NORTH PACIFIC RESEARCH BOARD PROJECT FINAL REPORT

Marine Habitat Use of North Pacific Albatrosses During the Non-breeding Season and Their Spatial and Temporal Interactions with Commercial Fisheries in Alaska.

NPRB Project 532 Final Report

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Abstract

Albatrosses are among a group of upper trophic level consumers that are highly migratory yet relatively abundant in Alaskan waters. Therefore, albatrosses are an important ecosystem component, but also vulnerable to fishery interactions. We studied the marine habitat use of three species of albatrosses and their spatial and temporal overlap with commercial fisheries using stable isotope analysis, satellite tacking, satellite remote sensing, and fisheries effort/seabird bycatch data. Albatross species showed strong differences in foraging niches and habitat associations. Short-tailed albatrosses had the strongest association with continental shelf break and slope regions (although, juveniles also frequented shelf habitats). Black-footed albatrosses were the most varied in habitat use, whereas Laysan albatrosses most often used oceanic habitats well offshore of the continental slope, but still north of the sub-arctic transition domain.

Short-tailed albatrosses had the greatest overlap with Bering Sea walleye pollock and Pacific cod fisheries and all three albatross species with Aleutian Islands sablefish and Pacific halibut fisheries, although short-tailed and Laysan more so with fisheries in the western Aleutians, including Atka mackerel. Black-footed and juvenile short-tailed albatrosses had the greatest overlap with Gulf of Alaska and west coast Pacific halibut and sablefish fisheries and overlapped a portion of the high seas tuna fishery. Laysan albatrosses overall had the least spatial overlap with North Pacific fisheries, spending the majority of time in areas devoid of fishing activities. These results provide an improved understanding of ecological relationships among North Pacific albatrosses, as well as indicating inter-specific differences in potential interactions with regional fisheries.

Key Words

Albatross, Aleutian Islands, Bering Sea, fishery interactions, isotopes, marine habitat use, *Phoebastria*, satellite remote sensing, satellite telemetry

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Study Chronology

March 2005: NPRB funding approved

August 2005: Field work for season 1 of 2 conducted

November 2005: Complete first season's tracking of satellite-tagged albatrosses

December 2005: Begin acquiring and processing remote sensing data layers and writing data analysis programs.

January 2006: Present preliminary results of year one tracking efforts at the Alaska Marine Science Meeting

May 2006: Begin efforts to obtain Alaska Groundfish Observer Program data through a collaborative agreement with NOAA. Also begin efforts to obtain fishery data from the International Pacific Halibut Commission and North Pacific pelagic tuna longline.

July 2006: Field work for season 2 of 2 conducted

November 2006: Complete first season's tracking of satellite-tagged albatrosses (including related tracking studies that occurred from the Torishima, Japan, breeding colony in February 2006; funded by the U.S. Fish and Wildlife Service and Japan Ministry of Environment).

January 2007: Present preliminary results at the Alaska Marine Science Meeting

February 2007: Present preliminary results to the North Pacific Fisheries Management Council – data on juvenile short-tailed albatrosses used to modify proposed changes to seabird deterrent regulations.

March 2007: Obtain NMFS Groundfish Observer Program data and North Pacific pelagic tuna longline data.

July 2007: Obtain IPHC fishery effort data

August 2007: Submit NPRB final report

Fall 2007: Manuscripts within this report will be submitted for publication. Data from NPRB projects R0322 and F0532 will be incorporated into Metavist, wdx the NPRB data archive.

Some results within this final report were presented in NPRB progress reports (twice annually, July 2005 – January 2007). All satellite tracking data from this project have been included in the BirdLife International Global Procellariiform Tracking Database. Portions of tracking data also were provided to NOAA Fisheries (NPFMC and U.S. Russia bilateral fisheries meetings), Canadian Wildlife Service, Minerals Management Service, U.S. Navy (via Geo Marine Inc.), Washington Sea Grant, British Columbia bird records, and Oregon bird records. Maps showing data will appear in two popular outlets, Audubon Magazine and a hard cover Albatrosses of the World book (photographs and essays by Tui De Roy).

Introduction

Globally, approximately 70% of albatross species are listed as threatened or endangered by the World Conservation Union (IUCN Red List) and incidental take in longline fisheries is thought to be a key cause in many of the declines (Gales 1998, Brothers et al. 1999). In Alaska, approximately 750 Laysan albatrosses (*Phoebastria immutabilis*) and black-footed albatrosses (*Phoebastria nigripes*) were killed annually between 1993 and 2004 in demersal longline fisheries (National Marine Fisheries Service, 2006). An estimated 12 short-tailed albatrosses were killed between 1993 and 2004 (National Marine Fisheries Service, 2006) and, although no observed fatalities have occurred since 1998, it is likely that some fishery-related mortality does occur each year (U.S. Fish and Wildlife Service, 2003). An additional 3,000 albatrosses were estimated to be taken annually in the Hawaiian longline fishery during a similar time period. (National Marine Fisheries Service 2001). Furthermore, estimated take of these albatrosses remains unquantified for other North Pacific fisheries (e.g. Russia and Japan), but international discussions among government agencies to obtain these data are in progress. Such compounded mortality has the potential to cause population declines in these long-lived, slowly reproducing species, as modeled by Lewison and Crowder (2003). Fortunately, agency and industry supported implementation of seabird deterrent devices and deterrent effectiveness studies have made great strides in reducing seabird bycatch in longline fisheries in recent years (Melvin et al. 2001, Gilman et al. 2003). However, seabird deterrents are not used in all fisheries that potentially harm albatrosses or in all regions where North Pacific albatrosses occur.

An understanding of how environmental conditions delineate important albatross foraging grounds and oceanic habitats is essential to assess potential fishery interactions, and how these conflicts may vary annually in response to natural changes in the marine environment. This information, in turn, can help to assess the efficacy of management actions. For seabird bycatch in the North Pacific, the greatest immediate concern is for the short-tailed albatross, owing to its endangered species status. Due to Endangered Species Act biological opinions issued by the U.S. Fish and Wildlife Service (FWS), the Alaska demersal groundfish fishery is authorized to take only four short-tailed albatrosses every two years, while only two per two years are authorized for the halibut fishery and two birds in five years for the trawl fishery (U.S. Fish and Wildlife Service, 2003). The National Marine Fisheries Service must re-evaluate mitigation efforts and potentially impose further fishery restrictions if these authorized take levels are exceeded. Improving our understanding of the marine distribution and the oceanic habitats exploited by albatrosses will benefit the long-term viability of Alaskan fisheries by defining when and where fishery-albatross interactions are most likely to occur and to what extent Alaska fisheries may be responsible for mortality of individual species throughout their broad range.

In a pilot study funded by NPRB (R0322), we focused our efforts solely on short-tailed albatrosses. In this study, we also included black-footed and Laysan albatrosses, which provides multiple benefits. First, these species too are incidentally taken in commercial fisheries and population declines at some colonies are thought to have been related to fisheries bycatch (Cousins and Cooper 2000, Gilman and Freifeld 2003). Second, the vast majority of North Pacific albatross satellite tracking effort to date has occurred during the breeding season (Nov – May; Fernandez et al. 2001, Scott Shaffer [Tracking of Pacific Pelagics, www.toppcensus.org] pers. comm.), therefore little satellite tracking data exist during the non-breeding period (when birds are free from the constraints of egg or chick attendance) and more predominantly in Alaskan waters. Published (Yesner 1976) and unpublished speculation exists as to whether Laysan albatross population growth during the 20th century may have expanded to fill the niche of the previously more abundant short-tailed albatross, thereby potentially limiting their current recovery. Lastly, a multi-species comparison of marine habitat use and overlap with commercial fishing effort would help identify habitat partitioning or lack thereof and explain potentially varying bycatch rates among these sometimes sympatrically occurring species. Furthermore, during a recent workshop to establish a global albatross tracking database for addressing Marine Important Bird Areas and albatross bycatch in all oceans (hosted by BirdLife International) the 28 researchers representing eight counties identified the non-breeding period to be a major gap in tracking data for nearly all species of albatrosses. This project helps to fill that gap for all albatross species in Alaskan waters.

We studied the marine habitat use of three species of albatrosses and the spatial-temporal interactions with commercial fisheries using satellite tacking of albatrosses, satellite remote sensing of marine habitats, and fisheries effort/seabird bycatch data. This was the first synoptic study of all North Pacific albatross species during the non-breeding period, when they are most common in Alaskan waters. We integrated satellite-tracking of albatrosses and remotely sensed data to compare marine habitat use among North Pacific albatrosses. Most albatrosses were captured at-sea near Seguam Pass, Aleutian Islands, in August 2005 and July 2006; seven short-tailed albatrosses also were captured in February 2006 at the breeding colony on Torishima, Japan. Between July and November, we successfully tracked 13 short-tailed (*Phoebastria albatrus*), 7 black-footed (*P. nigripes*), and 18 Laysan albatrosses (*P. immutabilis*) in Alaskan waters, accumulating over 15,000 locations.

Working Hypothesis (1): Albatrosses exploit foraging areas characterized by species-specific water depth, ocean temperature, and chlorophyll a concentrations.

Working Hypothesis (2): Diets as inferred by blood stable isotope signatures will reflect inter-specific differences in habitat use.

Working Hypothesis (3): Age and gender will influence at-sea movements, distribution, and habitat associations.

Working Hypothesis (4): Variation in marine habitat use will cause species-, gender-, and age-specific exposure to different fisheries inside and outside of Alaska.

Objectives

The primary objectives of this study were to: (1) Determine the at-sea distribution and movement patterns of North Pacific albatrosses where they are sympatric in summer foraging areas; (2) Identify marine habitat features influencing albatross distribution; (3) Determine relative trophic position and nutrient sources of albatross species through stable isotope analysis; (4) Identify the proportion of time albatrosses spend within the U.S. Exclusive Economic Zone off Alaska vs. other North Pacific Rim countries or international waters; (5) Assess spatial and temporal overlap with commercial fisheries; (6) Quantify the relative proportion of fishing effort that occurs within habitats used by Albatrosses.

Chapter 1: Resource Partitioning Of Non-Breeding North Pacific Albatrosses

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Abstract

Competition within foraging habitat is hypothesized to affect inter- and intra-specific differences in the pelagic distribution of upper trophic level consumers, including albatrosses. For North Pacific albatrosses, it has been suggested that anthropogenic exploitation causing near extinction of one species, the short-tailed albatross (*P. albatrus*), may have facilitated niche expansion of other species, particularly Laysan albatrosses (*P. immutablilis*), thereby increasing inter-specific foraging competition and potentially limiting population recovery of endangered short-tailed albatrosses. We tested the inter-specific foraging competition hypothesis by incorporating stable isotope analysis with the first simultaneous satellite tracking studying of all three North Pacific albatross species while sympatric on summer foraging grounds. Carbon isotope ratios and tracking data identify differences in primary foraging domains of neritic waters for short-tailed and black-footed albatrosses (*P. nigripes*) vs. oceanic waters for Laysan. Short-tailed and black-footed albatrosses also fed at higher trophic levels than Laysan. Habitat segregation additionally occurred at a broader geographic scale, with short-tailed albatrosses ranging more north into the Bering Sea than black-footed albatrosses, which ranged more to the southeast, and Laysan, which ranged more to the southwest. Observed resource partitioning during the non-breeding season suggests that inter-specific foraging competition is not likely hindering population recovery of the short-tailed albatross. Furthermore, our results indicate that differences in carbon isotope signatures among North Pacific albatross species is likely an indication of primarily nearshore vs. offshore foraging rather than latitudinal differences in distribution.

Keywords stable isotopes, carbon, nitrogen, *Phoebastria*, satellite telemetry

Introduction

Despite the immensity of ocean habitat, highly mobile, upper trophic-level consumers often congregate in specific regions that apparently provide greater foraging efficiency, but sometimes with an additional cost of increased competition for prey (Ballance et al. 1999; Worm et al. 2005). For seabirds, inter- and intra-specific foraging competition has been suggested to influence the geographic distribution of breeding colonies (Ainley et al. 2003; Furness and Birkhead 1984; Lewis et al. 2001), foraging distribution of sympatrically breeding species (Gonzalez-Solis et al. 2000; Phillips et al. 2005a), and even distributions of individuals during the post-breeding season (Phillips et al. 2005b).

Among the most mobile of pelagic seabirds, albatrosses often forage within convergence zones, areas of steep bathymetric relief, including seamounts and continental shelf edges, in addition to other biophysical features that concentrate prey resources (Waugh et al. 1999; Yen et al. 2004). Relative proportional use of these features and general distribution of individuals, however, can vary markedly within and among species, and is likely related to preferred prey types (Cherel et al. 2002; Waugh et al. 1999).

For North Pacific albatrosses (short-tailed, *Phoebastria albatrus*, black-footed, *P. nigripes*, and Laysan, *P. immutabilis*), vessel-based and satellite tracking data indicate broad-scale differences among species in geographic distribution, however, there also are large regions of spatial overlap (Melvin et al. 2006; Shuntov 1972; Springer et al. 1999). Limited dietary analyses of black-footed and Laysan albatrosses indicate some foraging niche divergence during the breeding season (samples from breeding colonies in Hawaii and Mexico: Harrison et al. 1983; Pitman et al. 2004) and non-breeding seasons (samples from driftnet fisheries in the North Pacific transition zone: Gould et al. 1997). Unfortunately, published diet data from short-tailed albatrosses are not available for comparison. Therefore, the degree of potential foraging competition vs. niche partitioning where all three species sympatrically occur is largely unknown.

North Pacific albatrosses breed at low latitude colonies, but migrate north during the post-breeding season. The waters off Alaska appear to be an important foraging destination for all three species and from colonies throughout their breeding ranges, particularly during the post-breeding season (Fernández et al. 2001; Fischer 2007; Suryan et al. 2006). Indeed, throughout recent millennia albatrosses have been hunted for food by Alaskan natives, although the relative occurrence of the three species has changed in archaeological remains (Yesner 1976). As populations of short-tailed albatrosses declined due to anthropogenic exploitation, their occurrence in archaeological remains also declined, whereas the occurrence of Laysan albatross remains increased. Yesner (1976) speculated (while acknowledging limited sample sizes) that increasing populations of Laysan albatrosses (> 1,000,000 individuals) may have expanded into the former range of a once even more abundant, but now very small, population of short-tailed albatrosses (< 3,000 individuals). Similar reasoning has fostered speculation (unpublished) of possible competitive exclusion limiting the population recovery of the endangered short-tailed albatross. We tested the inter-specific foraging competition hypothesis by incorporating dietary stable isotope analysis with the first simultaneous satellite tracking study of North Pacific albatross species while sympatric on post-breeding season foraging grounds.

Materials and methods

Albatrosses were captured at-sea near Seguam Pass, Aleutian Islands, Alaska (52^{o} 25.8′ N, 172^{o} 46.4′ W) between 3 – 12 August 2005 and 12 – 21 July 2006. We collected blood samples for stable isotope analysis from 77 albatrosses and satellite-tagged a subsample of these individuals (n = 31 albatrosses providing over three weeks of tracking data - 65% of transmitters deployed; Table 1).

Carbon and nitrogen isotope analysis was conducted on whole blood collected from the brachial vein, providing a time-integrated record of diet over an approximately 14 day period (Hobson and Clark 1992; Hobson and Clark 1993). Blood samples were stored frozen until oven dried and pulverized to a fine powder. Isotope analyses were conducted by the Colorado Plateau Stable Isotope Laboratory at Northern Arizona University (http://www.mpcer.nau.edu/isotopelab/index.html) using a DELTA^{plus} Advantage gas chromatograph mass spectrometer interfaced with a ConFlo III for high precision, automated continuous-flow analysis. Isotopic signatures, δ^{13}C and δ^{15}N, are expressed as ratios (‰) of the sample to international standards for carbon (Vienna Pee Dee Belemnite) and nitrogen (air).

Satellite tracking occurred between 8 August and 18 November 2005 and 14 July 30 November 2006. Transmitters were 35-100 g and < 2.5% of body mass. Satellite-derived position fixes were provided through Service Argos, Inc. We used a forward-backward speed filtering algorithm to cull erroneous locations (McConnell et al. 1992). We used a maximum speed cut-off of 80 km h^{-1}, which is consistent with speed thresholds previously used to filter Argos locations for short-tailed (Suryan et al. 2006), black-footed, and Laysan albatrosses (Hyrenbach et al. 2002). Duty cycles varied by transmitter and were either 24 hr on and 24 hr off, 8 hr and 24 hr off, or 8 hr on and 16 hr off. We, therefore, standardized tracking data by resampling and linearly interpolating movement paths with locations spaced at hourly intervals (BirdLife International 2004). We did not interpolate between filtered Argos locations separated by more than 26 hr (24 hr off cycle + 2 hr for transmitter inconsistencies).

We determined sea floor depth at each interpolated albatross location from the General Bathymetric Chart of the Oceans (British Oceanographic Data Centre, www.bodc.ac.uk). We used a grid of 1 min latitude and longitude resolution. We classified surface waters overlaying bathymetric domains as: continental shelf ($\leq$ 200 m depth), shelf break (> 200 m and $\leq$ 1 000 m), slope (> 1 000 m and $\leq$ 3 000 m), and oceanic (> 3 000 m). We calculated the proportion of time per domain for each albatross, thereby standardizing for differing transmitter deployment durations.

We used ArcGIS (v9.1, Environmental Systems Research Institute, Inc. [ESRI]) to process and analyze satellite tracking and bathymetric data. Statistical analyses were conducted in Matlab (v7.4.0, The MathWorks, Inc.). We used Kruskal-Wallis non-parametric tests to compare the proportion of time among species within each bathymetric domain (four separate tests) and analysis of variance to compare isotopic signatures among species and years. Bonferroni post hoc tests were used in cases of significant results from initial analyses. In all analyses, n is the number of albatrosses sampled or tracked (Table 1). Results were considered significant at $\alpha = 0.05$.

Results

Stable isotope signatures indicated foraging habitat segregation among albatross species. Short-tailed and black-footed albatrosses were significantly more carbon enriched (+ 1.03‰ – 1.26‰) compared to Laysan (ANOVA $F_{2,74} = 59.04$, $P < 0.001$; Fig. 1), but not significantly different from each other. Short-tailed and black-footed albatrosses also were most similar in δ^{15}N values, being more nitrogen enriched compared to Laysan ($F_{2,74} = 13.19$, $P < 0.001$; Fig. 1). The difference, however, was only statistically significant between black-footed and Laysan. A year effect and year*species interaction was not significant for δ^{13}C, but was for δ^{15}N ($F_{1,71} = 7.25$ and $F_{2,71} = 7.17$, $P = 0.009$ and 0.002, respectively). δ^{15}N values were elevated in 2005 compared to 2006 for black-footed (+2.01‰ , $n = 24$ and 16, respectively) and Laysan albatrosses (+1.17‰ , $n = 14$ and 15), but there was no difference between years for short-tailed ($n = 2$ and 6). In both years, however, the trend among species remained the same, with δ^{15}N values in short-tailed and black-footed albatrosses greater than Laysan.

Consistent with isotopic analyses, satellite tracking data demonstrated inter-specific differences in time within surface waters of bathymetric domains, with short-tailed and black-footed albatrosses being most similar and in contrast to Laysan (Fig. 2a). Short-tailed albatrosses spent significantly more time in continental shelf waters (Kruskal-Wallis $X^2_{2,28} = 6.90$, $P = 0.032$) and short-tailed and black–footed spent more time in shelf-break waters ($X^2_{2,28} = 14.99$, $P < 0.001$) relative to Laysan. Laysan albatrosses spent by far the greatest amount of time in oceanic waters, significantly more than the other two species ($X^2_{2,28} = 12.84$, $P = 0.002$). The amount of time in continental slope waters was not significantly different among species ($X^2_{2,28} = 3.11$, $P = 0.212$). Habitat segregation also occurred at a broader geographic scale, with short-tailed albatrosses ranging more north of the capture location (i.e., in the Bering Sea) than black-footed albatrosses, which ranged more to the southeast, and Laysan, which ranged more to the southwest (Fig. 2b).

Discussion

Our results indicate that although North Pacific albatrosses feed sympatrically at times on summer foraging grounds, in general they occupy different foraging niches with respect to foraging domain, trophic position, and overall distribution. $\delta^{13}C$ values confirm that by spending more time in shelf and slope regions, short-tailed and black-footed albatrosses gained more nutrients from neritic waters compared to Laysan albatrosses. Onshore-offshore gradients in $\delta^{13}C$ are common in marine systems (Cherel and Hobson 2007) and have previously been shown to differentiate neritic vs. oceanic foraging species of seabirds breeding in Alaska (Hobson et al. 1994). Short-tailed and black-footed albatrosses had $\delta^{13}C$ values similar to neritic foragers and Laysan intermediate between neritic and oceanic species reported by Hobson et al. (1994) for Gulf of Alaska seabirds, reflecting Laysan's use of both foraging domains, but oceanic to a greater extent than short-tailed and black-footed albatrosses.

Our results for black-footed and Laysan albatrosses are consistent with Gould et al.'s (1997) dietary analyses (prey remains and isotopic analysis of breast muscles) of carcasses recovered from drift nets, also occurring primarily during the non-breeding period. His results indicated that black-footed albatrosses foraged at one-third to one trophic level higher than Laysan, with black-footed consuming more squid and Laysan more fishes (including lantern fishes [Myctophidae], which have lower $\delta^{15}N$ values than squid). Gould et al.'s (1997) and our findings, however, contrast, in part, those from studies of breeding birds at Hawaiian colonies, which indicate that black-footed albatrosses actually consume more fish (Harrison et al. 1983) and hold a slightly (but not significantly) lower trophic position (Finkelstein et al. 2006) than Laysan. In all studies, however, black-footed albatrosses have significantly higher $\delta^{13}C$ values compared to Laysan.

We believe the above results are best explained by contrasting movement patterns of satellite-tagged birds during non-breeding vs. breeding seasons. During the non-breeding season, albatrosses were tagged at continental margins and although birds made excursions to offshore waters (with increasing duration for short-tailed, to black-footed, then Laysan), they often returned to shelf-slope habitat (data herein and Fischer 2007). The opposite was true for breeding black-footed and Laysan albatrosses in the Hawaiian islands studied by Harrison et al. (1983) and Finkelstein et al. (2006), where individuals tagged at offshore islands made excursions to distant continental margins, but at times (e.g., chick brooding period) both species foraged extensively in oceanic waters, possibly with greater diet similarity. Additionally, during the non-breeding season, black-footed albatross (and short-tailed) $\delta^{15}N$ values may be elevated because of greater foraging on fisheries discards, given that their distribution more extensively overlaps coastal groundfish fisheries, than Laysan (Fischer 2007).

Dietary information for breeding short-tailed albatrosses is not available, however, satellite tracking data indicate that foraging is also strongly associated with neritic waters (R. Suryan and G. Balogh, U.S. Fish and Wildlife Service, unpubl. data) and, therefore, carbon signatures of breeding short-tailed albatrosses are still likely elevated relative to breeding Laysan albatrosses. Our results indicate that differences in isotope signatures are best explained by differing primary foraging habitats and dietary intake, and to a lesser extent by differences in latitudinal distribution (Cherel and Hobson 2007; Finkelstein et al. 2006). We conclude that North Pacific albatrosses demonstrate resource partitioning at a broader scale even though occasionally co-occurring at a smaller scale at-sea and when they do co-occur, short-tailed albatrosses, being larger, often dominate feeding disputes (author's pers. obs.). There is currently little evidence for competitive exclusion of short-tailed albatrosses that might limit the recovery of this endangered species.

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Table 1. Number of albatrosses sampled (*n*) by species for stable isotope analysis and a summary of satellite tracking effort including *n*, median (range) number of days tracked per individual (years combined), and months of tracking for each year.

	n		# Days Tracked (range)	Tracking Months
Species	Isotopes	Satellite-tagged		
Short-tailed	8	6	61 (26-128)	Aug – Oct 2005 Jul – Nov 2006
Black-footed	40	7	46 (23-57)	Aug – Oct 2005
Laysan	29	18	61 (27-105)	Aug – Nov 2005 Jul – Oct 2006

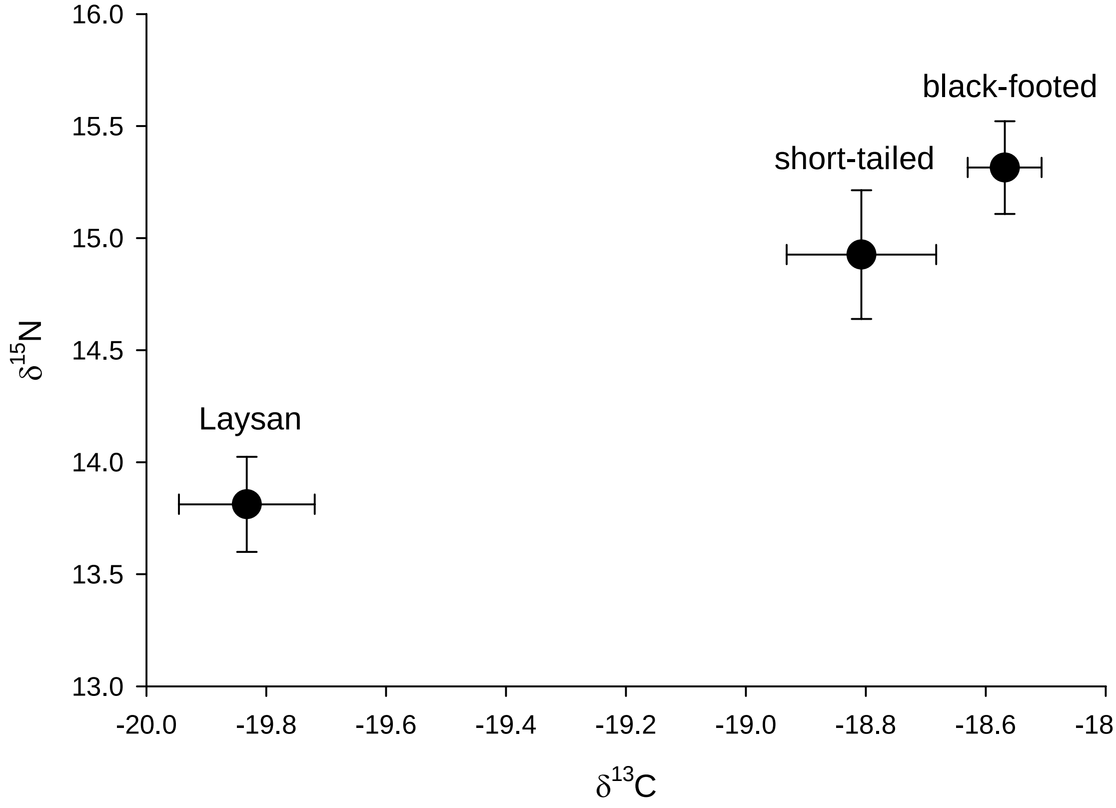

Figure 1. Stable isotope signatures (mean ± SE) of North Pacific albatrosses captured in Alaska during the non-breeding season.

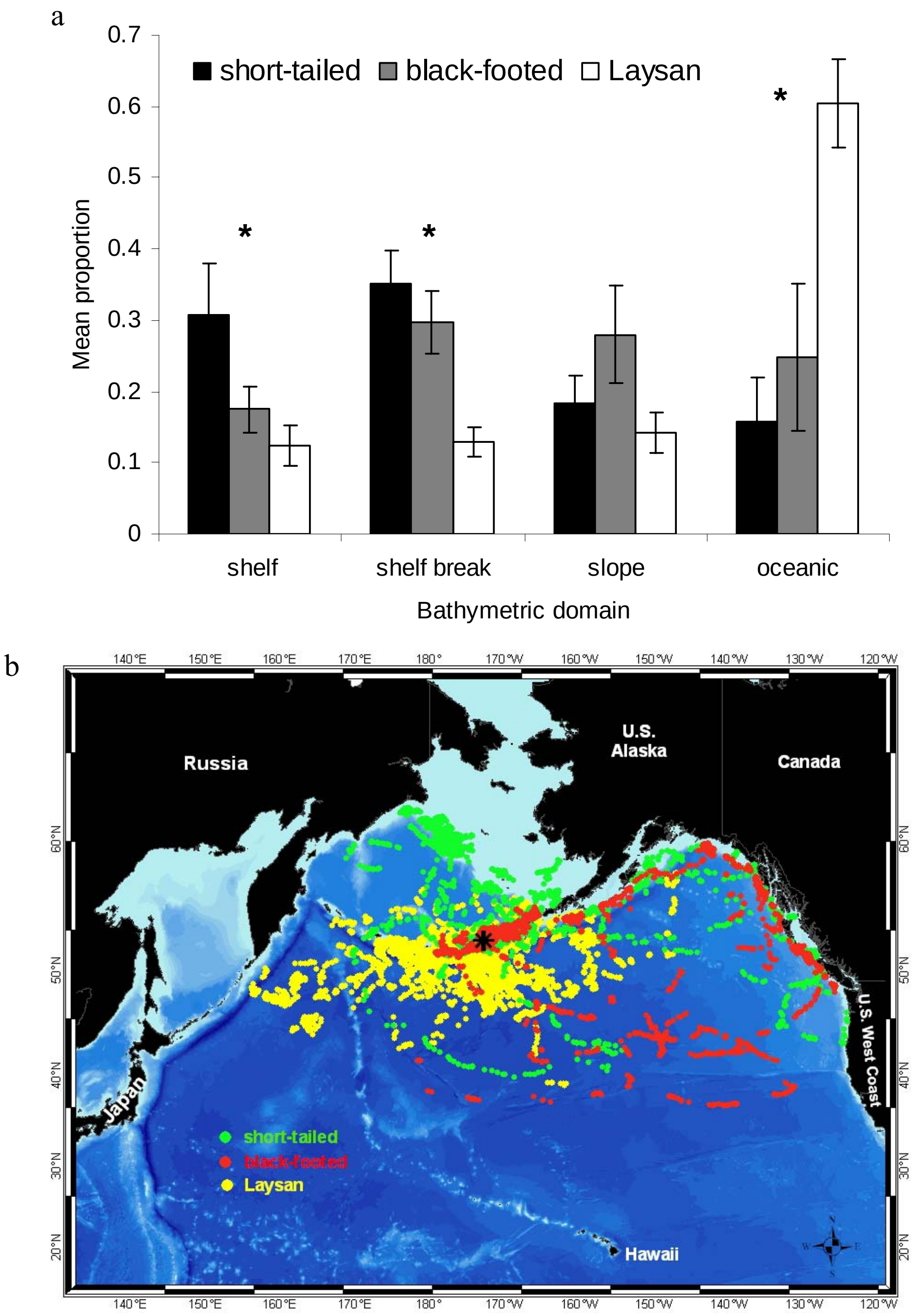

Figure 2. (a) Mean (+ SE, among albatrosses) proportion of time within bathymetric domains of shelf (<200m), shelf break (200-1000m), slope (1000-3000), and oceanic (>3000 m) for three species of albatrosses tracked July-November 2005 and 2006. An asterisk denotes significant within category differences among species. (b) Satellite tracking locations of three species of albatrosses captured at-sea near Seguam Pass (*), Alaska. Albatrosses were tracked during July – November 2005 and 2006.

Chapter 2: Marine Habitat Use of Black-footed and Laysan Albatrosses Off Alaska During the Post-breeding Season

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Abstract

The habitat use and foraging ecology of black-footed albatrosses (*Phoebastria nigripes*) and Laysan albatrosses (*P. immutabilis*) during the post-breeding season is poorly understood. During July – November in 2005 and 2006, we satellite-tracked 7 black-footed albatrosses and 18 Laysan albatrosses that were captured and tagged at-sea in the central Aleutian Islands, Alaska. We overlaid the satellite-tracks of these albatrosses on remotely-sensed habitat data to compare and contrast distribution and broad-scale marine habitat use by the two species. We used first-passage time analysis to identify meso-scale marine habitats associated with varying degrees of albatross area-restricted search (ARS) activity. Finally, we divided habitat variables into classes and compared the use of habitat classes by the two albatross species. Black-footed albatrosses ranged more widely than Laysan albatrosses, which remained closer to the productive, eutrophic waters near the Aleutian Islands. Black-footed albatrosses spent similar proportions of time over continental shelf, shelf break, slope, and oceanic waters, while Laysan albatrosses were associated mostly with oceanic waters. The two albatross species exhibited ARS activity at similar scales, about a 50-km radius. First-passage time, used as an index of ARS, was inversely related to wind speed and seafloor depth and positively related to gradients in depth, sea surface temperature, and chlorophyll *a* concentration for both species. Black-footed albatross ARS activity was inversely related to sea surface temperature and was greater for continental margin habitats relative to oceanic habitats; Laysan albatross ARS activity did not exhibit such strong relationships with sea surface temperature and seafloor depth. Despite inter-specific differences in distribution and broad-scale habitat use, ARS activity for both albatrosses was greater in vertically mixed waters (e.g., coastal upwelling and frontal zones) compared to vertically stratified waters (e.g., deep oceanic waters, weak frontal boundaries). Overall, black-footed albatross movements included more broad-scale ocean domains compared to Laysan albatrosses, which largely traveled over deep oceanic waters and remained in cooler and more chlorophyll-rich habitats. This study provides the first inter-specific comparisons of meso-scale habitat use for black-footed and Laysan albatrosses during the post-breeding season.

Keywords *Phoebastria*, First-passage time, Area-restricted search, Foraging behavior

Introduction

Distribution, density, and foraging activities of upper trophic-level marine predators tend to correspond with oceanographic features that induce prey aggregations (Polovina et al. 2004, Etnoyer et al. 2006). Spatial and temporal variation in prey patches in turn affect strategies of habitat selection by foraging predators across ocean basins (Fauchald 1999, Weimerskirch et al. 2005). Ranging world-wide over a diversity of oceanic habitats, albatrosses often aggregate in areas characterized by high primary productivity (such as continental shelves), transition and convergence zones, and areas of upwelling (Weimerskirch et al. 1988, Waugh et al. 1999, Hyrenbach et al. 2002, Suryan et al. 2006). Behavioral responses of albatrosses to meso-scale (10's – 100's km) oceanic features that enhance local productivity are reflected in increased area-restricted search activity in these areas (Pinnaud & Weimerskirch 2006).

Black-footed albatrosses (*Phoebastria nigripes*) and Laysan albatrosses (*P. immutabilis*) are distributed throughout much of the North Pacific Ocean and utilize a wide range of habitats throughout their annual cycle, including tropical to subarctic water masses and neritic to oceanic waters (Fisher & Fisher 1972, Gould 1983, Wahl et al. 1989, Fernández et al. 2001, Hyrenbach et al. 2002). During the breeding season, however, core foraging areas for these species include the North Pacific Transition Domain (28 – 45° N, 160° E – 130° W), the North Pacific Transition Zone Chlorophyll Front, and the continental shelves of the west coast of North America (black-footed) and the Aleutian Chain (Laysan) (Fernández et al. 2001, Hyrenbach et al. 2002). Hyrenbach et al. (2002) found inter-specific differences in habitat use during the chick-rearing period, with Laysan albatrosses consistently using cooler, more chlorophyll *a* rich waters compared to black-footed albatrosses. Additionally, regions of high productivity used by black-footed albatrosses were characterized by convergence zones, but mixing zones were more typically used by Laysan albatrosses. Habitat use of black-footed and Laysan albatrosses during the post-breeding season, however, is relatively poorly understood.

Habitat use of black-footed and Laysan albatrosses during the post-breeding season (July-October) has been inferred primarily from distribution and abundance data collected during vessel-based surveys and from mortalities due to fisheries bycatch. From these sources, plus limited satellite tracking information, we know that during the post-breeding season black-footed albatrosses occur regularly in deep oceanic subtropical and transition domain waters, as well as waters of the continental margin (shelf, shelf break, and slope) from California to the western Gulf of Alaska (Robbins & Rice 1974, Gould 1983, Fernández et al. 2001, Hyrenbach & Dotson 2003, Melvin et al. 2006). Conversely, post-breeding Laysan albatrosses occur mostly north of 40° N in transition domain or cooler waters, and are common in the area of mixing east of Japan where the Oyashio and Kuroshio currents meet. Laysan albatrosses are also common within the continental margin of the Aleutian Islands, and regularly occur over the shelf break and slope in the Bering Sea and western Gulf of Alaska during the post-breeding season (Fisher & Fisher 1972, Wahl et al. 1989, Dietrich 2003, Melvin et al. 2006). These distribution data are primarily the result of sampling near fishing grounds and limited surveys in pelagic waters, however, leading to potential biases in the results (Robbins & Rice 1974, Hyrenbach 2001). In addition, only descriptions of habitat use in relation to broad-scale marine habitat features can be inferred from these data, allowing for little interpretation of inter-specific habitat segregation in regions of sympatry.

Despite the apparent differences in distribution and broad-scale habitat use described above, both black-footed and Laysan albatrosses are regionally abundant within the central and eastern Aleutian Islands of Alaska during the post-breeding season. Information about the meso-scale habitat use of black-footed and Laysan albatrosses during the post-breeding season has not yet been collected for this region of significant range overlap. Here we present findings from the first satellite tracking study of black-footed and Laysan albatrosses in Alaskan waters during the post-breeding season. The objectives of this study were to: (1) identify broad-scale utilization of marine features; (2) describe and quantify meso-scale (10's – 100's km) habitat use; and (3) determine the extent of habitat segregation between black-footed and Laysan albatrosses off Alaska during the post-breeding season.

Methods

Satellite Telemetry

During August 2005 and July 2006 we deployed satellite transmitters on black-footed and Laysan albatrosses captured at-sea (see Gill et al. 1970 for detailed methods) near Seguam Pass (52.08º N, 172.95º W), central Aleutian Islands, Alaska. Only individuals that approached the boat within approximately 10 m were available for capture due to the limited range of our capture technique. If present in the group of birds attending the boat, banded individuals were targeted for capture. Once captured we visually inspected plumage condition; we did not deploy transmitters on individuals if plumage 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: $n = 9$), each for at least 23 days. Gender was determined from blood samples (ca. 100 µl; Fridolfsson & Ellegren 1999) collected from the brachial vein, and we determined the ages of tracked black-footed albatrosses from banding records. Reproductive status could not be determined for any of the tracked birds.

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 the bird's body mass. Transmitters were programmed to transmit at a 75- or 90-second 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. To account for the greater number of daily position fixes from individuals with satellite tags on the 24-h on:24-h off duty cycle (n = 9), we sub-sampled the locations to match an 8-h on:24-h off duty cycle.

We received position fixes for satellite-tagged albatrosses from the Argos System (CLS America, Inc, Largo, Maryland, USA). The Argos System assigned each position fix to one of six location quality classes; the highest quality locations were coded as level 3, and the lowest quality positions as level B. We used the Douglas Argos-Filter Algorithm (USGS, Alaska Science Center, http://alaska.usgs.gov/science/biology/spatial/douglas.html) to designate which position fixes would be retained for analyses. We used filtering criteria similar to those used in prior satellite telemetry studies of North Pacific albatrosses (Hyrenbach et al. 2002, Suryan et al. 2006). Consecutive position fixes requiring flying speeds in excess of 80 km h^{-1} were discarded. We retained all level 3 positions and all positions within 1 km of the subsequent location. Accuracy estimates from position fixes of stationary PTTs, based on a bench test, ranged from a mean of 0.29 ± 0.03 km for level 3 positions to 5.67 ± 1.00 km for level B positions. We could not monitor any potential direct effects of capture post-release. To be cautious, we excluded the first two days of tracking data for each tagged albatross from subsequent analyses to avoid using position fixes that may have been affected by capture. After the second day, many of the birds had dispersed greater than 100 km from the capture location.

Identifying Area-restricted Search Activity from Satellite Tracks

First-passage time (FPT) is a measure of how much time it takes for an individual to pass through a circle of a given radius and can be used to determine the location and spatial scale of area-restricted search (ARS) by each satellite-tagged individual (Fauchald & Tveraa 2003). We used FPT as a scale-dependent measure to quantify ARS along the tracks of satellite-tagged albatrosses. To calculate FPT, we linearly interpolated albatross tracks at 5-km intervals, retaining all original position fixes. FPT was then calculated for each of the interpolated and original positions at 5-km radius intervals from 5 to 200 km. The radius of maximum variance in FPT denotes the mean spatial scale of ARS activity and the optimum scale to model habitat used during ARS vs. transitory movements (Fig. 1; Fauchald & Tveraa 2003). To identify the radius of maximum variance for each individual, we plotted mean individual variance in FPT (log-transformed) against FPT radii. For each albatross species, the mean radius of maximum FPT variance was taken across all individuals that exhibited a defined peak in FPT variance (Suryan et al. 2006).

To reduce spatial autocorrelation, FPT data were not retained for analysis for each position fix, but rather were subsampled as described by Suryan et al. (2006). Briefly, the location of maximum FPT along an individual's trackline was selected; all locations with overlapping radii were then excluded. From the remaining points, we selected the position fix with the greatest FPT and we repeated the process until the entire track was sampled. Only original position fixes, not interpolated points, were used. For each FPT radius, we extracted the median value for each habitat variable (see below) within 10 km of the trackline.

We assumed that increased FPT indicated increased ARS activity and/or feeding attempts, at the designated spatial scale, while relatively high movement rates indicated more transitory movements. In black-legged kittiwakes (*Rissa tridactyla*) FPT was validated as a measure of foraging activity; FPT was shown to be significantly greater in regions where direct observations confirmed feeding attempts occurred compared to those where no feeding attempts occurred (Suryan 2006). Additionally, it has been shown that flight speed in breeding black-footed and Laysan albatrosses is negatively associated with turning angle and the number of landings on water, and thus reduced speeds are associated with increased ARS and foraging activity (Fernández & Anderson 2000). We therefore assumed that FPT and ARS are appropriate indicators of increased foraging activity in black-footed and Laysan albatrosses.

Marine Habitat Classification

We characterized marine habitats using seven variables: seafloor depth (Depth), chlorophyll *a* concentration (Chl *a*), sea surface temperature (SST), the gradients in each of these three variables (Depth Grad, Chl *a* Grad, and SST Grad), and wind speed (Wspd). Seafloor depth (m) data (1 minute latitude/longitude resolution; ± ~ 0.5% water depth) were obtained from the General Bathymetric Chart of the Oceans (British Oceanographic Data Centre, www.bodc.ac.uk). We obtained average monthly composites of Chl *a* (mg m^{-3}) and 8-day average composites of SST (ºC) (9-km resolutions) from the NASA/Goddard Space Flight Center (http://oceancolor.gsfc.nasa.gov/, level 3 post-processing). Chl *a* data were obtained as a merged file from sensors aboard two NASA satellites: Sea Viewing Wide Field of View Sensor (SeaWiFS) and the Moderate Resolution Imaging Spectroradiometer (MODIS). We used data for SST from MODIS. Using the Sobel Gradient Operator (Russ 1995), we calculated gradients in seafloor depth (Depth Grad), Chl *a* (Chl *a* Grad), and SST (SST Grad) over distance (3 x 3 pixels). Daily wind speed (Wspd; m s^{-1}) data at 10 m above the water surface (0.25° latitude/longitude resolution) were obtained from Remote Sensing Systems QuickSCAT sensor on the QuikBird satellite (http://remss.com/).

For analyses of inter-specific differences in habitat use, we divided each habitat variable into four classes. Seafloor depth classes were defined as: shelf (≤ 200 m), shelf break (> 200 m and ≤ 1000 m), continental slope (> 1000 m and ≤ 3000 m), and oceanic (> 3000 m). Following Hyrenbach (2002), we defined Chl *a* classes as: oligotrophic (≤ 0.1 mg m^{-3}), mesotrophic (> 0.1 mg m^{-3} and ≤ 0.3 mg m^{-3}), eutrophic (> 0.3 mg m^{-3} and ≤ 1.0 mg m^{-3}), and enriched (> 1.0 mg m^{-3}). Classes of SST were defined as: subarctic (< 10ºC), subarctic frontal zone (> 10ºC and ≤ 12ºC), North Pacific Transition Domain (> 12ºC and ≤ 15ºC), and subtropical to tropical (> 15ºC).

Statistical Analysis of Habitat Use

We used a model selection approach to identify which habitat variables were associated with variation in albatross area-restricted search activity, as indicated by first-passage time. We quantified albatross ARS in relation to habitat variables using mixed-effects linear models with FPT as a continuous response variable. There were multiple measures of FPT for each individual; therefore, the individual bird was included as a random effect to account for variation within individuals. The seven habitat variables were included as fixed effects. We considered all combinations of main effects. Models were ranked using Akaike's Information Criteria corrected for small sample size (AICc), and Akaike weights (W_i) were calculated. We created a 95% confidence set of main effects models (no interaction terms) for each species by ranking models in descending order by W_i, then adding models to the set until the sum of the weights was ≥ 0.95 (Burnham & Anderson 1998); Appendix A & B). To investigate potential interaction effects, we singly added 10 interactions of habitat variables to the 95% confidence set of main effects models. We considered models with ΔAICc values ≤ 2 units from the best approximating model as competing models. Interactions were only considered in models in which both main effects occurred.

Collinearity among explanatory variables was assessed using scatterplots and pair-wise estimates of Pearson correlation coefficients. We excluded models with highly correlated explanatory variables from the candidate model set; high correlation was considered at R ≥ 0.70. For black-footed albatrosses, Chl *a* and Chl *a* Grad were both highly correlated with Depth, Depth Grad, SST, and with each other. For Laysan albatrosses, Chl *a* and Chl *a* Grad were highly correlated with each other. Inter-specific differences in the collinearity of habitat variables precluded the use of the same candidate model set for both albatross species. We therefore evaluated models of variation in ARS for each species separately using the appropriate model set. We visually examined normality and residual plots to assess whether assumptions of normality and constant variance were met. First-passage time and four habitat variables (Chl *a*, Depth Grad, Chl *a* Grad, and SST Grad) required log transformation.

We assessed habitat use by each albatross species both in terms of time spent in each habitat class and the degree of ARS activity in each habitat class. The sum of FPTs in each habitat class was divided by the sum of FPTs to calculate the proportion of time each individual spent within habitat classes; the mean proportion of time spent within each habitat class was taken across individuals of each species. Non-parametric, Mann-Whitney tests were used to test for inter-specific differences in proportion of time spent within habitat classes.

To determine inter-specific differences in ARS activity within habitat classes, we used a two-factor mixed-model analysis of variance (mixed-model ANOVA) to compare mean FPT by species, habitat class, and their interaction. For each species, we calculated the mean FPT within habitat classes across individuals that had FPT values within the habitat class. The individual bird was included as a random effect.

First-passage time analyses and processing of remotely sensed data were conducted using Matlab software (The MathWorks, Inc.). All statistical analyses were conducted using SAS v9.1 (SAS Institute Inc.). We used filtered (see above) fixed positions to calculate minimum distances traveled in ArcGIS (ESRI, Redlands, CA, USA) in an Albers Equal Area Conic projection using the Calculate Movement Parameters tool in the Hawth's Analysis Tools for ArcGIS extension (www.spatialecology.com/htools), which assumes straight line distance between fixed positions. Data on Laysan albatross movements in the two years were grouped for analyses when no significant differences were found between years. We used log-transformed FPT for all analyses. Mean values are presented ± standard error. Statistical significance was set at $\alpha = 0.05$.

Results

Movements and Distribution

Mean tracking duration (total tracking days -2 days; see Methods) for black-footed albatrosses was 43 ± 5 days (range: 21-57 days, $n = 7$) and for Laysan albatrosses was 59 ± 5 days (range: 35-105 days, $n = 18$). The sex ratio (male:female) of tracked black-footed albatrosses was 4:3, and of tracked Laysan albatrosses was 17:1. Black-footed albatrosses ranged in age from 1.5 to > 40 years and all tracked individuals were from the Hawaiian population. One of the 18 tracked Laysan albatrosses was a known breeder on Guadalupe Island, Mexico and at least 3 years old (W. Henry, pers. comm.). The source population(s) and ages of all remaining tracked Laysan albatrosses were not known; however, based on feather wear, all individuals were believed to be at least 1.5 years old.

On average, black-footed albatrosses traveled greater distances per day (178 ± 34 km d^{-1}) and also exhibited greater variability in daily distance traveled among individuals ($F_{6, 17} = 5.89$, $P < 0.01$) compared to Laysan albatrosses (147 ± 9 km d^{-1}). Three of seven black-footed albatrosses remained entirely within the Aleutian Archipelago, traveling on average only 93 ± 19 km d^{-1}. The other four black-footed albatrosses traveled on average 242 ± 27 km d^{-1}, more than 2.5 times the average rate of the first three.

The two albatross species exhibited partial geographic segregation. Only the four far-ranging black-footed albatrosses traveled into the eastern Gulf of Alaska and to the west coast of Canada. Laysan albatrosses traveled widely in the western Aleutian Islands, a region not used by the satellite-tagged black-footed albatrosses. All four far-ranging black-footed albatrosses traveled south into the North Pacific Transition Domain between Alaska and Hawaii, while all satellite-tagged Laysan albatrosses remained north of or on the northern edge of this region (Fig. 2). Only one Laysan albatross traveled as far west as the continental shelf break off the Kuril Islands; none traveled to the Kuroshio Extension off Japan. Distributions of the two species showed extensive spatial overlap within the central Aleutian Islands, where they were tagged, while no individuals of either species made extensive movements into the adjacent Bering Sea.

Ten of the 18 tracked Laysan albatrosses (56%) made looping flights from the continental margin of the Aleutian Islands out over deep oceanic waters and then back to the continental margin. Several individual Laysan albatrosses exhibited this flight pattern multiple times, as exemplified by the movements of bird L32, which made four separate looping trips out over deep oceanic waters and back to the continental margin (Fig. 3).

Scale of Albatross Area-restricted Search Activity

Based on first-passage time (FPT) analysis, 5 of 7 black-footed albatrosses and 12 of 18 Laysan albatrosses exhibited a peak in variance in lnFPT. The peak occurred at a radius of 48 ± 8 km for black-footed albatrosses and at a radius of 47 ± 11 km for Laysan albatrosses; these mean radii where variance peaked were not significantly different ($t_{1,15} = 0.097$, $P = 0.92$). Therefore, we used a 50-km radius to measure FPT in all individuals of both species for subsequent analyses of habitat associations. At the 50-km radius, one black-footed albatross and one Laysan albatross with very local movements had fewer than three measurements of FPT after subsampling, and were excluded from further analyses of habitat use. A total of 100 and 315 FPT values for black-footed and Laysan albatrosses, respectively, were collected.

Variation in Albatross Area-restricted Search in Relation to Habitat

Model selection results indicated that area-restricted search (ARS) activity by black-footed albatrosses, as reflected by FPT, was influenced by the variables Wspd, Depth, SST, Depth Grad, and Depth Grad * SST (Table 1). All of these habitat variables were highly significant components of the 2 competing models and thus were considered important for explaining variation in black-footed albatross ARS ($R^2 \geq 0.48$; Table 2). The two competing models differed only in the inclusion of SST Grad (Table 1), a variable that was not a significant component of the model in which it appeared (Table 2). Model parameter estimates indicated ARS activity increased (longer FPT) with decreasing Wspd, Depth, and SST and with increasing gradients of Depth and SST (Table 2). Area-restricted search was inversely related to the interaction of Depth Grad * SST (Table 2), suggesting that the negative relationship between SST and black-footed albatross ARS is not as strong in areas of steep depth gradients (e.g., shelf break and slope habitats).

There were three competing models that best described variation in ARS activity of Laysan albatrosses in relation to marine habitat variables. All three competing models indicated that ARS activity in Laysan albatrosses was related to Wpsd, Depth, Depth Grad, Chl *a* Grad, and Wspd * Chl *a* Grad ($R^2 \geq 0.42$; Table 3). Wspd, Depth, Chl *a* Grad, and Wspd * Chl *a* Grad were highly significant components in all three competing models, but Depth Grad was not (Table 4). Competing models differed only in the inclusion of SST and SST Grad (Table 3), neither of which were significant components of the models in which they appeared (Table 4). As with black-footed albatrosses, model parameter estimates indicated that ARS activity in Laysan albatrosses increased with decreasing Wspd, Depth, and SST and with increasing gradients of Depth and SST (Table 4). Area-restricted search activity also increased with increasing Chl *a* Grad. Interestingly, ARS was inversely related to the interaction of Wspd * Chl *a* Grad (Table 4), suggesting that the inverse relationship between Laysan albatross ARS and Wspd is not as strong in areas with steep Chl *a* Grad (e.g. frontal zones).

Inter-specific Comparisons of Albatross Habitat Use

We observed large inter-specific differences in proportion of time spent over habitats defined by seafloor depth. Laysan albatross use of oceanic habitats was greater compared to black-footed albatrosses. Unlike black-footed albatrosses, habitat occupancy by Laysan albatrosses increased with increasing seafloor depth and Laysan albatrosses spent a disproportionately high percentage of time over oceanic waters (63.93 ± 6.22%; Fig. 4a). In contrast, black-footed albatrosses allocated time relatively evenly across depth classes, although there was a trend toward higher use of shelf break habitats (Fig. 4a). Compared to Laysan albatrosses, black-footed albatrosses spent a significantly greater proportion of time over shelf break waters, and significantly less time over oceanic waters (shelf break $U_{6,17} = 81$, $P < 0.05$; oceanic $U_{6,17} = 93$, $P = 0.002$).

All far-ranging black-footed albatrosses (n = 4) traveled over waters spanning the range of SST classes, including subtropical and tropical (> 15ºC) waters; however, only 3 of 17 Laysan albatrosses traveled over waters > 15ºC and only these three Laysan albatrosses traveled over oligotrophic waters. Both black-footed and Laysan albatrosses spent, on average, approximately half their time over subarctic waters (black-footed 54.67 ± 15.89%; Laysan 48.36 ± 6.93%; Fig. 5a), and more than two-thirds of their time over eutrophic waters (black-footed 70.23 ± 11.6%; Laysan 81.51 ± 3.74%). The mean proportion of time spent within classes of gradients in Depth, SST, and Chl *a* generally increased with increasing gradients for both species (Figs. 6a-c).

Our results suggested that although the modeled relationship between ARS and Depth is negative for both albatross species, Laysan albatross ARS activity was greater over oceanic waters compared to black-footed albatrosses (oceanic: mixed-model ANOVA $F_{1, 36} = 4.28$, $P = 0.05$; Fig. 4b). Greater ARS activity over oceanic waters for Laysan albatrosses, compared with black-footed albatrosses, may explain the significant inter-specific difference observed in the proportion of time spent within this domain. Within shelf break and slope waters, however, the degree of ARS activity did not differ significantly between species (shelf break: mixed-model ANOVA $F_{1, 36} = 0.82$, $P = 0.37$; slope: mixed-model ANOVA $F_{1,36} = 1.00$, $P = 0.32$; Fig. 4b). Wspd and Depth Grad were also common to all competing models of variation in ARS for both albatrosses; the degree of ARS activity in habitat classes of these variables did not differ significantly between species ($P > 0.16$; Fig. 7a). Within habitat classes of SST and Chl *a* in which both species spent the greatest proportion of time (see above), the degree of ARS activity did not differ between species (eutrophic Chl *a*: mixed-model ANOVA $F_{1, 29} = 0.13$, $P = 0.72$; subarctic SST: mixed-model ANOVA $F_{1,36} = 0.87$, $P = 0.36$; Fig. 5b). Trends in mean FPT values of black-footed and Laysan albatrosses among habitat classes are consistent with the parameter estimates of variables retained in the statistical models of ARS (Figs. 4a, 5a, & 7a-c).

We detected no significant inter-annual differences in the proportion of time or degree of Laysan albatross ARS activity within habitat classes; therefore, the observed differences should be chiefly related to habitat use or albatross species.

Discussion

First-passage Time

Within-species variation about the mean first-passage time has been described for other species of albatrosses and petrels (Suryan et al. 2006, Pinaud & Weimerskirch 2007, Robinson et al. 2007). Despite considerable individual variation about the mean FPT for both black-footed and Laysan albatrosses in this study, the 50-km FPT radius was the best scale to differentiate area-restricted search behavior from more transitory movements, given the resolution of the tracking data. We were able to explain more than 40% of the variation in FPT for both species using this FPT radius. The mean variation in FPT of seven Laysan albatrosses tracked during the breeding season with continuously transmitting PTTs was just over 36 km (Robinson et al. 2007). As expected, the scale at which Laysan albatross habitat use would be best evaluated using transmitters on a duty cycle (this study) was greater (just over 47 km).

At-sea Distribution

Those satellite-tagged black-footed and Laysan albatrosses that dispersed from the capture location in the central Aleutian Islands exhibited clear inter-specific differences in spatial distribution that were mostly as expected, based on previously described patterns of distribution (Gould 1983, Wahl et al. 1989, Melvin et al. 2006). Dispersing Laysan albatrosses remained largely north of 45° N and made extensive movements west of the International Date Line, while dispersing black-footed albatrosses traveled extensively south of 45° N and remained almost entirely east of the International Date Line. Despite long-distance dispersal from the capture site by more than half of tracked individuals for each species, a portion of individuals (43% of black-footed, 39% of Laysan) remained in the Aleutian Islands for the entire respective tracking period (range: 23-76 days).

Differential distribution by gender or by breeding site and individual variation in site fidelity may explain why albatrosses that dispersed from the Aleutian Islands did not travel to areas of the northwestern Pacific, where high densities of both albatross species have been reported. Satellite-tracked black-footed and Laysan albatrosses did not travel to the region off of Japan, where they are both abundant during at-sea surveys and in bycatch records (Fisher & Fisher 1972, Robbins & Rice 1974, Wahl et al. 1989, Fernández et al. 2001). Laysan albatrosses in particular are known for their use of the Kuroshio Extension throughout the annual cycle. Band recoveries, however, suggest that this region may be used more by younger Laysan albatrosses (Fisher & Fisher 1972); whether the same individuals also utilize the Aleutian Islands region during the post-breeding season is not known.

Our tracking data suggest that black-footed and Laysan albatrosses utilizing the Aleutian Islands region and the northeastern Pacific are not utilizing the northwestern Pacific during the same post-breeding season. Because we had small sample sizes of tracked individuals for both species and the source population for Laysan albatrosses was not known, we can only speculate about populational differences in post-breeding dispersal patterns. However, it is possible that black-footed and Laysan albatrosses from different breeding colonies are segregated at-sea during the post-breeding season, as demonstrated for some Southern Hemisphere albatrosses (Pinaud & Weimerskirch 2007). Additionally, our study occurred during the stage of the annual cycle when molt of flight and body feathers occurs. The feather molt of captured black-footed albatrosses in particular was advanced compared to that of captured

Laysan albatrosses (Fischer and Suryan, unpublished data). Breeding success and reproductive effort affect the onset, pace, and pattern of molt (Viggiano 2001), and differential molt patterns can affect flight efficiency and potentially the distribution (Edwards & Rohwer 2005) of albatrosses. Individual differences in stage of molt may also have influenced dispersal from the capture location. Lastly, individual variation in site fidelity to meso- and submeso-scale features within ocean basins could explain variable dispersal patterns among our tracked individuals, as it has in other albatross populations (Phillips et al. 2005).

Habitat Variables Associated with Variation in Area-restricted Search

In albatross and petrel species that depend on wind for movements, wind speed can affect rates of travel. Time between tracked locations is used to identify where ARS activity has likely occurred in FPT analysis, while fractal analysis uses turning angle along the trackline (Robinson et al. 2007). The highly significant inverse relationship between wind speed and FPT in our top models is consistent with findings from short-tailed albatrosses (*Phoebastria albatrus*; Suryan et al. 2006). Our results confirm the importance of including wind speed in models of habitat use in albatrosses, if FPT is being used as the measure of area-restricted search.

Commuting and looping movements are commonly employed by albatrosses throughout the year, and individuals regularly alternate between these two types of movements (Nicholls et al. 2000, Weimerskirch 2007). The two types of movement patterns have been linked to foraging strategies that enhance efficiency in a heterogeneous environment where prey density and predictability vary in space and time (Weimerskirch 2007). During the breeding season, black-footed and Laysan albatrosses as central place foragers utilize both movement types (Weimerskirch 2007). Interestingly, our data do not suggest that black-footed albatrosses used looping movements. Laysan albatrosses, however, appeared to utilize more transitory looping movements when over oceanic waters, which are typically low in both predictability and density of prey, and more localized foraging movements when over continental margin waters, which are typically higher in prey predictability and density.

It is not clear why individuals alternated looping movements over oceanic waters and more localized area-restricted search movements over the continental margin. Intense inter- and intra-specific competition for prey in areas of predictable prey concentrations along the continental margin may motivate individuals to forage elsewhere (Anderson & Ricklefs 1987). Alternatively, Laysan albatrosses may be searching for preferred prey items that are more available in oceanic waters; similar looping patterns by wandering albatrosses (*Diomedea exulans*) have been attributed to foraging for adult squids available over deep water (Weimerskirch et al. 2000). A single study of black-footed and Laysan albatross diets during the post-breeding seasons of 1990 and 1991, based on the stomach contents of albatrosses taken as bycatch in high-seas squid fishing operations in the North Pacific Transition Domain, suggests that myctophid fishes regularly occur in Laysan albatross diets but are rare in black-footed albatross diets (Gould et al. 1997). These energy-dense (Van Pelt et al. 1997) midwater fishes have significant trophic importance in the Western Subarctic Gyre and are an important component of the diet of Dall's porpoises in this region (Springer et al. 1999). It is plausible that Laysan albatrosses are using looping movements south of the Aleutian Islands and into the Western Subarctic Gyre to search for myctophids in oceanic regions were they are more abundant relative to the continental margin (Aron 1959).

Marine Habitat Use

Inter-specific similarities in model coefficients and lack of significant differences in first-passage time within habitat classes indicated that foraging strategies of black-footed and Laysan albatrosses are comparable within habitats defined by Depth, SST, Chl *a*, and their gradients. Prey abundance and predictability are generally elevated in continental margin waters relative to oceanic waters; high productivity frequently occurs in predictable locations, such as passes or areas of steep gradients in depth or temperature (Mackas & Tsuda 1999, Yen et al. 2004). Variation in ARS activity of black-footed and Laysan albatrosses largely followed the pattern of other upper-trophic level marine predators, with increased ARS in regions associated with high prey densities.

Interestingly, despite similarities in associations of ARS activity with habitat types, we observed inter-specific differences in time spent within habitat types. Our tracking data suggest that despite habitat overlap where black-footed and Laysan albatrosses are sympatric, black-footed albatrosses utilized a broader range of marine habitat domains compared to Laysan albatrosses. These broad-scale habitats differed with respect to depth, sea surface temperature, and chlorophyll *a* concentration. Habitat use by the two species differed most with regard to depth, with Laysan albatrosses strongly associated with oceanic waters and black-footed albatrosses using all depth domains relatively equally. Our findings also indicated that black-footed albatrosses dispersed more into subtropical and tropical waters (south of 45ºN), compared to Laysan albatrosses, which remained almost entirely within the North Pacific Transition Domain or cooler waters (Fig. 2). Far-ranging black-footed albatrosses visited waters that were low in chlorophyll concentration (i.e., oligotrophic), although spending only a relatively small proportion of time; only one of 17 tagged Laysan albatrosses visited this habitat domain. These observed inter-specific differences were not likely an artifact of a small sample of black-footed albatrosses because more restricted habitat use was observed in Laysan albatrosses, which were tracked for as long or longer than black-footed albatrosses.

The broad-scale habitat use by these two albatrosses during the post-breeding season was comparable to habitat use during the breeding season, despite the former no longer adhering to central place foraging. As observed during the breeding season, black-footed albatross movements were largely over nutrient-rich waters of the continental margin and along convergence fronts, while Laysan albatross movements were largely over nutrient-rich, subarctic waters, further offshore (Hyrenbach et al. 2002). The more northerly distribution of habitat use for both species during the post-breeding season compared to the breeding season likely reflects the absence of obligations at the breeding colony.

Distribution of Area-restricted Search in Relation to Habitat

Our tracking data suggested that subarctic waters of the eastern Aleutian Islands and the Gulf of Alaska are foraging areas for black-footed albatrosses during the post-breeding season, regions not utilized heavily by this species during the breeding season (Hyrenbach et al. 2002). Although at-sea surveys and bycatch records have indicated that black-footed albatrosses utilize these regions during the post-breeding season, relatively high fishing and survey efforts have made the relative importance of these regions difficult to gauge.

Most black-footed albatrosses tracked during this study utilized the chlorophyll-rich regions of the continental margin off southeast Alaska and British Columbia, and generally remained in regions further north than those used during the breeding season. Area-restricted search activity was evident in areas of high productivity near the central and eastern Aleutian Islands, in particular Seguam and Amukta passes. Additionally, the convergence region of the Transition Zone Chlorophyll Front was utilized by all four black-footed albatrosses that were tracked outside of the Aleutian Islands region. Buoyant zooplankton are believed to aggregate along this front, attracting mid- and upper-trophic level predators. This front migrates seasonally and annually but is generally located between 40º and 45º N during the summer months (Polovina et al. 2001).

Results of this study indicated that Laysan albatrosses remained within relatively chlorophyll-rich waters north of the North Pacific Transition Domain throughout nearly all tracks. Areas of concentrated ARS activity for Laysan albatrosses often coincided with predictable chlorophyll hotspots, such as the Western Subarctic Gyre and the deep waters south of Seguam Island. Relatively low FPT values over deep waters were often associated with looping movement patterns. Laysan albatrosses utilized the highly productive areas in the western Aleutian Islands, particularly Buldir and Amchitka passes, and the area near Bowers Ridge (Fig. 8). Several individuals returned to forage in Seguam and Amukta passes in the central Aleutian Islands after leaving the region following capture and PTT deployment. Few tracked Laysan albatrosses (n = 3) visited the Gulf of Alaska, a region where a few females, but not so many males, focused their foraging efforts during the breeding season (Hyrenbach 2002). Partial spatial segregation by gender is well documented in some albatross species during the breeding and post-breeding seasons (Prince et al. 1997, Phillips et al. 2005). The strong gender bias towards males in our sample of tagged Laysan albatrosses may explain why more tagged individuals did not travel to regions where Laysan albatrosses have been previously reported in large numbers. Investigations of gender-specific habitat preferences or dispersal patterns may provide insight into our observed male bias in the Aleutian Islands

Overall, our results demonstrate that black-footed and Laysan albatrosses differed in distribution and proportion of time spent among habitats, despite similar patterns of ARS activity in relation to habitat variables. Black-footed albatross movements included more broad-scale ocean domains compared to Laysan albatrosses, which largely traveled over oceanic waters and remained in cooler and more chlorophyll-rich habitats. These inter-specific differences in habitat use likely reflect differences in prey selection and foraging strategies. Our results are consistent with findings during the breeding season that indicate Laysan albatrosses consistently used cooler and more chlorophyll-rich waters compared to black-footed albatrosses (Hyrenbach et al. 2002). Also consistent with breeding season observations of habitat use (Hyrenbach et al. 2002), we found that during the post-breeding season black-footed albatrosses utilized areas of coastal upwelling or convergence (e.g., shelf break of British Columbia, North Pacific Transition Domain), while Laysan albatrosses utilized areas characterized by mixing (e.g., near passes, oceanic waters of the Subarctic Gyre). Our results support the conclusion that black-footed and Laysan albatrosses increase ARS activity in similar meso-scale marine habitats during the post-breeding season, but exhibit inter-specific differences in distribution and broad-scale marine habitat use.

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Table 1. Model selection statistics from mixed-effects linear models for first-passage time as a function of marine habitat variables for black-footed albatrosses during the post-breeding season. Models with ΔAICc $\leq$ 4 are presented.

Model No.	Model[a]	AICc	K	ΔAICc	R^2
1	Wspd + Depth + lnDepth Grad + SST + lnSST Grad + lnDepth Grad*SST	269.30	8	0.00	0.50
2	Wspd + Depth + lnDepth Grad + SST + lnDepth Grad*SST	270.40	7	1.11	0.48
3	Wspd + Depth + lnSST Grad + SST + Depth*lnSST Grad	271.80	7	2.54	0.47

[a] See Methods for explanatory variable abbreviations.

Table 2. Parameter estimates, *t*-values, and *P*-values for explanatory variables from competing black-footed albatross models (ΔAICc ≤ 2) using mixed-effects linear modeling relating first-passage time (FPT) to habitat variables at 50-km FPT radii.

Variable[a]	Model 1 $R^2 = 0.50$, ΔAICc = 0.00			Model 2 $R^2 = 0.48$, ΔAICc = 1.11		
	β	*t*	*P*	β	*t*	*P*
Wspd	-0.13	-4.09	<0.001	-0.14	-4.62	<.001
Depth[b]	-0.18	-3.16	0.002	-0.18	-3.11	0.003
lnDepth Grad	0.91	4.00	<0.001	0.99	4.49	<.001
SST	-0.35	-4.15	<0.001	-0.38	-4.67	<.001
lnSST Grad	0.16	1.09	0.28	.	.	.
lnDepth Grad*SST	-0.06	-3.74	<0.001	-0.062	-4.15	<.001

[a] See Methods for explanatory variable abbreviations.

[b] Depth presented as kilometers (km) instead of meters (m) to account for the ≥ 3 orders of magnitude difference in the range of values relative to the other parameters.

Table 3. Model selection statistics from mixed-effects linear models for first-passage time as a function of marine habitat variables for Laysan albatrosses during the post-breeding season. Models with ΔAICc ≤ 4 are presented.

Model No.	Model[a]	AICc	K	ΔAICc	R^2
1	Wspd + Depth + lnDepth Grad + lnSST Grad + lnChl a Grad + Wspd*lnChl a Grad	870.50	8	0.00	0.43
2	Wspd + Depth + lnDepth Grad + lnChl a Grad + Wspd*lnChl a Grad	871.80	7	1.29	0.42
3	Wspd + Depth + lnDepth Grad + SST + lnSST Grad + lnChl a Grad + Wspd*lnChl a Grad	872.30	9	1.81	0.43
4	Wspd + Depth + lnDepth Grad + lnSST Grad + lnChl a Grad + Wspd*lnDepth Grad	873.50	8	2.98	0.42
5	Wspd + Depth + lnDepth Grad + lnChl a Grad + SST + Wspd*lnChl a Grad	873.60	8	3.08	0.42

[a] See Methods for explanatory variable abbreviations.

Table 4. Parameter estimates, *t*-values, and *P*-values for explanatory variables from competing Laysan albatross models (ΔAICc ≤ 2) using mixed-effects linear modeling relating first-passage time (FPT) to habitat variables at 50-km FPT radii.

Variable[a]	Model 1 $R^2 = 0.43$, ΔAICc = 0.00			Model 2 $R^2 = 0.42$, ΔAICc = 1.29			Model 3 $R^2 = 0.43$, ΔAICc = 1.81		
	β	*t*	*P*	β	*t*	*P*	β	*t*	*P*
Wspd	-0.39	-3.34	0.001	-0.39	-3.42	<0.001	-0.38	-3.34	0.001
Depth[b]	-0.19	-4.69	<.001	-0.19	-4.67	<.0001	-0.18	-4.4	<.0001
lnDepth Grad	0.04	0.82	0.42	0.05	0.99	0.32	0.04	0.68	0.50
SST	.	.	.	.	.	.	-0.02	-0.57	0.57
lnSST Grad	0.03	0.30	0.76	.	.	.	0.02	0.25	0.80
lnChl a Grad	0.50	2.74	0.006	0.50	2.82	0.005	0.48	2.64	0.009
Wspd*lnChl a Grad	-0.06	-2.60	0.01	-0.06	-2.68	0.008	-0.05	-2.59	0.01

[a] See Methods for explanatory variable abbreviations.

[b] Depth presented as kilometers (km) instead of meters (m) to account for the ≥ 3 orders of magnitude difference in the range of values relative to the other parameters.

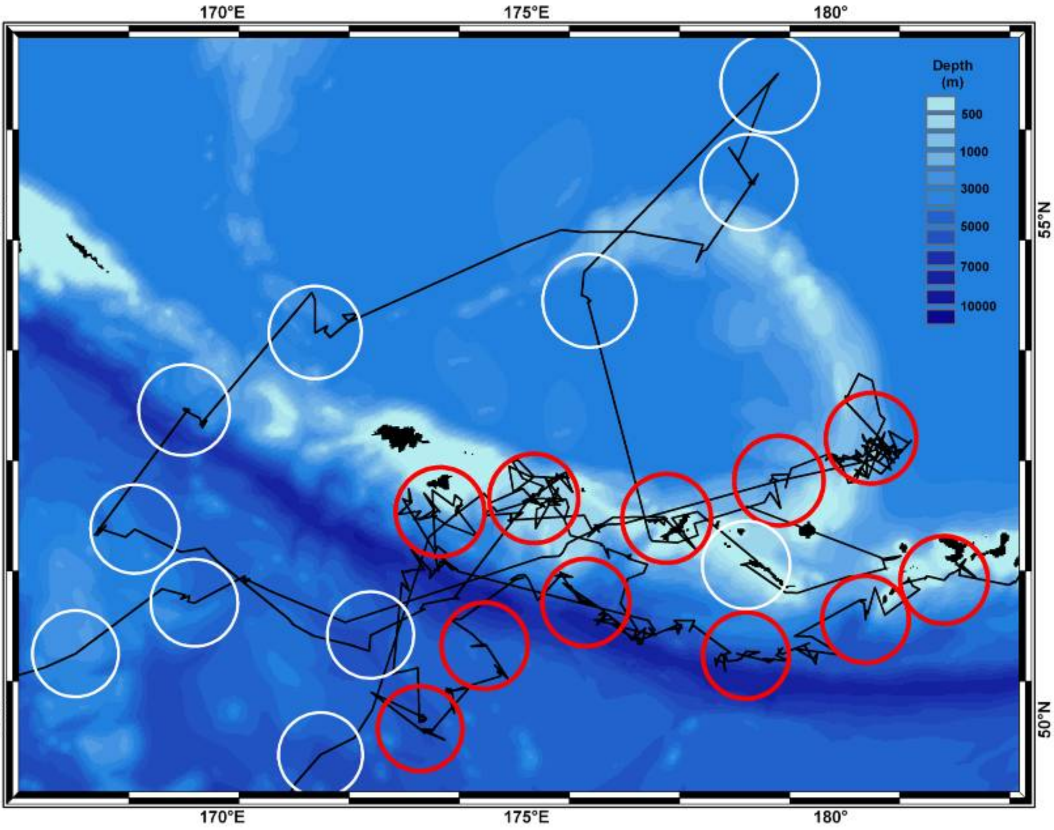

Figure 1. Portion of a Laysan albatross track (L57, black line) with first-passage time (FPT) radii of 50 km superimposed over a map of seafloor depth. Upper 50% (red circles) and lower 50% (white circles) of FPT values represent regions of area-restricted search activity and transitory behaviors, respectively.

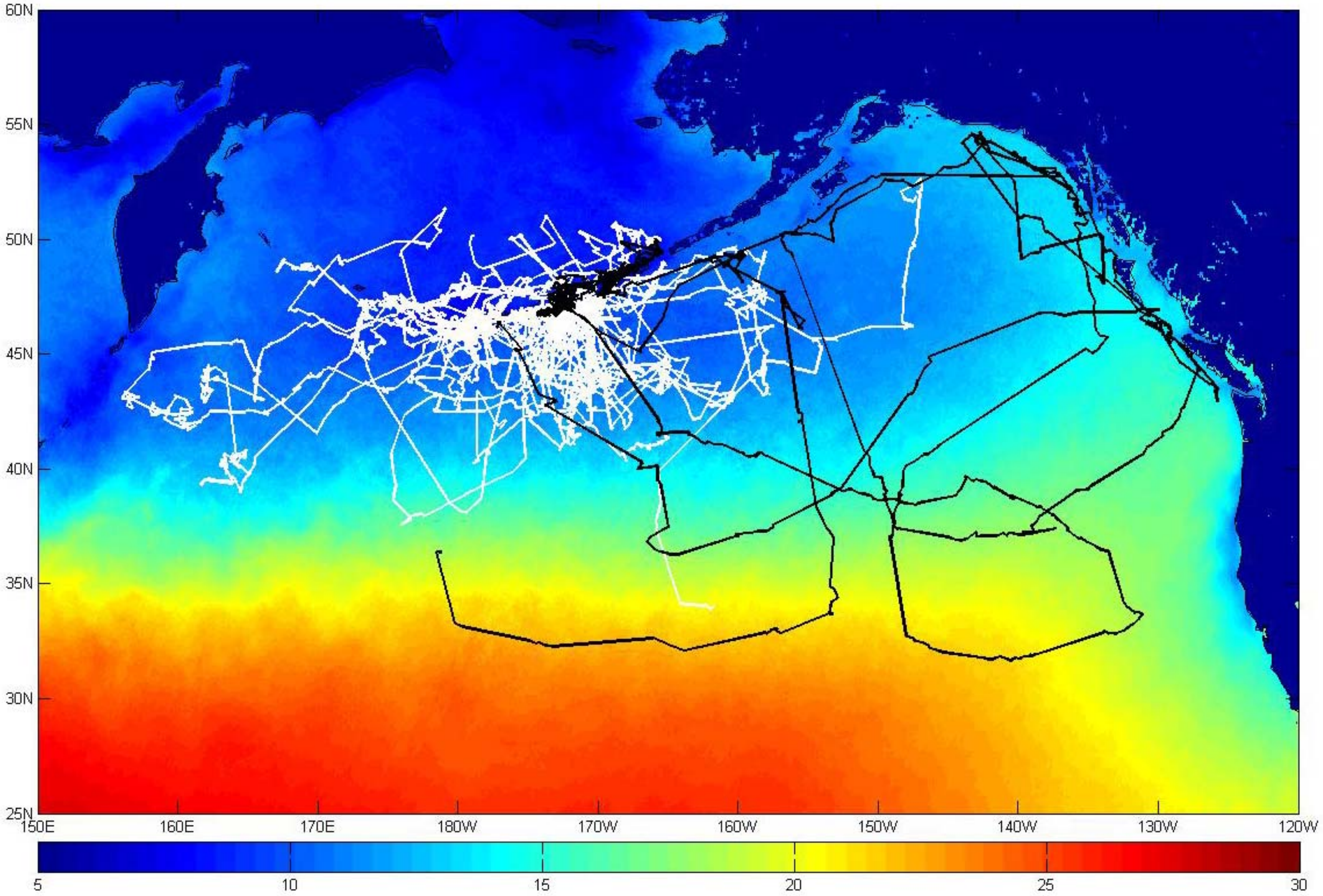

Figure 2. Tracks from all black-footed albatrosses (black lines) and Laysan albatrosses (white lines) captured near Seguam Pass, Aleutian Islands, Alaska (52.08º N, 172.95º W) superimposed over a composite image of sea surface temperature (ºC) for the study periods (July-October, 2005 & 2006).

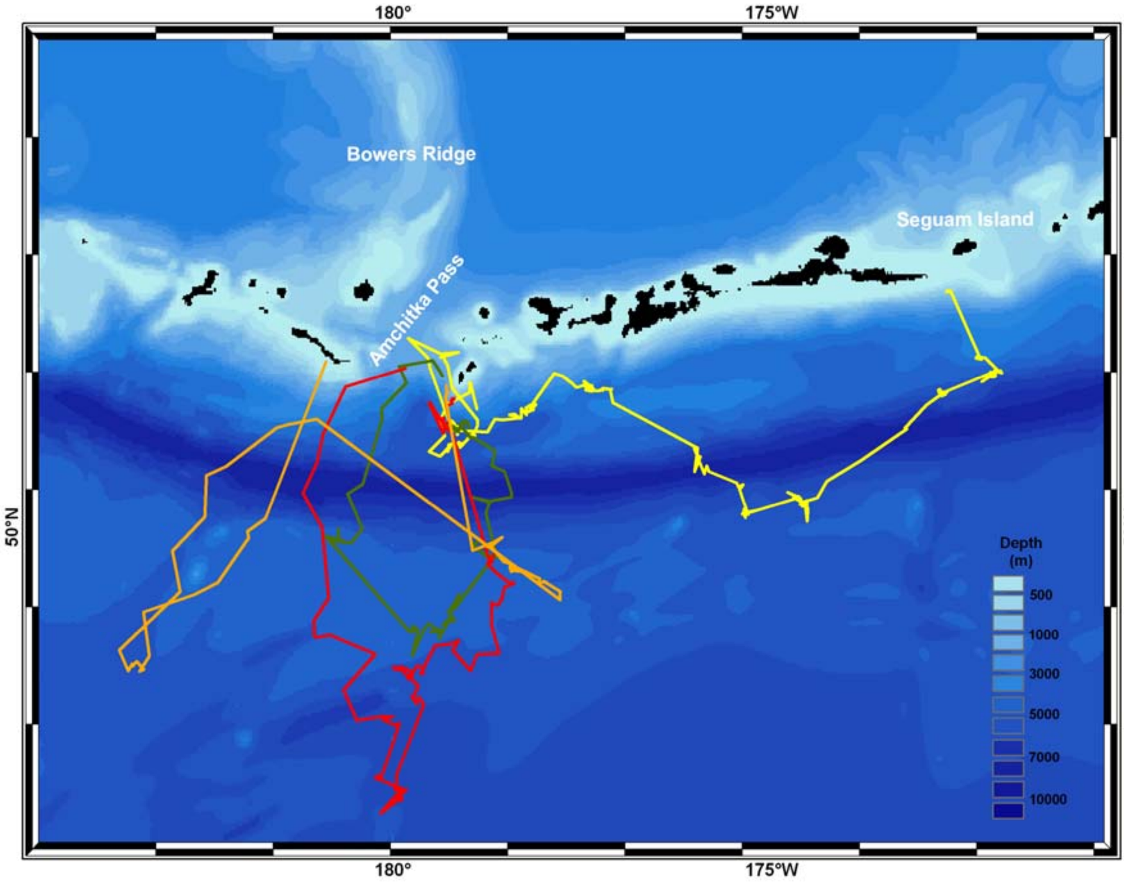

Figure 3. Portion of a Laysan albatross track (L32) that exemplifies looping movements superimposed on a map of seafloor depth. Colored lines represent four separate looping movements from the continental margin to deep oceanic waters and return during 67 days of tracking.

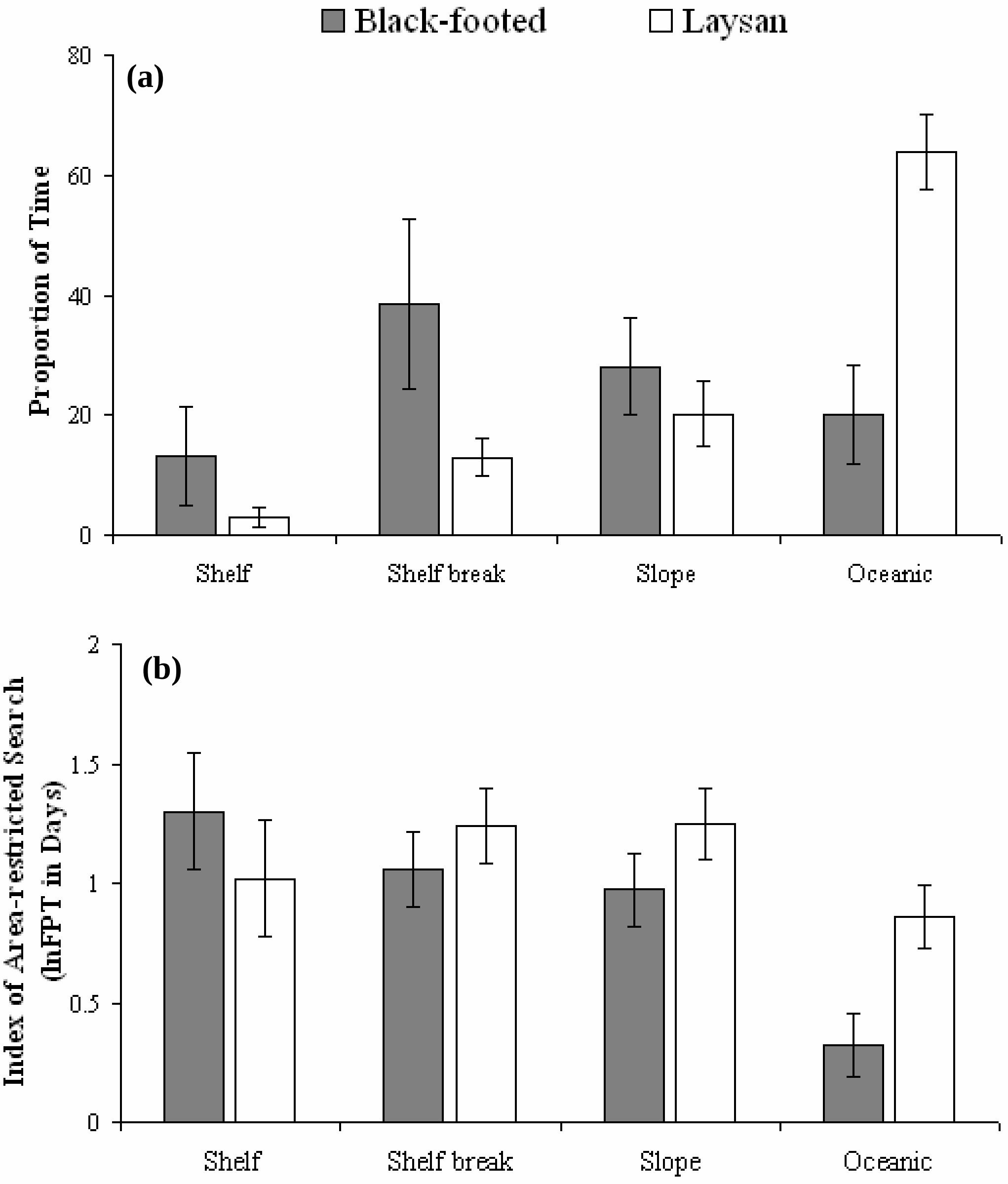

Figure 4. (a) Mean proportion of time (% of first-passage times [FPTs]) and (b) index of area-restricted search activity (mean natural log of FPT in days) for black-footed and Laysan albatrosses in relation to classes of depth (FPT radius set at 50-km for both species). Error bars are ± standard error.

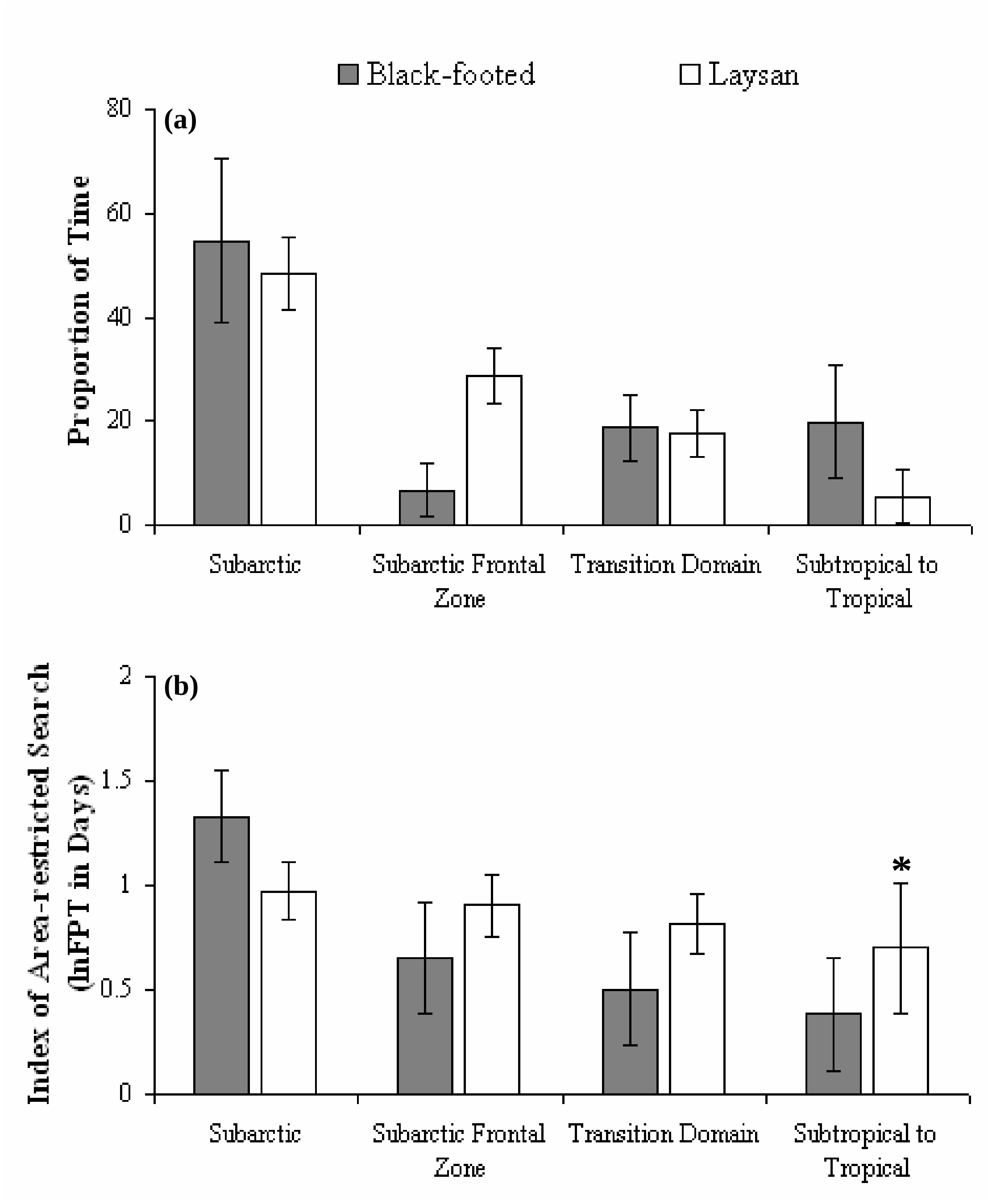

Figure 5. (a) Mean proportion of time (% of first-passage times [FPTs]) and (b) index of area-restricted search activity (mean natural log of FPT in days) for black-footed and Laysan albatrosses in relation to classes of sea surface temperature (FPT radius set at 50-km for both species). Error bars are ± standard error.* Only three Laysan albatrosses entered this habitat class.

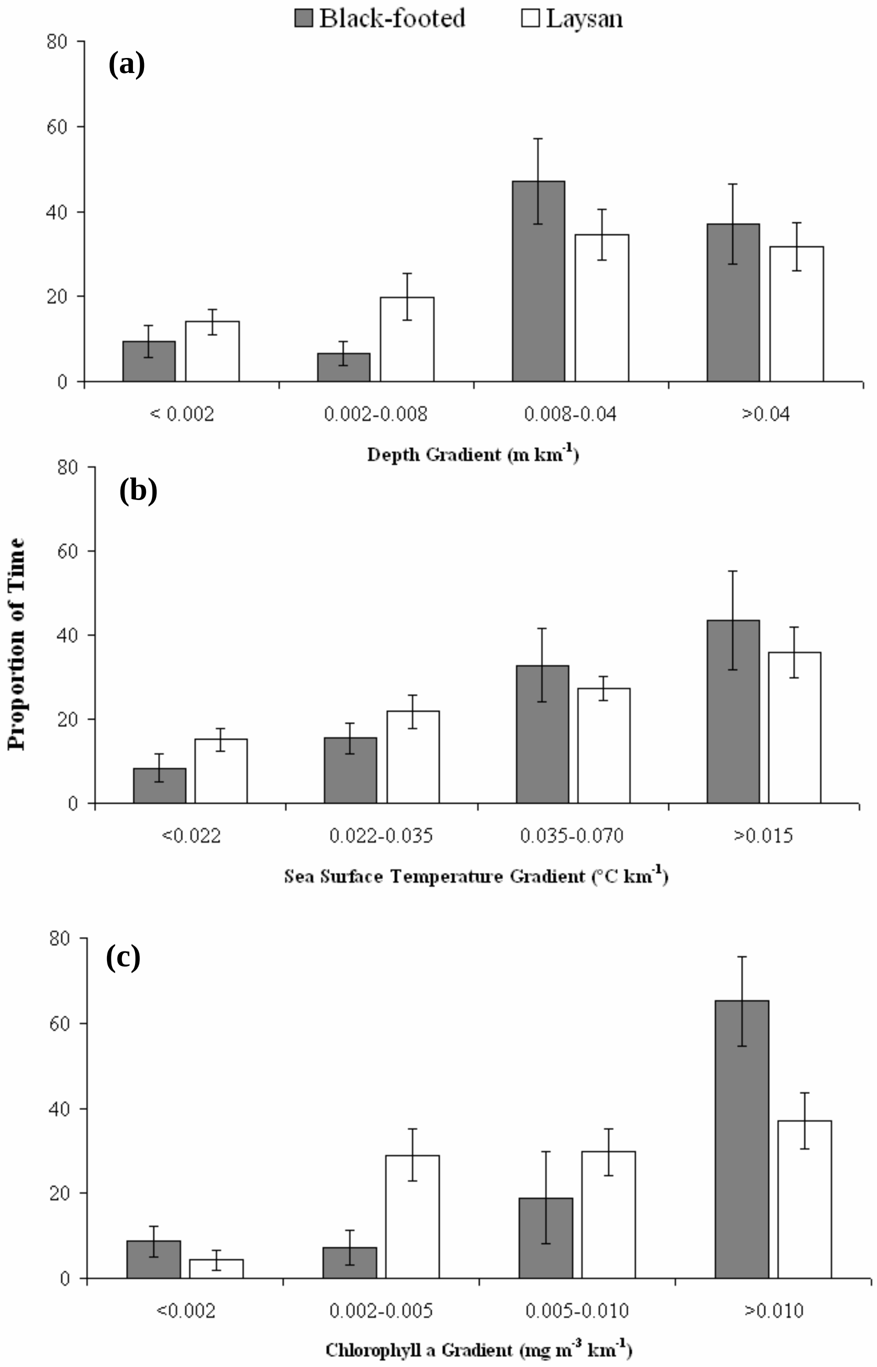

Figure 6. Mean proportion of time (% of first-passage times [FPTs]) for black-footed and Laysan albatrosses at 50-km FPT radii in relation to gradients in (a) depth, (b) sea surface temperature, and (c) chlorophyll *a* concentration. Each independent variable was divided into classes according to approximately equal sample sizes between groups and species. Error bars are ± standard error.

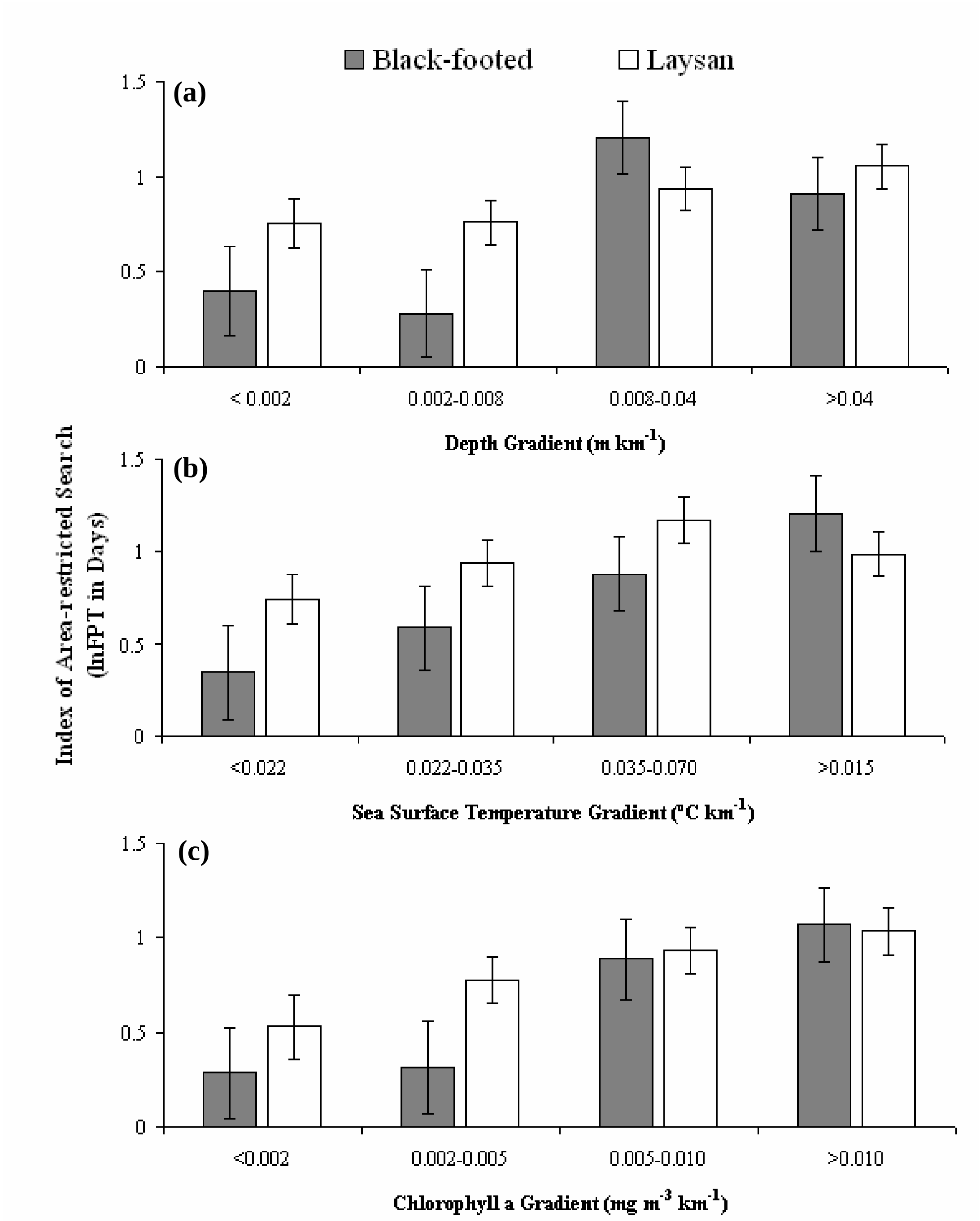

Figure 7. Index of area-restricted search activity (mean natural log of first-passage time [FPT] in days) for black-footed and Laysan albatrosses in relation to gradients of (a) depth, (b) sea surface temperature, and (c) chlorophyll *a* concentration (FPT radius was set at 50-km for both species). Each independent variable was divided into classes according to approximately equal sample sizes between groups and species. Error bars are ± standard error.

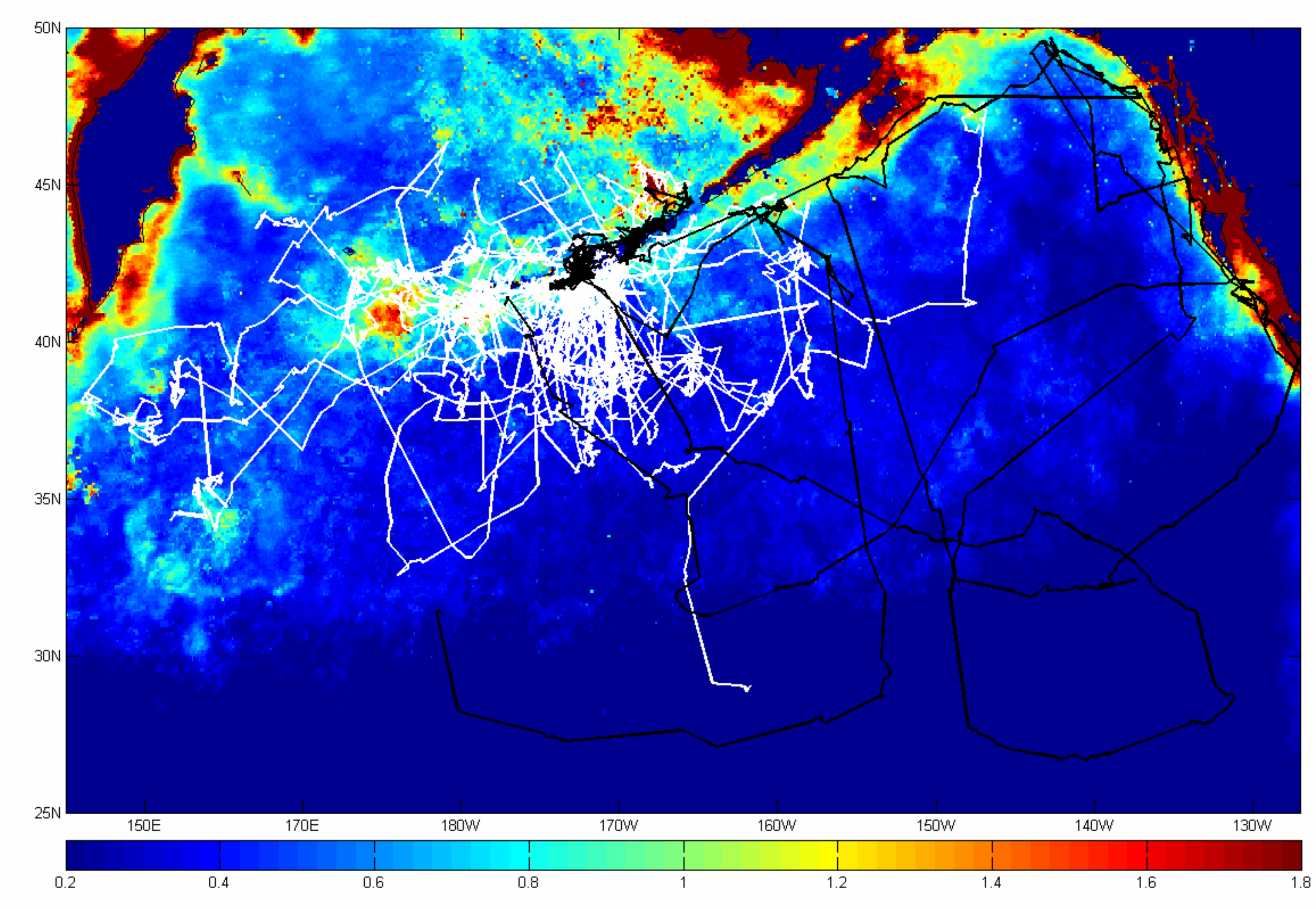

Figure 8. Tracks from all black-footed albatrosses (black lines) and Laysan albatrosses (white lines) captured near Seguam Pass, Aleutian Islands, Alaska (52.08º N, 172.95º W) superimposed over a composite image of chlorophyll *a* concentration (mg m^{-3}) for the study periods (July-October, 2005 & 2006).

Appendix A. List of the 7 models of the 95% confidence set of main-effects only (no interaction terms included), mixed-effects linear models used to model first-passage time as a function of marine habitat variables for black-footed albatrosses during the post-breeding season. Models are shown with Aikaike Information Criteria corrected for small sample size (AICc) values, number of parameters (K), change in AICc value (ΔAICc) from the top model, Akaike Weight, and goodness of fit index (R^2). Interaction terms were singly added to this model set to create a final model set from which the top competing models were used for further analyses.

Model No.	Model[a]	AICc	K	ΔAICc	Akaike Weight	R^2
1.	Wspd + Depth + lnDepth Grad + lnSST Grad	280.70	6	0.00	0.31	0.41
2.	Wspd + Depth + lnSST Grad + SST	281.10	6	0.08	0.30	0.42
3.	Wspd + Depth + lnDepth Grad + SST + lnSST Grad	282.30	7	0.94	0.20	0.43
4.	Wspd + Depth + lnSST Grad	283.40	5	2.70	0.08	0.39
5.	Wspd + Depth + SST	285.70	5	5.10	0.02	0.38
6.	Wspd + Depth + lnDepth Grad + SST	286.20	6	5.25	0.02	0.39
7.	Wspd + Depth + lnDepth Grad	286.30	5	5.63	0.02	0.36

[a] Explanatory variables: Wspd = Wind speed, Depth = seafloor depth, lnDepth Grad = natural log of depth gradient, lnSST Grad = natural log of sea surface temperature gradient, SST = sea surface temperature.

Appendix B. List of the 4 models of the 95% confidence set of main-effects only (no interaction terms included), mixed-effects linear models used to model first-passage time as a function of marine habitat variables for Laysan albatrosses during the post-breeding season. Models are shown with Aikaike Information Criteria corrected for small sample size (AICc) values, number of parameters (K), change in AICc value (ΔAICc) from the top model, Akaike Weight, and goodness of fit index (R^2). Interaction terms were singly added to this model set to create a final model set from which the top competing models were used for further analyses.

Model No.	Model[a]	AICc	K	ΔAICc	Akaike Weight	R^2
1.	Wspd + Depth + lnDepth Grad + lnSST Grad + lnChl *a* Grad	875.1	7	0.00	0.47	0.42
2.	Wspd + Depth + lnDepth Grad + lnChl *a* Grad	876.7	6	1.68	0.20	0.41
3.	Wspd + Depth + lnDepth Grad + SST + lnSST Grad + lnChl *a* Grad	876.8	8	1.72	0.20	0.42
4.	Wspd + Depth + lnDepth Grad + lnChl *a* Grad + SST	878.4	7	3.36	0.09	0.41

[a] Explanatory variables: Wspd = Wind speed, Depth = seafloor depth, lnDepth Grad = natural log of depth gradient, lnSST Grad = natural log of sea surface temperature gradient, SST = sea surface temperature, lnChl *a* Grad = natural log of Chlorophyll *a* concentration gradient.

***Chapter 3: Post-breeding Season Distribution Of Black-Footed And Laysan Albatrosses: 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 (*P. immutabilis*; *n* = 18) with data on fishing effort and distribution from commercial fisheries in the North Pacific Ocean in order to compare potential risk from bycatch. We captured and satellite-tagged albatrosses at-sea in the central Aleutian Islands, Alaska and tracked them during the post-breeding season, July – October 2005 and 2006. The spatial distribution of albatrosses varied by species and the distribution of fisheries varied by gear type and predominant species of catch. In Alaskan waters, fishing effort occurred almost exclusively within the continental margin (shelf and slope). Potential fishery interaction for black-footed albatrosses, which most often frequented these waters, was greatest with sablefish (*Anoplopoma fimbria*) longline and pot fisheries and with the Pacific halibut (*Hippoglossus stenolepsis*) longline fishery, and to a lesser extent with the Pacific cod (*Gadus macrocephalus*) pot fishery. In contrast, Laysan albatrosses spent as much time over oceanic waters as over the continental margin, thereby overlapping less with fisheries in Alaskan waters compared to 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 did Laysan albatrosses, overlapping west coast Canada fisheries and pelagic longline fisheries in the sub-arctic 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 population-level impacts from fisheries.

Keywords *Phoebastria*, Longlining, Trawling, Satellite telemetry

Introduction

Incidental seabird mortality in commercial fisheries is a global marine conservation concern (Rivera, 2000) and a widespread threat to albatross populations (Croxall & Gales 1998). Estimates of seabird bycatch rely largely on independent observers, which varies from nearly complete coverage 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 (Cuthbert et al. 2005, Hyrenbach & Dotson 2003, Prince et al. 1997, Suryan et al. 2007). In the North Pacific Ocean all three native albatross species (black-footed, *Phoebastria nigripes*, Laysan, *P. immutabilis*, and short-tailed, *P. albatrus*) are incidentally taken as bycatch in commercial fisheries (Melvin et al. 2006, Robbins & Rice 1974).

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 20ºN during the breeding season (November-June), and north of 30ºN during the post-breeding season (July-October) (Artyukhin & Burkanov 2000, Cousins et al. 2000, Melvin et al. 2001, Robbins & Rice

1974, Smith & 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 2006a). An additional 2,500 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).

Unlike mortality in longline fisheries that occurs when albatrosses are caught on gear (i.e., hooked), 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 (Sullivan et al. 2006, Weimerskirch et al. 2000). Consequently, albatross bycatch from trawl fisheries is difficult to quantify and is poorly understood in North Pacific fisheries. Nevertheless, Laysan albatross mortality has been documented in Alaskan trawl fisheries (National Marine Fisheries Service 2006a). No albatross mortality has been documented in Alaskan pot fisheries (National Marine Fisheries Service 2006a).

Since the late 1990's, 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, National Marine Fisheries Service 2006a, Smith & Morgan 2005). Bycatch of albatrosses in the North Pacific persists, however. Seabird bycatch avoidance measures are not required in fisheries throughout much of the North Pacific that is 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 during the post-breeding season, in an area of the North Pacific Ocean where both species are common, 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.

Methods

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 & Ellegren 1999). We determined the minimum ages of some tracked individuals (7 black-footed albatrosses and 1 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-second 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 hours (24 h off cycle +2 h for transmission inconsistencies). We could not monitor any potential direct effects of capture post-release. To be cautious, we excluded the first two days of tracking data for each tagged albatross from subsequent analyses to avoid using position fixes that may have been affected by capture. After the second day, many of the birds had dispersed greater than 100 km from the capture location.

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 m - 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 1995-2001; Dietrich 2003).

Fishing effort was defined as the number of hooks (longline) or pots set, or the number of tow hours (trawl). Individual set data (non-aggregated) during July–October in 2005 and in 2006 were spatially and temporally 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 2006b). 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 U.S. 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 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. & *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 5º x 5º 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 ºN.

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 (Hyrenbach & Dotson 2003, Polovina et al. 2001), 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 150ºW), effort for this portion of the Pacific is underrepresented for these years (Peter Williams, Ocean Fisheries Programme; pers. comm.). 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.

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 m to 1000 m), slope (> 1000 m to 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 m to 905 m. There was no Pacific halibut fishing effort reported at depths greater than 905 m.

Statistical 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 $\alpha = 0.05$.

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, data on fishing effort in longline, trawl, and pot fisheries obtained from NMFS's North Pacific Groundfish Observer Program, were summarized within 100 km by 100 km grid cells, which were used for visual representation only. Three or more unique vessels must occur within a grid cell or statistical area in order to be presented graphically; as a result, portions of fishery distributions that were included in analyses are not represented graphically. For longline effort, 69% of cod grid cells (99% of effort) 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 graphically represented at the same resolution as used for analyses, statistical areas and 5° x 5° cells, respectively.

Results

Demographics of Captured Albatrosses

The overall sex ratio of captured albatrosses was strongly male biased; 30 (73%) of 41 black-footed albatrosses ($\chi^2_1 = 8.80$, $P = 0.003$) and 26 (87%) of 30 Laysan albatrosses were male ($\chi^2_1 = 16.13$, $P < 0.001$). 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; pers. comm.). 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.

Distribution of Satellite-tracked Albatrosses and Fisheries Effort in the Alaskan EEZ

Within the Alaskan Exclusive Economic Zone (EEZ), the spatial distribution of 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), flatfish exclusive of halibut (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, 2a, & 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 & 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, 2b, & 3). The majority (94%) of the Atka mackerel (*Pleurogrammus monopterygius*) trawl fishery occurred in the western Aleutian Islands (Fig. 2a), 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 5º x 5º grid cell) within the Alaskan EEZ during 2000-2004 (Fig. 1). All observed fishing effort within Alaska occurred in habitats, as defined by broad-scale depth categories, used by albatrosses (Fig. 3).

Mean tracking duration (total tracking days minus 2 days; see Methods) 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 6,487 and 24,140 hourly interpolated points were used for black-footed and Laysan albatrosses, respectively. 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 & 4). Black-footed albatrosses spent significantly more time over continental margin waters (shelf, shelf break, and slope depth domains) than over oceanic waters within the Alaskan EEZ (Kruskal-Wallis $\chi^2_1 = 9.06$, $P < 0.01$, df = 6). Among the three depth domains of the continental margin, black-footed albatrosses spent similar proportions of time in each (Fig. 3). Therefore, 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 $\chi^2_1 = 1.20$, $P = 0.27$, df = 17). These inter-specific differences indicate that Laysan 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. 2a & 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).

Distribution of Satellite-tagged Albatrosses and Fisheries Outside Alaska

Black-footed albatrosses ranged from 60ºN to 36ºN and from 125Wº to just west of the International Date Line at 180º. This compares with Laysan albatrosses, which had a similar latitudinal range from 58ºN to 38ºN, but a more westerly longitudinal distribution, between 156ºW and 146ºE. Within the principal range of black-footed and Laysan albatrosses during the post-breeding season (north of 35ºN), pelagic longline fishing effort was reported almost exclusively (99 ± 0.01%) between 35ºN and 45ºN, 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 45ºN 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 45ºN. 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 35ºN to 40ºN and from 145ºE to 180º (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 7 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; 3 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.

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. Black-footed albatrosses had the potential to encounter fishing vessels throughout the regions and habitats that they most heavily utilized; conversely, Laysan albatrosses largely occupied regions and habitats not as heavily utilized by fisheries, especially longline fisheries. Inter-specific differences 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 chum 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 (Awkerman et al. 2006, Ryan & Boix-Hinzen 1999, Weimerskirch & Jouventin 1987). Gender differences in at-sea distribution can result in gender differences in overlap with fisheries (Weimerskirch & Jouventin, 1987). Gender differences in behavior or size may also lead to competitive displacement of females by males (Ryan & 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 (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.

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, an area of significant overlap with tagged Laysan albatrosses. 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 (Melvin et al. 2006, Wahl et al. 1989). Therefore, the potential exists for overlap 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 (González-Zevallos & Yorio 2006, Sullivan et al. 2006, Weimerskirch et al. 2000). 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). Prior to our study period there was greater fishing effort in the sablefish fishery in the western Aleutian Islands, overlapping considerably with Laysan albatross distribution, which may explain why bycatch of this species was greatest 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 & Morgan 2005). This suggests that there is potential for bycatch risk in similar fisheries that occur along the west coast of the conterminous U.S., where black-footed albatrosses are more abundant than Laysan albatrosses (Briggs et al. 1987) and seabird bycatch has not been quantified.

Additional bycatch risk is present in much of the range of black-footed albatrosses during the post-breeding season. Pelagic longline fisheries for tunas and billfishes in the western North Pacific are largely associated with subtropical to tropical waters or convergent fronts of temperature or chlorophyll (Polovina et al. 2001, Polovina et al. 2000). Black-footed albatrosses tracked during this study ranged into sub-tropical waters south of 45ºN (see Chapter 2) 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).

The Laysan albatrosses tracked during this study appeared to be at little risk of interactions with fisheries outside of the Alaskan EEZ because there was little overlap with reported or observed fisheries. Although individuals tracked from Alaska during this study did not travel to the Kuroshio Extension off Japan, this area is heavily used by Laysan albatrosses during the post-breeding and post-breeding dispersal periods (Fernández et al. 2001, Robbins & Rice 1974). The extensive pelagic longline fishing effort reported in this area may, therefore, be a considerable threat to Laysan albatrosses. 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. Black-footed albatrosses overlapped with fisheries in which bycatch is known to occur throughout their range during the post-breeding season, which was mostly within the continental margin of the Alaskan EEZ and the British Columbian EEZ and into the transition domain. There was little evidence that black-footed albatrosses spent time within regions devoid of fisheries. 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 than for Laysan albatrosses during the post-breeding season.

Acknowledgements

P. Sievert was instrumental in the success of at-sea captures and satellite tagging. We are grateful to the efforts of the captains and crew of the F/V Kema Sue. Frances Taylor with Birdlife International interpolated satellite tracking data prior to analyses. We thank S. Fitzgerald and M. Loefflad for facilitating access to the National Marine Fisheries Service Alaskan Groundfish Observer Program data; and T. Kong at the International Pacific Halibut Commission provided aggregated Pacific halibut fishery data. We thank … and … anonymous reviewers for insightful comments to improve the manuscript. Funding was provided by the North Pacific Research Board and the U.S. Fish and Wildlife Service. This research was approved by the animal care and use committee of Oregon State University and by permit from the U.S. Fish and Wildlife Service. This is contribution #XXX of the North Pacific Research Board.

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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 & 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	4,990	4,410	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	8,109	9,034	2,134,492	2,650,239
Flatfish	8	25	February-August	38	38	1,107	1,023	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. Proportion for 2005 only.

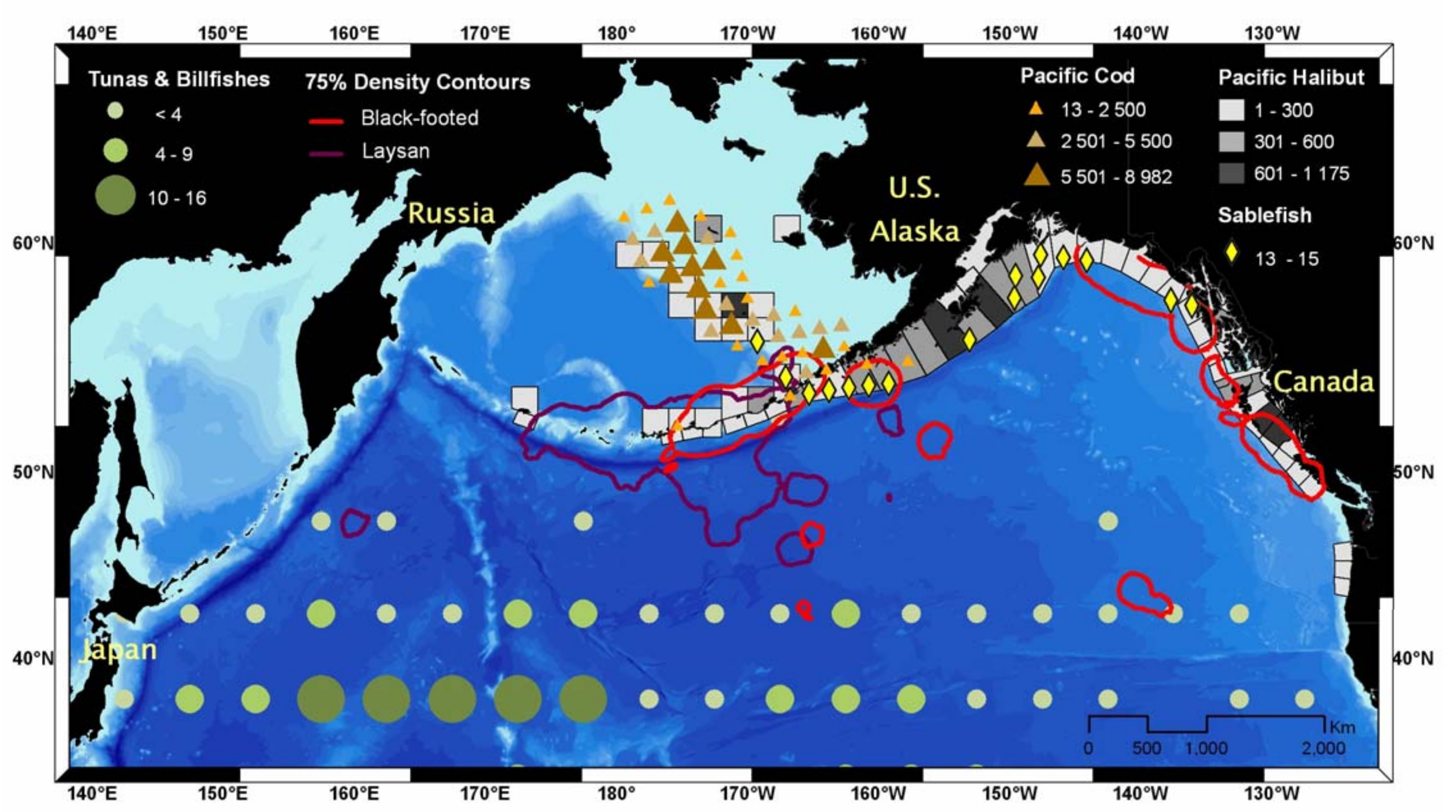


Figure 1. Overlap between black-footed and Laysan albatross 75% density contours of tracking hours and the spatial distribution of observed or reported longline fishing effort (1,000's of hooks) in the North Pacific during July-October (years and data sources vary with fisheries, see Methods). A portion of fishing distribution is not presented (see *Graphical Representation* in Methods). Most notably, sablefish effort in the central and western Aleutian Islands is not displayed. Fishing effort for tunas and billfishes east of 150ºW is underrepresented (see Methods).

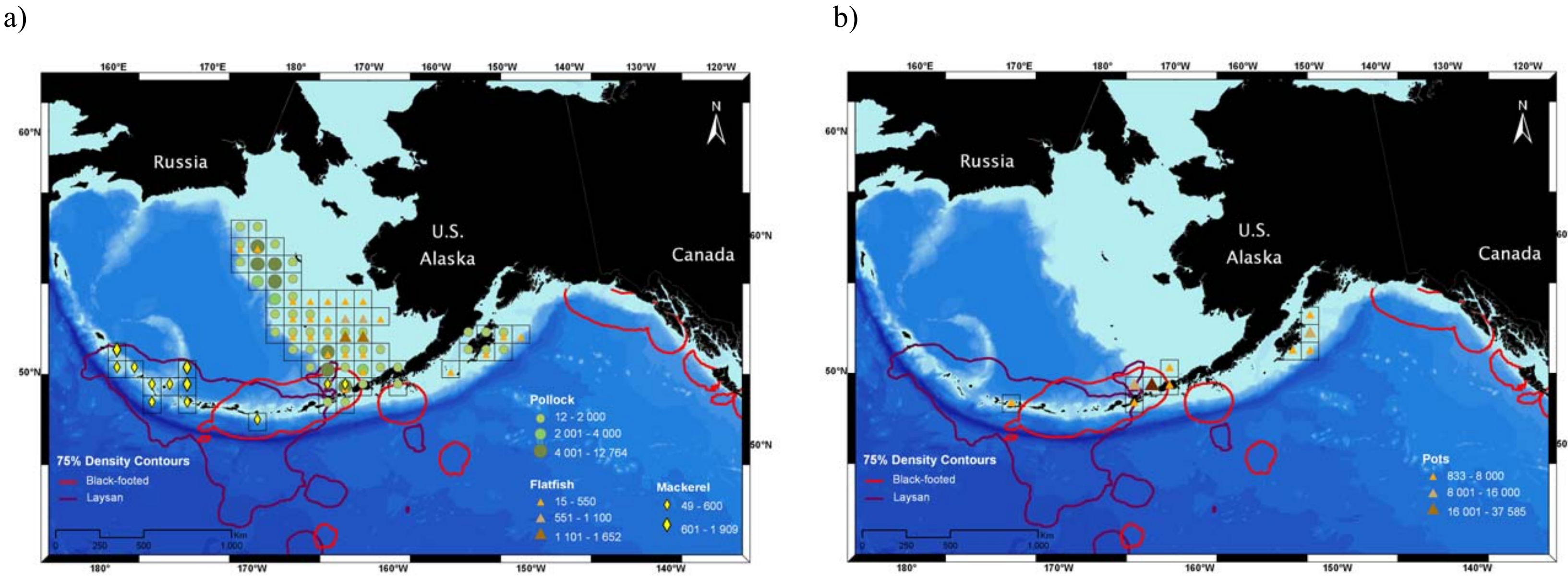


Figure 2. Overlap between black-footed and Laysan albatross 75% density contours and the spatial distribution of observed (a) trawl effort (tow hours) for walleye pollock, flatfish, and Atka mackerel, and (b) pot fishing effort (primarily Pacific cod and sablefish) in the Alaskan Exclusive Economic Zone, 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 *Graphical Representation* in Methods).

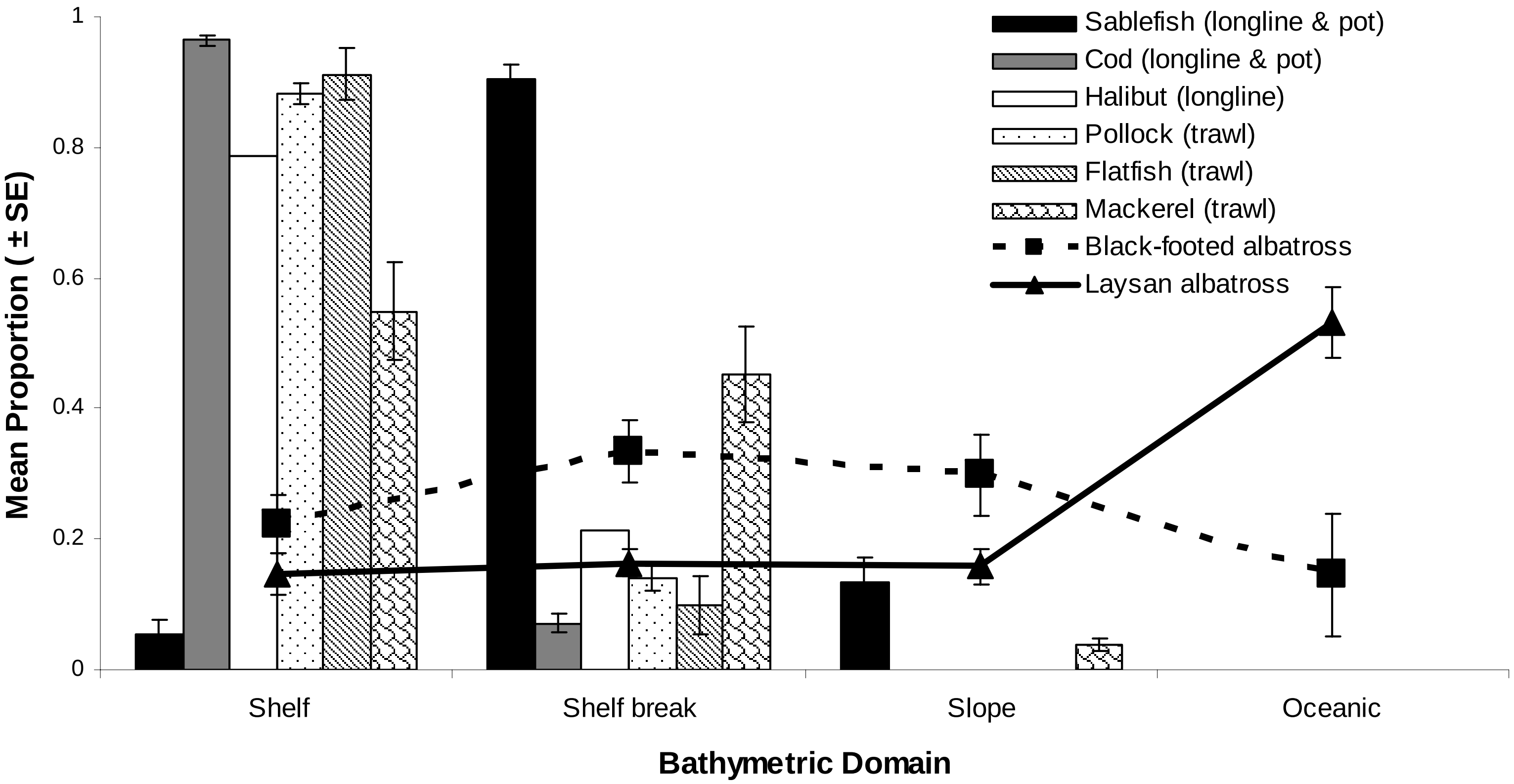


Figure 3. Mean (± SE, among vessels) proportion of fishing effort and mean (± SE, among albatrosses) proportion of black-footed and Laysan albatross tracking hours within the Alaskan Exclusive Economic Zone by bathymetric domain. Albatrosses were tracked during July-October, 2005 (black-footed and Laysan) and 2006 (Laysan). Individual vessel data were not available for the Pacific halibut fishery; therefore values represent the overall proportion of fishing effort by depth domain.

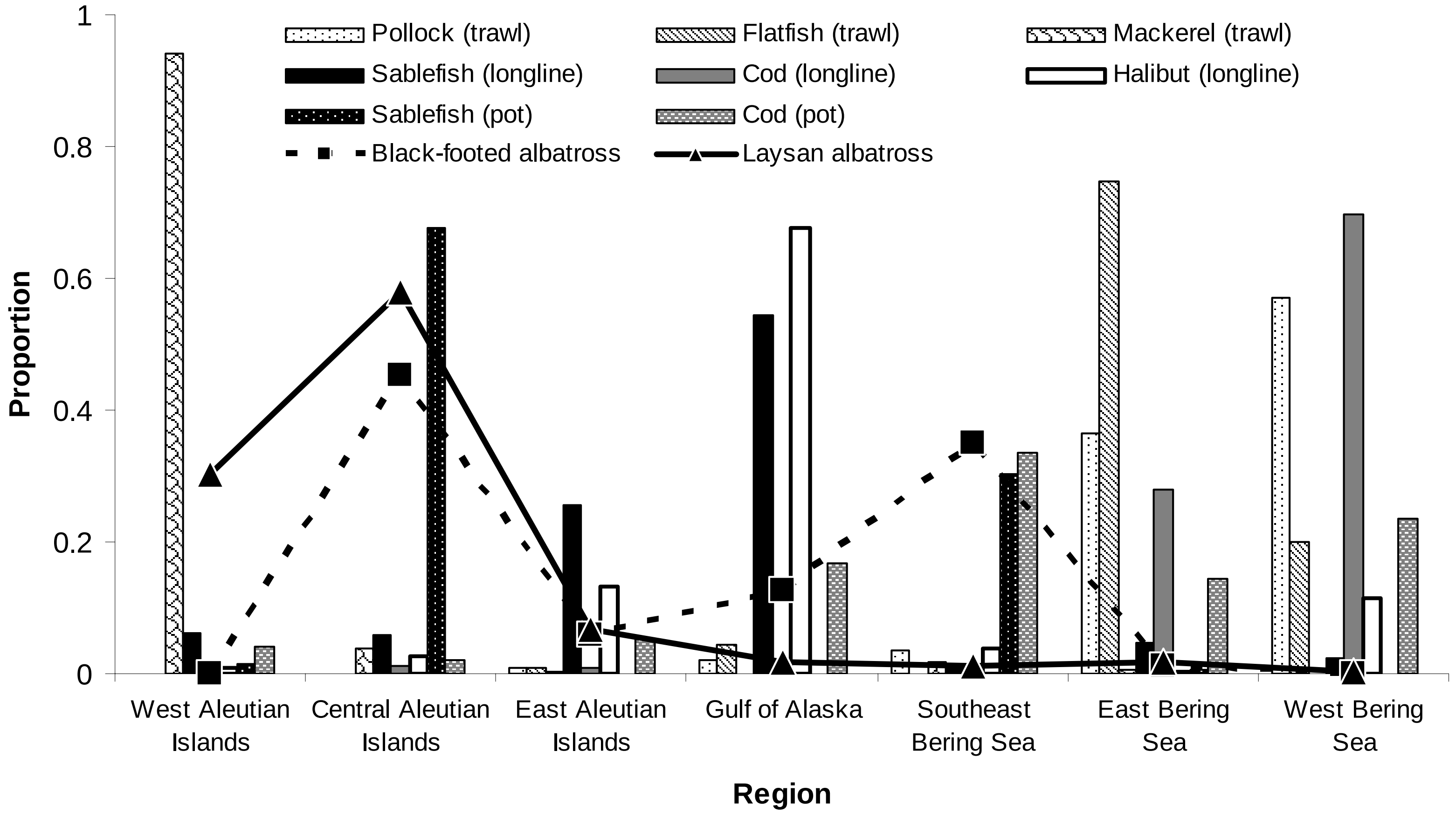
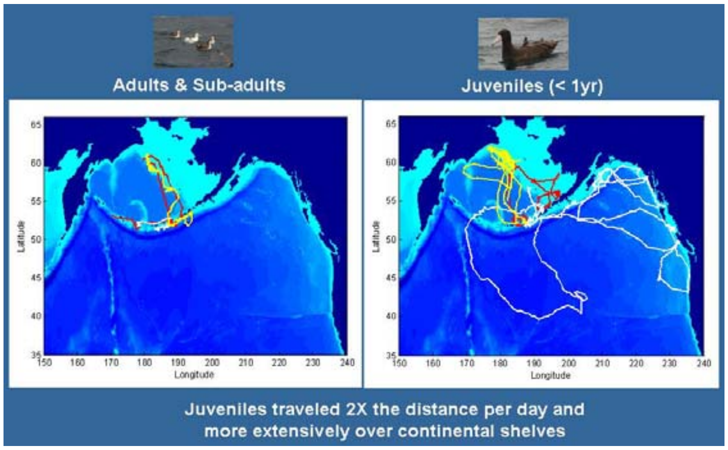


Figure 4. Proportion of observed or reported fishing effort (longline, trawl, and pot) and black-footed and Laysan albatross tracking hours within the Alaskan Exclusive Economic Zone by geographic region.

Conclusions

Our results demonstrate that North Pacific albatrosses exhibit resource partitioning during the non-breeding season, even though at times they are sympatric on foraging grounds. Resource partitioning occurred in prey consumed (i.e. tropic position) and geographic distribution, with short-tailed and black-footed more similar in their use of continental margin habitats compared to more oceanic habitats used by Laysan (Chapter 1). Differences in primary habitat use by albatrosses had important implication for potential interactions with commercial fisheries, which also target specific marine habitats and geographic regions depending on targeted catch. Among Alaskan fisheries, short-tailed albatrosses (particularly juveniles) had the greatest overlap with Bering Sea walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus macrocephalus*) fisheries and all three species with Aleutian Islands shelf-slope fisheries, such as sablefish (*Anoplopoma fimbria*), Pacific halibut (*Hippoglossus stenolepis*), and Atka mackerel (*Pleurogrammus monopterygius*). Black-footed and juvenile short-tailed albatrosses had the greatest overlap with Gulf of Alaska and west coast shelf-slope fisheries and overlapped a portion of high seas tuna fisheries in the sub-arctic transition domain between Alaska and Hawaii. Laysan albatrosses overall had the least spatial overlap with North Pacific fisheries, spending the majority of time in areas devoid of fisheries (Suryan et al. 2007, Chapter 3, and unpubl. data).

This study was instrumental in providing additional supporting evidence that juvenile (< 1 year old) short-tailed albatrosses have strikingly different movement patterns and venture more extensively over continental shelf habitats than adults and sub-adults (Fig. 1). These findings have already made important contributions to modifications of seabird deterrent regulations in continental shelf fisheries in Alaska. No similarly striking differences have been detected with other age classes. We have not yet further evaluated gender-specific differences for this species (e.g., Suryan et al. 2007), but will continue to pursue this topic with studies in collaboration with the Yamashina Institute for Ornithology. We were unable to address age or gender related differences in distribution and movement patterns of black-footed or Laysan albatrosses because we had a strong male



Juveniles traveled 2X the distance per day and more extensively over continental shelves

Figure 1. Movement paths from a sub-sample of three adult/sub –adult vs. three juvenile short-tailed albatrosses tracked during the summer, non-breeding period in Alaska.

bias in birds captured (75% male for black-footed and 87% for Laysan) and age classes were either not all represented (black-footed) or were unknown (Laysan).

Consistent with habitat use studies of short-tailed albatrosses (Suryan et al. 2006), wind speed and sea floor depth (or gradient), chlorophyll *a* concentration (or gradient), and sea surface temperature, respectively, were good to moderate predictors of albatross residence time. For example, residence time (first-passage time analysis; Chapter 2) was longer within a given foraging radius when birds were within shelf-slope habitats relative to oceanic habitats (although less so for Laysan albatrosses) and also longer within areas of higher bathymetric or chlorophyll *a* gradients. Therefore, even though there were inter-specific differences in time spent among habitats, albatrosses had somewhat similar foraging time budgets within a given habitat, at least at the coarse scale of our analyses. These results likely reflect different foraging strategies required for prey species in more productive, vertically mixed waters (e.g., coastal upwelling or frontal zones), vs. more vertically stratified or oligotrophic waters (e.g., oceanic zones or weak frontal boundaries).

Satellite tracking data collected during this study have been incorporated into Birdlife International's Global Procellariiform Tracking Database and will be used for North Pacific and global seabird bycatch initiatives. Tracking data for black-footed and Laysan albatrosses also will be used in collaborations with other albatross tracking studies in the North Pacific (e.g., Tracking of Pacific Predators and Oikonos Ecosystem Knowledge). Satellite tracking studies of short-tailed albatrosses will continue from breeding colonies in Japan, some of which includes pioneering efforts in re-establishing a third breeding colony to safeguard this endangered species (with partial funding from NPRB). A component of this work involves satellite tracking of juvenile short-tailed albatrosses as they leave the breeding colonies, which will augment our samples of these particularly far-ranging individuals. Further research on short-tailed albatrosses in Alaska may include focal studies of "hot spots" (e.g., Piatt et al. 2006) where large congregations of this species (including satellite-tagged birds) have occurred. In total, these efforts are providing an improved understanding of ecological relationships among North Pacific albatrosses, as well as identifying differences in potential interactions with regional fisheries. Continued integration of these results with seabird mitigation research (e.g., Melvin et al 2001, Robertson 2006, Gilman et al. 2007) will contribute to making Alaska's and other North Pacific fisheries among the most seabird safe commercial fisheries.

Scientific Publications

Fischer, K.N. 2008. Marine habitat use of black-footed and Laysan albatrosses during the non-breeding season and spatial and temporal overlap with commercial fisheries. M.S. Thesis. Oregon State University.

Fischer, K.N., R.M. Suryan, and D.D. Roby. *In prep*. Marine habitat use of black-footed and Laysan albatrosses off Alaska during the non-breeding season. Marine Ecology Progress Series or similar journal

Fischer, K.N., R.M. Suryan, D.D. Roby, and G.R. Balogh. *In prep*. Post-breeding season distribution of satellite-tagged black-footed and Laysan albatrosses: Inter-specific differences in spatial overlap with North Pacific fisheries. Biological Conservation or similar journal

Suryan, R.M. and K. N. Fischer. *In prep*. Resource partitioning of non-breeding North Pacific albatrosses. Oecologia or similar journal.

Suryan, R.M., K.N. Fischer, G.R. Balogh, P.R. Sievert, F. Sato, N. Nakamura, K. Ozaki. *In prep*. Movement patterns of juvenile short-tailed albatrosses: Contrasts with older age classes and implications for fishery interactions: Endangered Species Research or similar journal

Popular Articles

Balogh, G.R. 2008. Short-tailed albatross: Brush with oblivion. Audubon Magazine

Balogh, G.R. *In Press*. Short-tailed albatross - Dandies of the deep. *In*: T. de Roy, Albatrosses of the World.

Outreach

Webpage developed:	http://www.wfu.edu/albatross/shorttail/shorttail2.htm		
Exhibits/demonstration project developed:	Albatross exhibit – Hatfield Marine Science Center, Oregon State University. Operated by Oregon Sea Grant (see photograph of display at end of table)		
Conferences and Seminars:	Title	Mo/Yr	Presenter
NOAA/National Marine Mammal Lab, Seattle, WA	Inter-Specific Differences In Marine Habitat Use of Albatrosses: Use of Marine Production Zones And The Importance Of Wind, Waves, And Wind Loading.	04/207	R. Suryan
Pacific Seabird Group Meeting, Pacific Grove, CA.	Marine habitat use of black-footed and Laysan albatrosses off Alaska: Inter-specific variation during the non-breeding season.	02/07	K. Fischer
North Pacific Fisheries Management Council, Portland, OR.	Short-tailed albatross satellite tracking.	02/07	G. Balogh
Alaska Marine Science Meeting, Anchorage, AK.	Inter-specific differences in marine habitat use by albatrosses in Alaska.	01/07	G. Balogh
College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR.	Integrating satellite tracking and remote sensing data to study the distribution and marine habitat use of albatrosses.	11/06	R. Suryan
Research Advances in Fisheries, Wildlife, and Ecology, Oregon State University, Corvallis, OR.	Marine habitat use and overlap with commercial fisheries of black-footed and Laysan albatrosses during the non-breeding season	11/06	K. Fischer
North Pacific Marine Science Organization annual meeting, Yokohama, Japan	Kuroshio and Oyashio boundary currents: Critical foraging habitat for the short-tailed albatross (*Phoebastria albatrus*), one of Japan's natural monuments.	10/06	R. Suryan
North American Ornithological Conference, Veracruz, Mexico	Post-breeding season migration routes and foraging destinations of short-tailed albatrosses in the North Pacific Ocean.	10/06	D. Hyrenbach for R. Suryan
The Wildlife Society, Honolulu, HI.	At-sea movements and marine habitat use of black-footed and Laysan albatrosses during the non-breeding season.	10/06	K. Fischer
Short-tailed Albatross Symposium, Tokyo, Japan.	Marine Habitats of Short-tailed Albatrosses.	09/06	R. Suryan
Markham Research Symposium, Hatfield Marine Science Center,	Satellite tracking of black-footed and Laysan albatrosses off Alaska during the non-breeding season.	6/06	K. Fischer

Newport, OR.			
Pacific Seabird Group Meeting, Anchorage, AK.	Satellite tracking of black-footed and Laysan albatrosses off Alaska during the non-breeding season.	02/06	K. Fischer
Alaska Marine Science Meeting, Anchorage, AK.	Satellite tracking albatrosses in Alaska: Preliminary results of the 2005 field season.	01/06	R. Suryan
United States Arctic Research Commission 77th Meeting, Oregon	Satellite Tracking Studies of Albatrosses in the Bering Sea & Aleutian Islands.	10/05	R. Suryan
<u>Community Meetings:</u>			
Audubon Society, Corvallis, OR.	Movements and Migration in Pacific Albatrosses.	03/07	R. Suryan
<u>Presentations at Festivals/Events:</u>			
SeaFest, HMSC Open House, Newport, OR.	Satellite tracking albatrosses and seabird-fisheries interactions.	6/05 & 6/07	R. Suryan K. Fischer
<u>Workshop participation:</u>			
U.S. Fish and Wildlife Service, Albatross Action Plan for the North Pacific, April 2007, Seattle WA.			R. Suryan G. Balogh
<u>Presentations in Classrooms (K-12 and University):</u>			
Steller High School Ornithology Class	Island Biogeography and the Endangered Short-tailed Albatross	3/05	Greg Balogh
HMSC Coastal Ecology and Resource Management class, Newport, OR.	Seabird Ecology and Conservation	10/05 & 10/06	R. Suryan
HMSC Seminar for summer interns, Newport, OR.	Studying Seabirds in Japan, Alaska, and the Columbia River	6/06	R. Suryan
<u>Radio/Television Interviews:</u>	Dutch Harbor public radio	9/05	G. Balogh

Exhibit in the visitor center at Oregon State University's Hatfield Marine Science Center in Newport. This was designed as a temporary exhibit using a portion of our NPRB outreach funds, however, there now is interest in converting and expanding it into permanent exhibit space. This will require much more time and money and we are currently in search of funds for this effort.

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