birds could not be observed for long enough to verify this with the same confidence as the other observations.

The average number of albatrosses present when setting with the chute during sets 2 through 5 (calculated as the average of the albatross abundance of each of the 12 replicates (totes or sections) comprising these four sets) was 24.98. The average number of albatrosses present when setting under control conditions during sets 2 through 5 was 41.11 (Table 5). These results indicate a significant (*$p<0.05$) 39% lower bird abundance while using the chute.[4]

The effect of order was examined to see if there was a tendency for results to differ when control fishing was conducted first (which might attract more birds to both the control and chute trials) as opposed to when the chute was deployed first (which might discourage birds from interacting during both the chute and control fishing). Bird abundance was 24% lower during sets when chute replicates preceded control replicates than the bird abundance during sets when control replicates were first, but the difference was not statistically significant ($p>0.24$) (Table 5).

Table 5. Summary statistics for combined albatross species' abundance, attempt rate, contact rate, and capture rate (rates per 1,000 hooks).[1]

		Attempts		Contacts		Catch rate (set)[2]		Catch rate (haul)	
Factor	Abundance	Nominal[3]	Per bird[3]	Nominal	Per bird	Nominal	Per bird	Nominal	Per bird
Treatment									
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	*-39%	**-89%	**-84%	**-98%	**-95%	**-100%	**-100%	**-100%	**-100%
Order									
Control 1st (attract)	37.53[4]	65.74	1.99	43.37	1.03	3.48	0.086	2.39	0.065
Chute 1st	28.56[5]	81.75	2.50	34.41	1.03	3.15	0.095	1.86	0.050
Effect	-24%[6]	+24%	+26%	-21%	0%	-9%	+10%	-22%	-23%
Overall Mean	33.05	73.75	2.24	38.90	1.03	3.31	0.090	2.12	0.057

[1] Number of replicates and hooks/replicate as given for Laysan and Black-footed Albatrosses in Table 6.

[2] Using the perceived most reliable observation of birds caught during setting of 37 birds captured during sets 2-5 (Section 6.6).

[3] "Nominal" means not normalized for albatross abundance, and "per bird" means normalized for albatross abundance.

[4] This is the average albatross abundance during sets 3 and 4 (when the control treatment replicates preceded the chute treatment replicates).

[5] This is the average albatross abundance during sets 2 and 5 (when chute replicates preceded control replicates).

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[4] In Table 5, and for the remainder of the paper, a single * indicates the statistic is significant, where $p<0.05$ and ** indicates that the statistic is highly significant, where $p<0.01$.

[6] This means that the albatross abundance during sets when chute replicates preceded control replicates was 24% less than the albatross abundance in sets when control replicates preceded chute replicates.

Table 6. Summary statistics by species for Laysan and Black-footed Albatrosses for abundance, attempt rate, contact rate, and capture rate (rates per 1,000 hooks).

Laysan Albatross							
		Hooks/		Attempts/1,000 hooks		Contacts/1,000 hooks	
Factor	N	replicate	Abundance	Nominal[2]	Per bird[2]	Nominal	Per bird
Treatment							
Control	12	423	36.09	120.50	4.26	72.61	2.29
Chute	12	414	20.33	12.88	0.65	1.67	0.12
Effect			-44%	**-89%	**-85%	**-98%	**-95%
Order							
Control 1st (attract)	12	419	33.53	58.37	2.17	40.98	1.20
Chute 1st	12	418	22.88	75.01	2.74	33.31	1.22
Effect			-32%	+28%	+27%	-19%	+2%
Overall Mean	24	418	28.21	66.70	2.45	37.14	11.21

Black-footed Albatross							
		Hooks/		Attempts/1,000 hooks		Contacts/1,000 hooks	
Factor	N	replicate	Abundance	Nominal	Per bird	Nominal	Per bird
Treatment							
Control	12	423	5.02	11.88	2.17	3.32	0.71
Chute	12	414	4.66	2.23	0.48	0.18	0.03
Effect			-7%	*-81%	**-78%	**-95%	**-95%
Order							
Control 1st (attract)	12	419	4.00	7.37	1.56	2.40	0.53
Chute 1st	12	418	5.68	6.74	1.09	11.10	0.22
Effect			+42%	-9%	-30%	[1]-54%	[1]-58%
Overall Mean	24	418	4.84	7.06	1.32	1.75	0.37

[1] Order not significant, but ANOVA shows a statistically significant interaction for treatment x order.

[2] "Nominal" means not normalized for albatross abundance, and "per bird" means normalized for albatross abundance.

Figures 9 through 11 show a highly significant linear correlation between albatross abundance and attempts (R = 0.61**), contacts (R = 0.73**), and captures (using observed number of birds hauled aboard, R = 0.53**). As explained in Section 5.7, data from all 6 sets are used for these analyses. Section 8.2 includes a discussion on the rationale for normalizing seabird attempt, contact, and capture rates for bird abundance.

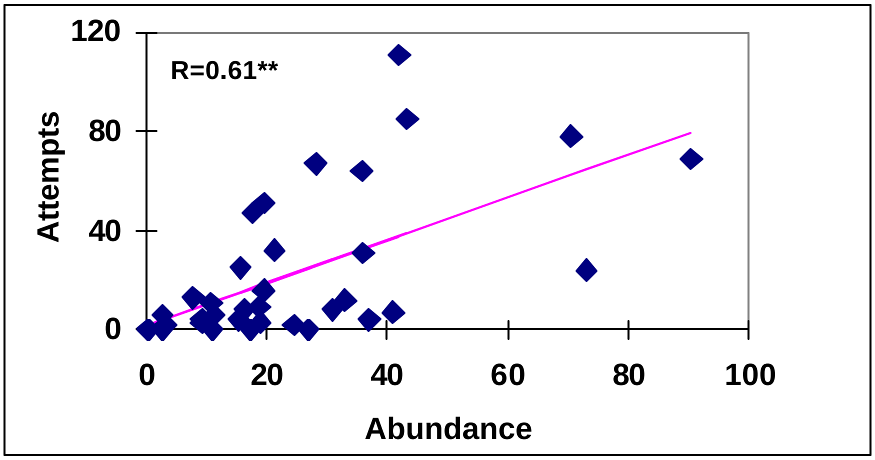

Figure 9. Abundance versus attempts (combined Laysan and Black-footed Albatrosses).

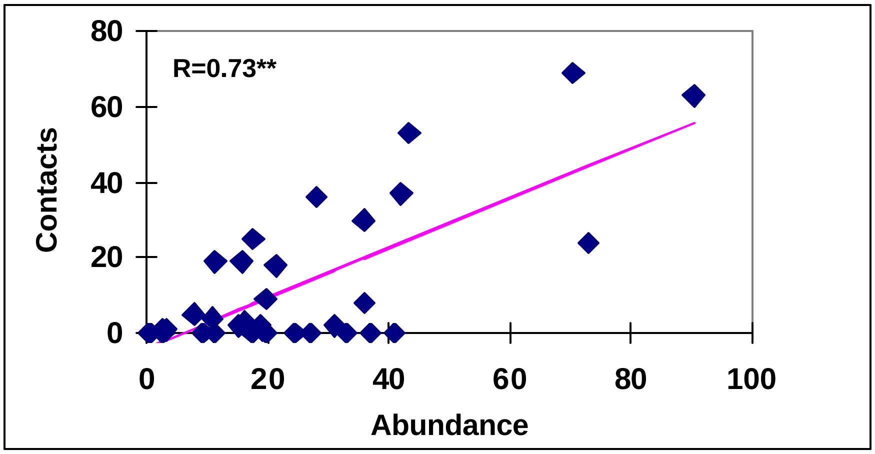

Figure 10. Abundance versus contacts (combined Laysan and Black-footed Albatrosses).

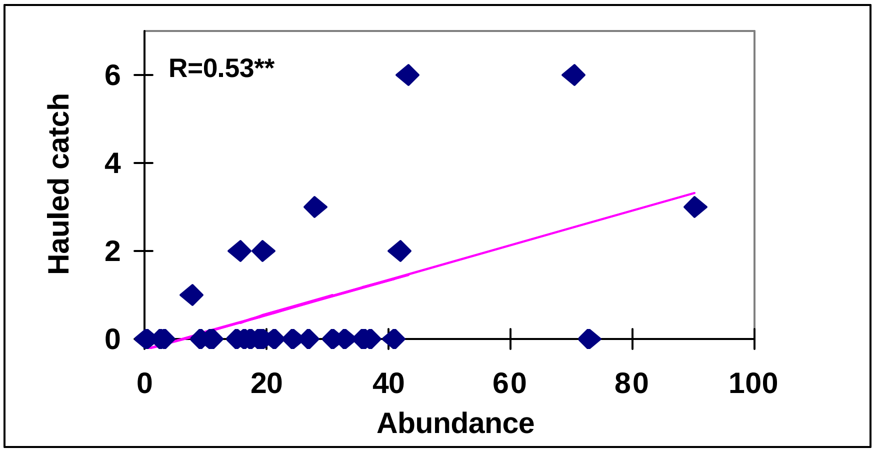

Figure 11. Abundance versus capture (using the number of birds observed hauled aboard, combined Laysan and Black-footed Albatrosses).

Data from sets 2 through 5 are used to assess the seabird attempt, contact, and capture rates when setting with the chute versus under control conditions, for reasons explained in Section 5.7. Seabirds contacted 7.7% of baited hooks set during control conditions, and seabirds contacted 0.2% of baited hooks set through the chute. 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 5).

6.3. Capture Rates

A minimum of 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 (Table 7). (Remaining results from necropsy will be available in November 2002). Tables 4 and 5 present results on the number of birds observed captured during setting and the number hauled aboard (Section 6.6).

Table 7. Summary of seabird catch and mortality information, including age, sex, and presence or absence of brood patch.

Set	Seabird Species	Age[1]	Sex	Brood Patch Present[2]	Position of Hook and Comments	Swivel Weight (g)
1	BFAL	Carcass discarded by U.S. National Marine Fisheries Service	--	YES	Lower bill. Yellow band on left leg #E149 (banded on Tern Island, French Frigate Shoals, Northwestern Hawaiian Islands) and metal band on right leg #13072554, successfully took squid bait.	38
2	LAAL	Released alive	--	--	Through leg above base of ankle. Released alive (the branch line had not yet been clipped onto the mainline and was able to be pulled aboard to release the hooked bird).	60
2	LAAL	Breeding Age	F	YES	Lower bill. Caught on fish bait.	60
3	LAAL	Breeding Age	M	YES	Down throat.	38
3	LAAL	Breeding Age	M	YES	Down throat.	60
3	LAAL	--	--	--	Down throat.	60
3	LAAL	Breeding Age	F	YES	Down throat.	60
3	LAAL	Breeding Age	M	YES	Through elbow.	60
3	LAAL	Breeding Age	F	YES	Down throat. Squid was bait.	60
3	LAAL	Breeding Age	M	YES	Through outer wing.	60
3	LAAL	Breeding Age	M	YES	Down throat.	60
3	LAAL	Breeding Age	M	YES	Down throat.	60
4	LAAL	Breeding Age	F	YES	Lower bill.	38
4	BFAL	Breeding Age	M	YES	Lower bill.	60
4	LAAL	Breeding Age	M	YES	Down throat.	60
4	LAAL	Breeding Age	M	YES	At elbow.	60
5	LAAL	--	--	--	Down throat.	60
5	LAAL	--	--	--	Down throat.	60
5	LAAL	Breeding Age	F	YES	Lower bill.	38
5	LAAL	Breeding Age	F	YES	Through elbow.	60
5	LAAL	Breeding Age	F	YES	Down throat.	60
5	LAAL	Breeding Age	M	YES	Tangle at back of head.	38
5	BFAL	Breeding Age	F	YES	Tangle at back of head.	38
5	LAAL	Breeding Age	M	YES	At elbow.	60
5	LAAL	Breeding Age	M	YES	Lower bill.	60

[1] Newly fledged ~ 0.5 years old; pre-breeders ~ 1.5 – 4.5 years old; breeding-age ~ >4.5 years old (Section 5.12) (Broughton, 1994).

[2] Significance of presence of a brood patch is discussed in Section 8.5.

Data from sets 2 through 5 only are used to assess the seabird capture rate when setting with the chute versus under control conditions, for reasons explained in Section 5.7. The catch rate during control sets, using the number of birds hauled aboard (and not the number of birds observed caught during setting), was 4.24 birds per 1000 hooks set (Table 5). Normalized for albatross abundance (standardized for the average number of albatrosses present during control replicates), the seabird catch rate under control conditions was 0.114 captures per 1000 hooks per albatross. Capture rates using the number of birds observed captured during setting are presented in Section 6.6. No birds were caught during chute treatment replicates. Section 8.19 estimates a capture rate with prolonged use of the chute.

6.4. Age, Sex, and Breeding Condition of Killed Birds

Necropsy results are reported in Table 7 (Jeremy Bisson, a graduate student of the University of Hawaii Department of Zoology, was authorized by the U.S. Fish and Wildlife Service to conduct the necropsy of the salvaged albatrosses). Methods employed to determine age, sex, and breeding condition of the birds are described in Section 5.12. Unfortunately 2 of the 24 salvaged albatrosses were provided to the U.S. National Marine Fisheries Service Pacific Island Area Office for mounting, and the taxidermist did not retain the bodies of these two birds for necropsy. Two of the salvaged albatrosses were provided to researchers for analysis of tissues for contaminants, and results from necropsies of these two birds was not available at the time of completing this report. Eight of the 20 birds that underwent necropsy analysis were female, and 12 were male. All 21 of caught birds assessed for presence or absence of a brood patch were found to possess a brood patch. None of the 20 salvaged albatrosses that underwent necropsy analysis were found to have bursas of Fabricius that visibly diverged from the intestine, and were therefore determined to all be of breeding age based on the method for aging described by Broughton (1994).

6.5. Swivel Weight

Of the 25 seabirds hauled aboard, 6 were caught on branch lines with 38 gram swivels, and the rest were caught on branch lines with 60g swivels (Table 7).

During the first 3 sets, there were 211 38g swivels on branch lines intermixed randomly throughout the gear, with remaining branch lines containing 60g swivels. During the last 3 sets, there were 163 branch lines with 38g swivels intermixed randomly throughout the gear, with remaining branch lines containing 60g swivels. The *Katy Mary* has a total of about 2800 branch lines. This mixture of two swivel weights was balanced for deterrent and control treatment replicates (the same proportion of light to heavy swivel weights were set under control conditions and through the chute).

The proportion of birds caught on light swivels was always higher than the proportion of light swivels in each of the 5 sets in which birds were caught (Table 8). It was hypothesized that lighter swivels would catch more birds during control sections because they do not cause the baited hook to sink as rapidly as the heavier swivels. A pairwise one-tailed t-test comparison of the log transformed data indicated that the proportion of birds caught on light swivels was significantly higher than expected due to chance (t = 4.49, **p = 0.0055, n=5).

Table 8. Proportion of birds caught on light swivels compared to the proportion of light swivels present during each set.

Set	Proportion of birds caught on lighter 38g swivels	Proportion of branch lines containing light swivels
1	1	0.0754
2	0.5	0.0754
3	0.111	0.0754
4	0.25	0.0582
5	0.33	0.0582

As explained in Section 5.7, data from set 1 are included in this analysis despite the application of an additional treatment (blue-dyed bait), because this additional treatment was balanced for both chute and control replicates and therefore does not create a source of error for this particular assessment. Data from set 6 are not included in this analysis because no birds were caught during this set.

6.6. Loss of Caught Birds Before Hauled Aboard

Table 4 provides data on birds observed caught during setting and birds hauled aboard. As explained in the footnotes of Table 4, 34 birds were observed caught during setting with the highest degree of confidence. An additional 4 birds were observed caught, but due to obstructions these 4 birds were not observed long enough to verify capture with the same degree of certainty as the other 34 birds. Another 2 birds were observed that may have been caught, but confidence in these observations was less than for the other observations.

Using the most conservative observation of birds caught during setting to estimate the percent of seabirds that fell from hooks before hauling during the six sets of the trip, 26.5% (9 of 34) birds fell from the gear prior to hauling. Using the least conservative observation of birds caught during setting, 37.5% (15 of 40) of birds fell from the gear prior to hauling. 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 of 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, using data from sets 2 through 5 (for reasons explained in Section 5.7) is 6.63 captures per 1000 hooks. When adjusted for albatross abundance (the average number of albatrosses present during control replicates of sets 2-5) 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 (Section 6.3).

6.7. Blue-Dyed Bait

Blue-dyed fish and squid (mixed, mostly fish, Section 4.1) bait was used during all of set 1. In set 1, when setting through the chute, 7 LAAL attempts were observed, and no contacts or captures were observed. In set 1, when setting under control conditions with blue-dyed fish and squid bait, 21 LAAL and 9 BFAL attempts were observed, 23 LAAL and 5 BFAL contacts were observed, and 1 BFAL was captured. During a portion of set 5 section C (10:20 to 10:35) blue-dyed squid was used as bait through the chute for 130 hooks (15 minutes), and no seabird attempts or contacts were observed. During a portion of set 5 section D (11:05 to 11:22) blue-dyed squid was used as bait during the control for the first 130 hooks (first 17 minutes), during which 5 LAAL and 1 BFAL contacts were observed, 8 LAAL and 0 BFAL attempts were observed, and one BFAL was observed caught but was not hauled aboard. During the remainder of set 5 section D normal bait was used without the chute.

Table 9 summarizes the results of seabird interactions during set 5 section D, comparing seabird interactions when blue-dyed squid was set versus seabird interactions when non-dyed squid was set, without the chute. Table 9 also summarizes the results on the effectiveness of blue-dyed squid in the Hawaii longline swordfish fleet from McNamara *et al*. (1999) and Boggs (2001).

Table 9. Comparison of seabird interactions with and without blue-dyed squid in this experiment, and results of the effectiveness of blue-dyed squid in the Hawaii longline swordfish fleet from Boggs (2001) and McNamara *et al*. (1999).

Seabird Interaction Rates	**Data from set 5 section D**			**Boggs (2001)[2]**			**McNamara *et al*. (1999)**		
	Blue squid	Undyed squid	Reduction	Blue squid	Undyed squid	Reduction	Blue squid	Undyed squid	Reduction
Contacts/1,000 hooks	46.15	123.36	0.63	45.00	630.00	0.93			
Contacts/1,000 hooks/albatross	1.36	2.68	0.49	0.43	7.60	0.94			
Captures/1,000 hooks	7.69[1]	18.37	0.58						

Captures/1,000 hooks/albatross	0.23[1]	0.40	0.43				0.12	2.23	0.95

[1] Capture data from the chute trial uses the most reliable observed number of captures during setting (Section 6.6).

[2] Contact rates are averages of rates reported by Boggs (2001) for Laysan and Black-footed Albatrosses.

The experiment was not designed to assess the effectiveness of blue-dyed fish bait. The data on mixed blue-dyed fish and squid bait from this experiment does not allow for an assessment of this seabird deterrent method's effectiveness because there was no control treatment in set 1 to compare to the blue-dyed bait treatment (no undyed bait was used in set 1). Because bird abundance was very low during the first set, and recognizing that there were likely other confounding factors between different sets, it was decided not to use data from a subsequent set as a control treatment to compare to the blue-dyed bait data of set 1.

6.8. Seabird Interactions During Haul

The first haul commenced prior to dusk at 17:50, and up to 10 Laysan and 10 Black-footed Albatrosses were observed astern of the vessel, with fewer birds present throughout the nighttime haul, which ended at 04:10. The second haul commenced at 18:36, and up to 10 Laysan and 2 Black-footed Albatrosses were observed astern of the vessel. The third haul was completed at about 4:30. The third haul commenced at 15:56, and up to 35 Laysan and 1 Black-footed Albatrosses were observed astern. The third haul was finished at 02:15. The fourth haul started at 17:42, during which up to 12 Black-footed and 6 Laysan Albatrosses, and 12 Sooty Terns (*Sterna fuscata*) were observed astern. The fourth haul ended at 02:56. The fifth haul commenced at 18:45, during which 10 Laysan and 5 Black-footed Albatrosses were observed, as well as a juvenile Masked Booby (*Sula dactylatra*) and a Sooty Storm-petrel (also called a Tristam's Storm-petrel) (*Oceanodroma tristrami*), astern. The fifth haul was completed at 05:00. During the sixth haul, which commenced at 16:45, four Black-footed Albatrosses and two Brown Noddies (*Anous stolidus*) perched on the line buoys were observed until dark, and after dark no seabirds were observed during the remainder of the haul. Seabirds did not interact with fishing gear during any of the six hauls.

6.9. Relationships between Attempts, Contacts, and Captures

Figures 12 through 15 show a highly a significant linear correlation between contacts and captures on the haul (R = 0.84**), contacts and the most reliable estimate of captures observed during setting (Section 6.6, Table 4, R = 0.89**), contacts and the most conservative estimate of captures observed during setting (Section 6.6, Table 4, R = 0.88**), attempts and contacts (R = 0.87**), and attempts and captures on the haul (R = 0.76**). As explained in Section 5.7, data from all 6 sets are used for these analyses. Further analysis could be conducted to determine the best fit for modeling these relationships.

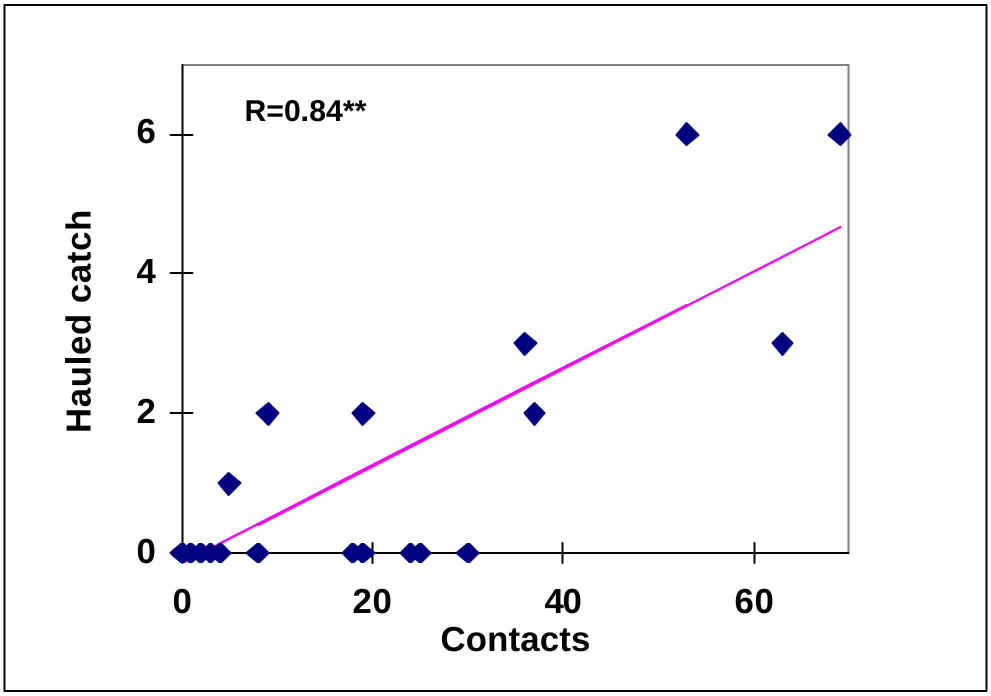

Figure 12. Contacts versus capture using the number of birds observed hauled aboard (combined Laysan and Black-footed Albatrosses).

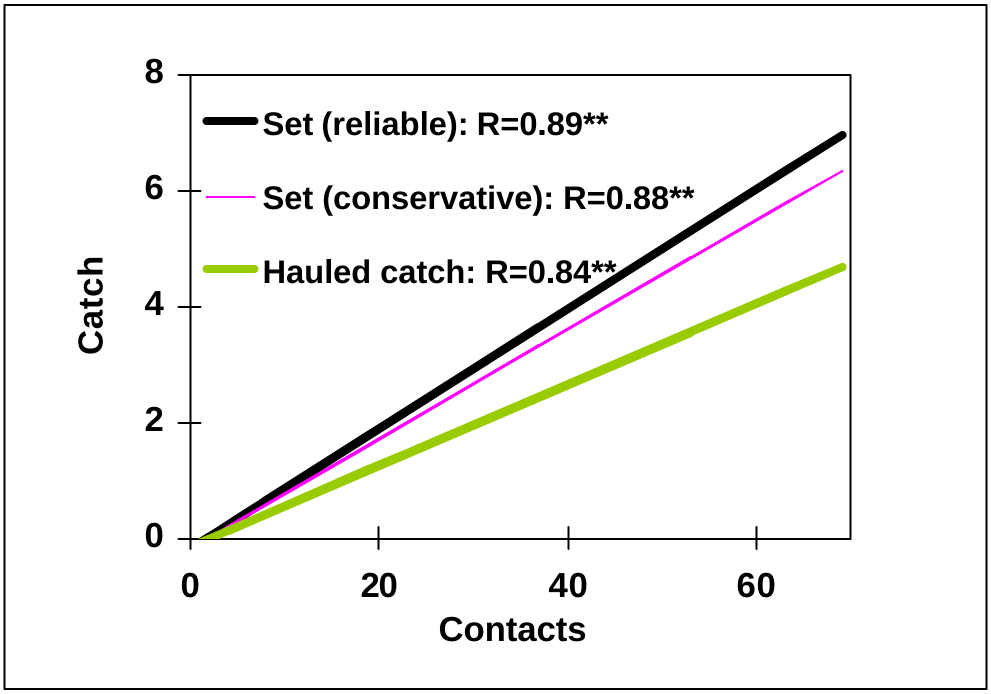

Figure 13. Contacts versus three estimates of capture, (a) most reliable estimate of capture observed during setting, (b) most conservative estimate of capture observed during setting, and (c) number of birds hauled aboard (refer to Section 6.2, Table 4 for explanation of reliable and conservative estimates of capture on the set, for combined Laysan and Black-footed Albatrosses).

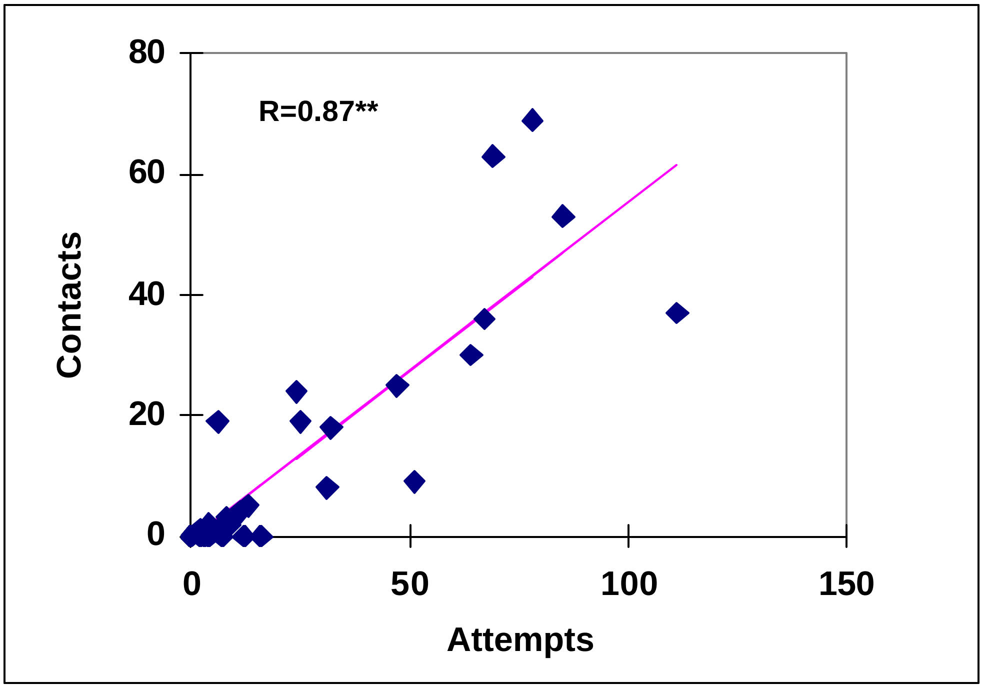

Figure 14. Attempts versus contacts (combined Laysan and Black-footed Albatrosses).

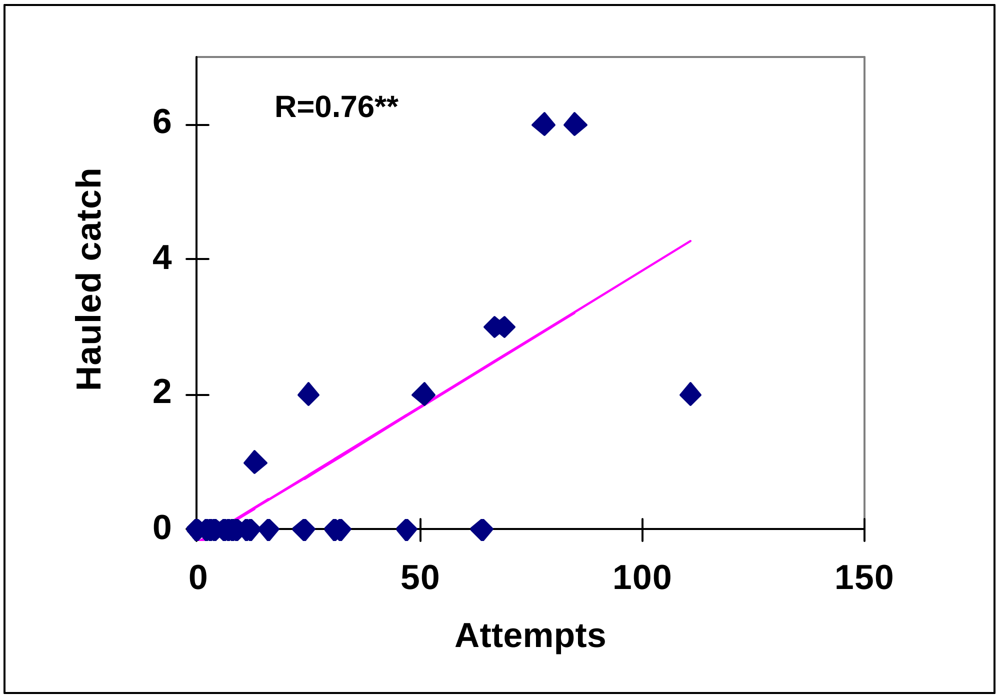

Figure 15. Attempts versus capture using the number of birds hauled aboard (combined Laysan and Black-footed Albatrosses).

7. RESULTS FROM COMMERCIAL DEMONSTRATION

We collected information to determine if the Hawaii longline industry would support and comply with rules requiring use of the chute. We attempted to determine if fishers will perceive that the underwater setting chute (a) is effective at avoiding seabird interactions, (b) requires nominal effort to install and employ, (c) requires a minimal amount of alteration of traditional fishing practices, and (d) is cost effective or better yet, able to increase fishing efficiency. Investigators collected information on bait retention, hook setting rate, catch per unit effort, and incidence of branch line tangles (a safety hazard) when setting through the chute compared to a control. Also, upon return of the *Katy Mary* from the at-sea trial of the chute, the vessel captain and crew were interviewed to assess their perceptions of the chute design and installation, change in bait retention, intrusion on normal fishing operations, whether they would voluntarily choose to use the chute, whether they would prefer to use the chute versus current regulatory-required seabird avoidance measures, and the potential acceptance of the chute by the Hawaii longline fleet.

7.1. Bait Retention

Bait retention when setting with the chute and under control conditions is summarized in Table 10. For five of the six sets 200 hooks were checked for the presence or absence of baits, and for one set with the chute 100 hooks were checked. 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).

Table 10. Bait retention summary.

	Baited hooks set through chute (n = 700)				Baited hooks set under control conditions (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	

7.2. Hook Setting Rates

Table 11 summarizes the hook setting intervals with and without the chute.

Table 11. Hook setting rates under deterrent and control treatments.

Set Number	Chute or control	Hooks set	Start time	End time	Total seconds	Rate (seconds/hook)	Average Rate for Set
Set 1	Chute	473	11:58	12:55	3420	7.2	7.2
	Control	480	7:50	8:54	3840	8.0	7.4
	Control	468	8:54	9:46	3120	6.6	
	Control	466	9:46	10:45	3540	7.6	
Set 2	Chute	463	10:26	11:36	4200	9.1	9.1
	Control	469	13:06	13:58	3120	6.6	7.9
	Control	238	13:58	14:22	2160	9.1	
Set 3	Chute	234	12:45	13:15	1800	7.8	7.8
	Control	457	9:27	10:21	3240	7.1	6.9
	Control	458	10:21	11:12	3060	6.7	
	Control	222	11:12	11:37	1500	6.8	

Set 4	Chute	453	11:26	12:26	3600	7.9	7.9
	Control	475	7:50	8:50	3600	7.6	7.0
	Control	453	8:50	9:40	3000	6.6	
	Control	437	9:40	10:29	2940	6.7	
Set 5	Chute	408	9:10	10:09	3540	8.7	8.7
	Control	511	11:05	12:07	3720	7.3	7.3
	Control	481	12:07	13:02	3300	6.9	
	Control	409	13:02	13:55	3180	7.8	
Set 6	Control	437	7:37	8:36	3540	8.1	6.7
	Control	472	8:36	9:17	2460	5.2	
	Control	432	9:17	10:07	3000	6.9	
	Control	426	10:07	10:55	2880	6.8	
	Control	466	10:55	11:46	3060	6.6	

Only sections where the time to deploy and retract the chute are not included are reported. This was done because the time to deploy and retract the chute would not be a factor under normal fishing operations if the vessel crew were conducting the entire set with or without a chute.

The average hook setting rate for sets made with the chute was 8.14 seconds per hook (n = 5 sets, s.e. = 0.34 seconds). For combined control set sections reported in Table 11, the average hook setting rate was 7.20 seconds per hook (n = 6 sets, s.e. = 0.18 seconds). The difference was statistically significant (t = 2.60, two tailed p < 0.029).

7.3. Chute Change in CPUE

An estimated gain in fishing efficiency in terms of Catch Per Unit Effort (CPUE) when setting with the chute versus the control with albatrosses present (as in the experiment) was calculated to be 29.6% based on 90.1% bait retention with the chute and 69.5% bait retention without the chute (Table 8).[5] Without albatrosses present, an additional 0.2% of the bait is retained with the chute, and an additional 4.8% is retained without the chute (Section 8.11.1), resulting in an estimated CPUE gain of 21.5% with the chute.[6] Based on average hook setting intervals (Section 7.2), without the chute the *Katy Mary* would have averaged 5.6 hours to set 2,800 hooks. With the chute, the vessel would have only been able to set 2,477 hooks in 5.6 hours, an 11.5% reduction in fishing effort and catch per set. The remaining 323 hooks could be set through the chute in 44 minutes 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.

7.4. Chute Design

The chute could be manufactured with a modified design to address many of the *Katy Mary's* crew's complaints about the chute. (a) The chute trough was initially too rounded and was modified before the at-sea trial began. The manufacturer could redesign the trough to better facilitate deployment of branch lines. (b) The water inlet hose fitting in the chute trough needs to be located on the port side to avoid obstructing use of the V bracket. (c) The V bracket base could be strengthened and could be redesigned to better fit the chute to minimize crew effort required to deploy and retract the chute. (d) The safety gate swivel joint, which locks out of the way during chute deployment by screwing it to the nut welded to the side of the chute, requires that the operator remember to disengage it before retracting the chute,

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[5] The 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).

[6] The 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 this locks the chute to the V bracket, preventing the chute from sliding upward to be retracted. This design risks having the crew trying to retrieve the chute without first disengaging the stowed safety gate, which could damage the V bracket or other part of the chute assembly. It might be possible to redesign the system for stowing the safety gate swivel joint to eliminate this risk of damage. (e) The water holes in the rim of the chute's trough could be designed to avoid projecting water outward from the trough, which gets the crew wet during setting when there is a strong wind from the stern, which can be a safety hazard, and the chute could be designed to send more water through the trough to help deploy the branch lines. (f) The manufacturer could install quick release fittings on the water hose to the chute's trough. And (g) the manufacturer could design the rail to make sliding the bracket and chute across the rail easier.

7.5. Chute Installation

The chute was not installed in a manner that was intended to be permanent. The installation could be modified to eliminate some of the crew's complaints with use of the chute. If the chute were to be permanently installed on the *Katy Mary*, the captain would install it on the port side of the stern to keep baited hooks set through the chute out of prop turbulence, and would reconfigure the setting and hauling operations to facilitate setting from the port/stern corner. Also, the chute would be installed lower so that the trough would be at a more convenient height for crew to set branch lines.

7.6. Safety Hazard

Branch line tangles are a safety hazard to crew during hauling (Section 5.18). Table 12 summarizes observations of branch line tangles when setting under control and chute treatments, observed during hauling. During sets 2-6, the average branch line tangle rate (number of branch line tangles per 1000 hooks) when setting with the chute was higher than when setting under the control treatment, however the results were not statistically significant (pairwise t-test, $p>0.1$) perhaps due to low sample size ($n=5$).

By the end of the 4th set, the investigator and crew determined that the increased incidence of branch lines tangles when using the chute was being caused by crew prematurely grasping the mainline in anticipation of clipping on the branch line. When crew improved the timing of clipping on the branch line to the mainline with setting the branch line through the chute, crew perceived that this problem of branch line tangling in the chute was reduced to levels comparable with setting under control conditions.

Table 12. Branch line tangles under deterrent and control treatments observed during hauling.

Set No. Control or Deterrent[1]	# Hooks	Number of Mainline Twists[2]	Number of Branch line Loops[3]	Branch line Tangle Rate (Number of branch line tangles per 1000 hooks)
Set 2 Control	1174	1	0	0.9
Set 2 Chute	1166	5	10	12.9
Set 3 Control	1137	3	5	7.0
Set 3 Chute	1127	9	14	20.4
Set 4 Control	1365	6	10	11.7
Set 4 Chute	1402	2	26	20.0
Set 5 Control	1401	12	13	17.8
Set 5 Chute[4]	1271	8	5	10.2
Set 6 Control	2233	7	7	6.3
Set 6 Chute[5]	471	0	11	23.4
TOTAL Control	8725	29	35	8.7 (average)[6]
TOTAL Chute	6639	24	66	17.4 (average)[6]

[1] Branch line tangles in set 1 were not observed. Set 1 observations led to the realization that setting with the chute was causing a higher incidence of branch line tangles, providing the impetus to record different types of tangles during subsequent sets, and to investigate possible solutions.

[2] "Mainline twist" = branch line is twisted around the mainline

[3] "Branch line loop" = the hook of a branch line is attached to the hook or clip of another branch line or to the mainline.

[4] After the fourth set, the cause of the branch line tangles when setting with the chute was identified as being when the crew prematurely grasp the mainline in anticipation of clipping the branch line to the mainline, which was remedied by having this crew improve their timing of branch line clip-on by focusing on avoiding grasping the mainline too early.

[5] Crew were observed to be less attentive when setting the last tote of this set, the only tote set with the chute during this set.

[6] Average of 5 replicates.

7.7. Degree of Effort to Install and Employ

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 (Section 7.2), the trough design and placement made it difficult to set branch lines (Sections 7.4 and 7.5), crew had difficulty sliding the chute across the rail, a safety hazard was created from a higher incidence of branch line tangles (Section 7.6), and the effort required to deploy and retract the chute was perceived as being high. The chute can be deployed by 2 crew, and retrieved by 3 crew manually or 2 crew with mechanical assistance. As discussed in Sections 7.4, 7.5, and 7.6, 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 mainline, and more crew experience using the chute to reduce the hook setting interval with the chute.

7.8. Voluntary Use of the Chute by the *Katy Mary*

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.

7.9. Preference Between Chute Versus Currently Required Seabird Avoidance Measures

The crew generally would prefer using the underwater setting chute to blue-dyed bait (required for both the tuna and swordfish fleets) and night setting (was to be required for the swordfish fleet). One crew member explained that while he finds using blue-dyed bait to be less effort than using the chute, because he perceives that the chute is more effective at avoiding seabird interactions and may reduce bait loss, he would prefer to use the chute over blue dyed bait.

7.10. Suitability for Fleet-Wide Use

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* (Table 1). The *Katy Mary* has a high hook setting interval relative to the rest of the Hawaii tuna fleet, which implies that setting with the chute may not require a decrease in the normal hook setting interval on other Hawaii tuna vessels, and the safety hazard from increased incidence of branch line tangles may not occur when setting with the chute on these other vessels. It will likely require more thought to determine where to mount and store the chute on smaller vessels.

7.11. Potential for Fleet-Wide Voluntary Compliance

If the chute is demonstrated to significantly increase bait retention when compared to normal setting operations, then this could create enough of an economic incentive for fleet-wide use of the chute at all fishing grounds, and not just in areas with abundant seabirds. However, there is a perception that one component of the Hawaii longline fishery has a lower seabird conservation ethic and would not likely make a concerted effort to avoid and minimize seabird mortality. There is also a perception that some individuals will always object to being told how to fish, regardless of the requirement. As a result, enforcement through U.S. Coast Guard overflights and presence of onboard observers is perceived as necessary to increase compliance with regulations requiring the use of seabird avoidance measures.

8. DISCUSSION

8.1. Sink Profile, Rate, and Depth of Branch Lines

The sink rate of baited hooks does not determine the effectiveness of an underwater setting chute's ability to avoid seabird interactions. The underwater setting chute design is effective at avoiding interactions between seabirds and baited hooks because the chute's shaft encases the baited hooks to a depth below the diving range of seabirds that interact with the Hawaii longline fleet. The sink rate of baited hooks inside the chute's shaft is not a factor in the chute's ability to avoid birds.

However, if baited hooks occasionally rise to the surface after exiting the chute, and the hooks rise to a shallow enough depth to be accessed by seabirds, as recorded by one of the TDRs deployed through the chute (Set 6, TDR 215, Table 3 and Figure 6), then this profile would reduce the effectiveness of the chute. The cause of the single outlier, where the TDR rose to the surface, is unclear. Delayed clipping of a branch line to the mainline can cause a baited hook to be pulled up towards the sea surface from the chute exit depth. Or, a heavy yaw could cause a hook to be set into the vessel's prop turbulence, bringing the hook towards the sea surface.

With this outlier removed, the mean TDR sink rate set through the chute to a depth of 5m was lower than the mean sink rate for TDRs set under the control treatment (Table 3), perhaps because the chute reduces turbulence compared to the control.

The difference in the mean average set depth of TDRs under deterrent and control treatments, which was not statistically significant, might be explained by TDRs having been placed different distances from buoys, because gear is brought to different average depths during separate sets, and because different sections of one set may settle to different depths.

The hook sink rate observed in this experiment was about 30m/minute over the first 5m, about 3 times faster than the mainline sink rate reported for the Hawaii tuna fleet (Table 1). Hooks are expected to sink faster than the mainline for the first 5 meters because weights are located close to the hooks. Also, the *Katy Mary* used mostly 60g swivels within 46cm (18 inches) to hooks, which are heavier weights placed closer to hooks than most vessels in the tuna fleet. While branch line weights may not be the primary factor controlling mainline sink rates, the heavier weights used by the *Katy Mary* may further explaining why the sink rate measured by the TDRs in this trial was much faster than the reported mainline sink rate for the Hawaii tuna fleet.

8.2. Bird Abundance and Behavior

The maximum effectiveness of the chute at reducing seabird interactions is expected to occur when interest in the fishing vessels is minimized by hiding from the birds the fact that crew are actually setting baited hooks. However, the balanced design of the experiment, where setting with the chute was alternated with setting under control conditions (Section 5.7), meant that birds were attracted to the vessel as soon as control setting allowed birds to see baits being thrown overboard. When control setting came before setting with the chute, albatrosses attracted to the vessel during the control replicates likely followed the vessel for a while when setting with the chute began. The results (Section 6.2) did indicate that bird abundance was 24% lower during sets when chute replicates preceded control replicates than the bird abundance during sets when control replicates were first, but the difference was not statistically significant. This is consistent with Boggs (2001), who found that albatross abundance was lowest when deterrent treatments preceded control treatments (order 2 mean = 31.6 and 34.5, n = 24) and the effect of order (of deterrent versus control treatments) was significant (two-way ANOVA, F = 4.0 and 4.3, P = 0.01 and 0.007, d.f. = 3, for Black-footed and Laysan Albatrosses, respectively). When Boggs (2001) normalized the contact rate for bird abundance, this effect of order of treatment was not significant. Thus, the chute might be more effective than our results demonstrated if the chute were to be used consistently to keep seabird abundance and searching intensity low.

Figures 9 through 11 show a highly significant linear correlation between albatross abundance and attempts, contacts, and captures, and justifies normalizing attempt, contact, and capture rates for albatross abundance.

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 deterrent method(s). Based on the results from this chute trial (Section 6.2, Figure 11), 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. However, the results from the two experiments would show the same percent effectiveness of reducing seabird attempts, contacts, and captures compared to a control.

Therefore, normalizing capture, contact, and attempt rates for bird abundance is important to allow accurate comparisons between seabird interaction rates (attempt, contact, and capture rates) reported from multiple experiments. Normalizing seabird interaction rates is not as important when comparing results from several experiments on the percent effectiveness of a seabird deterrent method at reducing interactions compared to controls (e.g. see Section 6.2 Table 5 and Section 6.7 Table 9). Normalizing seabird interaction rates for significant confounding factors, when possible, makes rates reported from multiple experiments more comparable.

When setting with the chute, albatrosses were generally observed to have a different behavior than when setting under control conditions. When setting with the chute, albatrosses were generally observed to be roaming widely around the vessel, and when setting under control conditions, with bait visible to the seabirds, the albatrosses were generally observed to be actively searching, which generally involved continual passage on a specific flight path over the point where baits entered the water.

Black-footed and Laysan albatrosses were observed to dive underwater from floating on the sea surface, and to occasionally dive from the air and remain submerged up to 3 seconds, however, birds typically were unsuccessful at bringing baits to the surface after these longer periods of submergence.

Interactions between Laysan and Black-footed Albatrosses were infrequent, however, interactions between Laysan Albatrosses were common.

8.3. Seabird Attempts and Contacts with Baited Hooks

Boggs (2001) observed that under control conditions of setting under normal Hawaii swordfish longline techniques, Black-footed Albatrosses had a contact rate of 8.3 contacts per 1000 hooks per albatross, and Laysan Albatrosses had a contact rate of 6.9 contacts per 1000 hooks per albatross.

McNamara *et al*. (1999) observed 10.7 attempts with fishing gear per 1000 hooks per bird, and no contacts during control conditions for Hawaii longline tuna fishing, where 1,526 hooks were observed set under tuna control conditions. McNamara *et al*. (1999) observed 76.7 attempts per 1000 hooks per bird, and 32.8 contacts per 1000 hooks per bird during control conditions for Hawaii swordfish longline fishing during the daytime, where a total of 1,212 hooks were observed set under swordfish control conditions during the daytime.

During the swordfish control replicates of Boggs (2001) and McNamara *et al*. (1999), squid was used as bait, which is a bright white and easily seen by albatrosses, while 90% of the bait used in this trial was fish (Section 4.1), which is blue and likely harder for albatrosses to see during setting than squid (Section 8.12). Furthermore, the swordfish control sets made by McNamara *et al*. (1999) were made mostly at dusk, when seabirds have a peak in foraging activity. During the tuna sets observed by McNamara *et al*. (1999), there were an average of only 2.5 albatrosses present, all of which were Black-footed Albatrosses. The bird abundance was too low to assess albatross interactions with gear. These factors, and perhaps other confounding factors discussed in Sections 2 and 8.4, may explain the differences in attempt and contact rates during control replicates observed in this trial versus those reported by Boggs (2001) and McNamara *et al*. (1999).

8.4. Catch and Mortality

McNamara *et al*. (1999) observed 22 albatross mortalities during normal swordfish setting techniques with setting occurring during the daytime for 1,224 hooks observed set, a capture rate of 18 captures per 1000 hooks, and when normalized for bird abundance, the capture rate is 2.2 captures per 1000 hooks per bird (an average of 8 seabirds were present during control sets). The same factors discussed in Section 8.3, of use of squid for bait, and conducting control replicates at dusk, are likely explanations for the different capture rates from this trial and that reported by McNamara *et al*. (1999).

As discussed in Section 2, there are numerous confounding factors that 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, seabird abundance, and the complex of seabird species present (Brothers, 1991; Brothers, 1995; Bergin, 1997; Environment Australia, 1998; Brothers *et al*., 1999; Cousins *et al*., 2001; Gilman, 2001b; Anderson and McArdle, 2002).

For instance, during the chute trial when setting under control conditions, investigators observed that when the wind came from the stern or starboard side of the vessel, albatrosses were able to hover close to the port/stern corner of the *Katy Mary* and better access baits as they landed on the water surface. Even when setting downwind, the usual practice by longline vessels, which is expected to be best for avoiding seabird interactions to prevent birds from hovering over the area where baits enter the water, when there was a strong wind, seabirds would glide upwind past the port/stern corner to a position over where baits were entering the water. Wind direction and speed has been found to have a significant effect on gear sink rate (Anderson and McArdle, 2002). Thus, wind speed and direction when setting are additional confounding factors influencing seabird mortality.

8.5. Age, Sex, and Breeding Condition of Killed Birds

Pre-breeders can possess well-developed brood patches (Broughton, 1994), thus the presence of a brood patch in the albatrosses killed in this experiment does not definitively indicate that the bird was brooding or rearing a chick.

Several authors have hypothesized that juvenile seabirds are more susceptible to being caught in longline fisheries (Brothers, 1991 and 1995; Cousins *et al*., 2001). Brothers (1991) found that 17 of 21 (81%) albatrosses killed on a Japanese pelagic longline southern bluefin tuna vessel were juveniles. This was the only publication found to provide results on age classes of albatrosses killed in longline fisheries. In this study, none of the 20 salvaged albatrosses that underwent necropsy analysis were found to have bursas of Fabricius that visibly diverged from the intestine, and were therefore determined to all be of breeding age based on the method for aging described by Broughton (1994) (Table 7).

Several factors may determine the age class of albatrosses killed in a longline fishery. Fishing grounds' proximity to albatross breeding colonies, time of year, and albatross age class seasonal foraging distribution are likely relevant factors. For instance, in this experiment, the fishing trip was too early to interact with newly fledged albatrosses, and the location of fishing grounds was very close to breeding colonies during the brooding and chick-rearing period when breeders were making short-distance foraging trips (Section 8.17).

8.6. Swivel Weight

Statistical analysis of results showed that the magnitude of swivel weights affects their efficacy as a bird deterrent measure, specifically that 60g swivel weights are significantly ($*p = 0.0055$) more effective than 38g weights. The U.S. National Marine Fisheries Service's rules for Hawaii tuna longline vessels fishing North of 23 degrees N. latitude require 45g weights located within 1m of baited hooks (U.S. National Marine Fisheries Service, 2001b and 2002). The Hawaii tuna fleet places 38 to 80g weights 20 to 90cm from the hook (Table 1).

While a proven method to reduce seabird interactions with gear, adding weight to branch lines is not used by many pelagic longline vessels because of crew safety concerns (McNamara *et al*., 1999; Anderson and McArdle, 2002). Human fatalities and serious injuries have resulted when taught branch lines with weighted swivels break and project the weight back towards the vessel and hit crew during hauling (Anderson and McArdle, 2002). In the Hawaii longline fleet, the incidence of injuries is far less now that wire leaders are almost exclusively used. Longlines with integrated weight (a lead core) may prove a safe way to weight branch lines (Robertson *et al*., 2002).

8.7. Loss of Caught Birds Before Haul

Regardless of what the precise percentage of loss of caught birds before hauling was during this trip, this observation that falloff does occur highlights the need for a directed study to more accurately assess the degree and significance of the falloff. Results would allow managers to more precisely assess the significance of seabird mortality in longline fisheries.

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. For instance, the researcher observed one of the dead albatrosses fall from a hook during hauling, which was recovered when the vessel reversed direction to collect the carcass.

There is an unknown degree of error with observations of caught seabirds during setting. One way to eliminate this error would be to conduct a directed study where hooked birds (e.g. poultry) are set at typical fishing grounds, soaked for a typical amount of time, and then hauled to provide a more precise measure of the percentage of bird falloff. There have been no such research experiments conducted to measure the percent of caught birds that fall from longline hooks. Observed captures of seabirds during setting during this and other experiments may be overestimates, as there is an unknown degree of certainty that seabirds observed caught do not free themselves before the observation is obstructed by waves, foraging seabirds, or some other obstruction. And, 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, in set 5, section E, the researcher observed a maximum of 2 albatrosses captured during setting, and three albatrosses were hauled aboard, indicating that at least one more albatrosses was caught during this section than the researcher was able to observe during setting (Table 4).

We do know that 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; Cousins and Cooper, 2000). 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 (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.

Albatrosses have also been observed dying on their nests due to hook wounds (e.g. Weimerskirch and Jouventin (1987) 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 (Brothers, 1995). 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 (Tasker and Becker, 1992; Brothers, 1995), further supporting the hypothesis that actual seabird mortality rates caused directly and indirectly by longline fisheries are higher than reported (Brothers, 1991).

8.8. Effectiveness of Blue-Dyed Bait

A comparison of the data from the pair of replicates in set 5 when blue-dyed squid was set through the chute (section C) and set without the chute (section D) indicates obvious effectiveness of the chute at reducing seabird interactions even with a background condition of blue-dyed squid bait. During set 1 when blue-dyed mixed fish and squid bait was used in combination with the chute and without a chute, seabird contacts and captures were eliminated only with the chute, indicating obvious effectiveness of the chute at reducing seabird interactions with a background condition of blue-dyed fish and squid (mixed) bait.

The data from set 5 section D presented in Table 9 demonstrate that blue-dyed squid bait did successfully reduce seabird contacts and captures on a Hawaii longline tuna vessel compared to normal bait. Despite possibly not having been dyed dark enough to meet the regulatory standard for darkness, the blue-dyed bait treatment still was found to have some efficacy at avoiding bird interactions (Section 6.7).

The effectiveness of blue-dyed squid in this experiment at reducing seabird contacts and captures was much lower than the effectiveness observed by Boggs (2001) and McNamara *et al*. (1999). When expressed as contacts per 1,000 hooks per albatross, in this trial, blue-dyed squid was 49% effective at reducing contacts compared to a control, while Boggs (2001) observed 94% effectiveness.

When expressed as captures per 1,000 hooks per albatross, in this trial, (using the number of seabirds observed caught during the set) blue-dyed squid was 43% effective at reducing captures compared to a control, while McNamara *et al*., (1999) observed 95% effectiveness. There are several potential confounding factors between this experiment and previous studies of blue-dyed squid, which may explain the lower effectiveness of blue-dyed squid at reducing contact and capture rates observed in this experiment compared to the previous studies:

(a) This trial was conducted on a vessel targeting tuna, while the two previous studies on blue-dyed squid were conducted on vessels targeting swordfish. The control treatment in this trial likely results in significantly lower seabird contacts and captures compared to the control treatment used in the experiments on vessels targeting swordfish. In the Hawaii longline fleet, the hook sink rate of vessels targeting tuna are expected to be much faster than the sink rate on swordfish vessels (Table 1). Tuna vessels place weights much closer to the hook than swordfish vessels. Therefore, the control treatment used in this trial, where undyed squid bait was set on branch lines with 60g swivels located 46cm (18 inches) from the hook, using a mainline shooter to set the mainline slack, would be expected to have a faster hook sink rate and fewer seabird contacts and captures compared to the control treatment employed in Boggs (2001) and McNamara *et al*. (1999), where 60g swivels were located 3.7 m from the hook, and the mainline was set taught;
(b) There was only one replicate in this trial, the smallest sample size possible, resulting in very low statistical power; and
(c) Review of a video taken during the research trial showed that the bait dyed blue during this experiment may not have been dyed dark enough to meet the standard of darkness specified in regulations. Federal regulations require Hawaii longline tuna vessels, when fishing north of 23 N latitude, to use completely thawed bait[7] that has been dyed blue to an intensity level specified by a color quality control card issued by the U.S. fishery management authority (U.S. National Marine Fisheries Service, 2002a).

Additional confounding factors that may have existed between the three experiments, which may have contributed to the different observed effectiveness of blue-dyed squid, include: (a) differences in vessel setting speed (a faster setting speed gives birds more immediate access to baited hooks); (b) different wind speed and direction in relation to the setting direction (this is critical, especially when using 60g weights 18 inches from the hooks); and (c) intra and inter-annual variability. For example, Melvin *et al*. (2001) found in a two year study on seabird avoidance measures that there were significant differences (up to a 3 fold difference) in catch of seabirds in controls between years, indicating that inter-annual variation is a large confounding factor.

Another possible but unlikely explanation for the difference in observed effectiveness of blue-dyed squid is that the albatrosses have become habituated to this treatment. It is possible, albeit remotely, that, since the Hawaii fleet has changed their gear to generally use weights close to hooks, this configuration has reduced the area of opportunity for seabirds to access baited hooks. The Laysan and Black-footed Albatrosses may have subsequently changed their behavior to concentrate their search over the location where baits hit the water, where the cue to the bird is now bait movement through the air and impact on the sea surface. The cue to the birds before this change in weighting design may have also included the birds seeing bait slowly sinking astern of the vessel. This change in weighting regime may have reduced the benefit of dyeing the bait blue, as the current cue of bait movement through the air and impact on the sea surface may not be significantly concealed by the color of the bait.

McNamara *et al*. (1999) observed that if blue-dyed squid were thrown over or into the turbulent propeller wash, the dyed bait would be highly visible by birds searching from above when the bait was over or in the white turbulent water, relative to when the bait was over or in adjacent clear blue water. Non-dyed bait would likely be concealed better from seabirds than dyed bait when set into turbulent water. Asking fishermen to throw baited hooks clear of the prop turbulence might have the effect of making the baited hooks immediately available to searching seabirds further from the vessel hull.

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[7] Contrary to results of other studies, Anderson and McArdle (2002) found that partially thawed squid bait had a faster sink rate than completely thawed bait. It is possible that some frozen baits are denser than sea water, such as bait that is brine frozen (Anderson and McArdle, 2002).

Fishermen are not likely avoiding setting baited hooks into prop turbulence when using blue-dyed bait, which brings the efficacy of blue-dyed bait as a seabird deterrent measure into question.

Research has not been conducted on the effectiveness of blue-dyed fish bait, such as sanma (deep blue dorsally and silver ventrally from the lateral line) or sardines, used in the Hawaii longline tuna fleet. McNamara *et al*. (1999) notes that the camouflaging effect of dying fish baits blue may be reduced in bright sunlight, and that the dye washes more rapidly from sanma compared to squid. Dying fish may also be ineffective because the scales are easily brushed off after the bait dries when hooks are baited, revealing a conspicuous silver color again. This experiment was not designed to assess the effectiveness of blue-dyed fish bait, as explained in Section 6.7. An experiment is planned for 2003 that will test the effectiveness of blue-dyed fish bait at reducing seabird interactions with longline gear in the Hawaii longline fishery.

8.9. Strategic Offal Discards

The Hawaii seabird regulations require the discharge of offal or spent bait while setting or hauling longline gear as a means to distract birds from baited hooks (U.S. Fish and Wildlife Service, 2000; U.S. National Marine Fisheries Service, 2000 and 2002).

The *Katy Mary* discarded most of its offal (spent bait, fish bycatch, fish heads) during hauling operations. Seabirds observed following the vessel during hauling would likely have remained interested in the vessel without the discharge of this offal due to the awareness of the presence of bait remaining on hooks and caught fish being hauled aboard. For this reason, during line hauling in most pelagic fisheries, it is unlikely that retaining offal will diminish bird interest, and it may not be possible for some pelagic vessels to prevent material from washing overboard.

There are mixed evaluations of the effectiveness of strategic offal discharge (Cherel *et al*., 1996; Brothers, 1995 and 1996; McNamara *et al*., 1999). The results of research on the short-term effectiveness of strategic offal discharge in a pelagic longline fishery showed reduced seabird interactions with longline gear after offal is thrown overboard (McNamara *et al*., 1999), and results of a study of the short-term effectiveness of strategic offal discharge in a demersal longline fishery observed reduced seabird capture (Cherel *et al*., 1996). In the long-term, strategic offal discharge may reinforce the association that birds make with specific longline vessels being a source of food. While discharging offal and fish bycatch during setting can distract birds from baited hooks (Cherel *et al*., 1996; McNamara *et al*., 1999), this practice is believed to have the disadvantage of attracting birds to the vessel, increasing bird abundance, searching intensity, and capture (Brothers *et al*., 1999). For instance, results from Commission for the Conservation of Antarctic Marine Living Resources studies in demersal longline fisheries have shown that vessels consistently discharging offal attract larger numbers of birds to their vessels (<www.ccamlr.org/English/e_pub…asures/>), likely resulting in increased seabird bycatch rates. Brothers (1996) hypothesizes that seabirds learn to recognize by smell specific vessels that provide a source of food, implying that vessels that consistently discharge offal and fish bycatch will have higher seabird abundance and capture than vessels that do not discharge offal and fish waste.

When setting with the underwater setting chute, birds were observed to be primarily roaming and not actively searching for bait, and bird abundance was significantly lower during chute replicates than during control replicates (Section 6.2). This indicates that it would be counterproductive to discharge offal and bait, as this would cause seabirds to gain interest in searching and foraging in the area around the vessel and would increase bird abundance. 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. Even one discarded bait during setting can rapidly cue previously disinterested birds into an intense searching mode. If there is, for instance, a tote box tangle during setting with the chute that results in bringing a baited hook to the surface, seabirds are much more likely to detect this baited hook if offal and bait have been discarded and attracted the birds' attention to the setting area. Therefore, to maximize the chute's ability to hide from seabirds the discharge of baited hooks during setting, no offal should be discarded during setting when using the underwater setting chute in order to minimize having seabirds gain interest in searching and foraging for food in the area where longline gear is being set.

8.10. Seabird Interactions on Haul

McNamara *et al*. (1999) observed seabird interactions on the haul of Hawaii swordfish longline vessels, where hauling occurred during the day, and found that during normal swordfish hauling operations (control conditions, no seabird mitigation methods employed) there were 1.2 contacts per 1000 hooks hauled per bird (a total of 26 albatrosses were hooked during observed swordfish hauls of 37,807 hooks or 0.7 birds hooked per 1000 hooks hauled), and 15.5 attempts per 1000 hooks hauled per bird.

Hauling operations during the trial of the underwater setting chute occurred at dusk and at night, which might partially explain why no seabirds were observed interacting with the fishing gear, as bird abundance and searching intensity is generally lower at night. Also, because the *Katy Mary* branch line lengths were close to the distance from the hauling roller to the stern of the vessel, the baited hooks are brought to the surface adjacent to the starboard side of the vessel, and seabirds tend to be wary of coming too close to the vessel. Thus, the *Katy Mary*, using this length of branch line, would not be expected to have seabird bycatch problems during hauling even during the day when bird abundance and searching intensity is higher. Also, the *Katy Mary* has three crew hauling branch lines into three totes simultaneously, which reduces the incidence of delays in recovering branch lines (delays can lead to baited hooks coming to the surface astern of the vessel, where they become accessible to seabirds). Furthermore, because the *Katy Mary* uses a 60g weight near the hook, this helps keep baited hooks underwater until the final moment of hauling aboard.

For vessels that do have problems with seabird capture during line hauling, the use of branch line pulling machines increases branch line recovery rate about threefold, reducing opportunities for birds to sieze incoming hooks (Brothers *et al*., 1999).

8.11. Commercial Demonstration

Do the results from this trial indicate that the underwater setting chute (a) is effective at avoiding seabird interactions with fishing gear, and is there a perception that the chute will work given the range of fishing gear and practices of the Hawaii fleet, and variable conditions (weather, bird abundance, etc.); (b) requires a minimal amount of additional effort for crew to install and operate, and not pose a safety hazard to crew members, and (c) is cost effective or better yet, increases fishing efficiency?

The project was both a commercial demonstration and scientific experiment. Investigators recognize the need for industry buy-in that the chute is practicable (both economical and not cumbersome to install and employ). If the vessel captain, crew, and vessel owner did not endorse the chute, regardless of the results from the scientific experiment, the longline industry would not likely support further testing or regulations providing for the chute's use in the fishery. And if the chute becomes mandatory, compliance with required use of the chute would be expected to be significantly lower than if industry takes ownership for prescribing use of the chute.

8.11.1. Bait retention. Bait retention (Table 8) 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 conservatively assume that every seabird contact (defined in Section 5.10) 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 (Section 6.1). For instance, the amount of removal of baits from hooks by fish would 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. 9.8% of baits are lost due to mechanical action and other non-seabird factors when setting through the chute (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 of hooks.

In summary, there was a savings of 20.6% of baits 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 catch per unit effort from setting with the chute at all fishing grounds, both at areas with abundant albatrosses and at grounds without albatrosses.

8.11.2. Hook setting rates. Section 7.2 indicated that it took significantly longer to set using the chute than setting under control conditions. This is not expected to be a problem for several reasons: (a) The hook setting interval using the chute is expected to improve gradually as crew gains 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 crew of these other vessels to reduce their normal slower hook setting interval; (c) Certain design features of the chute were noted to be impractical and once corrected, could result in increased setting efficiency and a faster hook setting interval; and (d) While the *Katy Mary* experienced a slower hook setting interval when using the chute versus setting under control conditions, the crew was able to get most or all of the hooks set anyway, and the cause of ending sets was not usually running out of mainline.

8.11.3. CPUE and revenue. 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 in increased hook setting interval when setting with the chute, results in a range of possible efficiency gains using the chute. Assuming vessels have enough time and mainline to complete slower sets using the chute, or that vessels will not have to reduce their conventional hook setting interval when using the chute (Section 8.11.2), the gain would be 29.6% with abundant albatrosses and 21.5% without albatrosses (Section 7.3). However, if slower setting with the chute reduces efficiency by 11.5% (Section 7.3), then the net gain in efficiency would be 14.7% with abundant albatrosses and 7.5% without albatrosses.[8]

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 2,500 pounds and grosses $5,000 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 1,875 – 7,400 pounds or $3,750 - $14,800 per trip, and an additional 28,125 – 111,000 pounds or $56,250 - $222,000 per year.

8.11.4. Safety hazard. Branch line tangles are a safety hazard to crew during hauling. Crew are at risk of injury during hauling if a hook is attached to a clip, another hook, or the mainline; or when a branch line is twisted around the mainline, especially near the end of the haul when the crew is less attentive. For instance, if a hook were attached to a clip on the mainline where there was a knot in the mainline (where a break in the mainline had been mended), this could result in serious injury to the hand of the crew handling the mainline. While setting through the chute appeared to increase the incidence of branch line tangles, results were not statistically significant.

Starting with the 5th set, crew consciously attempted to correct a mistake of prematurely grasping the mainline in anticipation of branch line clip-on to the mainline, and during the 5th set, the branch line tangle rate for replicates using the chute was lower than for replicates set under the control treatment (Table 12). During the final 6th set, crew were less attentive to preventing mistiming the grasping of the mainline, and the branch line tangle rate when setting with the chute was higher than when setting replicates under the control treatment. This may indicate that, if a crew increases their proficiency using the chute with prolonged use and remain attentive to the timing of clipping branch lines onto the mainline, the higher incidence of branch line tangles when setting with the chute observed during this trip may be overcome.

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[8] 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 * 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 * 1.215 = 1.075).

8.11.5. Target catch. The study assessed how the chute affects bait loss, hook setting interval, and mainline setting depth, but did not directly assess how use of the chute affects target catch.

8.11.6. Chute design, installation, and effort to employ. There is substantial benefit of having a person with extensive experience with the design and use of the chute to provide technical assistance to each vessel during the initial trial of the chute. For instance, the participation of Nigel Brothers and Dave Chaffey with the installation and trial of the chute for this experiment was critical. A certain amount of skill is required to install the chute to make it suitable for each individual vessel. Without Nigel's participation during the trial, the cause of the safety hazards from branch line tangles when setting with the chute may not have been identified and reduced, and the captain may have ended the experiment if the incidence of branch line tangles was not satisfactorily resolved. Thus, in order to facilitate broad, industry-wide use of the chute in Hawaii, management authorities and industry should provide for training opportunities to build the capacity to install and use the chute.

8.12. Squid

At least 2 of the 25 seabirds (8%) caught in the trial were caught on hooks with squid bait (Table 7). Of the total 15,363 hooks set during the trial, approximately 806 hooks (5.2%) contained squid bait.

While these data do not show a significant difference in capture on squid bait than would be expected by chance, the hypothesis is raised that fishing with squid bait rather than fish bait may result in a larger risk of bird interaction than fish bait. Using squid as bait might cause a slower sink rate of branch lines than using fish bait. Squid is also believed to be more difficult for seabirds to remove from hooks and might result in a higher incidence of seabird fights for possession and more hectic behavior, increasing the likelihood of a seabird getting hooked than if fish were used as bait.

8.13. Seabird Species Observed Interacting with Fishing Gear

Besides Laysan and Black-footed Albatrosses, additional seabird species observed during the trip were Masked Boobies (*Sula dactylatra)*, Short-tailed Shearwaters (*Puffinus tenuirostris*), Streaked Shearwaters (*Calonectris leucomelas*), Sooty Shearwaters (*Puffinus griseus*), Sooty Storm-petrels (also called Tristam's Storm-petrel) (*Oceanodroma tristrami*), Band-rumped Storm-petrels (*Oceanodroma castro*), Leach's Storm-petrels (*Oceanodroma leucorhoa*), Grey-backed Terns (*Sterna lunata*), Sooty Terns (*Sterna fuscata*), Great Frigatebirds (*Fregata minor*), Bonin Petrels (*Pterodroma hypoleuca*), Grey Phalaropes (*Phalaropus fulicaria*), Brown Noddies (*Anous stolidus*), and possibly a Mottled Petrel (*Pterodroma inexpectata*). While several species of seabirds were expected to be in the area of the experiment location, including shearwaters, boobies, petrels, terns, frigatebirds, and albatrosses, only Black-footed and Laysan Albatrosses attempted to contact baited hooks and were caught, consistent with research conducted by Boggs (2001) and McNamara *et al*. (1999).

8.14. Observed Capture Rates Compared to Capture Rate Estimates from Other Sources

Based on U.S. National Marine Fisheries Service observer records from 1994-1998, after observing 1,250 Hawaii longline tuna sets, 16 birds were observed caught (0.013 birds caught per set or approximately 0.0078 captures per 1,000 hooks) (U.S. Fish and Wildlife Service, 2000; Cousins *et al*., 2001).

There have been only 186 observed tuna sets north of 23 N latitude from 1994 through 1998, where two albatrosses were observed caught (one Laysan and one Black-footed Albatross were observed caught) (U.S. Fish and Wildlife Service, 2000), which provides a capture rate of 0.003 captures per 1000 hooks.

These capture rate estimates are not available normalized for seabird abundance, and therefore are not useful for comparison with the capture rate recorded during the control treatment in this trial. This trial observed a control capture rate of 4.24 captures per 1000 hooks (0.114 captures per 1000 hooks per albatross), which is significantly higher than previous capture rate estimates for the Hawaii longline tuna fleet. This difference is explained by this trial being located at fishing grounds with high albatross abundance, while the typical fishing grounds for the Hawaii tuna fleet is at grounds with lower albatross abundance.

8.15. Bycatch of Non-Seabird Species

The project did not test how the employment of an underwater setting chute on Hawaii longline tuna vessels affects the bycatch of species other than seabirds. Setting using the chute is not expected to affect bycatch of fish, sea turtles, or marine mammals, as the chute only affects the entry of the branch lines into the water, and does not change the setting depth or any other aspect of the fishing gear that would be expected to alter bycatch rates of non-seabird species. If setting with the chute causes a change in effort (the total number of hooks that a vessel sets) or a change in bait retention from the conventional setting method, these changes may cause a change in total bycatch of sensitive species.

8.16. Combination of Seabird Deterrent Measures

The study was not designed to investigate how effective the underwater setting chute is in combination with other seabird avoidance measures except for use of a line setting machine (mainline shooter) with weighted branch lines as typically employed by the Hawaii longline tuna fleet.

8.17. Timing of Experiment

Black footed, Laysan, and Short-tailed Albatrosses initiate breeding in October, lay eggs in December, the incubation period lasts about 65 days, the brooding period lasts 18 days, the chick-rearing period lasts 121 days, adults finish caring for chicks by early June, chicks fledge soon after the adults leave the colony, and by mid-July the colony is deserted (Hyrenbach *et al*., 2002; Niethammer *et al*., 1992; U.S. Fish and Wildlife Service, 2000). In late February, when this at-sea trial was conducted, many of the North Pacific albatrosses that interacted with the *Katy Mary* that were breeders were in the beginning of their chick-raising period. (See Section 6.4 for information on what percentage of the 24 albatrosses killed during this experiment were breeders).

According to satellite telemetry data, Black-footed and Laysan Albatrosses mix short and long foraging trips during the nestling period, make short trips close to the colony (travelling on the order of 100s of kilometers) during the brooding period (chick is 0-18 days old), and beginning when chicks are approximately 19 days old (beginning of chick-rearing period), parents mixed short and long trips[9] (on long trips, the birds travel on the order of 1,000s of kilometers) (Hyrenbach *et al*., 2002; Fernandez *et al*., 2001). Thus, in late February, when most breeding Black-footed and Laysan Albatrosses were in the beginning of their chick-rearing period, albatross abundance at the fishing grounds where the research experiment was conducted was slightly after its peak.

We can hypothesize that for the albatrosses that were killed in this experiment that were breeding, this likely resulted in the death of the birds' chicks due to starvation and it will be several years before the remaining adult albatrosses find new pairs and resume breeding (Brothers, 1995). Hawaii swordfish vessels would historically be at the fishing grounds where the experiment was conducted during February.

8.18. Relationships Between Attempts, Contacts, and Captures

The results confirming the hypothesis that there is a highly a significant linear correlation between contacts and captures, and between attempts and capture, (Figures 12 and 13) have implications for designing research on seabird deterrent methods. Research to test the effectiveness of seabird avoidance methods can be designed to observe seabird attempts and contacts during deterrent and control treatment replicates and use a model to use these data to estimate a capture rate. This means that researchers could attach baits to branchlines using clips instead of hooks to minimize the risk of injuring seabirds during the experiment, assuming that the vessel owner and crew agree to forfeit catching fish during the research.

Further analysis could be conducted to determine the best fit for modeling the relationship between contacts and captures, and between attempts and captures.

8.19. Capture Rate Estimate for the Chute During Long-term Use

Because we know there is a linear correlation between contact and capture rates (Section 6.9), we can use the ratio between the seabird contact rate under control conditions and capture rate under control conditions to estimate a capture rate for the chute under long-term use. A conservative estimate for the

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[9] On long foraging trips, Black-footed Albatrosses were generally observed to travel to the continental shelf of North America from 24 to 48 degrees N latitude (central California to British Colombia), while Laysan Albatrosses travel to the North Pacific Transition Zone (a broad, weak, eastward-flowing, surface current composed of a series of fronts, located in the North Pacific Ocean between the Subtropical Gyre to the south and the Subarctic Gyre to the north) and the Aleutian chain (Hyrenbach *et al*., 2002).

chute's capture rate with long-term use is 0.103 captures per 1000 hooks and when normalized for albatross abundance, is 0.00579 captures per 1000 hooks per albatross. During long-term use, the chute is conservatively estimated to reduce the seabird capture rate by 98% when expressed as seabird captures per 1000 hooks when compared to a control. During long-term use, when expressed as capture per 1000 hooks per albatross, the chute is expected to reduce seabird capture by 95% compared to a control. It is likely that this estimated capture rate for sets using the chute is an overestimate if the assumption is correct that performance with the chute will gradually improve with prolonged use, as the frequency of human errors that result in seabird capture, such as mistiming clipping branch lines onto the mainline when setting with the chute, and experimentation with the placement of the weight in the chute, will gradually lower as the crew increases their proficiency using the chute. As explained in Section 6.2, Table 4, most (8 of 10) seabird contacts with baited hooks when setting with the chute were observed to be a result of an error onboard that can be overcome with prolonged use of the chute.

Using the estimate of the perceived most reliable observed number of birds captured during setting (Section 6.6), during long-term use of the chute, the chute is conservatively estimated to result in a capture rate of 0.162 captures per 1000 hooks, or 0.00919 captures per 1000 hooks per albatross. During long-term use of the chute, when expressed as capture per 1000 hooks, where the number of captures is based on the number of birds observed caught during setting (and not the number of birds hauled aboard), the chute is expected to reduce seabird capture by 98% compared to a control. During long-term use of the chute, when expressed as capture per 1000 hooks per albatross, where the number of captures is based on the number of birds observed caught during setting (and not the number of birds hauled aboard), the chute is expected to reduce seabird capture by 95% compared to a control.

8.20. Implications for Hawaii Tuna Fleet

The underwater setting chute is expected to be as effective at avoiding seabird interactions and have the same requirements for altered fishing technique throughout the Hawaii longline tuna fleet as observed on the *Katy Mary* (Table 1). The *Katy Mary* has a high hook setting interval relative to the rest of the Hawaii tuna fleet, which implies that setting with the chute may not require a decrease in the normal hook setting interval on other Hawaii tuna vessels, and the safety hazard from branch line tangles may not be a problem when setting with the chute on these other vessels. It will likely require more thought to determine where to mount and store the chute on some of the smaller Hawaii tuna vessels, however, in Australia, the chute has been successfully installed and operated on vessels as small as 42 feet.

The fishing grounds for the Hawaii longline tuna fleet has primarily been south of 23 N. latitude where few albatrosses forage: from 1994 to 1998, over 85% of sets by the Hawaii longline tuna fleet were conducted south of 23 N. latitude (U.S. Fish and Wildlife Service, 2000); in 2000, 90.4% of the Hawaii longline tuna fleet's sets were made south of 23 N. latitude (853 sets or 9.6% of total tuna sets were made north of 23 N. latitude) (U.S. National Marine Fisheries Service Honolulu Laboratory unpublished longline logbook data); and in 2001 91.0% of the Hawaii longline tuna fleet's sets were made south of 23 N. latitude (1057 sets or 9.0% of total tuna sets were made north of 23 degrees N. latitude in 2001) (U.S. National Marine Fisheries Service Honolulu Laboratory unpublished longline logbook data). The vessels are not required to employ seabird avoidance measures when fishing south of 23 degrees N. latitude (U.S. National Marine Fisheries Service, 2002a and 2002b).

The Hawaii tuna fleet currently causes a relatively small amount of albatross mortality (the Hawaii longline tuna fleet killed an estimated 116 birds in 2000 (Section 2)), and with fleetwide effective use of the chute, the fleet can expect to kill even fewer birds.

8.21. Implications for Other Longline Fleets and Global Benefits from Local Collaboration

The fate of the Hawaii swordfish longline fishery is unknown. If the Hawaii swordfish fishery is authorized to resume in the future, the underwater setting chute would likely be as practicable and effective at avoiding seabird interactions in this fishery as it was observed to be on the *Katy Mary*. The swordfish fleet traditionally fished at grounds with a relatively high incidence of seabird interactions, had a high seabird bycatch rate, and resulted in significant seabird mortality (approximately 3,000 Laysan and Black-footed Albatrosses were killed annually in the Hawaii swordfish and mixed set fleet from 1994 to 1998 (U.S. National Marine Fisheries Service, 2000)). The Hawaii swordfish fleet had a significantly slower hook setting interval than the tuna fleet (Table 1), meaning that the swordfish fleet would not have to slow their hook setting interval to use the chute, and the swordfish fleet would be less likely to have branch line tangles when setting with the chute than occurred with the *Katy Mary* trial. Thus, the safety hazard issue, which was overcome on the *Katy Mary* anyway, is not likely to exist for use of the chute in the swordfish fishery. The swordfish vessels use longer branch lines than the tuna vessels, making the timing of clipping the branch line onto the mainline less critical, where creating tension on the branch lines from a delay in clipping the branch line onto the mainline will be more easily avoided. Results from trials in Australia where squid is used as bait indicate that squid is deployed successfully through the chute. Certain brands of lightsticks have been deployed successfully in the Australian trials, but certain lightsticks brands can create jams in the chute.

It is hypothesized that the Hawaii swordfish fishery had a slower hook sink rate over the first few meters than the Hawaii tuna fishery hook sink rate, however no published data are available to confirm this. The tuna fishery uses 38 to 80 g swivels within 20 to 90 cm from the hook, while the swordfish vessels placed weights 5 to 7 m from the hook, which is expected to result in a slower sink rate of the baited hooks. But the Hawaii swordfish fleet used larger and heavier hooks than the tuna fleet, which would increase the swordfish baited hook sink rate. Regardless, a slower sink rate of baited hooks is not expected to result in higher seabird interactions in the Hawaii swordfish fishery when setting with the chute, as long as the hooks are kept clear of the prop wash, because the chute would deliver the baited hooks sufficiently below the sea surface out of reach of the North Pacific seabirds' diving capabilities.

The chute may also have potential in other pelagic longline fisheries, and an underwater setting chute has been designed for use in demersal longline fisheries (Brother *et al*., 1999; Lokkeborg, 2001; Melvin *et al*., 2001; Dunn and Steel, 2001; Ryan and Watkins, 2002; Mustad, no date). The underwater setting chute has the potential to be suitable for use on large distant water longliners. A chute was used on a large longline vessel in New Zealand, where operational difficulties were encountered related to deploying and recovering the 11m long steel chute (Molloy *et al*., 1998).

Unfortunately, no single seabird avoidance measure can be expected to effectively and practicably address seabird bycatch in all longline fisheries and in all regions (Brothers *et al*., 1999). For instance, the preliminary results of the broad performance assessment of the chute in Australia's pelagic longline fleet indicate that, due to the seabird species complex that interacts with the fishing vessels and their bait scavenging abilities and behavioral interactions, the chute may not be an effective seabird deterrent without being combined with additional mitigation measures and alterations to existing gear and fishing techniques in Australian waters where this seabird assemblage is seasonally present (personal communication, Barry Baker, Environment Australia, April 2002; personal communication, Andrew McNee, Australian Fisheries Management Authority, April 2002). The chute trial in Australia has exceeded a target seabird catch rate of 0.05 captures per 1000 hooks, and the trial is being continued to attempt to identify the cause of the higher-than-desired bird catch rate, to determine whether the chute can be modified to improve its effectiveness, and decide on the future direction of the chute in Australian longline fisheries (personal communication, Ingrid Holliday, Australian Fisheries Management Authority, 22 April 2002). 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), getting caught on baited hooks and bringing baited hooks to the surface to make them available to larger albatrosses, petrels, and skua species, if these other species are present.

The Australian fleet may need to make alterations to their gear and fishing techniques, and perhaps use the chute in combination with other seabird deterrent measures, to effectively avoid and minimize seabird interactions. For instance, when compared to the Hawaii tuna fishery, which uses 38 to 80 g swivels within 20 to 90 cm from the hook, the Australian longline tuna fleet, which places 20g or 38g weights (if any) 3 to 4 fathoms from the hook, is likely to have a slower hook sink rate than the Hawaii fishery, making baited hooks available to diving seabirds longer than if the weights were placed closer to the hooks. Also, in the Australian fishery, the effect that live bait use makes on seabird capture is as yet unclear (the majority of the fleet uses a high proportion of live bait). The live bait is sufficiently small that it may be prone to flushing out of the chute prematurely or swim out of the chute at a shallow depth. And, the live bait, after being delivered at depth through the chute, may choose to swim towards the sea surface and increase its access to seabirds. The research component of the trial of the chute in Australia has been canceled due to high seabird mortality, but the performance assessment component of the trial continues. A progress report on the Australian trial is currently being prepared and is expected to be available in 2002 (personal communication, Ingrid Holliday, Australian Fisheries Management Authority, 22 April 2002).

By working constructively and collaboratively with the Hawaii longline swordfish and tuna fisheries to find practicable solutions to the bycatch of sensitive species, government management authorities and conservation groups can achieve results with regional and global implications. The U.S. Pacific Ocean longline fleets face severe regulatory restrictions if they cannot find bycatch solutions, providing the industry with a significant incentive to collaborate with conservation interests to find practicable solutions. These bycatch solutions might be suitable for other longline fleets that currently are killing significant numbers of seabirds, sea turtles, sharks, marine mammals, and other sensitive wildlife, and could be spread internationally through international accords, regional fora, and through communication between longline industry. The Hawaii longline fleet is a very small component of total longline fishing effort in the North Pacific: the Hawaii longline fishery representes 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; Crowder and Myers, 2001; Cousins *et al*., 2001). Significantly 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 than the conservation benefit achieved from closing these fisheries. Closure of 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 with poor management (Crowder and Myers, 2001). Furthermore, if the U.S. Government can identify effective and practicable seabird deterrent measures that may be suitable in foreign longline fleets, the U.S., as one of the world's largest swordfish market (the U.S. consumes about 25% of global swordfish landings (Ward and Elscot, 2000)), has the ability to significantly influence the management of foreign longline fisheries by influencing consumer demand through eco-labeling schemes and educational campaigns (e.g. see Marine Stewardship Council, 1998; Gilman *et al*., 2002).

The Hawaii chute project's collaboration between an environmental non-governmental organization, fishing industry, and government management authority serves as a model for future efforts to address the mortality of seabirds in longline fisheries, and other conservation initiatives.

8.22. Enforceability

In Hawaii, given the resources of the U.S. Coast Guard and U.S. National Marine Fisheries Service for enforcement, enforcement of seabird mitigation measures is most feasible for night setting, and closed areas when VMS is mandatory, for fishing seasons, and for fixed gear deterrent measures, which do not require active participation by crew to employ and which do not lower efficiency. Enforcement is significantly less feasible and crew compliance is likely not as high for operational measures, seabird avoidance measures that require the crew to spend significant time and energy and change their behavior and habits to employ (e.g. tori line and other towed deterrents, and strategic offal discharge) (LCDR Michael Tosatto, personal communication, 5 April 2000, U.S. Coast Guard). In other words, crew are more likely to effectively deploy seabird avoidance measures that are not difficult or time consuming to operate and do not disrupt their longstanding fishing practices, and voluntary compliance with regulations requiring seabird avoidance measures will be highest for such measures. Furthermore, seabird avoidance measures that pose a safety hazard (e.g. attaching weights to branch lines in pelagic fisheries can risk crew safety if, during hauling, the line breaks and weights become projectiles, and attaching weights to groundlines in demersal fisheries can risk crew safety by increasing the likelihood of crew members getting hooked during setting and by increasing the chance of parting the gear during hauling) or are thought to reduce profits (e.g. weights on branch lines may reduce catch rates by making the gear more visible to target species) will not facilitate voluntary compliance (Brothers *et al*., 1999; Melvin *et al*., 2001).

The underwater setting chute promises to be an effective and practicable seabird avoidance method, which could promote voluntary compliance. If the chute is demonstrated to significantly increase fishing efficiency when compared to normal setting operations, this could create an economic incentive for fleet-wide use of the chute at all fishing grounds, and not just in areas with abundant seabirds. However, there is a perception that there are fishers in the Hawaii longline fishery who would not likely make a concerted effort to use required seabird deterrent methods because they generally object to being told how to fish regardless of the requirement, they are unwilling to change longstanding fishing practices, or because they do not have a high seabird conservation ethic. As a result, enforcement through U.S. Coast Guard overflights and presence of onboard observers is perceived as necessary to increase compliance with regulations requiring the use of seabird avoidance measures. Compliance with required seabird avoidance measures is expected to increase with an increase in onboard observer coverage, even though observers do not have enforcement responsibilities or authorization.

If the chute were required in regulations, the U.S. Coast Guard and U.S. National Marine Fisheries Service could enforce compliance via dock-side 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. However, because of the large expanse of the Hawaii longline fleet's fishing grounds and the limited resources of U.S. enforcement agencies, besides limiting fishing to certain seasons and requiring seabird measures that are enforceable through VMS (night setting and closed areas), enforcement of other mitigation measures facilitate limited enforcement. Thus, identifying effective and practicable seabird mitigation measures and implementing other incentive instruments (e.g. see Gilman *et al*., 2002) that are likely to maximize voluntary compliance is a priority, as well as maximizing onboard observer coverage of the fleet.

8.23. Recommendations for Management Authorities

Recommendations are made for management authorities to authorize use of the chute with adequate branch line weighting and a mainline shooter as an alternative to other currently required seabird deterrent measures for an adequate period of time 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, explained in detail in Section 8.9. It is also recommended that management authorities institutionalize an incentives program for use and additional performance assessment of the chute.

Making the chute an alternative seabird deterrent measure will provide stakeholders with time to make the chute commercially available, develop the capacity for requisite training to install and use the chute, create incentives for vessels to voluntarily use the chute, and conduct a commercial demonstration and continued performance assessment. The continued trials have the potential benefit of confirming the expectations that the chute (a) will perform consistently under variable conditions found at different fishing grounds, seasons, years, different weather conditions, various light conditions, etc.; (b) will perform consistently under the suite of fishing methods and gear used by the fleet; (c) is likely economically advantageous due to increased bait retention; (d) does not require significant effort to install and employ; and (e) does not require significant changes to normal fishing practices. The continued trials will also provide an opportunity for increasing industry familiarity with and voluntary support for use of the chute.

Longer-term trial of the chute will also provide an opportunity to test the expectation that albatrosses are not capable of habituating to the chute. For instance, it is possible that the Laysan and Black-footed Albatrosses could increase their effort to obtain baited hooks when set through a chute, and make full use of their diving proficiency, once they learn that vessels setting with the chute are putting bait in the water, and catch rates of albatross when setting with the chute could potentially increase over time.

Furthermore, long-term trial of the chute is expected to result in contact and capture rates lower than observed in this trial. It is expected that there would be fewer mistakes resulting in access of baited hooks to seabirds the longer a crew uses the chute.

Given available resources for enforcement, it is recognized that this bottom-up approach to develop a sense of ownership for the chute by industry with concomitant voluntary compliance for potential eventual mandatory use of the chute, is needed. Alternative incentive methods to promote vessel use of the chute could include free distribution and installation of chutes, and making training opportunities available (Gilman *et al*., 2002). The *Katy Mary* was not permitted to retain possession of the chute at the end of the trial, as is the practice with the chute trials in Australia. This practice in Hawaii should change.

Once the chute is commercially available, capacity for requisite training is built, and broad industry support for use of the chute is developed, if at this future date available information indicates that the chute is the most consistently[10] effective deterrent method at avoiding seabird capture, and that expected industry compliance for using the chute is at least equal to expected compliance for use of other seabird deterrent measures, then managers should make fleet-wide use of the chute mandatory.

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[10] Consistent in that it is effective at reducing seabird contacts, attempts, and mortality across fishing grounds, seasons, and changing annual conditions, and under various fishing methods and gear used by the fleet.

9. CONCLUSIONS

Results from a short at-sea trial of an underwater setting chute in the Hawaii longline tuna fishery indicate that the chute may be both effective at avoiding seabirds as well as practicable for use by vessel crew. Based on the results of the short-term experiment and commercial demonstration, the chute promises to (a) significantly reduce seabird mortality in the Hawaii longline fleet, (b) require a minimal amount of effort to install and employ, and (c) increase fishing efficiency.

Short-term recommendations are made for management authorities to authorize use of the chute with adequate branch line weighting and a mainline shooter, where the discharge of offal and spent bait while setting with the chute is prohibited to minimize bird abundance and searching behavior, as an alternative to other currently required seabird deterrent measures. It is further recommended that management authorities institutionalize an incentives program for use and additional performance assessment of the chute, make the chute commercially available, and develop the capacity for requisite training to install and use the chute. This will help develop industry support for use of the chute, and if determined to be desirable, make future fleet-wide mandatory use of the chute feasible.

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