BIOLOGICAL CONSERVATION

Post-breeding season distribution of black-footed and Laysan albatrosses satellite-tagged in Alaska: Inter-specific differences in spatial overlap with North Pacific fisheries

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ABSTRACT

We integrated satellite-tracking data from black-footed albatrosses (*Phoebastria nigripes*; $n = 7$) and Laysan albatrosses captured in Alaska (*Phoebastria immutabilis*; $n = 18$) with data on fishing effort and distribution from commercial fisheries in the North Pacific in order to assess potential risk from bycatch. Albatrosses were satellite-tagged at-sea in the Central Aleutian Islands, Alaska, and tracked during the post-breeding season, July–October 2005 and 2006. In Alaskan waters, fishing effort occurred almost exclusively within continental shelf and slope waters. Potential fishery interaction for black-footed albatrosses, which most often frequented shelf-slope waters, was greatest with sablefish (*Anoplopoma fimbria*) longline and pot fisheries and with the Pacific halibut (*Hippoglossus stenolepis*) longline fishery. In contrast, Laysan albatrosses spent as much time over oceanic waters beyond the continental shelf and slope, thereby overlapping less with fisheries in Alaska than black-footed albatrosses. Regionally, Laysan albatrosses had the greatest potential fishery interaction with the Atka mackerel (*Pleurogrammus monopterygius*) trawl fishery in the Western Aleutian Islands and the sablefish pot fishery in the Central Aleutian Islands. Black-footed albatrosses ranged further beyond Alaskan waters than Laysan albatrosses, overlapping west coast Canada fisheries and pelagic longline fisheries in the subarctic transition domain; Laysan albatrosses remained north of these pelagic fisheries. Due to inter-specific differences in oceanic distribution and habitat use, the overlap of fisheries with the post-breeding distribution of black-footed albatrosses is greater than that for Laysan albatrosses, highlighting inter-specific differences in potential vulnerability to bycatch and risk of population-level impacts from fisheries.

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1. Introduction

Incidental seabird mortality in commercial fisheries is a global marine conservation concern (Rivera, 2000) and a widespread threat to albatross populations (Croxall and Gales, 1998). Estimates of seabird bycatch rely largely on independent observers, observer coverage varies from nearly complete in some fisheries to total absence in many others.

Spatial overlap of albatross distributions with commercial fisheries have, therefore, been widely used and endorsed as a tool to assess the magnitude of potential bycatch and to aid in directing mitigation efforts (Prince et al., 1997; Hyrenbach and Dotson, 2003; Cuthbert et al., 2005; Suryan et al., 2007). In the North Pacific Ocean all three albatross species (black-footed, *Phoebastria nigripes*, Laysan, *Phoebastria immutabilis*, and short-tailed, *Phoebastria albatrus*) are incidentally taken as bycatch in commercial fisheries (Robbins and Rice, 1974; Melvin et al., 2006).

Bycatch of black-footed and Laysan albatrosses occurs in demersal and pelagic longline fisheries throughout their ranges, spanning much of the North Pacific north of 20°N during the breeding season (November–June), and north of 30°N during the post-breeding season (July–October) (Robbins and Rice, 1974; Artyukhin and Burkanov, 2000; Cousins et al., 2000; Melvin et al., 2001; Smith and Morgan, 2005). Approximately 990 black-footed and Laysan albatrosses were killed annually between 1994 and 1999 in demersal longline fisheries in the Alaskan Exclusive Economic Zone (EEZ) (National Marine Fisheries Service, 2006b). An additional 2500 albatrosses were taken annually in pelagic longline fisheries in the Hawaiian EEZ during the same time period (National Marine Fisheries Service, 2001). Based on estimates from Hawaiian fisheries, additional bycatch in unobserved pelagic longline fisheries occurring in international waters of the North Pacific may have been responsible for thousands of additional albatross mortalities annually during this time period (Cousins et al., 2000).

Estimates of seabird mortality in fisheries can vary in their accuracy between gear types. Unlike mortality in longline fisheries that occurs when albatrosses are caught on gear (i.e., hooked) and often times brought onboard with the fishery catch, albatross mortality in trawl fisheries occurs mostly, although not exclusively, as the result of contact with cables associated with the trawl door or net monitoring devices and carcasses are not recovered in the net (Weimerskirch et al., 2000; Sullivan et al., 2006). Consequently, albatross bycatch from trawl fisheries is difficult to quantify. Nevertheless, Laysan albatross mortality has been documented in Alaskan trawl fisheries (National Marine Fisheries Service, 2006b). Limited seabird mortality has been observed in the Alaskan pot fisheries and likely results from collisions with the gear before it is set; no albatross mortality has been reported by observers in these fisheries (National Marine Fisheries Service, 2006b).

Since the late 1990s, industry- and government-led initiatives in Alaska, Hawaii, and Canada have resulted in requirements for seabird bycatch avoidance measures during some longline fishing operations, or as a condition of licensing. Consequently, significant reductions in bycatch of both black-footed and Laysan albatrosses have occurred in the last decade (Melvin et al., 2001; Smith and Morgan, 2005; National Marine Fisheries Service, 2006b). Bycatch of albatrosses in the North Pacific persists, however. Seabird bycatch avoidance measures are not required in a variety of fisheries throughout much of the North Pacific utilized by these albatrosses, compliance with regulations and efficacy of mitigation measures are variable, and levels of bycatch in many fisheries remain unknown. Population level impacts of fisheries bycatch are

likely occurring for black-footed albatrosses and may be affecting Laysan albatross populations to a lesser extent (IUCN, 2006; Veran et al., 2007). Despite these concerns, relatively little is known about the spatial overlap between fisheries and the at-sea distribution of these albatrosses, particularly during the post-breeding season.

In this study we used satellite-tracking data from black-footed and Laysan albatrosses captured in Alaska, an area of the North Pacific Ocean where both species are common during the post-breeding season, to evaluate the relative risk of interaction with the dominant fisheries they could encounter. Here, we analyzed the spatial overlap of albatrosses with Alaskan groundfish fisheries, in which albatross bycatch is quantified, as well as albatross overlap with fisheries beyond Alaska, in which bycatch is not well quantified. The objectives of this study were to (1) evaluate potential for interaction between albatrosses and fisheries in the Alaskan EEZ based on spatial overlap by region and habitats used; (2) evaluate albatross distribution with respect to fishing effort occurring outside of the Alaskan EEZ; and (3) evaluate inter-specific differences in overlap with fisheries to evaluate relative risk of interaction during the post-breeding season.

2. Methods

2.1. Satellite-tracking of albatrosses

During August 2005 and July 2006 we captured 41 black-footed albatrosses and 30 Laysan albatrosses at-sea (see Gill et al., 1970 for detailed description of capture methods) near Seguam Pass, Central Aleutian Islands, Alaska (52.08°N, 172.95°W). Only individuals that approached the boat within approximately 10 m were available for capture due to the limited range of our capture technique. If banded albatrosses were present in the group of birds attending the boat they were targeted for capture. We deployed satellite transmitters on a subsample of captured individuals. We visually inspected body feather condition of each captured individual and did not deploy transmitters on individuals whose feather condition appeared poor (i.e., extensive molting, advanced feather wear). We tracked seven black-footed albatrosses (all in 2005) and 18 Laysan albatrosses (2005: $n = 9$; 2006: $n = 9$). Albatross gender was determined from blood samples (ca. 100 μl) collected from the brachial vein (Fridolfsson and Ellegren, 1999). We determined the minimum ages of some tracked individuals (seven black-footed albatrosses and one Laysan albatross) that were previously banded as adults or nestlings using banding records. The reproductive status of tracked birds could not be determined.

We attached transmitters to the dorsal feathers of albatrosses using adhesive tape (#4651, Tesa Tape, Inc., Charlotte, North Carolina; see Wilson et al., 1997 for detailed description of attachments methods). Transmitters (KiwiSat 202, Sirtrack Limited, Havelock North, New Zealand and PTT100s, Microwave Telemetry, Inc., Columbia, MD, USA), including all attachment materials, weighed 40–60 g, <2.5% of each bird's body mass. We received position fixes for satellite-tagged albatrosses from the Argos System (CLS America, Inc., Largo, Maryland, USA) and used the Douglas Argos–Filter Algorithm

(USGS, Alaska Science Center, http://alaska.usgs.gov/science/biology/spatial/douglas.html) to determine which position fixes were retained for analyses. We used position fix filtering criteria similar to those used in prior satellite-telemetry studies of North Pacific albatrosses (Hyrenbach et al., 2002; Suryan et al., 2006). Briefly, consecutive positions that would require flying speeds in excess of 80 km h^{-1} were discarded. We retained all highest quality (level 3) position fixes and all positions within 1 km of a consecutive position fix.

Transmitters were programmed to transmit at a 75- or 90-s repetition rate on one of three duty cycles: (1) 8 h on:24 h off, (2) 24 h on:24 h off , or (3) 8 h on:16 h off. We linearly interpolated movement paths at hourly intervals, thereby standardizing tracking data among individuals (Birdlife International, 2004). We did not interpolate between position fixes separated by more than 26 h (24 h off cycle +2 h for transmission inconsistencies). We excluded the first 2 days of tracking data for each tagged albatross from subsequent analyses in order to avoid using position fixes that may have been affected by capture.

2.2.   Fisheries data

We used commercial catch and effort data for demersal longline, pot, and trawl groundfish fisheries in Alaska (excluding Pacific halibut [Hippoglossus stenolepsis] fisheries; see below) obtained from the National Marine Fisheries Service's (NMFS) North Pacific Groundfish Observer Program. Data were collected by independent observers certified by NMFS. Observer coverage varied with vessel size. Observers were present during 100% of fishing days on vessels ⩾38.1 m overall length, and 30% of fishing days on vessels 18.3–38 m in length. Observers were not required on vessels <18.3 m; therefore fishing effort from vessels of this size were not included in analyses. During observed fishing days, sets were randomly selected to be sampled for effort, catch, and location statistics. Vessel size and therefore observer coverage, however, varies among fisheries. For example, a greater percentage of the total landings of Pacific cod (Gadus macrocephalus, 88%) were sampled than that of sablefish (Anoplopoma fimbria, 18%; based on data from 1995 to 2001; Dietrich, 2003).

Fishing effort was defined for each gear type using units most appropriate for evaluations of seabird bycatch risk, the number of hooks (longline) or pots set, or the number of tow hours (trawl; National Marine Fisheries Service, 2006b). Individual set data (non-aggregated) during July–October in 2005 and in 2006 were spatially and temporally (months and years) aggregated for subsequent analyses. A given set was assigned to a catch species based on the predominant species caught (by weight) in the haul. Detailed descriptions of sampling methodologies for the observer program are available from NMFS (National Marine Fisheries Service, 2006a). We used means among unique vessels for characterizations of groundfish fisheries by depth. We assumed that observed effort was an adequate representation of relative fishing effort among species, gear types, and locations (Suryan et al., 2007).

We obtained fishing catch and effort data for the commercial Pacific halibut fishery (demersal longline) in Alaska, Canada, and the west coast of the conterminous US from the International Pacific Halibut Commission (IPHC). Independent observers are not required on vessels targeting Pacific halibut; rather, these data were compiled by the IPHC from the portion of fishing logbooks submitted by the fishing fleet. Fishing catch and effort data for 2005 and 2006 were summed across all study months (July–October) and study years, and aggregated by IPHC statistical reporting areas (Fig. 1) and by 181-m depth intervals. Data were only available for reporting areas in which three or more vessels submitted useable data. Data from 60% of total landings (by weight) during the study period were included in our analyses.

Pelagic longline fishing effort and catch statistics for tuna (Thunnus spp.) and billfish (marlins [Makaira spp. and Tetrapturus spp.] and broad-bill swordfish [Xiphias gladius]) fisheries in international waters of the North Pacific Ocean were compiled by the Oceanic Fisheries Programme of the Secretariat of the Pacific Community (http://www.spc.int/oceanfish/). Data were submitted to the Ocean Fisheries Programme from participating countries in a variety of formats (e.g., log sheets, observer program data) and combined to create a best possible database. From this public domain database, we obtained monthly effort and catch statistics in 5° × 5° cells. Effort was provided as an estimate of total hooks set across all catch species; catch statistics (number caught and weight) were aggregated by species. We analyzed fishing effort data within the latitudinal bounds of our albatross tracking data, which included all fishing effort north of 35°N.

Data from the Ocean Fisheries Programme were not available from the two years of our study; therefore, we used the mean fishing effort and catch statistics during our study months (July–October) from the preceding 5 years (2000–2004). By using data from multiple years, we attempted to account for inter-annual variation in the spatial distribution of these pelagic fisheries (Polovina et al., 2001; Hyrenbach and Dotson, 2003), which are more spatially dynamic than the demersal fisheries described above. Due to inconsistencies in data reporting for the Eastern Pacific (all grid cells east of 150°W), effort for this portion of the Pacific is underrepresented for these years (Peter Williams, Ocean Fisheries Programme, personal communication). The proportion of fishing effort represented by the available data for fisheries in the East Pacific cannot be estimated; however, these data indicate the minimum fishing effort and minimum geographic extent of fisheries in this region.

2.3.   Bathymetric data

We used seafloor depth (m) data (1-minute latitude/longitude resolution) from the General Bathymetric Chart of the Oceans (British Oceanographic Data Centre, www.bodc.ac.uk) to assign a depth value to each albatross location and gear retrieval location from the NMFS's North Pacific Groundfish Observer Program dataset. For albatross and North Pacific Groundfish Observer Program data, bathymetric domains were defined as: shelf (⩽200 m), shelf break (>200–1000 m), slope (>1000–3000 m), and oceanic (>3000 m). For International Pacific Halibut Commission data, bathymetric domain definitions were adapted to fit the data aggregations; shelf was defined as ⩽181 m and shelf break as >181–905 m. There was no Pacific halibut fishing effort reported at depths greater than 905 m.
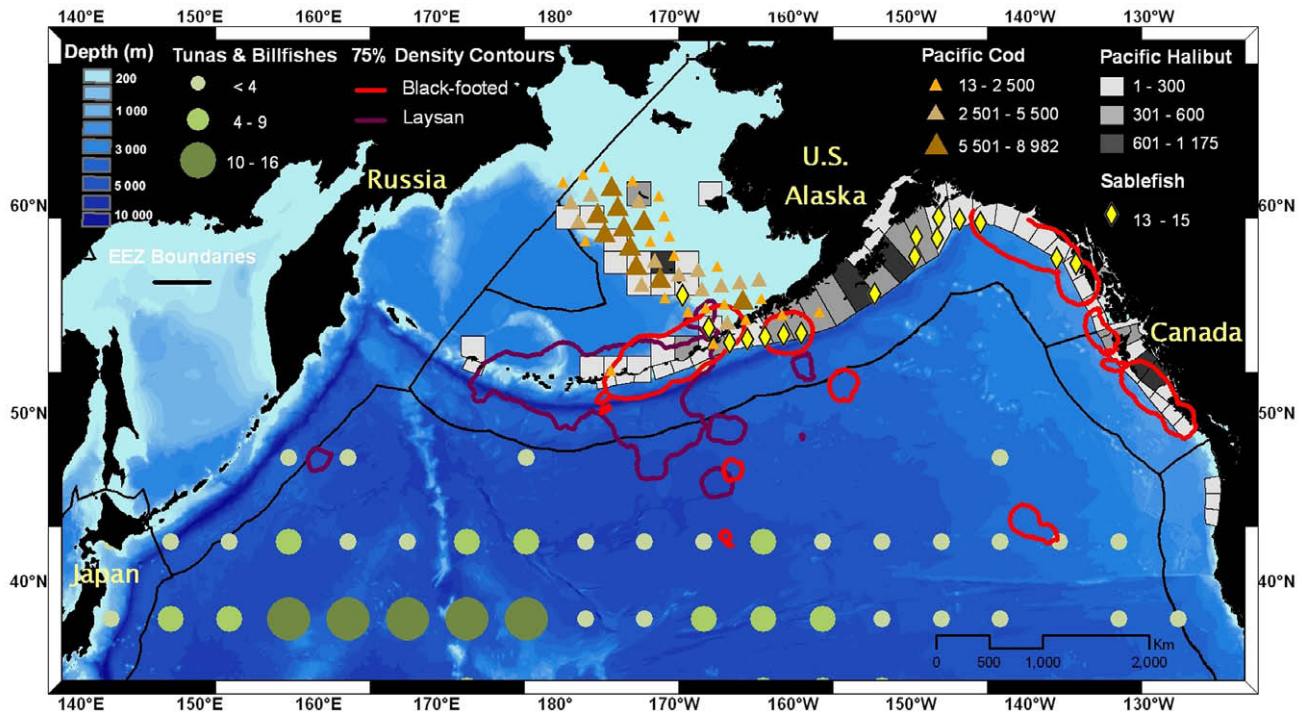
Fig. 1 – Overlap between black-footed and Laysan albatross 75% density contours of tracking hours and the spatial distribution of observed or reported longline fishing effort (1000s of hooks) in the North Pacific during July–October (years and data sources vary with fisheries, see Section 2). Most notably, sablefish effort in the Central and Western Aleutian Islands is not displayed. Fishing effort for tunas and billfishes east of 150°W is underrepresented (see Section 2). The North Pacific subarctic transition domain is located at about 40–45°N during the study months (Polovina et al., 2001).

2.4.   Analyses

We used ArcGIS (ESRI, Redlands, CA, USA) to spatially integrate albatross tracking data with fisheries data. All statistical analyses were conducted using SAS v9.1 (SAS Institute Inc.). Sex ratios were compared using χ^2 Goodness of Fit tests. Mean values are presented ±1 standard error. Non-parametric Kruskal–Wallis tests were used for intra-specific comparisons. Statistical significance was set at $\alpha = 0.05$.

2.5.   Graphical representation of geographic distribution

For mapping of albatross distributions, we created 75% density contours of albatross tracking hours using the Spatial Analyst extension of ArcGIS (ESRI, Redlands, CA, USA) in an Albers Equal Area Conic projection. We selected a smoothing factor of 110 km and a grid size of 11 km for creating these density contours, which were used for visual representation only, not for analyses.

In order to maintain confidentiality when spatially displaying commercial fishing effort on a map, data on longline, trawl, and pot fisheries obtained from NMFS's North Pacific Groundfish Observer Program, were summarized within 100 km by 100 km grid cells. Three or more unique vessels must occur within a grid cell or statistical area in order to be presented spatially on a map; as a result, portions of the complete dataset that were included in analyses and shown in Figs. 3 and 4 are not represented on maps in Figs. 1 and 2. For longline effort, 69% of cod grid cells (99% of ef-

fort) and 38% of sablefish grid cells (63% of effort) are presented. For trawl effort, 78% of walleye pollock cells (99% of effort), 56% of flatfish cells (96% of effort), and 63% of Atka mackerel cells (99% of effort) are presented; for pot effort, 28% of cells (54% of effort) are presented. Pacific halibut demersal longline fishing effort and pelagic longline fishing effort are represented on the map at the same resolution as used for analyses, statistical areas and 5° × 5° cells, respectively.

3.   Results

3.1.   Demographics of captured albatrosses

The overall sex ratio of captured albatrosses was strongly male biased; 30 (73%) of 41 black-footed albatrosses ($\chi_1^2 = 8.80$, $P = 0.003$) and 26 (87%) of 30 Laysan albatrosses were male ($\chi_1^2 = 16.13$, $P < 0.001$). The sex ratio (male:female) of tracked albatrosses was also male biased, although less so for black-footed (4:3; $n = 7$) than Laysan (17:1; $n = 18$). The ages of tracked black-footed albatrosses ranged from 1.5 to >40 years and all tracked individuals were from the Hawaiian population. One of the tracked Laysan albatrosses was banded; it was a known breeder on Guadalupe Island, Mexico and at least 3 years old (R. William Henry, University of California Santa Cruz; personal communication). The source population(s) and ages of all remaining satellite-tracked Laysan albatrosses were unknown; however, based on feather wear, they were believed to be at least 1.5 years old.
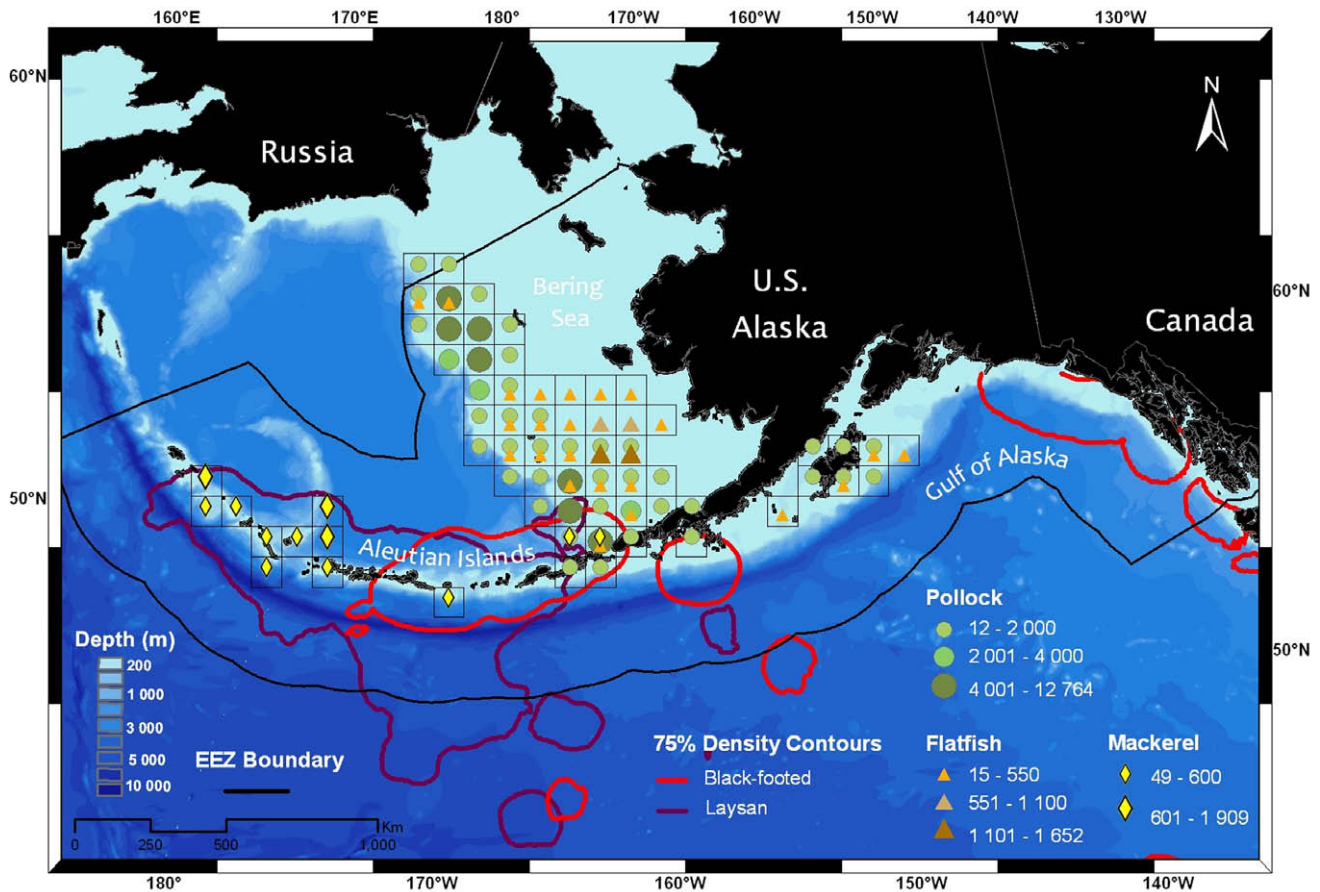
Fig. 2 – Overlap between black-footed and Laysan albatross 75% density contours and the spatial distribution of observed (a) trawl effort (tow hours) for walleye pollock, flatfish, and Atka mackerel in the Alaskan Exclusive Economic Zone, July–October 2005 and 2006. Data are summarized within 100-km by 100-km grid cells. A portion of fishing distribution is not presented (see Section 2).

3.2. Distribution of fisheries effort and satellite-tracked albatrosses in the Alaskan EEZ

Within the Alaskan Exclusive Economic Zone (EEZ), the spatial distribution of observed fisheries varied by gear type and predominant species of catch, while the distribution of albatrosses differed by species. During our study period, the largest fisheries, as measured by effort and catch, were for walleye pollock (*Theragra chalcogramma*, predominately trawl), and Pacific cod (predominately longline; Table 1). Effort in these fisheries occurred largely in the Bering Sea (>94%) and exclusively on the shelf and shelf break (Figs. 1–3). The Pacific halibut fishery occurred largely in the Gulf of Alaska (68%) and Eastern Aleutian Islands (13%) and also exclusively on the shelf and shelf break (Figs. 1 and 3). Sablefish fisheries (pot and longline) occurred largely from the Central Aleutian Islands east through the Gulf of Alaska; however, in contrast with the other fisheries, occurred largely on the shelf break (90 ± 2%) and slope (14 ± 4%; Figs. 1 and 3). The majority (94%) of the Atka mackerel (*Pleurogrammus monopterygius*) trawl fishery occurred in the Western Aleutian Islands (Fig. 2), and occurred primarily on the shelf (55 ± 7%) and shelf break (45 ± 7%, Fig. 3). Throughout the Alaskan EEZ, groundfish fisheries occurred exclusively within the continental

margin (shelf, shelf break, and slope; Fig. 3); pelagic longline fisheries were reported only occasionally (2 months in 2002, in one 5° × 5° grid cell) within the Alaskan EEZ during 2000–2004 (Fig. 1).

Mean tracking duration (total tracking days minus 2 days; see Section 2) for the sample of black-footed albatrosses was 43 ± 5 days (range: 21–57 days, $n = 7$) and for the sample of Laysan albatrosses was 59 ± 5 days (range: 35–105 days, $n = 18$). A total of 6487 and 24,140 hourly interpolated points were used for black-footed and Laysan albatrosses, respectively. Laysan albatross distribution was similar between years (depth: Kruskal–Wallis $\chi_1^2 < 1.87$, $P > 0.17$, $df = 17$; regional: Kruskal–Wallis $\chi_1^2 < 3.37$, $P > 0.07$, $df = 17$), therefore, we combined data from both years in all analyses. Satellite-tagged individuals of both black-footed and Laysan albatrosses spent the greatest proportion of time within the Alaskan EEZ (76 ± 10% and 78 ± 6%, respectively).

Within the Alaskan EEZ, the black-footed albatrosses tracked in this study spent the most time in the Central Aleutian Islands, Gulf of Alaska, and the southeast corner of the Bering Sea. Tracked Laysan albatrosses, in contrast, spent the most time in the Central and Western Aleutian Islands (Figs. 1 and 4). Among the three depth domains of the continental margin (shelf, shelf break, and slope domains), black-
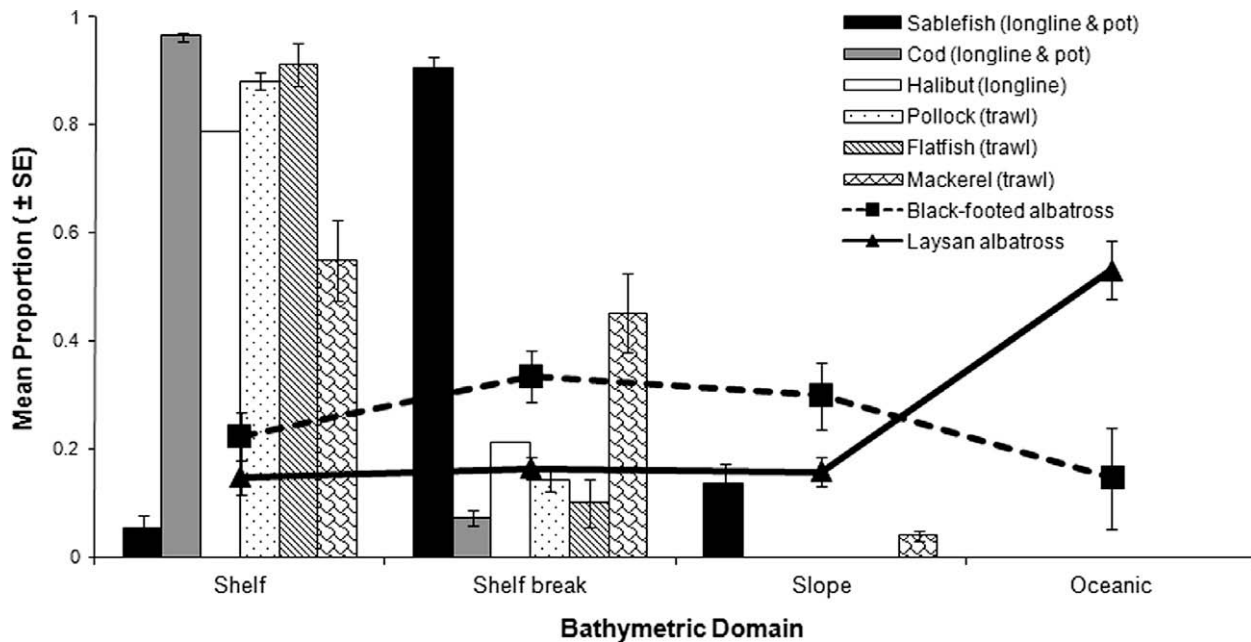
Fig. 3 – Mean (±SE, among vessels) proportion of fishing effort and mean (±SE, among albatrosses) proportion of black-footed and Laysan albatross tracking hours within the Alaskan Exclusive Economic Zone by bathymetric domain. Individual vessel data were not available for the Pacific halibut fishery; therefore values represent the overall proportion of fishing effort by depth domain.
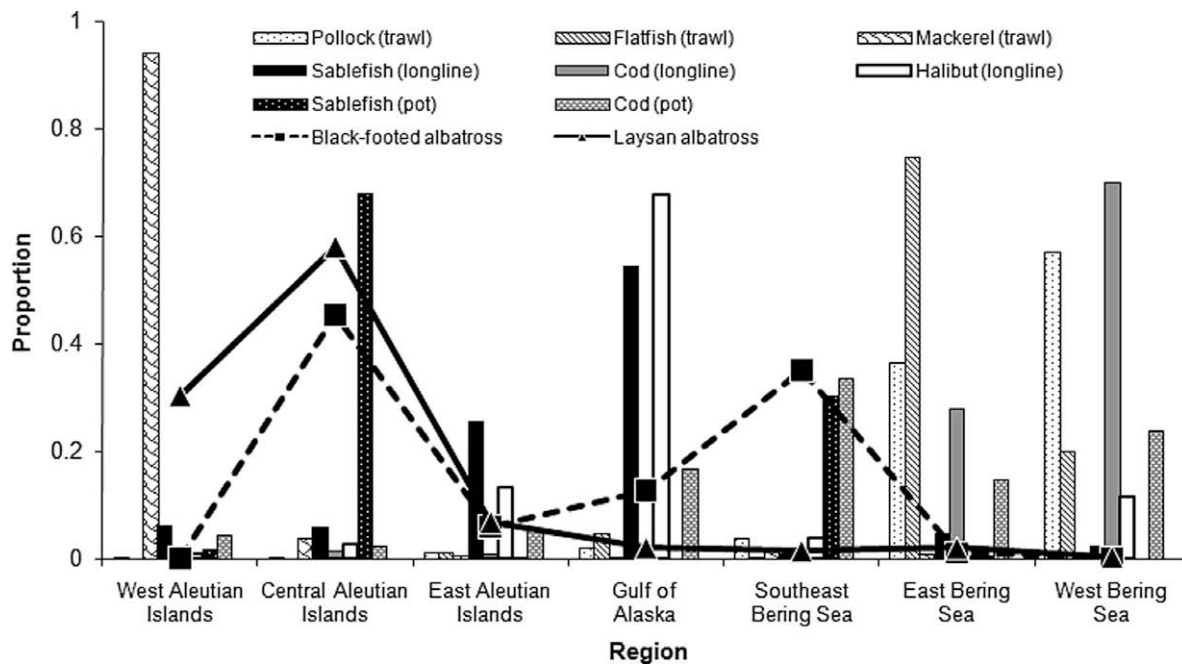

Fig. 4 – Proportion of observed or reported fishing effort (longline, trawl, and pot) and black-footed and Laysan albatross tracking hours within the Alaskan Exclusive Economic Zone by geographic region.

footed albatrosses spent similar proportions of time in each (Fig. 3). Overall black-footed albatrosses spent significantly more time over continental margin waters than over oceanic waters within the Alaskan EEZ (Kruskal–Wallis $\chi_1^2 = 9.06$, P < 0.01, df = 6). Potential interactions with fisheries for black-footed albatrosses were greatest for sablefish fisheries

and the Pacific halibut fishery, and to a lesser extent the pot cod fishery, with which they also overlapped regionally.

In contrast, Laysan albatrosses spent similar proportions of time over oceanic and continental margin waters (all three depth domains combined; Kruskal–Wallis $\chi_1^2 = 1.20$, P = 0.27, df = 17). These inter-specific differences indicate that Laysan

Table 1 – Summary of fishing effort in the Alaskan Exclusive Economic Zone during July–October, used to assess overlap with satellite-tracked black-footed albatrosses (2005) and Laysan albatrosses (2005 and 2006)

	% Of effort among species by gear type[a]	% Of total annual effort during study period	Peak effort months[b]	Number of unique vessels		Number of observed sets		Sum of total observed effort	
	2005–2006	2005–2006	2005–2006	2005	2006	2005	2006	2005	2006
Longline (hooks)									
Cod	86	53	August–February	39	40	4990	4410	75,800,655	69,521,127
Halibut[c]	7	45[d]						5,922,900	6,078,600
Sablefish	<1	17	March–June	19	39	164	318	643,769	1,372,500
Trawl (tow hours)									
Pollock	80	60	July–October, February	130	122	8109	9034	2,134,492	2,650,239
Flatfish	8	25	February–August	38	38	1107	1023	266,849	229,507
Mackerel	6	72	September–October, February	17	18	912	867	168,334	169,376
Pot (pots)									
Cod	52	39	September–October, January–February	31	26	391	362	45,372	36,639
Sablefish	46	54	April–October	4	7	449	387	36,446	36,043

a Observer requirements vary with vessel size; therefore, relative proportions of observed effort may differ from relative proportions of total effort (e.g., vessels fishing for sablefish are typically smaller than those fishing for Pacific cod, and have reduced observer coverage).
b Months over which >80% of the annual effort occurred.
c Pacific halibut data were from the International Pacific Halibut Commission.
d % Of total annual weight reported, total annual effort not available.

albatrosses overlapped less with fisheries in the Alaskan EEZ than did black-footed albatrosses. Regionally, Laysan albatrosses had the greatest potential interaction with the Atka mackerel trawl fishery in the Western Aleutian Islands and the pot sablefish fishery in the Central Aleutian Islands (Figs. 2 and 4). A small proportion of time was spent by black-footed and Laysan albatrosses (0.9 ± 0.9% and 1.9 ± 1.3%, respectively) in the Eastern and Western Bering Sea, where almost all (>94%) of the trawl effort for flatfish and pollock, plus the longline effort for Pacific cod, occurred (Fig. 4).

3.3. Distribution of satellite-tagged albatrosses and fisheries outside Alaska

Black-footed albatrosses ranged from 60°N to 36°N and from 125W° to just west of the International Date Line at 180°. This compares with Laysan albatrosses, which had a similar latitudinal range from 58°N to 38°N, but a more westerly longitudinal distribution, between 156°W and 146°E. Within the principal range of black-footed and Laysan albatrosses during the post-breeding season (north of 35°N), pelagic longline fishing effort was reported almost exclusively (99 ± 0.01%) between 35°N and 45°N, and mostly (80 ± 4%) west of the International Date Line.

Black-footed albatrosses that entered international waters (n = 4) spent on average 29 ± 7% of their overall time in waters south of 45°N and east of the International Date Line. Albacore tuna (*Thunnus alalunga*) was the predominant (84 ± 7%) species of reported catch (by weight) east of the International Date Line; consequently, it is likely that this is the pelagic longline fishery with which there is the greatest potential for interaction with black-footed albatrosses. In contrast, Laysan albatrosses that traveled into international waters (n = 12) spent little time (0.01 ± 0.4%) south of 45°N. Despite a more westerly distribution, the Laysan albatrosses tracked in this

study overlapped very little with the extensive pelagic longline fisheries in the Kuroshio Extension off Japan, which is located from 35°N to 40°N and from 145 °E to 180° (Fig. 1). West of the International Date Line, overall catch was largely comprised of broad-bill swordfish (38 ± 2%) and bigeye tuna (33 ± 4% [*T. obesus*]).

Three of seven satellite-tracked black-footed albatrosses (43%) traveled to the EEZ of British Columbia, Canada, and spent 15 ± 8% of their time there on average. Within this region, the proportion of time black-footed albatrosses spent over the shelf (10 ± 5%; range = 0–18%) and shelf break (30 ± 16%; range = 0–55%) varied among individuals. Thirty-two percent (5, 579, 300 hooks) of the total reported longline effort for Pacific halibut occurred within the British Columbian EEZ. As in the Alaskan EEZ, the Pacific halibut fishery occurred exclusively within shelf (60%) and shelf break (40%) waters. No satellite-tracked Laysan albatrosses entered the British Columbian EEZ; three Laysan albatrosses (17%), however, entered the Russian EEZ, but on average spent little time (6 ± 4%) in that region. Neither black-footed or Laysan albatrosses in this study entered the EEZ of the conterminous United States.

4. Discussion

Our data suggest that because of inter-specific differences in distribution and habitat use, black-footed albatrosses had greater exposure to the extensive demersal fisheries within the continental margin and greater exposure to pelagic longline fisheries in the Eastern North Pacific, compared to Laysan albatrosses. Throughout the regions and habitats they most heavily utilized, black-footed albatrosses had the potential to encounter fishing vessels; conversely, Laysan albatrosses largely occupied regions and habitats not as heavily utilized by fisheries, especially longline fisheries. Inter-specific differ-

ences in post-breeding season distributions of sympatrically breeding albatrosses in the southern hemisphere have also been associated with differential overlap with fisheries (Prince et al., 1997). Inter-specific behavioral differences can also affect vulnerability to fisheries bycatch in areas of overlap (Gales et al., 1998). More aggressive behavior in attacking fish discards and approaching the boat by black-footed albatrosses compared to Laysan albatrosses (KNF & RMS, personal observation) suggests that black-footed albatrosses may be more susceptible to interactions with fishing gear compared to Laysan albatrosses in areas of overlap with fisheries.

A significant bias toward males in the albatrosses captured for this study suggests gender differences in risks of fishery interaction resulting from differences in distribution or behavior, as has been observed for other albatrosses (Weimerskirch and Jouventin, 1987; Ryan and Boix-Hinzen, 1999; Awkerman et al., 2006). Gender differences in at-sea distribution can result in gender differences in overlap with fisheries (Weimerskirch and Jouventin, 1987). Gender differences in behavior or size may also lead to competitive displacement of females by males (Ryan and Boix-Hinzen, 1999). Both are plausible explanations for the strong male bias in our sample of albatrosses captured at-sea. Consequently, male black-footed and Laysan albatrosses could be at higher risk of bycatch in the Central Aleutian Islands compared to females. A potential sex-bias in fisheries bycatch is of particular conservation concern for albatrosses because population-level impacts of bycatch can be exaggerated by sex-biased extrinsic mortality (Weimerskirch et al., 1997).

Consistent with distributional patterns observed during at-sea surveys in the Alaskan EEZ (Kuroda, 1988; Melvin et al., 2006), tagged black-footed albatrosses had the greatest regional overlap with fisheries in the Central and Eastern Aleutian Islands, and the Gulf of Alaska and tagged Laysan albatrosses with fisheries in the Central and Western Aleutian Islands. Greater use of the continental margin habitats by black-footed albatrosses compared to Laysan albatrosses during the post-breeding season is consistent with observed inter-specific differences in habitat use during the breeding season (Hyrenbach et al., 2002). These combined inter-specific differences resulted in the greatest spatial overlap occurring between black-footed albatrosses and the longline and pot sablefish fisheries and the longline Pacific halibut fishery within the continental margin. Similarly noted distributions of Alaskan demersal groundfish fisheries by Dietrich, 2003 (years 1995–2000) and Suryan et al., 2007 (years 2002–2003) and similarly noted inter-specific differences in albatross distributions (Kuroda, 1988; Hyrenbach et al., 2002; Melvin et al., 2006) to those observed in this study suggest that overlap between Alaskan groundfish fisheries and albatrosses are generally consistent between years.

Despite apparent lower risk to Laysan albatrosses of interaction with fisheries in the Alaskan EEZ, especially longline fisheries, our results suggest that the risk of interaction with Alaskan trawl fisheries may have been greater for Laysan albatrosses compared to black-footed albatrosses. Trawl effort for Atka mackerel during the post-breeding season was concentrated in the Western Aleutian Islands, a region of significant overlap with tagged Laysan albatrosses and a region where Laysan albatrosses outnumber black-footed alba-

trosses in at-sea surveys (Kuroda, 1988; Melvin et al., 2006). Additionally, although Laysan albatrosses in this study did not make extensive movements into the Bering Sea, at-sea survey data has demonstrated their use of this region during the post-breeding season (Wahl et al., 1989; Melvin et al., 2006). Therefore, overlap exists between Laysan albatrosses and the extensive longline fishery for Pacific cod and trawl fisheries for pollock and flatfish on the Bering Sea shelf. The conservation consequences of overlap with trawl fisheries are difficult to assess, although significant levels of albatross mortality have been documented in some southern hemisphere trawl fisheries (Weimerskirch et al., 2000; González-Zevallos and Yorio, 2006; Sullivan et al., 2006). Continued efforts to improve measurement and mitigation of risks in these North Pacific trawl fisheries (Melvin et al., 2004) may be particularly relevant to Laysan albatross conservation.

The results of this study support the hypothesized relationship between albatross bycatch numbers in the Alaskan longline groundfish fisheries and spatial and temporal overlap with fisheries (Dietrich, 2003). Although the sablefish fishery represents a relatively small portion of the overall observed longline effort in the Alaskan EEZ, both black-footed and Laysan albatross bycatch has been highest in this fishery (Dietrich, 2003). This is consistent with the spatial overlap observed in our study, especially for black-footed albatrosses. Overlap of black-footed albatrosses with the unobserved Pacific halibut longline fishery was similar to that of the longline sablefish fishery. Albatross bycatch in the Pacific halibut fishery, however, is not well understood because no systematic observer program has been in place (Melvin et al., 2006). Laysan albatross bycatch in the Alaskan EEZ before the implementation of seabird avoidance measures was greatest during April–June (Dietrich, 2003), coincident with the peak months of longline effort for sablefish, but not overlapping our study period (July–October). Although there was little observed sablefish fishing effort that overlapped tracked Laysan albatrosses in the Western Aleutian Islands, greater fishing effort in this region in the months prior to tracking may explain why bycatch of Laysan albatrosses was highest in the sablefish fishery.

Outside the Alaskan EEZ, overlap with fisheries is also likely to be greater for black-footed albatrosses compared to Laysan albatrosses. Some of the satellite-tracked black-footed albatrosses also utilized the continental margin within the British Columbian EEZ, where they have been taken as bycatch in Pacific halibut, sablefish, and rockfish (Sebastes spp.) longline fisheries (Smith and Morgan, 2005). This suggests that there is potential for bycatch risk in similar fisheries that occur along the west coast of the conterminous US, where black-footed albatrosses are more abundant than Laysan albatrosses (Briggs et al., 1987) and seabird bycatch has not been fully quantified.

Additional bycatch risk is present in much of the range of black-footed albatrosses during the post-breeding season; black-footed albatrosses that overlapped with the demersal longline fisheries within the continental margins of Alaska and British Columbia also traveled to regions used by pelagic longline fisheries. Pelagic longline fisheries for tunas and billfishes in the Western North Pacific are largely associated with subtropical to tropical waters or convergent fronts of temper-

ature or chlorophyll (Polovina et al., 2000, 2001). Black-footed albatrosses tracked during this study ranged into subtropical waters south of 45°N and overlapped with the pelagic longline fishery for albacore tuna. Bycatch of black-footed and Laysan albatrosses in pelagic longline tuna fisheries in Hawaii is well-documented and, therefore, overlap with similar fisheries likely poses a risk of bycatch (Cousins et al., 2000).

Bycatch risk for black-footed and Laysan albatrosses exist beyond the regions utilized by individuals tracked during this study. Although Laysan albatrosses tracked during this study appeared to be at little risk of interactions with fisheries outside of the Alaskan EEZ because little overlap occurred with reported or observed fisheries, neither black-footed nor Laysan albatrosses were tracked to the Kuroshio Extension east of Japan. However, at-sea surveys and bycatch records show Laysan albatrosses to be abundant and black-footed albatrosses in lesser numbers in this region of the Western Pacific during the post-breeding and post-breeding dispersal periods (Fisher & Fisher, 1972; Robbins and Rice, 1974; Kuroda, 1988; Wahl et al., 1989; Fernández et al., 2001). The extensive pelagic longline fishing effort reported in this area may, therefore, be a considerable threat to Laysan albatrosses in particular. As a result of fishing practices (e.g., time of day, bait type), albatross bycatch has been found to be greater in pelagic longline fisheries targeting broad-bill swordfish compared to tunas (Cousins et al., 2000). Therefore, albatrosses using this region may be especially vulnerable to bycatch because of the relatively high catch of swordfish during the post-breeding season, compared to the Eastern Pacific.

Our results demonstrate that spatial overlap of black-footed and Laysan albatrosses with fisheries differed between albatross species and among fisheries. The results of this study may help to explain why basin-wide black-footed albatross bycatch estimates exceed those of Laysan albatross, despite Laysan albatross breeding population estimates of more than nine times those of black-footed albatross (Naughton et al., 2007). Black-footed albatrosses tracked from Alaska during the post-breeding season overlapped with fisheries in which bycatch is known to occur throughout their range, which was mostly within the continental margin of the EEZs off Alaska and British Columbia and into the North Pacific subarctic transition domain. Our tracking results provide little evidence that black-footed albatrosses spent time within regions devoid of fisheries during the post-breeding season. Conversely, Laysan albatrosses remained largely over oceanic waters, away from the concentration of fisheries within the continental margin, and north of the pelagic longline fisheries. Consequently, our results suggest that the potential threat from fisheries bycatch was greater for black-footed albatrosses tracked from Alaska than for Laysan albatrosses during the post-breeding season.

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REFERENCES

Artyukhin, Y.B., Burkanov, V.N., 2000. Incidental mortality of seabirds in the drift net salmon fishery by Japanese vessels in the Russian Exclusive Economic Zone, 1993–1997. In: Kondratyev, A.Y., Litvinenko, N.M., Kaiser, G.W. (Eds.), Seabirds of the Russian Far East. Canadian Wildlife Service, Ottawa, Ontario, pp. 105–115.

Awkerman, J.A., Huyvaert, K.P., Mangel, J., Shigueto, J.A., Anderson, D.J., 2006. Incidental and intentional catch threatens Galápagos waved albatross. Biological Conservation 133, 483–489.

Briggs, K.T., Tyler, W.B., Lewis, D.B., Carlson, D.R., 1987. Bird communities at sea off California: 1975–1983. Studies in Avian Biology 11, 1–74.

Cousins, K.L., Dalzell, P., Gilman, E., 2000. Managing pelagic longline–albatross interactions in the North Pacific Ocean. Marine Ornithology 28, 159–174.

Croxall, J.P., Gales, R., 1998. An assessment of the conservation status of albatrosses. In: Robertson, G., Gales, R. (Eds.), Albatross Conservation and Biology. Surrey Beatty & Sons, Chipping Norton, Australia, pp. 45–65.

Cuthbert, R., Hilton, G., Ryan, P., Tuck, G.N., 2005. At-sea distribution of breeding Tristan albatrosses *Diomedea dabbenena* and potential interactions with pelagic longline fishing in the South Atlantic Ocean. Biological Conservation 121, 345–355.

Dietrich, K.S., 2003. Factors affecting seabird bycatch in Alaska longline fisheries. Unpublished M.S. Thesis, University of Washington, Seattle, WA, p. 110.

Fernández, P., Anderson, D.J., Sievert, P.R., Huyvaert, K.P., 2001. Foraging destinations of three low-latitude albatross (*Phoebastria*) species. Journal of Zoology 254, 391–404.

Fisher, H.I., Fisher, J.R., 1972. The oceanic distribution of the Laysan albatross, *Diomedea immutabilis*. Wilson Bulletin 84, 7–27.

Fridolfsson, A.-K., Ellegren, H., 1999. A simple and universal method for molecular sexing of non-ratite birds. Journal of Avian Biology 30, 116–121.

Gales, R., Brothers, N., Reid, T., 1998. Seabird mortality in the Japanese tuna longline fishery around Australia, 1988–1995. Biological Conservation 86, 37–56.

Gill, D.E., Sladen, W.J.L., Huntington, C.E., 1970. A technique for capturing petrels and shearwaters at sea. Bird-Banding 41, 111–113.

González-Zevallos, D., Yorio, P., 2006. Seabird use of discards and incidental captures at the Argentine hake trawl fishery in the Golfo San Jorge, Argentina. Marine Ecology Progress Series 316, 175–183.

Hyrenbach, K.D., Dotson, R.C., 2003. Assessing the susceptibility of female black-footed albatross (*Phoebastria nigripes*) to

longline fisheries during their post-breeding dispersal: an integrated approach. Biological Conservation 112, 391–404.

Hyrenbach, K.D., Fernandez, P., Anderson, D.J., 2002. Oceanographic habitats of two sympatric North Pacific albatrosses during the breeding season. Marine Ecology Progress Series 233, 283–301.

Birdlife International, 2004. Tracking ocean wanderers: the global distribution of albatrosses and petrels. In: Results from the Global Procellariiform Tracking Workshop, 1–5 September, 2003, Gordon's Bay, South Africa. Cambridge, UK.

IUCN, 2006. 2006 IUCN Red List of Threatened Species. <www.iucnredlist.org>.

Kuroda, N., 1988. A distributional analysis of *Diomedea immutabilis* and *D. Nigripes* in the North Pacific. Journal of the Yamashina Institute for Ornithology 20, 1–20.

Melvin, E.F., Parrish, J.K., Dietrich, K.S., Hamel, O.S., 2001. Solutions to seabird bycatch in Alaska's demersal longline fisheries. Washington Sea Grant Program. Project A/FP-7, Seattle, WA, p. 45.

Melvin, E.F., Dietrich, K.S., Thomas, T., 2004. Pilot tests of techniques to mitigate seabird interactions with catcher processor vessels in the Bering Sea pollock trawl fishery: final report. Washington Sea Grant Program, Seattle, WA, p. 12.

Melvin, E.F., Wainstein, M.D., Dietrich, K.S., Ames, K.L., Geernaert, T.O., Conquest, L.L., 2006. The distribution of seabirds on the Alaskan longline fishing grounds: implications for seabird avoidance regulations. Washington Sea Grant Program. Project A/FP-7, Seattle, WA, p. 20.

National Marine Fisheries Service, 2001. Final environmental impact statement. Fishery Management Plan Pelagic Fisheries of the Western Pacific Region. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Honolulu, HI.

National Marine Fisheries Service, 2006a. North Pacific Groundfish Observer Manual. North Pacific Groundfish Observer Program. Alaska Fisheries Science Center, Seattle, WA.

National Marine Fisheries Service, 2006b. Summary of seabird bycatch in Alaskan groundfish fisheries, 1993–2004. National Marine Fisheries Service, Seattle, WA.

Naughton, M.B., Romano, M.D., Zimmerman, T.S., 2007. A Conservation Action Plan for Black-Footed Albatross (*Phoebastria nigripes*) and Laysan Albatross (*P. immutabilis*), Ver. 1.0. US Fish and Wildlife Service, Portland, OR. p. 37.

Polovina, J.J., Kobayashi, R.D., Parker, M.D., Seki, P.M., Balazs, H.G., 2000. Turtles on the edge: movement of loggerhead turtles (*Caretta caretta*) along oceanic fronts, spanning longline fishing grounds in the central North Pacific, 1997–1998. Fisheries Oceanography 9, 71–82.

Polovina, J.J., Howell, E., Kobayashi, D.R., Seki, M.P., 2001. The transition zone chlorophyll front, a dynamic global feature defining migration and forage habitat for marine resources. Progress in Oceanography 49, 1–4.

Prince, P.A., Croxall, J.P., Trathan, P.N., Wood, A.G., 1997. The pelagic distribution of South Georgia albatrosses and their relationships with fisheries. In: Robertson, G., Gales, R. (Eds.), Albatross Biology and Conservation. Surrey Beatty & Sons, Chipping Norton, Australia, pp. 137–167.

Rivera, K.S., 2000. The FAO international plan of action for reducing incidental catch of seabirds in longline fisheries-seabirds: what are countries doing? Marine Ornithology 28, 175–178.

Robbins, C.S., Rice, D.W., 1974. Recoveries of banded Laysan albatrosses (*Diomedea immutabilis*) and black-footed albatrosses (*D. nigripes*). In: King, W.B. (Ed.), Pelagic Studies of Seabirds in the Central and Eastern Pacific Ocean, Smithsonian Contributions to Zoology. Smithsonian Institute Press, Washington, DC, pp. 232–277.

Ryan, P.G., Boix-Hinzen, C., 1999. Consistent male-biased seabird mortality in the Patagonian toothfish longline fishery. Auk 116, 851–854.

Smith, J.L., Morgan, K.H., 2005. An Assessment of Seabird Bycatch in Longline and Net Fisheries in British Columbia. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia. p. 51.

Sullivan, B.J., Reid, T.A., Bugoni, L., 2006. Seabird mortality on factory trawlers in the Falkland Islands and beyond. Biological Conservation 131, 495–504.

Suryan, R.M., Sato, F., Balogh, G.R., David Hyrenbach, K., Sievert, P.R., Ozaki, K., 2006. Foraging destinations and marine habitat use of short-tailed albatrosses: a multi-scale approach using first-passage time analysis. Deep-Sea Research Part II 53, 370–386.

Suryan, R.M., Dietrich, K.S., Melvin, E.F., Balogh, G.R., Sato, F., Ozaki, K., 2007. Migratory routes of short-tailed albatrosses: use of exclusive economic zones of North Pacific Rim countries and spatial overlap with commercial fisheries in Alaska. Biological Conservation 137, 450–460.

Veran, S., Gimenez, O., Flint, E., Kendall, W.L., Doherty Jr., P.F., Lebreton, J.-D., 2007. Quantifying the impact of longline fisheries on adult survival in the black-footed albatross. Journal of Applied Ecology 44, 942–952.

Wahl, T.R., Ainley, D.G., Benedict, A.H., DeGrange, A.R., 1989. Associations between seabirds and water-masses in the northern Pacific Ocean in summer. Marine Biology 103, 1–11.

Weimerskirch, H., Jouventin, P., 1987. Population dynamics of the wandering albatross, *Diomedea exulans*, at the Crozet Islands: causes and consequences of the population decline. Oikos 49, 315–322.

Weimerskirch, H., Brothers, N., Jouventin, P., 1997. Population dynamics of wandering albatross *Diomedea exulans* and Amsterdam albatross *D. Amsterdamensis* in the Indian Ocean and their relationships with long-line fisheries: conservation implications. Biological Conservation 79, 257–270.

Weimerskirch, H., Capdeville, D., Duhamel, G., 2000. Factors affecting the number and mortality of seabirds attending trawlers and long-liners in the Kerguelen area. Polar Biology 23, 236–249.

Wilson, R.P., Putz, K., Peters, G., Culik, B., Scolaro, J.A., Charrassin, J.B., Ropert-Coudert, Y., 1997. Long term attachment of transmitting and recording devices to penguins and other seabirds. Wildlife Society Bulletin 25, 101–106.