



AN ABSTRACT OF THE THESIS OF

Amelia J O'Connor for the degree of Master of Science in Marine Resource Management presented on July 31, 2013.

Title: Distributions and Fishery Associations of Immature Short-tailed Albatrosses, *Phoebastria albatrus*, in the North Pacific

Abstract approved:

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Robert M. Suryan

Short-tailed albatrosses (*Phoebastria albatrus*, hereafter “STAL”) migrate throughout the North Pacific, overlapping with multiple large scale fisheries. In the Bering Sea, documented bycatch of this species is a focal conservation concern, due to the fact that this species is listed as “endangered” under the U.S. Endangered Species Act. We conducted the first year-round tracking study of immature ( $\leq 3$  years) STAL, an understudied age class, between 2008 and 2012. We quantify seasonal distributions and fisheries associations. Our findings highlight regional differences in distributions and areas of high vessel associations within the Bering Sea.

We examined travel distances across seasons and bird demographics, seasonal ranges of birds, and whether core use areas differed among ages, sexes, or source colonies. Source colonies include Torishima, the main STAL colony, and an anticipated new colony on Mukojima where birds were translocated and hand-reared. Linear mixed models (LMM) were used to evaluate travel distances across temporal and demographic (sex, age, and source colony) variables. Kernel density estimations (KDE) were used to quantify range and core areas. These areas were further analyzed using overlap indices.

Regional variations were found in core areas of sexes and age classes. Moreover, STAL in first year of flight have a broader distribution than other ages, which may suggest a period of learning foraging skills or exploratory movements. We also found no concerning differences in year-round distributions between colonies (which included translocated and non-translocated birds), and documented via satellite tracking an initial return to Mukojima by a three year old translocated bird.

In the Bering Sea, we examined seasonal distributions and STAL association with Bering Sea/Aleutian Island fisheries. Associations (defined here as STAL locations within 2 hours and 10 kilometers from a vessel setting gear), were quantified spatially and examined with a LMM. STAL-vessel associations occurred year round but predominately during summer and fall months along shelf-break and near canyon habitats. Additionally, the relative abundance of associations with longline vessels vs. other gear types increased from summer to fall, when most STAL bycatch was documented. While greater vessel associations and one bycatch event did occur within STAL high use areas, STAL bycatch during this study period occurred in areas of low longline association. We also did not find variations in fisheries association between translocated and non-translocated STAL.

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Distributions and Fishery Associations of Immature Short-tailed Albatrosses,  
*Phoebastria albatrus*, in the North Pacific

by  
Amelia J. O'Connor

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Amelia J. O'Connor, Author

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## CONTRIBUTION OF AUTHORS

Robert M. Suryan, Kiyooki Ozaki, Fumio Sato, and Tomohiro Deguchi secured funding, initiated studies, and conducted field work, collection, and filtering of satellite tracking data used in both Chapter 2 and 3. Furthermore, Robert M. Suryan contributed to at all other stages of research, including study design, feedback on analysis, interpreting results and revisions for both Chapter 2 and 3.

## TABLE OF CONTENTS

	<u>Page</u>
Chapter 1 – General Introduction .....	1
Background .....	1
Juvenile Distributions .....	2
Seabird-Fishery Interactions.....	2
Research Approach .....	3
References .....	5
Chapter 2 - At-sea distribution of immature short-tailed albatrosses, <i>Phoebastria albatrus</i> , including seasonal and demographic variability .....	9
Abstract .....	9
Introduction .....	9
Methods.....	12
Satellite telemetry.....	12
Travel distances .....	13
Area utilization.....	14
Overlap analyses .....	15
Results.....	16
Travel distance .....	16
Area utilization.....	16
Flight year distributions and overlap.....	17
Sex distributions and overlap.....	18
Source colony distributions and overlap.....	18
Discussion .....	19
Immature STAL distributions .....	19
Seasonal variability .....	20
Demographic variability .....	21
Conclusion.....	24
References .....	26
Tables .....	30
Figures.....	31
Chapter 3 - Short-tailed albatrosses and Alaskan fisheries in the Bering Sea: an investigation into fine scale associations .....	36

## TABLE OF CONTENTS (Continued)

	<u>Page</u>
Abstract .....	36
Introduction .....	37
Methods.....	39
Immature STAL tracking and seasonal distributions .....	39
North Pacific groundfish observer data .....	41
Seabird-vessel associations and analyses .....	42
Results.....	43
Seasonal STAL distribution and mortalities .....	43
Alaskan Bering Sea fisheries effort and distribution.....	44
Vessel-bird association .....	45
Discussion .....	47
Vessel-bird associations and distributions.....	48
Documented STAL bycatch and associations.....	49
Variability in associations.....	51
Conclusion.....	53
References .....	54
Tables .....	58
Figures.....	60
Chapter 4 - synopsis and conclusions.....	64
Research aims .....	64
Primary findings .....	64
Contributions and future directions .....	65
Bibliography.....	67

## LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
Figure 2.1. Immature bird core area (50% kernel) polygons and point locations showing total extent of travel. Refer to Figure 2.3 for bathymetry. ....	31
Figure 2.2. Core area (50% kernel) polygons showing summer, fall, winter and spring distributions. Refer to Figure 2.1 for geographic locations. ....	32
Figure 2.3. Core area (50% kernel) polygons of first and second flight years showing overlap in the North Pacific. Refer to Figure 2.1 for geographic locations. ....	33
Figure 2.4. Core area (50% kernel) polygons of male and female birds showing overlap in the North Pacific. Refer to Figure 2.1 for geographic locations. ....	34
Figure 2.5. Core area (50% kernel) polygons of Mukojima and Torishima birds showing overlap in the North Pacific. Refer to Figure 2.1 for geographic locations. ....	35
Figure 3.1a-d. The core area (50% kernel) contour of immature short-tailed albatrosses in the Bering Sea for (from left to right) (a) summer, (b) fall, (c) winter and (d) spring. Also included are the documented takes for that given season. Recent takes (2010-2011) are highlighted. ....	60
Figure 3.2. STAL time spent in canyons (ordered North to South) as a percent of total hours in the Bering Sea by season. ....	61
Figure 3.3. Alaskan fishing vessel and STAL association abundance and locations. Pie charts depict the gear type of vessels associated with STAL within association hotspots near individual canyons. ....	62
Figure 3.4. Percent of Alaska BSAI area STAL locations within 10km and 2hr of BSAI vessel gear deployment or retrieval by season and gear type. ....	63

## LIST OF TABLES

<u>Table</u>	<u>Page</u>
Table 2.1. Summary statistics for harness and tape attached satellite transmitters. Transmitter durations are given in days. Total locations are also displayed by season. ...	30
Table 2.2. Travel distance (km/day) restricted maximum likelihood Linear Mixed Model (LMM) results for source colony, flight year, sex, and season factors. Bird ID was used as the random effect and the number of birds comprising each factor level is reported. An ANOVA F-test is also reported with P-values for individual factors. ....	30
Table 2.3. Percent of hourly interpolated location data allocated into national and international waters.....	30
Table 3.1. Summary statistics for harness and tape attached satellite transmitters inside the Bering Sea study area (June 2008-2012). Transmitter durations (min and max) within this study area are given in days. Total locations are also displayed by season. ....	58
Table 3.2. Summary statistics for fishing effort by gear type (2008-2012). Gear deployment durations are given in hours. Total sets are also displayed by season.....	58
Table 3.3. Summary statistics for STAL-vessel association data by gear deployment and retrieval (2008-2012). Association mean and standard deviation are displayed in kilometers. Total associations are also displayed by season.....	58
Table.3.4. Restricted maximum likelihood Linear Mixed Model results for immature STAL <10km association distances with fishing vessel gear deployments. Estimated mean and standard error (in km) are reported only for factors with P-value <0.1. P-values were calculated from ANOVA F-values. Individual vessel and bird were used as random effects.....	59

Distributions and Fishery Associations of Immature Short-tailed Albatrosses,  
*Phoebastria albatrus*, in the North Pacific

## CHAPTER 1 – GENERAL INTRODUCTION

### Background

For over four decades, conservation and research efforts through the International Union for Conservation of Nature and Endangered Species Act have been working to identify and recover species in decline. Many of these species are long lived and have suffered declines from anthropogenic causes. This is the case for the short-tailed albatross (*Phoebastria albatrus*).

Short-tailed albatrosses (STAL) declined from being the most abundant albatross in the North Pacific (over 1 million) to near extinction in the 1940s (Austin 1949). This decline resulted from extensive hunting at breeding islands (Hasegawa and DeGange 1982). During this period, STAL were extirpated from all breeding colonies, until natural recolonization of Torishima by a few individuals in the early 1950s (Hasegawa and DeGange 1982). Today, the STAL population has reached an estimated 3,400 individuals (Paul Sievert and Hiroshi Hasegawa unpubl. data) and continues to grow at a rate of 7% annually (USFWS 2008). Recent recovery efforts by the U.S. and Japan included translocating one-month-old chicks from the natal colony and hand-rearing them on a different island, Mukojima, to establish a new breeding colony (Deguchi et al. 2012). Translocation research has documented similar distributions for juvenile translocated and non-translocated STAL and found juveniles traveling to new areas where adults were not

observed, specifically the Sea of Okhotsk and western Bering Sea (Deguchi et al. in press).

### **Juvenile Distributions**

Adult and juvenile distributions have been shown to differ for a variety of marine species (Weimerskirch and Jouventin 1987, Tamaki and Ingole 1993, Booth and Wellington 1998). For seabirds, differential distributions between age classes can result from competitive exclusion (Weimerskirch et al. 2006), learning foraging skills (Weimerskirch et al. 2006, Alderman et al. 2010), and breeding requirements (Alderman et al. 2010). Additionally, variable aerodynamic performance between age classes can limit distribution ranges for some age classes and not others (Shaffer et al. 2001).

The distribution of juvenile age classes remains unstudied for many seabirds and can have critical implications for a species (Weimerskirch and Jouventin 1987, Gales 1997). For wandering albatross, a high rate of fisheries mortality for females and juvenile birds was observed due to foraging in different areas than males (Weimerskirch and Jouventin 1987). These fisheries related mortalities may have caused population declines for several albatross species (Weimerskirch et al. 1997).

### **Seabird-Fishery Interactions**

Fisheries bycatch, the incidental capture of non-target species, is a major concern for fisheries management (Croxall 2008, Barbraud et al. 2012, Croxall et al. 2012) and has contributed to losses in global marine biodiversity (Soykan et al. 2008). Seabird bycatch on fishing vessels has been studied in multiple areas around the globe (Ryan et al. 2002, Awkerman et al. 2006, Soykan et al. 2008, Huang and Yeh 2011, Barbraud et al.

2012). Fishing vessels, however, may interact with seabirds in more ways than bycatch related mortalities. Other associations have been shown to have a varying range of effects, including variable or limited foraging overlap (Torres et al. 2013), foraging on fisheries discards (Votier et al. 2010, Louzao et al. 2011), competition depleting nearby fish stocks (Votier et al. 2010), and vessel strike related mortalities (Melvin et al. 2011) .

In the Bering Sea, previous studies have shown extensive broadscale overlap between multiple trawl and longline Bering Sea fisheries and STAL (Suryan et al. 2007). It has been previously estimated that on average one STAL a year is taken as incidental bycatch in the Bering Sea longline fisheries (Stehn et al. 2001). However, more recent estimates reached 15 projected STAL takes in 2010 alone (NMFS 2011). Three of the 15 documented takes since 1983 occurred in the fall of 2010 and 2011 on Pacific cod longline vessels.

### **Research Approach**

My goal with this study was to use year-round and multiyear (2008-2012) satellite tracking data to quantify juvenile ( $\leq 1$  year) and immature ( $\leq 3$  years) STAL migrations in the North Pacific and their overlap with fisheries in the Bering Sea. Prior to this research, STAL distributions had been examined through vessel observations (Piatt et al. 2006) and satellite tracking (Suryan et al. 2006, Suryan et al. 2007, Suryan et al. 2008, Suryan and Fischer 2010), mostly consisting of adult birds. Although juvenile STAL distributions have been examined within their first six months of flight (Deguchi et al. in press), my research is the first to examine immature and juvenile STAL with year-round tracking data.

Variability in immature STAL annual distributions, described in chapter 2, and fisheries associations, described in chapter 3, is assessed across temporal and demographic variables. We chose STAL demographics based on previous research which found variability across albatross sexes (Shaffer et al. 2001, Suryan et al. 2007), ages (Weimerskirch and Jouventin 1987, Deguchi et al. in press), and source colonies (Alderman et al. 2010). In addition, variability is examined across study years and seasons. For chapter 3, individual vessel characteristics (vessel and gear type)(Dietrich et al. 2009) and target species (Suryan et al. 2007) is also examined. Distributions and overlap are quantified and examined using kernel density estimators for core areas and ranges (Fieberg and Kochanny 2005, Bugoni et al. 2009, Deguchi et al. in press) and overlap indices (Fieberg and Kochanny 2005). Additional analyses include restricted maximum likelihood estimations of Linear Mixed Models (Bolker et al. 2008).

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## **CHAPTER 2 - AT-SEA DISTRIBUTION OF IMMATURE SHORT-TAILED ALBATROSSES, *PHOEBASTRIA ALBATRUS*, INCLUDING SEASONAL AND DEMOGRAPHIC VARIABILITY**

**Amelia J. O'Connor, Robert M. Suryan, Kiyooki Ozaki, Fumio Sato, and Tomohiro Deguchi.**

### **Abstract**

Limited data from previous studies indicate that the distribution of subadult ( $\leq 3$  years), especially juvenile, short-tailed albatrosses (STAL, *Phoebastria albatrus*) is considerably different than that of adults. Furthermore, these younger birds have a greater incidence of bycatch in commercial fisheries (eight of ten documented bycatch mortalities were subadult birds). We tracked 41 juvenile birds for up to three years post-fledging ( $n=41,689$  locations) between June 2008 and June 2012. Our goal was to quantify year round distributions of immature STAL by examining travel distances across seasons and bird demographics, seasonal ranges of birds, and whether core areas vary between ages, sexes or source colonies. Our findings quantify regional variations in immature STAL core areas across seasons and demographics. We also observe initial return of immature birds to source colonies.

### **Introduction**

Seabird distributions during the non-breeding season can reveal species vulnerabilities and are generally unknown for juvenile birds. Vulnerabilities in the non-breeding season, for instance foraging overlap with fisheries, can threaten species populations (Weimerskirch and Jouventin 1987, Gales 1997). Furthermore, quantifying non-breeding distribution can be challenging. Two general methods are used to quantify seabird distributions: vessel-based observations (Huettmann and Diamond 2000, Piatt et

al. 2006) and remote tracking studies (Croxall et al. 2005, Fischer et al. 2009).

Observations from vessels may present biases and limit data to where and when vessels are present. Remote tracking can be conducted using geolocator devices (Croxall et al. 2005, Gonzalez-Solis et al. 2007, Egevang et al. 2010) and satellite transmitters (Suryan et al. 2007, Fischer et al. 2009) and is not limited to vessel survey routes. Although satellite transmitters produce superior quality data to geolocators, few studies utilize this method on juvenile birds (Weimerskirch et al. 2006, Suryan et al. 2007, Alderman et al. 2010, Deguchi et al. in press) and even fewer have obtained year-round data (Croxall et al. 2005).

Seabird distribution varies across demographic and temporal variables. Studies have found differential distributions between sexes (Weimerskirch et al. 1993, Phillips et al. 2004) and age classes (Weimerskirch and Jouventin 1987). These distributional differences occur when one group is traveling farther (Catry et al. 2005) or in a different direction (Torres et al. 2013) from breeding locations. Seasonal and annual differences may occur in response to migratory shifts (Huettmann and Diamond 2000) or changes in food availability, respectively. Such differences indicate a need for multi-year and multi-demographic studies.

Endangered short-tailed albatrosses (STAL) are in recovery from near extinction. As one of three North Pacific albatrosses (*Phoebastria spp.*), STAL breed on sub-tropical islands and forage over oceanic and neritic habitats (Hasegawa and DeGange 1982, Suryan et al. 2008), concentrating along highly biologically productive shelf break areas (Schneider et al. 1987, Piatt et al. 2006). STAL breeding grounds are limited to

Torishima, an island southeast of Japan, and areas in the Senkaku Islands (USFWS 2008). Through international recovery efforts, fledglings have been translocated and hand-reared on an uncolonized island, Mukojima (Deguchi et al. in press). Success of this new colony depends on translocated STAL returning to and breeding at this new site.

STAL non-breeding distribution has been studied through multiple methods, although some seasonal and age-specific variability remain unstudied. Translocated and non-translocated juvenile STAL distributions have been studied during summer and fall months and show regions of potential variability (Deguchi et al. in press). Immature ( $\leq 3$  years) STAL distribution data from previous studies are limited to seasonal satellite tracking, which included few individuals (Suryan et al. 2006, Suryan et al. 2008, Suryan and Fischer 2010), or ship-based observations (Piatt et al. 2006). Moreover, the limited data on juvenile and immature STAL indicate extensive overlap with multiple fisheries (Piatt et al. 2006, Suryan et al. 2007) and spatial variability from adults (Suryan et al. 2007).

The goal of this study is to quantify immature ( $\leq 3$  years) STAL spatial distributions and travel distances, including seasonal and demographic variability. Multi-year (2008-2012) satellite tracking data were used to examine immature distributions for 41 STAL. Seasonal variation was quantified through travel distances and spatial distributions. Demographic variability was examined spatially across three significant population demographics: flight years, sexes, and source colonies (translocated and non-translocated). Additionally, immature time spent within national and international waters was quantified. Based on previous studies, we expect seasonal variability in distributions,

differential distributions for flight years and sexes, and similar distributions for source colonies. This study tests previous observations for a relatively understudied age class and quantifies year-round immature STAL distribution.

## **Methods**

### *Satellite telemetry*

Juvenile STAL (0.3 yrs.) were tagged with Microwave Telemetry solar powered global positioning system (GPS)/Argos PTT-100 satellite transmitters annually in early May from 2008 through 2011 (n = 10 in 2008, n = 14 in 2009, n = 12 in 2010, and n = 14 in 2011). Juveniles were tagged at source colonies just prior to fledging. An equal number of Mukojima and Torishima birds were tagged each year. Sex was determined using blood samples and molecular methods (Fridolfsson and Ellegren 1999).

Transmitters weighed 22 grams (less than one percent of STAL body mass) and recorded up to six location fixes per day in two to four hour intervals. Locations were transmitted through Argos (CLS America, Inc.) every three days. Position accuracy was <10m and data were filtered to remove erroneous locations (< 3%). These locations and occasional device-specific errors were filtered using an algorithm based on animal speed (<50 km/hr) (McConnell et al. 1992) pattern recognition for occasional time-related errors in GPS positions (Deguchi et al. in press).

Transmitters were attached using two methods: tape and harnesses. Most (n=38) transmitters were attached using Tesa<sup>®</sup> tape and generated up to six months of data starting in late May ( $5.3 \pm 4.1$  mean fixes per day, Table 2.1). A sample of 12 birds, with GPS transmitters attached using figure eight-shaped harnesses (Higuchi et al. 1996,

Higuchi et al. 2004), provided location data for up to approximately three years ( $3.9 \pm 1.4$  mean fixes per day, Table 2.1). Because most birds had transmitters attached with tape, more fixes occurred in summer and fall months than in winter and spring months (Table 2.1). For more detailed description of STAL capture and tracking methods, see Deguchi et al. (in press).

For this study, we used only birds that survived post-fledging to sustained flight and excluded locations during the post-fledging “drift” period prior to sustained flight (Deguchi et al. in press). The final tracking dataset included 41 birds (30 taped, 11 harnessed) and 41,689 locations spanning 25 May 2008 to 31 May 2012 (Table 2.1). The STAL population is estimated to be 3400 birds (Paul Sievert and Hiroshi Hasegawa unpubl. data), roughly half of which are immature birds. Thus, this sample size ( $n=41$ ) consists of  $\sim 2.2\%$  of the immature population, though harnessed birds ( $n=11$ ) contribute most locations (Table 2.1).

#### *Travel distances*

To examine travel distances, monthly travel rates were calculated for individual birds. We used distance and duration between locations to determine mean travel rate for a given month. Months with less than 10 days of tracking data for an individual were excluded. Only the first and second years of flight were included in travel distance calculations. No tagged birds exhibited sustained flight for more than 10 days in May; therefore, June is considered the first full month of flight for all birds. Thus, a year of flight for any given bird spans from June to June. This travel distance dataset includes 336 months from 41 birds, ranging from two to 25 months for an individual.

We used a restricted maximum likelihood (REML) Linear Mixed Model (LMM; R Development core team 2012) to evaluate if distances traveled varied across flight years, sexes, source colonies, or seasons. Travel distance data were square root transformed to improve normality ( $W=0.99$ ,  $p=0.005$ ). ANOVA F-test results were used to evaluate factor significance (Bolker et al. 2008). Individual bird was used as the random effect and bird sample size was recorded for all factor levels (Table 2.2).

#### *Area utilization*

To quantify spatial distributions, we randomly subsampled tracking data ( $n=41,689$  locations) by month and ran kernel density estimations (KDE) for immature birds, seasons, flight years, sexes, and source colonies. Random subsampling was done to represent months equally for year-round and seasonal distributions and to run KDEs in Geospatial Modeling Environment (GME; Beyer 2012). Number of locations were randomly sampled in R (R Development core team 2012) based on the month with lowest total locations for that demographic (e.g. sex) with a maximum of 10,000 total for GME software (locations sampled per month: immature  $n=833$ , flight year  $n=518$ , sexes  $n=515$ , source colonies  $n=499$ ). Because seasonal overlap was not examined, each season was sampled based on the month with the lowest number of locations or maximum 10,000 locations (locations sampled per month: summer  $n=3333$ , fall  $n=1492$ , winter  $n=1126$ , spring  $n=2145$ ). Random subsampling reduced total locations; however, it did not reduce the total number of tracked birds contributing locations in any given month.

Data were converted into an equal area projection for KDEs in GME. We used a smoothed cross-validation (SCV) bandwidth estimator. This estimator produced contours

that most closely encircled location clusters and has been shown to be superior to more commonly used cross-validation estimators (Duong and Hazelton 2005). KDE and resulting utilization distribution (UD) grids are probabilistic and alterations in parameters can change the resulting grid. We used a Gaussian kernel, 1 km cell size and the GME default scaling factor (1,000,000x weights). GME's "kde" and "isopleth" functions created range (95%) and core area (50%) contours. These contour levels were chosen based on previous studies (Ostfeld 1986, Suryan et al. 2007). Maps were created in ArcGIS (ESRI, Redlands, CA, USA) and show 50% kernel contours created in GME with bathymetry data (British Oceanographic Data Centre, [www.bodc.ac.uk](http://www.bodc.ac.uk)).

To determine geospatial distributions, tracking data were hourly interpolated in Matlab (The Math Works, Inc.). With interpolated data (n=194,139) we calculated time spent within national and international waters, within and outside exclusive economic zones (EEZ; 200 nautical miles from coastline). Results were displayed as percent of total travel hours (Table 2.3).

#### *Overlap analyses*

To evaluate demographic (e.g. flight years) distribution overlap, we calculated UD grids and overlap indices in R using the `adehabitatHR` tool (Calenge 2012). To recreate GME UD grids, we used the "kernelUD" function with recommended bivariate normal kernel (Worton 1995) which is equivalent to the Gaussian kernel. The same 1km grid size was used. The smoothing parameter (h=1) was selected based on the match to GME output. Although this smoothing parameter value identified the same regions of

overlap and inconsistencies for demographics (Figure 2.3-5), there were slight variations in the number of contour polygons from GME contours.

We report three indices to describe overlap: the home range overlap (HR), the probability home range overlap (PHR), and the utilization distribution overlap index (UDOI) (Fieberg and Kochanny 2005). The HR and PHR are reported as percentages. These statistics quantify kernel polygon overlap and calculate the probability of one subgroup being in the same area as the other, respectively. The UDOI provides an overlap index that accounts for non-uniform spatial use. This index will equal zero for no overlap, one for high overlap in uniform distributions, and greater than one for high overlap in non-uniform distributions (Fieberg and Kochanny 2005). We calculated overlap for the 50% and 95% contours.

## **Results**

### *Travel distance*

Mean daily travel distance among demographic variables (source colony, flight year, and sex) did not vary (Table 2.2,  $P > 0.05$ ). However, mean travel distances did vary among seasons, ranging from  $155 \pm 5$  km/day in summer to  $326 \pm 10$  km/day in winter (Table 2.2,  $P < 0.001$ ). Mean travel distance in spring ( $294 \pm 9$  km/day) was closer to winter distances, and fall ( $215 \pm 5$  km/day) was intermediate between summer and winter.

### *Area utilization*

Distributions of immature birds illustrate dispersal from source colonies near Japan, through the Bering Sea, and down along Canada and in some cases the US West Coast (Figure 2.1; Figure 2.2). Annually, birds ranged in latitude from  $25^{\circ}\text{N}$  to  $66^{\circ}\text{N}$ ,

remaining north of the Hawaiian Islands and south of the Bering Strait. In summer, all birds went to the Bering Sea, with some birds first traveling north through the Sea of Okhotsk and others through more southern routes. In fall, birds moved north within the Bering Sea and east along the Aleutian Islands. In winter, some birds remained near the Aleutian Islands or traveled south along the US West Coast while others returned to Japan and the Kuril Islands. In spring, birds along the US West Coast moved north, and some returned to the Western Pacific and home colonies. Although 6 of 11 birds tracked over one year returned to the Western Pacific, only two immature birds actually returned to colonies. Both were females and returned to their respective source colonies. One from Torishima returned in late winter of her second year and one from Mukojima returned in early spring of her third year.

Immature STAL spent time in both national and international waters. Eighty-two percent of immature hours tracked between June 2008 and June 2012 were spent within national waters (Table 2.3). Most (70%) of their time was spent within Russian and Alaskan waters (Table 2.3). Based on seasonal dispersal (Figure 2a-d), immature time in Russian and Alaskan Bering Sea waters was highest in the fall. Of the 18% spent in international waters, only 5% were spent in the Bering Sea (Table 2.3).

#### *Flight year distributions and overlap*

From the first to second flight year, distributions became slightly more constricted. Flight year overlap is high for ranges (81%, 85% PHR and 1.39 UDOI) while PHR and UDOI suggest low to moderate overlap for core areas (68%, 40% PHR and 0.20

UDOI). Core areas in the Sea of Okhotsk and far southern extent in the Eastern Pacific were not observed for the second flight year (Figure 2.3).

#### *Sex distributions and overlap*

Female and male distributions vary in specific regions and extent. Males and females exhibited high overlap in ranges (76%, 91% PHR and 1.45 UDOI) while in core areas the PHR and UDOI suggest low to moderate overlap (66%, 44% PHR and 0.21 UDOI). Male core areas were further from shelf margins in the Sea of Okhotsk and east of Japan. Male distribution also extended further south in the Eastern Pacific (Figure 2.4). Additionally, regional differences occurred for females in the Commander Islands west of the Aleutian Islands (Figure 2.4). Most (15 of 20) females spent time at these islands while only eight males did. Females accumulated approximately five times as many locations near these islands as males.

#### *Source colony distributions and overlap*

Torishima and Mukojima colony birds showed regional variation. Torishima birds and Mukojima birds exhibited high overlap in overall range (76%, 92% PHR and 1.51 UDOI), but low to moderate overlap in core areas (62%, 46% PHR and 0.21 UDOI). Source colony core areas differed in the Eastern Pacific along the US West Coast. Here, three Torishima colony birds traveled farther south and accumulated nearly twice as many locations as four Mukojima birds (Figure 2.5). This difference was in large part due to one individual that returned to the area annually. No translocated birds from Mukojima exhibited core area polygons outside of Torishima bird core areas (Figure 2.5).

## **Discussion**

Few studies have quantified juvenile albatross distributions; of these studies, all found that juvenile distributions differed from those of adults (Weimerskirch and Jouventin 1987, Weimerskirch et al. 2006, Alderman et al. 2010). Juveniles have been observed foraging in different areas than adults, suggesting that they may have been exposed to different vulnerabilities (Weimerskirch et al. 2006, Alderman et al. 2010). This study is the first to examine full, year-round satellite tracking of immature albatross, including translocated and non-translocated birds, and compare first and second years of flight. Our results show regional variations in immature STAL core areas across seasons and demographics as well as initial successes for translocated birds.

### *Immature STAL distributions*

Immature STAL have a broader spatial range in comparison to findings of previous STAL tracking. Our year-round tracking suggests immature birds range farther north and southeast than previously shown (Suryan et al. 2006, Suryan et al. 2007, Suryan and Fischer 2010). Specifically, immature ranges into the Sea of Okhotsk and the Bering Strait was not observed in adult studies (Suryan et al. 2007). However, immature core areas did overlap with many of the key foraging areas identified in previous STAL studies, specifically near the Kuril Islands, Bering Sea shelf margins, and Aleutian Islands (Piatt et al. 2006, Suryan et al. 2006). Based on these observations, we suggest that, while immature STAL travel to many of the same foraging areas, they may be traveling farther from colonies and exploring different areas than adults. For immature STAL, we hypothesize a combination of learning foraging grounds and irregular return to

source colonies to explain their wider spatial range. Immature ranges may also be restricted by other factors including food availability or aerodynamic performance (Shaffer et al. 2001, Suryan et al. 2008).

Other studies examining post-fledgling albatross distributions have suggested low overlap with adults. Weimerskirch et al. (2006) found juvenile wandering albatross (*Diomedea exulans*) foraged in less productive sub-tropical waters where adults did not. This distribution was hypothesized to be a measure of avoiding competition with adults. Alderman et al. (2010) found post-fledgling shy albatross (*Thalassarche cauta*) foraging farther from source colonies than previously tracked adults. Potential explanations for adults remaining near colonies included guarding nests or pair bonding (Alderman et al. 2010). The STAL population, similar to shy albatross, is greatly reduced from historical numbers and may therefore be less likely to exhibit distributions based on competitive exclusion.

#### *Seasonal variability*

Seasonal variability was exhibited in juvenile travel distances and core areas. Most notably, distributional variations and increased travel distances occurred when STAL core areas shifted south of the Bering Sea (with the exception of the Aleutians Islands) in the winter and spring. This behavior has been observed for other non-nesting migrants that travel to the Bering Sea in the summer (Shuntov 1998). Constricted ranges in the Bering Sea in winter and spring may be a response to ice location and extent, winter storms in the North, or food availability (Shuntov 1998). Moreover, Shuntov (1993) suggested that fishing fleet location may also influence bird distributions in this

area. In winter and spring, the northern limits of ranges are slightly south of the northernmost canyon on the eastern Bering Sea shelf, Navarin Canyon. This is significant because Navarin canyon is an observed hotspot for STAL (Piatt et al. 2006). Limited access to this canyon and nearby highly productive shelf areas may signal birds to travel south. All four years of this study were cold years in the Bering Sea and ice extent reached much of the northeastern Bering Sea in the spring, including Navarin Canyon (Stabeno et al. 2012, Brown and Arrigo 2013). Maximum ice extent in 2008 reached all Bering Sea canyons except Bering canyon on the southern shelf (Stabeno et al. 2012). Alternatively, winter storms or food availability may also explain retreat out of the northern Bering Sea in winter and spring.

#### *Demographic variability*

We found regional variations in core areas of all demographics we examined. However, all demographics exhibited core areas in productive shelf margins in the Bering Sea and near the Aleutian and Kuril Islands, consistent with previously quantified STAL foraging areas (Suryan et al. 2006). These areas of overlap may suggest that innate cues play an important role in immature STAL dispersal. Overall, there is notable variation between travels of individual immature STAL inside of annual distribution core areas and ranges. While we examine only regional demographic variations, previous year-round and multi-year tracking studies have shown that individual birds exhibit different migration routes (Croxall et al. 2005) and variability in annual foraging grounds (Kappes et al. 2010). Furthermore, both individual and demographic variations present implications for conservation of immature STAL.

### *Age classes*

Our findings suggest spatial constriction of year-round distribution in the second year at sea and may represent birds learning favorable foraging grounds. More similar to adult tracking data (Suryan et al. 2007), second flight year STAL did not travel as far southeast along the US West Coast or into the Sea of Okhotsk. Alderman et al. (2010) suggested juvenile shy albatross learn foraging areas as they mature rather than follow innate cues. Moreover, in juvenile wandering albatrosses, travel speeds reach a maximum near six months of age, equivalent to that of adults, suggesting an initial period of learning foraging techniques (Weimerskirch et al. 2006). Although we did not observe increased travel rates from first to second flight year for STAL, this learning period may be indicated spatially by core area constriction. In addition, because second year birds undergo molting of flight feathers, this energy expenditure and compromised flight performance could contribute to reduced core areas. Alternatively, this may be a response to innate cues signaling second year birds to return to their source colonies (1 of 9 birds observed in this study returned to its source colony in the second flight year).

Similarities in first and second flight year distributions may additionally support the hypothesis that innate cues play a role in initial dispersal. For wandering albatrosses, juvenile dispersal was suggested to result from a combination of innate cues and learning foraging (Weimerskirch et al. 2006). The initial dispersal into the Bering Sea and Aleutian Islands was observed in first and second years and previous adult tracking. This dispersal could suggest that first year STAL initially follow innate cues and then refine

foraging areas. Alternatively, first year STAL may acquire directional cues from parental feeding before fledging.

### *Sexes*

Many avian studies have observed differential distributions in sexes for adults (Weimerskirch et al. 1993, Phillips et al. 2004, Catry et al. 2005). These distribution variations have been attributed to competition (Catry et al. 2005) and size dimorphism (Shaffer et al. 2001, Phillips et al. 2004). We observed some variations in core areas of immature male and female STAL that may suggest males travel farther south in the Eastern Pacific and females prefer different areas in the southern Bering Sea, specifically the Commander Islands. For immature STAL, size dimorphism is not typical (Badyaev 2002) and competition is unlikely for a species far depleted from historical numbers. Alternatively, females may exhibit a greater innate cue for returning to source colonies which may discourage travel farther south in the Eastern Pacific. Both of the individuals observed returning to source colonies were females. We are unsure why females spend more time than males near the Commander Islands.

### *Source colonies*

Our year-round comparison of translocated Mukojima and non-translocated Torishima STAL shows similar overlap as a first six months comparison (Deguchi et al. in press). However, areas of differing core areas changed for immature birds. Deguchi et al. (in press, Oryx) found Mukojima and Torishima birds overlapping 74% in ranges and 58% in core areas. Moreover, they observed Mukojima birds spending more time in the Sea of Okhotsk. Our findings over a longer tracking period indicated slightly higher

overlap. We observed more similar distributions in the Sea of Okhotsk. The most notable difference we observed was immature Torishima birds traveling farther from colonies in the Eastern Pacific. Both Deguchi et al. (in press) and our findings suggest that despite some differences initially, translocated birds are eventually traveling and foraging in similar general areas.

Translocations are difficult, in particular for migratory species, and successes are associated with multiple site- and species- specific variables (Wolf et al. 1998). For STAL we suggest translocation has had no concerning effects on immature distributions. Distribution variations observed for translocated birds are not concerning because core areas are not occurring outside of non-translocated bird core areas. Moreover, differential distributions have been observed in juvenile albatross with different natal colonies. Alderman et al. (2010) found variation in range size between juvenile shy albatross with different source colony islands. Furthermore, they suggest environmental factors (e.g. chl. a) at source colonies may affect foraging distributions. Additionally for STAL, the return of one translocated female to the new colony, Mukojima, advocates less concern for core area variations.

## **Conclusion**

Distributional variations for immature STAL have implications for conservation. Factors affecting immature distributions may include aerodynamic performance (Shaffer et al. 2001, Suryan et al. 2008), environmental conditions (Alderman et al. 2010), and foraging skill (Weimerskirch et al. 2006, Alderman et al. 2010). Furthermore, Suryan et al. (2007) found STAL (mostly adults) spending less time in international and Russian

waters than we found for immature birds. This variability may imply different extents of vulnerability to specific fisheries for immature and adult birds. In contrast, we observed little variation in distribution for translocated Mukojima birds and observed return to the new colony.

Immature STAL distributions extend across most of the North Pacific. As populations continue to grow we may observe STAL, especially immature birds, recolonizing historical ranges and exploring new areas. Our findings show immature STAL traveling into the Bering Strait and south along the Baja Peninsula, Mexico. There is evidence that STAL historically occupied the North Atlantic prior to sea level rise in the middle Pleistocene (Olsen & Hearty 2003). While travel through the low wind areas in the Central Pacific may provide a barrier to the North Atlantic, continual loss of arctic sea ice may present a pathway to these historical areas.

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## Tables

Table 2.1. Summary statistics for harness and tape attached satellite transmitters. Transmitter durations are given in days. Total locations are also displayed by season.

Attachment method	# birds	Loc./day (M±Sd)	Min dur.	Max dur.	Total loc.	Sum. (JJA)	Fal. (SON)	Win. (DJF)	Spr. (MAM)
<b>Tape</b>	30	5.3±4.1	23	177	16754	13317	3079	0	358
<b>Harness</b>	11	3.9±1.4	84	1099	24935	8389	5656	4352	6538

Table 2.2. Travel distance (km/day) restricted maximum likelihood Linear Mixed Model (LMM) results for source colony, flight year, sex, and season factors. Bird ID was used as the random effect and the number of birds comprising each factor level is reported. An ANOVA F-test is also reported with P-values for individual factors.

Factor	Levels	Est. Mean	St. error	F-value	P-value	Bird n
<b>Source colony</b>	Torishima	202	9	2.29	0.08	20
	Mukojima	180	6			21
<b>Flight Year</b>	First	191	5	0.00	0.99	41
	Second	181	7			9
<b>Sex</b>	Male	182	9	1.94	0.10	21
	Female	199	6			20
<b>Season</b>	Sum.(JJA)	155	5	58.35	0.00	41
	Fall(SON)	215	5			30
	Win.(DJF)	326	10			10
	Spr.(MAM)	294	9			30

Table 2.3. Percent of hourly interpolated location data allocated into national and international waters.

Waters	Area/ country	Percent time
<b>International 18.3%</b>	Bering Sea	1.1
	Other	13.4
<b>National 81.7%</b>	Japan	7.2
	Russia	32.2
	Alaska	37.9
	Canada	1.7
	US West Coast	2.6

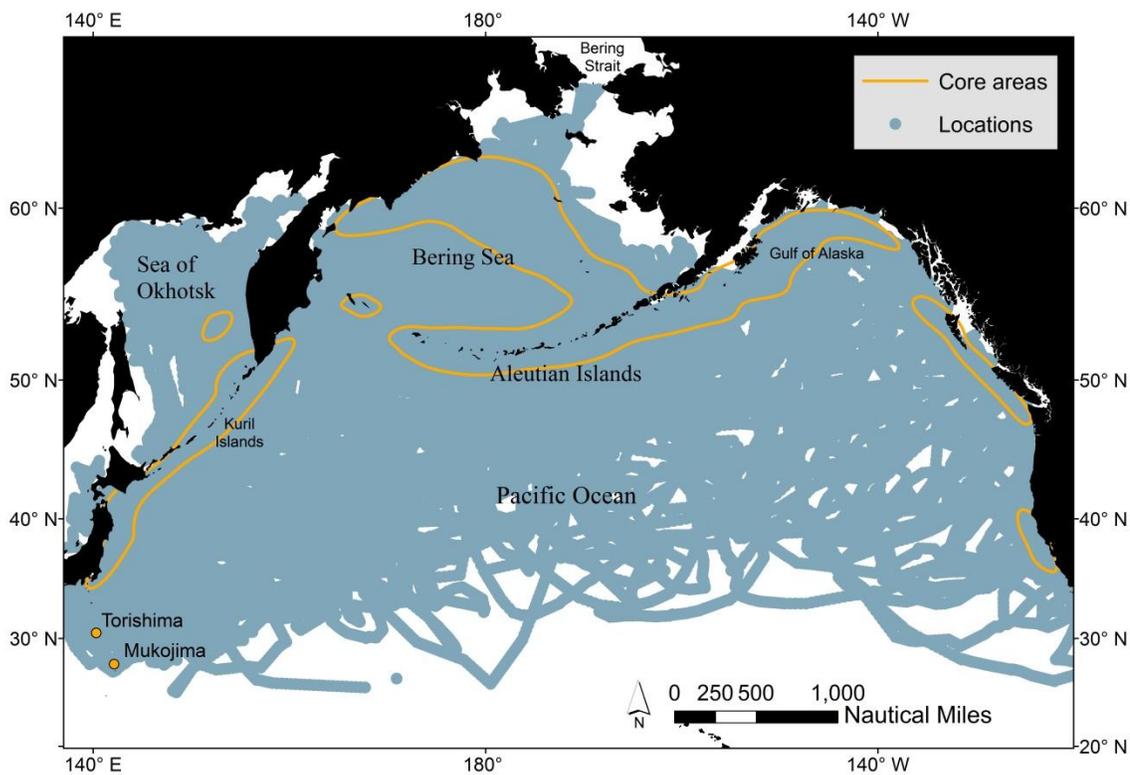
**Figures**

Figure 2.1. Immature bird core area (50% kernel) polygons and point locations showing total extent of travel. Refer to Figure 2.3 for bathymetry.

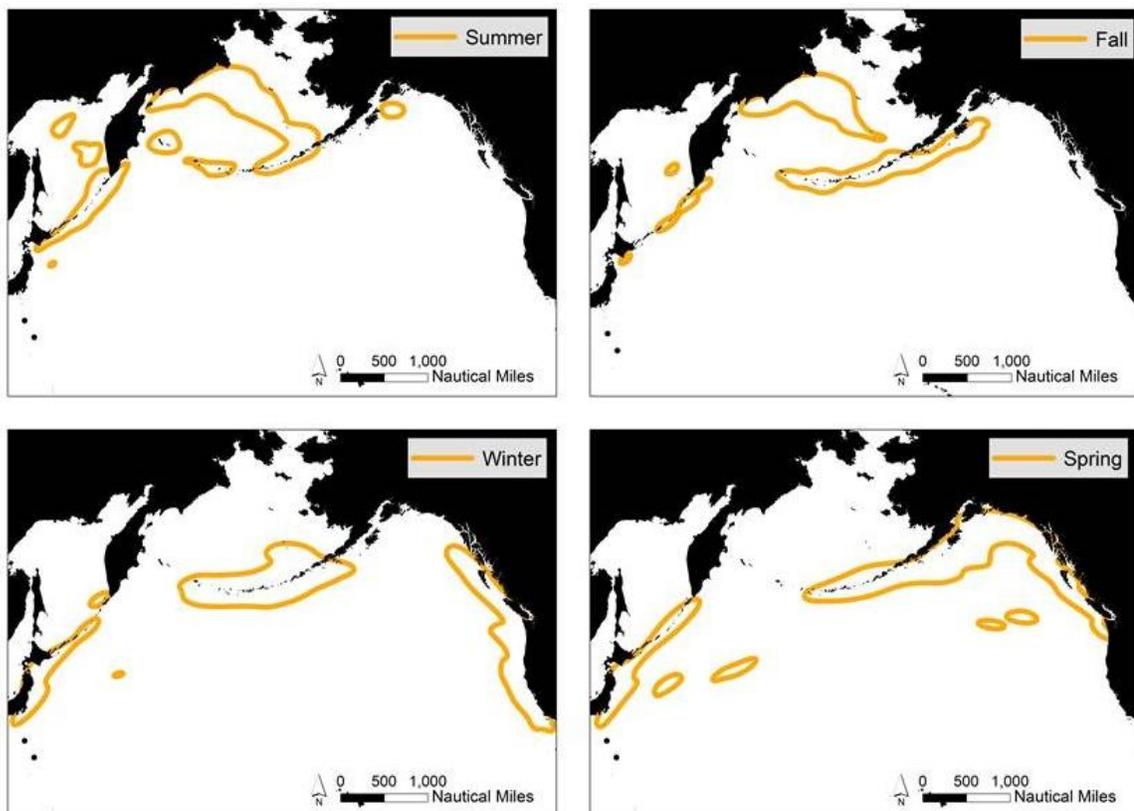


Figure 2.2. Core area (50% kernel) polygons showing summer, fall, winter and spring distributions. Refer to Figure 2.1 for geographic locations.

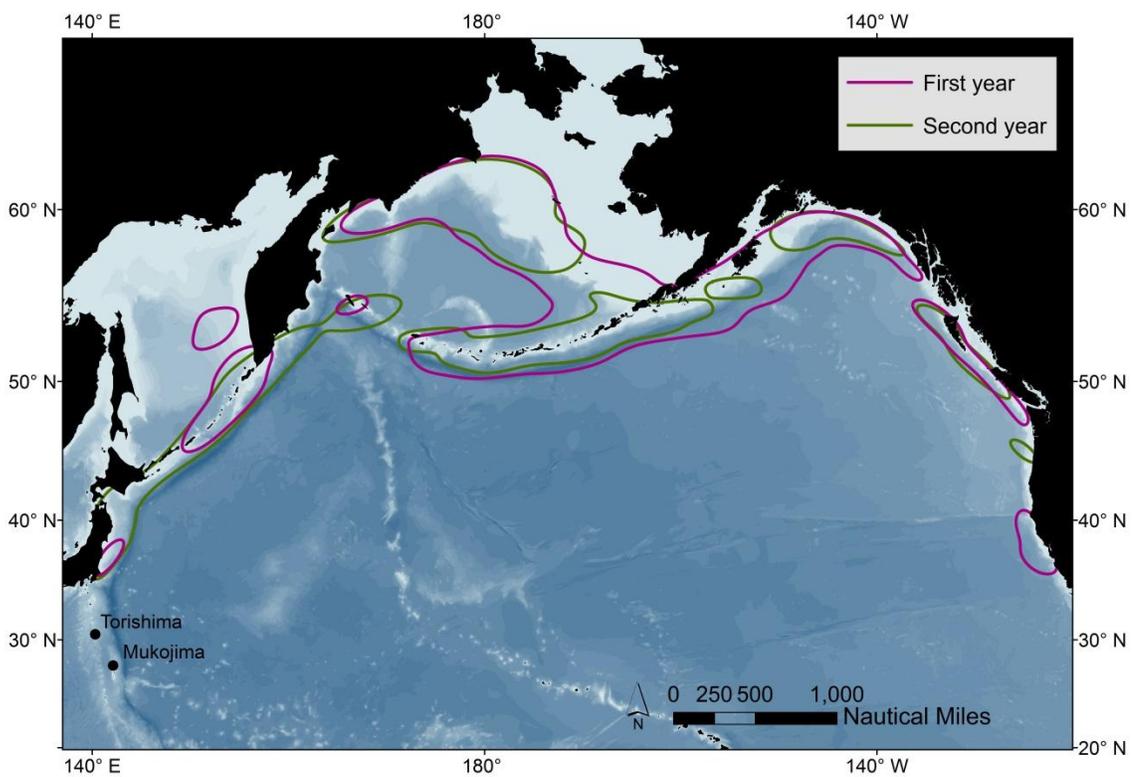


Figure 2.3. Core area (50% kernel) polygons of first and second flight years showing overlap in the North Pacific. Refer to Figure 2.1 for geographic locations.

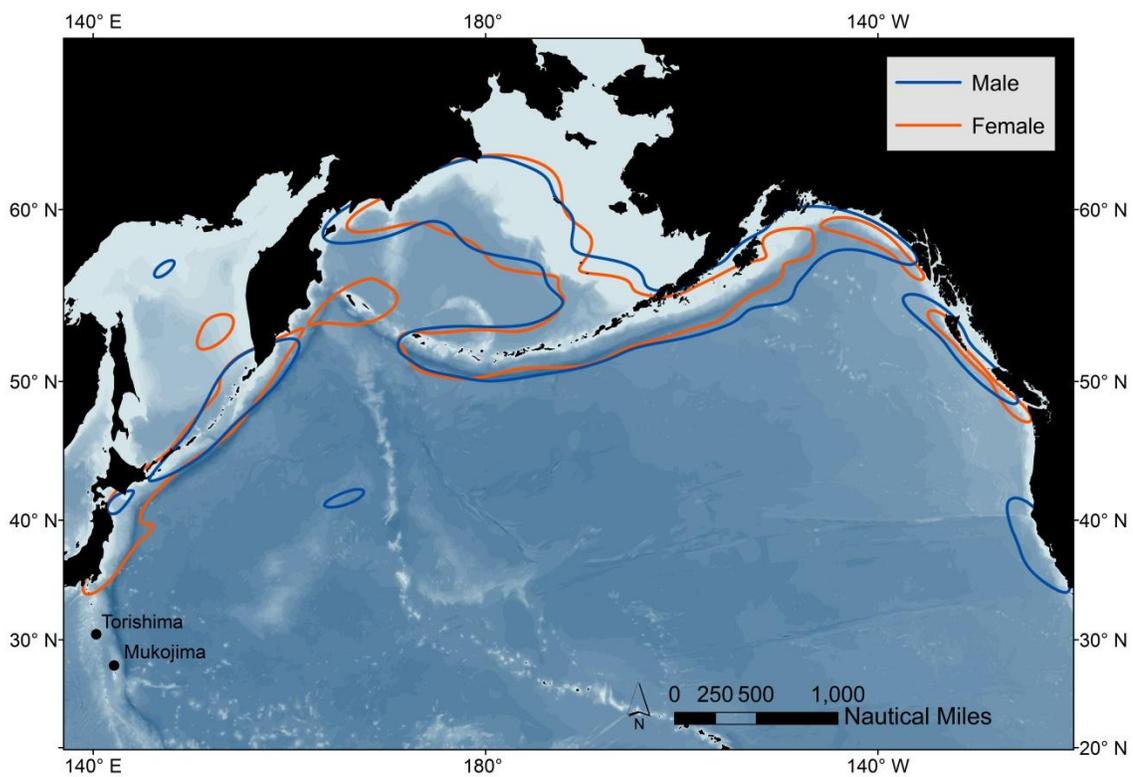


Figure 2.4. Core area (50% kernel) polygons of male and female birds showing overlap in the North Pacific. Refer to Figure 2.1 for geographic locations.

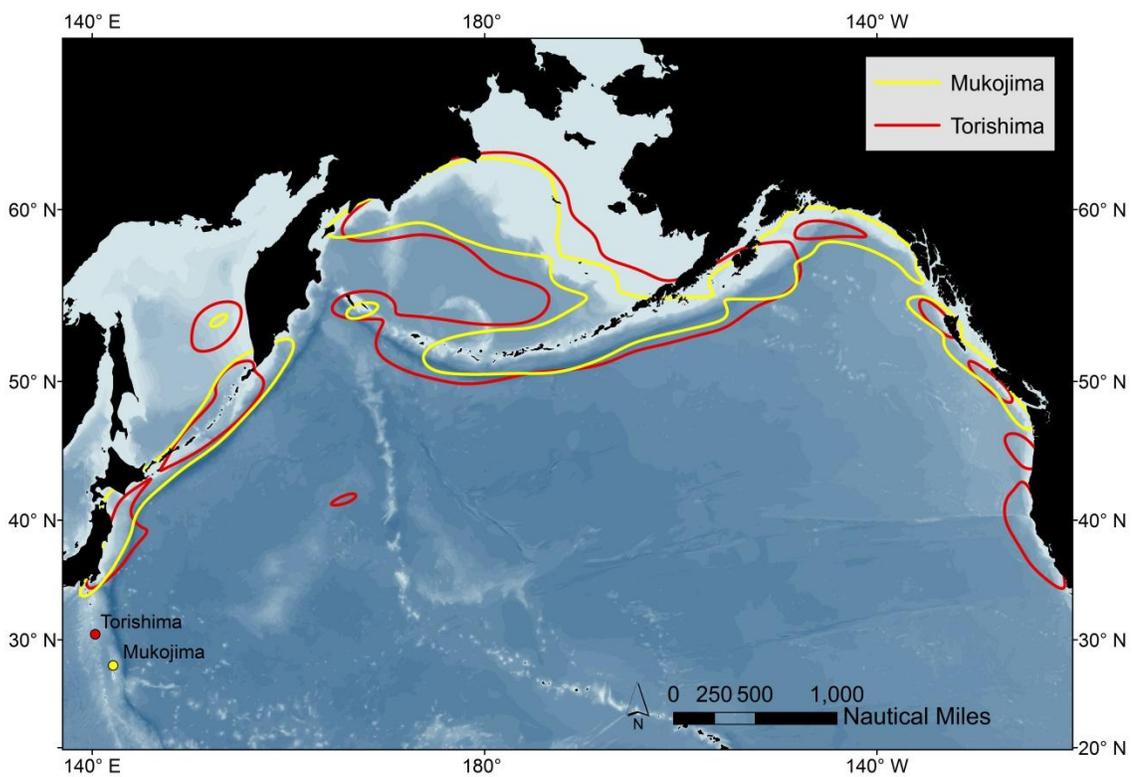


Figure 2.5. Core area (50% kernel) polygons of Mukojima and Torishima birds showing overlap in the North Pacific. Refer to Figure 2.1 for geographic locations.

### **CHAPTER 3 - SHORT-TAILED ALBATROSSES AND ALASKAN FISHERIES IN THE BERING SEA: AN INVESTIGATION INTO FINE SCALE ASSOCIATIONS**

**Amelia J. O'Connor, Robert M. Suryan, Kiyooki Ozaki, Fumio Sato, and Tomohiro Deguchi**

#### **Abstract**

In the Bering Sea, the distribution of short-tailed albatross (STAL), *Phoebastria albatrus*, overlaps extensively with commercial fisheries. STAL spend much of their non-breeding period, particularly in summer and fall, foraging along the Bering Sea outer continental shelf and break-slope habitats. These common grounds have resulted in incidental STAL mortalities, most of which occurred in the fall season and were immature birds ( $\leq 3$  years). Because STAL is listed as “endangered” under the U.S. Endangered Species Act, these incidental mortalities pose a potential conservation concern. We used four years (2008 - 2011) of STAL GPS tracking and North Pacific Groundfish Observer Program data to assess fine scale associations between STAL and vessels. These datasets include 16,325 locations from 36 immature STAL, 11 of which were tracked for multiple years, and 142,305 set locations from 261 vessels within the Bering Sea. Through this study we quantify seasonal distributions of STAL and vessels and examine associations, when STAL are within 10km of a vessel at the time of gear deployment, to better understand interactions and explain documented bycatch events. Additionally, we examine variability in association distances across STAL, vessel, temporal, and habitat related variables. STAL-vessel associations occurred year-round but predominately during summer and fall months along shelf-break and near canyon habitats. Although STAL bycatch documented in the longline fishery during this study

period occurred *temporally* when STAL associations were closest to vessels, mortalities occurred *spatially* in areas of low longline association abundance. Furthermore, two of three documented bycatch events between 2008 and 2011 occurred outside of STAL core and high vessel association areas.

## **Introduction**

Seabirds interact with fishing vessels in a variety of complex ways (Furness 2003). For seabirds, these interactions may be minor, such as coincident habitat use (Torres et al. 2013); or extensive, such as resource competition (Okes et al. 2009, Votier et al. 2010), foraging reliability on vessel discards (Votier et al. 2010, Louzao et al. 2011), and mortalities (Lewison and Crowder 2003, Tuck et al. 2011, Gonzalez et al. 2012). For fishermen, these more extensive interactions can mean loss of bait, potential damage to gear, time removing unwanted species, and ultimately a diminished potential for target species catch (Moore and Žydelis 2008). In some cases, bycatch-related mortalities have been shown to threaten the continuing viability of seabird species, particularly albatrosses (Weimerskirch and Jouventin 1987, Gales 1997).

Seabird and fishing vessel interactions have been examined through vessel sightings and bycatch observations and overlaying tracking and distribution data. Studies investigating bycatch have found variability in seabird mortalities between individual vessel characteristics (Klaer and Polacheck 1998, Dietrich et al. 2009). Moreover, consumption of discards from vessels has been shown to vary across individual birds (Votier et al. 2010). Studies examining spatial overlap have observed temporal (e.g. year) and demographic (e.g. vessel type and bird sex) variability (Suryan et al. 2007, Torres et

al. 2013). These complexities advocate for spatial and temporal fine scale analyses to better understand and quantify seabird-vessel interactions.

In the Bering Sea, bycatch of short-tailed albatrosses (STAL; *Phoebastria albatrus*) has been a conservation focus, in part because STAL is listed as “endangered” under the U.S. Endangered Species Act. As a result, seabird mitigation gear for both sablefish (*Anoplopoma fimbria*) and Pacific cod (*Gadus macrocephalus*) longline vessels has been developed and implemented (Melvin and Parrish 2001, Lokkeborg 2011). Although mitigation gear (e.g. streamer lines and weights) has been shown to significantly reduce seabird bycatch (Lokkeborg 2011), STAL bycatch still occurs (NMFS 2011). Most notably, three STAL mortalities were documented in the fall of 2010 and 2011 on Pacific cod longline vessels (NMFS 2011). Moreover, because seabird bycatch are particularly difficult to document, total STAL bycatch in 2010 alone was estimated to be 15 birds. This estimate was considerably higher than previous years (NMFS 2011).

STAL distributions overlap extensively with multiple Alaskan trawl and longline fisheries (Suryan et al. 2007). However, because STAL distributions show regional variations, both temporally and among albatross demographics (Chapter 2, Suryan et al. 2007), association or interactions with fisheries may also vary. For example, eight out of ten recorded incidental STAL takes since 1983 in Alaskan waters were three year old or younger birds, and nine occurred between late August and November (Yamashina Institute for Ornithology and NMFS, unpublished data).

This study investigates observed STAL bycatch variability by quantifying distributions of, and fine scale associations (<10km) between, immature ( $\leq 3$  years) STAL and fishing vessels. First, we determine seasonal distributions of immature STAL in the Bering Sea, identifying shifts in core areas and whether documented bycatch mortalities occurred within these areas. Second, STAL tracking data are compared with NMFS Groundfish Observer Program data to find where associations occur and with what type of vessels they occur. Third, we analyze whether association distances, the distance between a bird and vessel within an association, vary across habitat, temporal, demographic, or fisheries-related variables.

## **Methods**

### *Immature STAL tracking and seasonal distributions*

We tagged juvenile STAL (0.3 yrs.) prior to fledging with Microwave Telemetry solar powered global positioning system (GPS)/Argos PTT-100 satellite transmitters in early May from natal colonies between 2008 and 2012 (n = 10 in 2008, n = 14 in 2009, n = 12 in 2010, and n = 14 in 2011). An equal number of Mukojima and Torishima colony birds were tagged each year. Sex was determined using blood samples and molecular methods (Fridolfsson and Ellegren 1999). Transmitters weighed 22 grams (<1% of STAL body mass) and recorded up to six GPS location fixes per day in 2-4 hour intervals. Locations were transmitted through Argos (CLS America, Inc.) every three days. Position accuracy was <10m and data were filtered to remove erroneous locations (< 3%). Locations were filtered using an algorithm based on animal speed (<50 km/hr) and occasional device-specific errors (Deguchi et al. in press).

Transmitters were attached using two methods - tape and harnesses. Most (n=38) GPS transmitters were attached using Tesa<sup>®</sup> tape and generated up to six months of data starting in late May or early June ( $5.3 \pm 4.1$  mean fixes per day in Bering Sea study area; Table 3.1). A sample of 12 birds, with GPS transmitters attached using figure eight shaped harnesses (Higuchi et al. 1996, Higuchi et al. 2004), provided location data for up to three years ( $3.9 \pm 1.4$  mean fixes per day in Bering Sea study area, Table 3.1). For more detailed description of STAL tracking methods see Deguchi et al. (in press).

STAL tracking data were cropped to the Bering Sea/Aleutian Island (BSAI) study area and separated into seasons (summer n=4492, fall n=5019, winter n=765, spring n=742; Table 3.1) to run kernel estimations. Kernel estimations were run in the Geospatial Modeling Environment (GME; Beyer 2012) using a smoothed cross-validation (SCV) bandwidth estimator. This estimator produced contours that encircled location clusters most closely and has been shown to be superior to more commonly used cross-validation estimators (Duong and Hazelton 2005). Map figures were created in ArcGIS (ESRI, Redlands, CA, USA) and show 50% kernel contours created in GME with bathymetry data (British Oceanographic Data Centre, [www.bodc.ac.uk](http://www.bodc.ac.uk)). All spatial analyses were conducted in Alaska Albers Equal Area projection, North American 1983 datum.

To quantify canyon use we interpolated STAL satellite tracking data into hourly intervals (n=74,727) using purpose-built programs in Matlab (The Math Works, Inc.). For each season, data locations were counted within 50 nautical mile buffers from the center of Navarin, Pervenets, Zemchug, Pribilof, and Bering canyons. Results were displayed as

a portion of total seasonal hours within the Bering Sea. All non-map figures were created in R (R core team 2012).

#### *North Pacific groundfish observer data*

Vessel location data and fishing effort data were provided by the National Marine Fisheries Service (NMFS) North Pacific Groundfish Observer Program for the BSAI area. All observed trawl (pelagic and non-pelagic), pot, and longline set location data were obtained from 2008 through 2011. These data were recorded by NMFS-trained observers and vary by fishery and vessel size. Larger vessels (>38m) represent the majority of the fishing effort and have 100% observer coverage. Observers on catcher-only trawlers in the walleye pollock (*Theragra chalcogramma*) fishery sample every set (AFSC 2010). Although freezer longliners also have 100% coverage, not all sets are sampled. For these vessels, observers randomly select gear sets. For sampled sets, the following are recorded: vessel information, date, set and retrieval time, location and depth, duration that the gear is at fishing depth, hooks deployed, seabird mitigation gear, and catch statistics (AFSC 2010).

BSAI observed sets between 2008 and 2011 consisted primarily of longline (n=34,997), pelagic trawl (n=47,621), and non-pelagic trawl (n=142,350) from 261 vessels (Table 3.2). Although pot fishing was also observed, it was not examined here because of its relatively low sample size (n=45). Fishing effort for each gear type persisted year round, although it varied by season (Table 3.2). Moreover, sets per day and duration of sets varied by gear type (Table 3.2). Longline set durations (mean  $\pm$  SE=

15.3±7.7hrs) were greater than trawl set durations (5.2±3.5hrs); although, on average, more trawl sets occurred daily (Table 3.2).

#### *Seabird-vessel associations and analyses*

To examine STAL associations with fishing vessels, we calculated distances between vessel locations during gear deployment or retrieval and all STAL locations occurring within 10 km and two hours of gear deployment or retrieval. STAL tracking data were limited to the BSAI Alaskan exclusive economic zone (EEZ) for this analysis. Two hour time conditionals were used for associations because it reflected the minimum time between location fixes for STAL satellite transmitters. For a given association, depth, date, vessel, and bird demographic data were extracted along with distance and time between locations. All associations were computed in Matlab (The Math Works, Inc.).

We assessed associations using linear mixed models (LMM) for distance between STAL and vessels. The response variable was distance between STAL and vessel during gear deployment when distances were less than 10km and two hours from gear deployment or less than 20km and two hours from gear deployment if the same bird location was also less than 10km and two hours from gear retrieval for that vessel. This variable will hereafter be referred to as association distance. The latter criteria for association distances were included because these birds appeared to be associated with the vessel during the relatively short period of time between gear deployment and retrieval. Five new vessels and 222 sets were added using the latter criteria, but did not change the proportion of vessel gear types that was observed using only the first criteria.

The distance of 10 kilometers was chosen based on previous studies of albatross-vessel associations (Skov and Durinck 2001, Torres et al. 2013). The Restricted Maximum Likelihood (REML) fit LMM was chosen based on robustness to unbalanced study designs (Bolker et al. 2008) and model performance. Data were square root transformed to more closely satisfy the REML LMM normal distribution and evaluated graphically and quantitatively ( $W=0.96$ ,  $p<0.001$ ).

To explain variability within association distances, we selected vessel, STAL, habitat, and temporal related variables based on previous research (Chapter 2, Suryan et al. 2007, Dietrich et al. 2009, Torres et al. 2013). The REML LMM was fit in R (R core team 2012) using the “lme4” package (Bates et al 2013). ANOVA F-test results were used to evaluate factor significance, following Bolker et al. (2008). STAL and vessel were used as random effects.

## **Results**

### *Seasonal STAL distribution and mortalities*

Seasonal immature STAL distribution in the Bering Sea is not uniform. In the summer, core areas occupy Bering Sea shelf margins including those around the Aleutian and Commander Islands (Figure 3.1a). In the fall, core areas shift north away from the southern Bering Sea shelf (Figure 3.1b). In contrast, winter core areas move south to the southern shelf and remain along the Aleutians (Figure 3.1c). By winter no core areas remain in the northern Bering Sea. This southern retreat continues in the spring as core areas move off the southern shelf and further eastward along the Aleutian chain (Figure 3.1d).

Similarly, seasonal shifts are reflected in STAL canyon use. In summer and fall, nearly one third of albatross time is spent near canyons (within 93km), predominantly near Navarin and Pervenets canyons (Figure 3.2). In winter and spring, less time is spent near canyons and more southern canyons are favored (Figure 3.2). In general, there is a sequential shift to northern canyons in late summer and fall, then a retreat towards the southeast in the winter and spring (Figures 3.1a-d; Figure 3.2).

#### *Alaskan Bering Sea fisheries effort and distribution*

Across four years (2008-2011) there were over 80,000 observed sets within the BSAI fisheries. These sets were dominated by three main fisheries: the pollock trawl, flatfish trawl, and Pacific cod longline fisheries. In these four years, the pollock trawl fishery made up over 99% of the pelagic trawl effort and 35% of the total effort within the BSAI area. The majority of non-pelagic trawl sets and 28% of all BSAI sets were from the flatfish trawl fishery. The Pacific cod longliners made up 22% of the total sets and slightly less than 90% of all longline sets. Sablefish and arrowtooth flounder (*Atheresthes stomias*) make up most of the remaining 10% of longline vessels' target catch.

Longline, pelagic trawl, and non-pelagic trawl vessels all exhibited seasonal fluctuations in effort. Furthermore, these fluctuations contrast in certain seasons. Longline vessels show highest levels of effort in fall and the lowest in spring (Table 3.2). Pelagic trawl vessel effort is highest in summer and lowest in fall and spring (Table 3.2). In contrast, non-pelagic trawl vessel effort is highest in spring and lowest in winter

(Table 3.2). There also are some annual variations in behavior; most notably there was a reduction of observed longline effort in 2010.

Although all Alaskan fishing effort is on the shelf or shelf-break areas (<1000 meters), there are seasonal spatial shifts within these areas. Most significant for STAL, spatial shifts occur in late summer and early fall. From summer to fall seasons longline effort doubles within the BSAI area and trawl effort diminishes slightly. First, pelagic trawl vessel effort diminishes along the Bering Sea shelf in mid-September, most notably in areas near Zemchug canyon. Second, longline effort increases around mid-August across the entire Bering Sea shelf, including near Zemchug, and most drastically near Bering canyon.

#### *Vessel-bird association*

Associations between Alaskan fishing vessels and STAL focus along outer shelf margins and near canyons (Figure 3.3). Specifically, we found the greatest concentrations of associations near Navarin, Pervenets, and Zemchug canyons and an area on-shelf (east) from Pribilof canyon (Figure 3.3). Each of these association hotspots were composed of different proportions of vessel gear types. Non-pelagic trawl vessels comprised most associations in the Navarin and Pribilof “hotspots” (Figure 3.3). Most associations in the southern Bering Sea and Aleutian Islands were also with non-pelagic trawl vessels. Pelagic trawl vessels comprised most associations near Pervenets and Zemchug canyons and nearly half of the associations on-shelf from Pribilof canyon. Longline vessel associations occurred near Navarin and Zemchug Canyons, whereas almost no longline associations occurred south of Pribilof Canyon.

Seasonally, there are also variations in STAL associations across vessel gear types (Figure 3.4). In the summer, nearly 20% of STAL locations in the BSAI fishing area are associated with fishing vessels with observers (Figure 3.4). This percentage drops slightly in the fall to 15% and then down to <5% in the winter. During spring, STAL are associated with vessels nearly 15% of the time. STAL associations with pelagic trawl vessels decrease from ~10% in the summer to <1% in the spring (Figure 3.4). Non-pelagic trawl associations are highest in the spring (~10%), near 7% in summer and fall and 0% in the winter. Longline associations are near 3% of STAL locations for spring, summer and fall and decrease to ~1% in winter. Most notably for STAL, the proportion of longline association relative to the proportions for other gear types increases from summer to fall (Figure 3.4).

The LMM examined association distances across habitat, temporal, STAL, and vessel related variables. We found significant ( $P<0.05$ ) or strong indications ( $P<0.1$ ) of variability across all variable types (Table 3.4). Temporal and habitat related variables revealed significance in association distances across seasons ( $P<0.05$ , Table 3.4), some variability across depth ranges ( $P<0.1$ , Table 3.4), and no variability between study years ( $P=0.27$ , Table 3.4). For seasons, STAL distance to gear deployments decreased slightly from summer ( $5.36\pm 0.17\text{km}$ ) to fall ( $5.05\pm 0.37\text{km}$ ) and were highest in winter ( $8.18\pm 0.55\text{km}$ ). STAL were closest to vessels during gear deployment in the fall ( $5.05\pm 0.37\text{km}$ ) and farthest in the winter ( $6.78\pm 0.50\text{km}$ ). For depth, STAL were slightly closer to gear deployments in shelf break habitats (200-1000m depth;  $4.76\pm 0.22\text{km}$ ) than in shelf habitats (<200m depth;  $5.05\pm 0.37\text{km}$ ).

STAL and vessel related variables demonstrated some association variability across flight years ( $P < 0.1$ ) and variability across vessel target catch ( $P < 0.005$ ; Table 3.4). However, no variability was shown across sexes, colonies, vessel type, or gear type (Table 3.4). STAL in their first flight year ( $5.05 \pm 0.37 \text{ km}$ ) were slightly closer to gear deployments than STAL in their second year ( $5.94 \pm 0.19 \text{ km}$ ). STAL were closest to gear deployments targeting sablefish ( $4.48 \pm 0.97 \text{ km}$ ) and rockfish ( $4.01 \pm 0.57 \text{ km}$ ), and farthest from those targeting Pacific cod ( $7.76 \pm 0.49 \text{ km}$ ) and pollock ( $8.11 \pm 0.85 \text{ km}$ ).

## **Discussion**

In summary, immature STAL are most widely distributed throughout the Bering Sea in summer and fall. They associate with vessels most extensively on outer shelf areas near canyon habitats. However, STAL bycatch events in Alaska fisheries do not occur in STAL core areas or areas of high STAL-vessel association. We also find no variation in association distances for translocated and non-translocated STAL.

Few studies have examined fine-scale associations of vessel and seabirds (Votier et al. 2010, Granadeiro et al. 2011, Torres et al. 2013) and fine-scale results may differ from those of large-scale overlap studies (Torres et al. 2013). Furthermore, even fewer studies examining seabird-fisheries interactions have assessed interactions with juvenile birds. Juvenile seabirds have been observed in different areas than adults (Weimerskirch et al. 2006, Alderman et al. 2010, Deguchi et al. in press) and their inexperience may make them more attracted to fishing vessels (Weimerskirch et al. 2006). In Bering Sea Alaskan fisheries, 70% of STAL bycatch events involved immature birds ( $\leq 3 \text{ yrs}$ ). Through this study we examined associations (i.e., spatial ( $< 10 \text{ km}$ ) and temporal ( $< 2 \text{ h}$ ))

co-occurrences) between immature STAL and Alaskan fishing vessels. Our findings demonstrate spatial, demographic, and temporal variability in STAL-vessel associations. Moreover, we find documented bycatch occurring outside of STAL core use and high STAL-vessel association areas.

*Vessel-bird associations and distributions*

Albatross overlap with BSAI fishing vessels is largely dictated by where on the Bering Sea shelf area birds forage (Fischer et al. 2009). Almost all Alaskan BSAI fisheries effort is concentrated on the shelf, although not all fisheries use the same areas of the shelf. STAL have been shown to forage predominantly near shelf break and slope habitats (Piatt et al. 2006, Suryan et al. 2006). Therefore, interactions between fishing vessels and STAL are most likely to occur along shelf margin areas. This is supported by Bering Sea documented bycatch, all of which occurred near the Bering Sea shelf break. These areas of co-occurrence, however, vary between vessel types and seasons.

Distributions and associations of immature STAL and Alaskan vessels varied intra-annually and spatially across the Bering Sea shelf margins between 2008 and 2012. STAL occurrence in these areas is focused within summer and fall months and around northern shelf and canyon areas, specifically near Navarin, Pervenets, and Zemchug canyons. Fishing effort in the summer is predominantly from pelagic and non-pelagic trawl vessels, and in the fall is predominantly from longline and non-pelagic trawl vessels. Shifts in effort between pelagic trawl and longline vessels occurred near Zemchug and east of Bering canyon, these areas are where we hypothesized STAL associations with longline vessels would occur.

Although the greatest increase in longline effort in the fall occurred near Bering canyon, all STAL associations near this area were with non-pelagic trawl vessels. This is likely because STAL distribution moves north along the Bering Sea shelf (i.e., away from Bering canyon) in the fall and most associations in the area probably occurred in summer months when STAL distribution was more uniform (Figure 3.1a,b). Conversely, we did find longline associations near Zemchug canyon where there was also an observed increase in longline activity in the fall. The percent of STAL locations associated with longline vessels, however, did not increase from summer to fall. While the percent of STAL locations associated with pelagic trawl vessels did decrease in the fall, as expected. This suggests that, although longline associations did not increase in the fall, they comprised a larger proportion of total associations in fall than in summer (Figure 3.4).

#### *Documented STAL bycatch and associations*

Our goal with this study was to investigate observed bycatch variability by quantifying associations between immature STAL and Alaska's fishing fleets. Unexpectedly, what we found is that bycatch events did not occur in the same areas as associations. Three STAL bycatch were documented in late summer and fall during our study period, two of which were in areas where no STAL-vessel associations were found (Figure 3.3). The single STAL mortality documented within an association area, near Pervenets canyon, was taken on a longline vessel where a low proportion of longline associations were observed. Areas with greater abundance of longline associations, near Navarin and Zemchug canyons, had historic but no recent documented STAL bycatch. It is uncertain why recent bycatch events occurred where they did. One theory is that

bycatch is occurring in areas with relatively low food availability. For example, an albatross may be transiting between preferred foraging grounds and, because food is scarce, a vessel may become a more attractive food source. In contrast, all historic documented STAL bycatch events within Alaskan BSAI fisheries occurred within association areas.

Although recent bycatch did not occur in expected areas, our findings do support the fall and juvenile STAL trend observed in documented bycatch. One theory for this trend is that STAL foraging on discards from trawl vessels become more associated with longline vessels after trawl fleet effort diminishes in late summer. The proportion of STAL association with longline vessels relative to other gear types increased from summer to fall (Figure 3.4). Moreover, associations in fall were slightly closer to vessels than in summer (Table 3.4). STAL in their first year of flight were also slightly closer to vessels (Table 3.4). Although our findings support this theory, bycatch events are spatially variable within Alaska fishing grounds. These results indicate that it is not prudent to only focus mitigation efforts in high STAL use or high vessel association areas.

Additionally, it is important to note that, although most documented STAL bycatch occurred in longline fisheries, trawl fisheries may have a greater incidence of unrecorded bycatch. While albatross bycatch has been documented extensively in longline fisheries (Melvin and Parrish 2001, Tuck et al. 2003, NMFS 2011), it is also known to occur in trawl fisheries (Sullivan et al. 2006, Watkins et al. 2008). Furthermore,

trawl fishing vessels made up the majority of STAL associations in spring, summer, and fall months (Figure 3.4).

#### *Variability in associations*

Distance variations in associations with BSAI gear deployments may reflect coincident habitat use. Slightly closer associations occurred in shelf break areas (depths 200-1000 meters) and with vessel targeting sablefish and rockfish, also occurring along shelf break areas. These results were expected based on STAL shelf break and slope preference (Piatt et al. 2006, Suryan et al. 2006). Previous research has also suggested STAL may overlap with the sablefish longline fishery based on coextensive habitat use (Suryan et al. 2007). Similarly, black-footed albatrosses (*Phoebastria nigripes*) forage mostly in shelf slope waters and also overlap with the BSAI sablefish longline fishery (Fischer et al. 2009). Notably, STAL associations both with vessels targeting rockfish and those targeting sablefish occurred along shelf break areas in the Aleutian Islands and not in areas of high association, abundance, or recorded bycatch.

Association distances across age and season, however, may indicate more than coincident habitat use. Closer association with juvenile (first flight year) birds and during the fall season may reflect attraction to vessels. Juvenile birds are relatively inexperienced with fishing vessels and foraging in general; therefore, they may be more likely to seek vessels out as a food source (Weimerskirch et al. 2006). Alternately, juveniles may occur closer to vessels because of their broader range (Chapter 2, Deguchi et al. in press). They may explore farther onto shelf areas where more vessels are fishing. Short-tailed albatrosses were closest to vessel sets during the fall, which was expected,

due to the fact that most of the documented STAL bycatch on Alaskan vessels occurred during the fall.

Our findings also did not demonstrate association distance variations across vessel type (i.e. catcher-processor or mothership) and gear type (i.e. longline or trawl) variables. Seabirds may be attracted to vessels in order to forage on offal discard (Garthe et al. 1996, Gremillet et al. 2008, Favero et al. 2011), bait (Melvin and Parrish 2001, Pierre and Norden 2006), and discarded non-target catch (Rindorf et al. 2000). A previous study found bycatch to vary across vessel types (Dietrich et al. 2009). This may result from different vessel types and gear types having different types of discards, some more desirable to seabirds than others. We hypothesized that STAL association distances would be closer to longline catcher-processor vessels because we were looking at distance to gear deploy. During gear deployment, longline vessel would have baited hooks in the water and trawl vessel would not have fish in their nets. One explanation for the lack of variation in association distance across vessel types is that distance within vessel associations is not capturing attraction to vessels for food sources but rather extent of coincident habitat use.

Recent studies examining vessel interactions have similarly found that seabird and fishing vessel overlap can reflect a shared foraging area (Torres et al. 2013). Torres et al. (2013) demonstrated that Buller's albatrosses (*Thalassarche bulleri*) forage independently of vessels over half the time they are within 10km; on average, only 10% of foraging within an association consisted of foraging from a vessel. Although up to 20% (in summer) of STAL locations were within 10km of a fishing vessel, many of these

occurrences may have been independent of the vessel. For STAL, more fine-scale albatross and vessel tracking data may help better examine STAL interactions with Alaskan fishing vessels.

### **Conclusion**

We found seasonal and spatial variation in STAL distribution and vessel associations. Notably, vessel association did not differ between translocated and naturally reared birds. Temporally, STAL were more closely associated with longline vessels during the fall, when bycatch-related mortalities were observed. Some bycatch mortalities, however, occurred outside of STAL high use and high vessel association areas.

Future research may benefit by deploying and examining temporally finer scale STAL and vessel tracking data to better assess associations and identify vessel-dependent foraging (Torres et al. 2013). In addition, physical (e.g. sea surface height) and biological (e.g. chlorophyll a) explanatory variables could be examined in models. Although our STAL-vessel association results suggest more coincident habitat use than foraging reliance, there are still implications for these associations. Beyond potential for bycatch-related mortalities, fishing activities can impact seabirds through competition for resources (Okes et al. 2009) and strike-related mortalities (Watkins et al. 2008, Melvin et al. 2011). Overall, our finding suggests seabird bycatch mitigation readiness in BSAI fisheries needs to be range wide if fishing-related mortalities are to be minimized.

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## Tables

Table 3.1. Summary statistics for harness and tape attached satellite transmitters inside the Bering Sea study area (June 2008-2012). Transmitter durations (min and max) within this study area are given in days. Total locations are also displayed by season.

<b>Attachment method</b>	<b># birds</b>	<b>Loc./day (M±Sd)</b>	<b>Min dur.</b>	<b>Max dur.</b>	<b>Total loc.</b>	<b>Sum. (JJA)</b>	<b>Fal. (SON)</b>	<b>Win. (DJF)</b>	<b>Spr. (MAM)</b>
<b>Tape</b>	25	5.2±4.1	1	103	7758	5762	1996	0	0
<b>Harness</b>	11	4.1±1.4	19	413	8567	4037	3023	765	742

Table 3.2. Summary statistics for fishing effort by gear type (2008-2012). Gear deployment durations are given in hours. Total sets are also displayed by season.

<b>Gear type</b>	<b># vessels</b>	<b>Sets/day (M±Sd)</b>	<b>Dur. (M±Sd)</b>	<b>Total sets</b>	<b>Sum. (JJA)</b>	<b>Fal. (SON)</b>	<b>Win. (DJF)</b>	<b>Spr. (MAM)</b>
<b>Longline</b>	51	24.5±15.2	15.3±7.7	34997	8215	13182	8608	4992
<b>Pelagic trawl</b>	108	53.4±31.1	5.2±3.5	47621	22153	7402	10783	7283
<b>Non-Pel. trawl</b>	102	108.6±2281.8	NA	59687	15630	15285	10550	18222

Table 3.3. Summary statistics for STAL-vessel association data by gear deployment and retrieval (2008-2012). Association mean and standard deviation are displayed in kilometers. Total associations are also displayed by season.

<b>Gear</b>	<b>Total vessel</b>	<b>Total STAL</b>	<b>Assoc. dist (M±Sd)</b>	<b>Total Assoc.</b>	<b>Sum. (JJA)</b>	<b>Fal. (SON)</b>	<b>Win. (DJF)</b>	<b>Spr. (MAM)</b>
<b>Deploy</b>	97	27	5.71±2.64	893	629	195	14	55
<b>Retrieve</b>	102	29	5.56±2.70	980	771	205	17	47

Table.3.4. Restricted maximum likelihood Linear Mixed Model results for immature STAL <10km association distances with fishing vessel gear deployments. Estimated mean and standard error (in km) are reported only for factors with P-value <0.1. P-values were calculated from ANOVA F-values. Individual vessel and bird were used as random effects.

<b>Model</b>	<b>Factor</b>	<b>Level</b>	<b>Est.±S.E.</b>	<b>P-value</b>
	Depth (meters)	<200	5.05±0.37	0.077
		200-1000	4.76±0.22	
	Year	NA	5.05±0.37	0.273
	Season	Sum(JJA)	5.35±0.17	0.032
		Fal(SON)	5.05±0.37	
		Win(DJF)	6.78±0.50	
		Spr(MAM)	5.25±0.31	
	Flight year	Year 1	5.05±0.37	0.071
		Year 2	5.94±0.19	
		Year 3	5.61±0.74	
	Colony	NA	5.05±0.37	0.980
	Sex	NA	5.05±0.37	0.451
	Vessel gear	NA	5.05±0.37	0.642
	Vessel type	NA	5.05±0.37	0.879
	Target Sp.	Atka mackerel	5.05±0.37	0.013
		P. cod	7.67±0.49	
		Rockfish	4.01±0.57	
		Pollock	8.12±0.85	
		Sablefish	4.49±0.97	
		Arr./Kam. flounders	5.99±0.42	
		Other flatfish	5.52±0.38	

## Figures

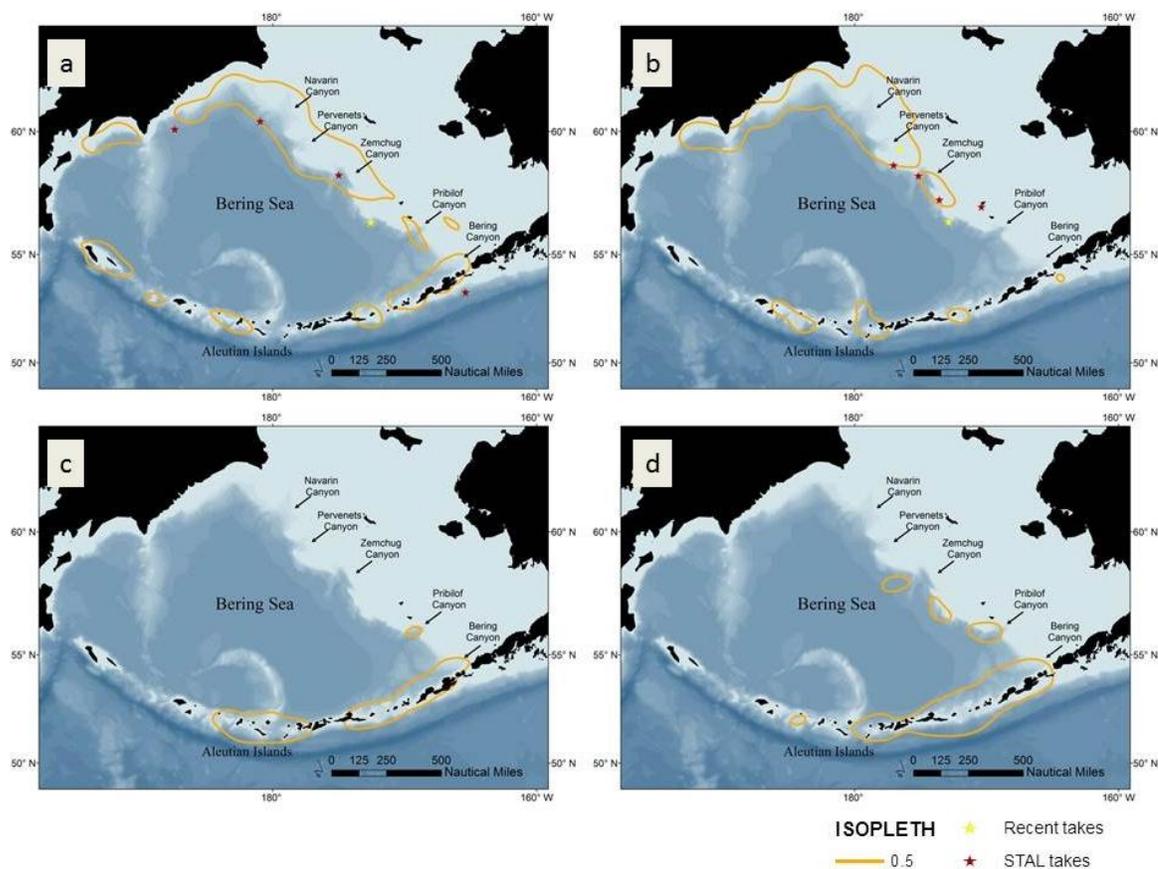


Figure 3.1a-d. The core area (50% kernel) contour of immature short-tailed albatrosses in the Bering Sea for (from left to right) (a) summer, (b) fall, (c) winter and (d) spring. Also included are the documented takes for that given season. Recent takes (2010-2011) are highlighted.

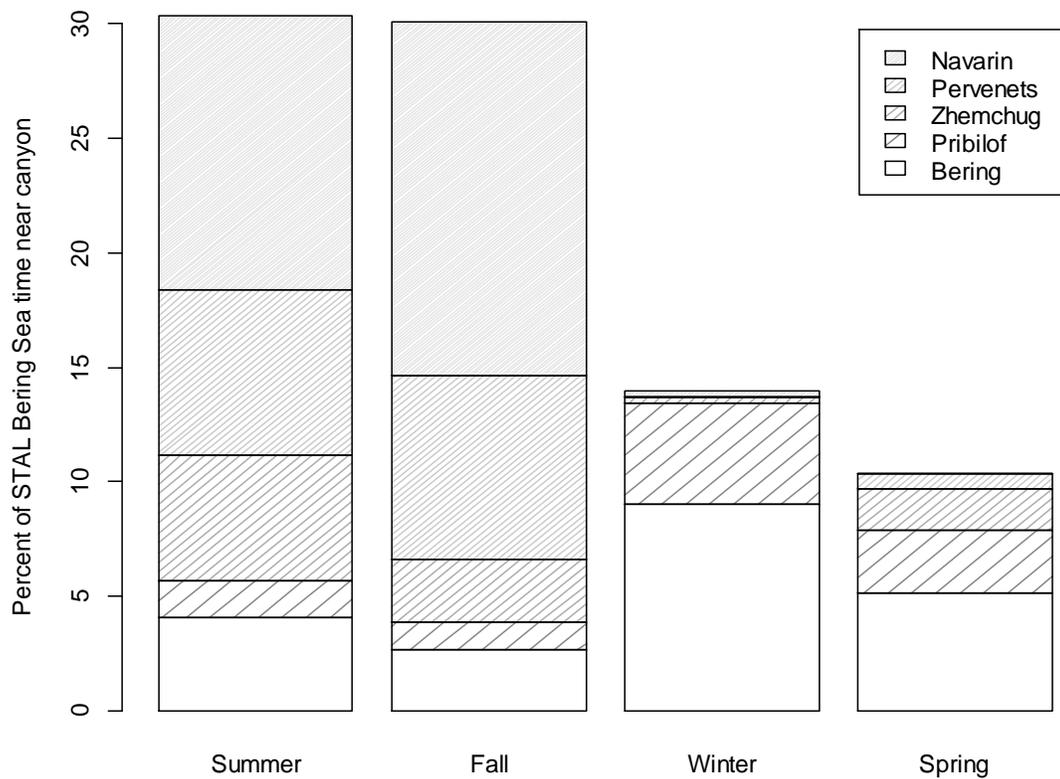


Figure 3.2. STAL time spent in canyons (ordered North to South) as a percent of total hours in the Bering Sea by season.

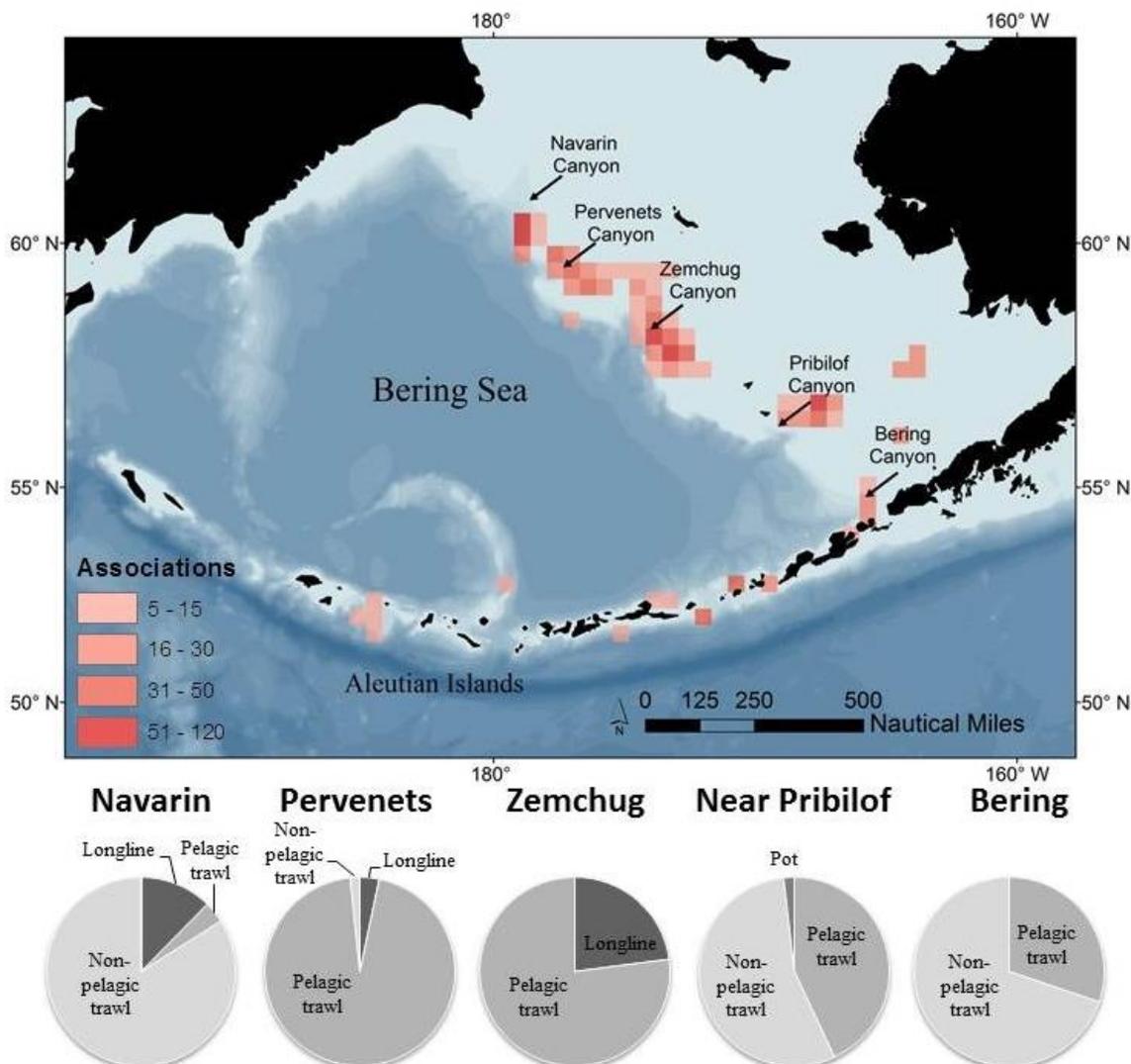


Figure 3.3. Alaskan fishing vessel and STAL association abundance and locations. Pie charts depict the gear type of vessels associated with STAL within association hotspots near individual canyons.

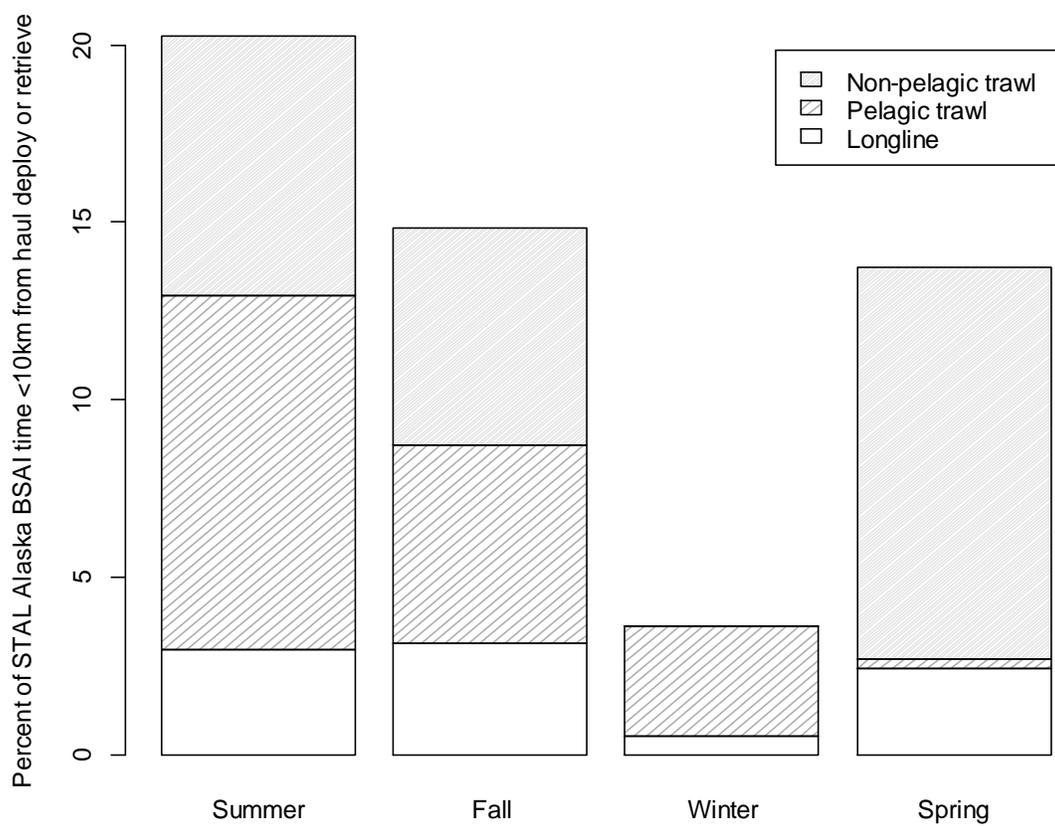


Figure 3.4. Percent of Alaska BSAI area STAL locations within 10km and 2hr of BSAI vessel gear deployment or retrieval by season and gear type.

## **CHAPTER 4 - SYNOPSIS AND CONCLUSIONS**

### **Research aims**

Through this research I aimed to quantify year-round distribution and Bering Sea fishery associations for immature ( $\leq 3$  years) short-tailed albatross (STAL). My methods included quantifying kernel density probability distributions, assessing overlap indices, and analyzing variability through Linear Mixed Models (LMM). Density plots and overlap indices allowed me to examine variability across core areas of immature STAL sexes, ages, and source colonies. By overlaying North Pacific Groundfish Observer Program data with STAL satellite tracking data I was able to examine temporal and spatial co-occurrences (associations) between STAL and fishing vessel sets. LMMs allowed me to further examine temporal, spatial, and demographic (e.g. vessel type) variation in STAL-vessel associations. I also examine theories of why STAL bycatch in the Bering Sea occurs primarily in fall. Through these analyses I was able to shed light on temporal and regional variability in immature STAL distributions and fisheries associations.

### **Primary findings**

My analyses in chapter 2 revealed seasonal as well as regional variations for core areas of STAL sexes and age classes. Seasonally, STAL traveled from colonies near Japan, into the Bering Sea, and in some cases down along the US west coast. Most notably, distributional variations and increased travel distances were observed when STAL core areas moved south within the Bering Sea in the winter and spring. STAL in their first year of flight have a broader distribution than in their second year, which may

suggest a period of learning foraging skills and locating preferred foraging grounds. Findings also show no major variation in distributions of translocated and non-translocated birds and document an initial return to colony for one translocated bird.

In chapter 3, I found STAL-vessel associations (a STAL location within 2hr and 10 kilometers from a vessel during gear deployment) concentrated along shelf-break and near canyon habitats during summer and fall months. Moreover, analyses suggest that STAL associations may represent coincident habitat use rather than vessel attraction. STAL bycatch documented in the fall occurred after observed increases in relative abundance of longline associations relative to other gear types. STAL bycatch during this study period, however, occurred in areas of low longline association, and two of three bycatch events occurred outside of STAL core and vessel association areas. I observed no variations in fisheries associations between translocated (hand-reared) and non-translocated (naturally-reared) STAL.

### **Contributions and future directions**

This study provides two important novelties to seabird research. First, we examined year-round migrations of immature ( $\leq 3$  years) albatrosses, including variability within relevant demographics (e.g. source colonies). Second, we used fine-scale analyses to examine immature albatross associations within a major U.S. fishery. Furthermore, our findings will help to inform STAL conservation efforts. Through quantification of distributions and fisheries associations we documented initial successes for translocated STAL and suggested that that bycatch mitigation vigilance is equally important outside of STAL core areas.

Future research for STAL would benefit from further examining fine-scale fisheries associations outside of U.S. fisheries. For instance, we found vessel associations concentrated near canyon habitats, but it is unclear whether this also applies to Russian or Japanese fisheries. Further analyses could also examine Bering Sea canyon food web structures and their relation to top predators like STAL and commercial fisheries.

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