



Overlap of North Pacific albatrosses with the U.S. west coast groundfish and shrimp fisheries

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ABSTRACT

We used a combination of seabird data (both fishery-dependent and fishery-independent) and fishing-effort data to evaluate the relative fisheries risk of five west coast groundfish fisheries and one shrimp fishery to black-footed (*Phoebastria nigripes*), short-tailed (*P. albatrus*) and Laysan albatrosses (*P. immutabilis*). To assess risk, an overlap index was derived as the product of total fishing effort and at-sea survey density of black-footed albatross. This index was used as the primary tool to estimate overlap with the endangered, relatively rare short-tailed albatross, which show similar habitat utilization from satellite telemetry tracks. Telemetry data indicate Laysan albatross primarily occur offshore beyond observed fishing effort. Black-footed and short-tailed albatross-fishery overlap was highest at the shelf-break (201–1000 m) north of 36° N. Overlap and reported albatross mortality indicate that the sablefish (*Anoplopoma fimbria*) longline and Pacific hake (*Merluccius productus*) catcher-processor fisheries pose the greatest risk to these species; the near-shore rockfish (*Sebastes* spp.) longline, pink shrimp (*Pandalus jordani*) trawl, California halibut (*Paralichthys californicus*) trawl, and non-hake groundfish trawl fisheries pose relatively little risk. Implementing proven seabird bycatch-reduction measures will likely minimize albatross mortality in the highest-risk fishery, sablefish longline.

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1. Introduction

A major goal of sustainable fishery management is to minimize sources of incidental mortality, particularly of threatened species. Albatrosses are among the most threatened seabird groups; 17 of the world's 22 albatross species are listed as critically endangered, endangered or vulnerable (IUCN, 2011). In common with many pelagic seabirds, albatrosses are susceptible to population declines due to a range of anthropogenic threats (fishery bycatch, invasive species, and marine contaminants; Croxall et al., 2012) and

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life-history traits (delayed age of first reproduction and low fecundity; Croxall and Rothery, 1991). Incidental mortality (bycatch) in commercial fisheries has been identified as one of the major factors contributing to global declines in albatross populations (Weimerskirch and Jouventin, 1987; Croxall et al., 1990; Croxall and Gales, 1998). In recognition of the global threat fisheries pose to seabirds, several international agreements were established to stem seabird mortality, including the International Plan of Action for Reducing the Incidental Mortality of Seabirds in Capture Fisheries (IPOA-Seabirds) and the Agreement for the Conservation of Albatrosses and Petrels (ACAP).

Albatrosses are attracted to fishing vessels, which provide food in the form of bait, offal and catch discarded at sea (discards). In longline fisheries, albatrosses can be caught or entangled as they forage for baited hooks and drown as the fishing gear sinks (Brothers, 1991; Melvin et al., 2001). In trawl fisheries, albatross mortality can result from net entanglement and/or collisions with the trawl warps or net monitoring cables (Bartle, 1991; Weimerskirch et al., 2000; Sullivan et al., 2006). Fortunately, incidental albatross bycatch in many fisheries can be mitigated using established tools and methods. Bird-scaring lines (also calledtori lines or streamer lines) can keep birds away from hooks and cables, seasonal closures and setting longlines at night can avoid periods of intense albatross-fishery interactions, weighting fishing gear can limit bird access to hooks and nets, and offal management can be used to limit bird attraction to fishing vessels (Løkkeborg, 2011).

In general terms, IPOA-Seabirds calls for fishing nations and Regional Fisheries Management Organizations to develop plans of action that characterize the extent of seabird bycatch in longline, trawl and gillnet fisheries under their jurisdiction; if seabird bycatch is found to be problematic, parties are directed to develop plans to reduce that bycatch through required mitigation (FAO, 1999, 2009). An Ecological Risk Assessment approach has been successfully used to identify the extent of seabird bycatch risk in fisheries (Hobday et al., 2011; Tuck et al., 2011). Key elements in this approach include evaluating the conservation status of birds caught incidentally and establishing the degree of overlap between seabird distributions and fishing effort (Tuck et al., 2011; Small et al., 2012). Overlap indices such as these do not explicitly consider susceptibility to capture but do indicate the level of possible encounters. In the presence of uncertainty they can offer a precautionary approach to determining if, where, and to what extent a fishery poses a potential threat to rare and vulnerable seabird populations (Birdlife-International, 2004; Cuthbert et al., 2005; Petersen et al., 2008). Overlap analyses are useful for guiding the application of mitigation strategies, especially when available bycatch data confirm bird vulnerability to the fishing gear (Tuck et al., 2011; Small et al., 2012).

Three albatross species occur in the North Pacific: short-tailed albatross (*Phoebastria albatrus*), black-footed albatross (*P. nigripes*), and Laysan albatross (*P. immutabilis*). All are internationally listed as either vulnerable or near-threatened (IUCN, 2011; Table 1); all are killed incidentally in commercial fisheries throughout their range (Artyukhin et al., 2006; Fitzgerald et al., 2008; Smith and Morgan, 2005; Jannot et al., 2011; Table 1); and are listed for protection under ACAP (2012). Black-footed and Laysan albatrosses nest in the central Pacific, and breeding populations are two to three orders of magnitude larger than those of short-tailed albatross (Table 1). Black-footed populations are increasing in the western North Pacific (Chiba et al., 2007) and Laysan albatross have recently expanded into the Eastern Pacific (Henry, 2011). Concern for fishery mortality of short-tailed albatross is most acute in the United States due to their perilously small breeding populations (600 breeding pairs; Hasegawa and Sievert, 2012, unpubl. data). Unlike black-footed and Laysan albatrosses, short-tailed albatross nest in the western Pacific and are categorized as endangered under the US

Endangered Species Act (ESA; Federal Register 2000, 65 FR 46643). Prior to short-tailed albatross being hunted to near extinction in the early 20th century (Hattori, 1889; Austin, 1949), their numbers were similar to those of black-footed and Laysan albatrosses. Fishery interactions are likely to increase as short-tailed and other North Pacific albatrosses repopulate their former ranges thanks to recover efforts.

The issue of seabird bycatch came to the fore in the demersal trawl and longline fisheries of the west coast of the United States with the completion of an analysis, based on fishery observer data (2002–2006), of the extent of bycatch in these fisheries (NWFSC, 2008). The most recent analysis of these data (2002–2009, Jannot et al., 2011) revealed chronic annual mortality of black-footed albatross in the sablefish (*Anoplopoma fimbria*) demersal longline fishery (annual mean = 43 albatrosses, 95% CI = 23), and detectable mortality in the Pacific hake (*Merluccius productus*) catcher-processor trawl fleet, (annual mean = 1, 95% CI = 1). Relatively low levels of adult mortality such as these merit conservation concern because fishery mortality may be underestimated and albatross are far-ranging and can suffer mortality in many fisheries, resulting in cumulative negative population effects (Lewison and Crowder, 2003; Niel and Lebreton, 2005; Véran et al., 2007; Lebreton and Véran, 2012). Concern increased in 2011 when fishery observers documented the death of a short-tailed albatross hooked on a sablefish longline (NWFSC, 2011).

In neighboring US Pacific longline fisheries, incidental-take limits are in place for short-tailed albatross under the ESA. These fisheries include the Alaskan groundfish longline and trawl fisheries and Hawaiian pelagic longline fisheries. In addition to incidental take limits, mitigation measures are mandatory for the Alaskan and Hawaiian longline fisheries. Although neither short-tailed albatross take limits nor mandatory seabird bycatch mitigation is in place for the west coast groundfish fisheries at this time (Table 1), outreach and research efforts are underway to improve the understanding of the risk posed by these fisheries to albatrosses and to encourage the use of seabird bycatch mitigation technologies.

In this study, we evaluate the spatial and temporal overlap of five west coast fisheries targeting groundfish (two longline fisheries and three trawl fisheries) and one targeting pink shrimp (trawl fishery) with North Pacific albatrosses to determine which fisheries pose a potential threat to albatrosses and where and when those threats occur. Data sources included fishery-independent (ship-based survey and satellite tracking) and fishery-dependent seabird data (opportunistic short-tailed albatross sightings, fishery seabird surveys) and fishing effort (fishery observer program, log books, and landings data). We also determined the extent to which black-footed and Laysan albatross distributions reflect the distribution of the relatively rare short-tailed albatross. By structuring our analysis by depth and management area for all components of the fishery, we also endeavored to provide a framework for management actions.

2. Methods

2.1. Study area

We divided the Eastern Pacific, U.S. Exclusive Economic Zone (EEZ), which includes the states of California, Oregon and Washington, into analysis regions based on the boundaries of the International North Pacific Fisheries Commission (INPFC) management areas and ocean bathymetric domains (Fig. 1). Management areas delineated by latitude and longitude are the following: Vancouver (north of 47° 30' N), Columbia (47° 30' N to 43° N), Eureka (43° N to 40° 30' N), Monterey (40° 30' N to 36° N), and

Table 1
Status, trends and bycatch in US domestic fisheries for North Pacific albatrosses (*Phoebastria* spp.). Seabird bycatch mitigation and take limits for short-tailed albatross are noted as required (req.) or not (not req.) by region.

Species	Breeding pairs (IUCN status ^a)	Population trend ^b	Reported as bycatch in U.S. North Pacific fisheries ^c (take limits and seabird mitigation required)		
			Alaska (req.)	Hawaii (req.)	U.S. west coast (not req.)
Short-tailed (<i>P. albatrus</i>)	600 (V)	Increasing	Yes	No	Yes
Black-footed (<i>P. nigripes</i>)	61,000 (V)	Increasing	Yes	Yes	Yes
Laysan (<i>P. immutabilis</i>)	590,000 (NT)	Stable	Yes	Yes	No

^a V, vulnerable; NT, near-threatened, IUCN (2011).
^b Short-tailed: Hasegawa and Sievert (unpubl. data); black-footed and Laysan: Arata et al. (2009).
^c Alaska: Fitzgerald et al. (2008); Hawaii: NMFS (2010); U.S. west coast: Jannot et al. (2011).

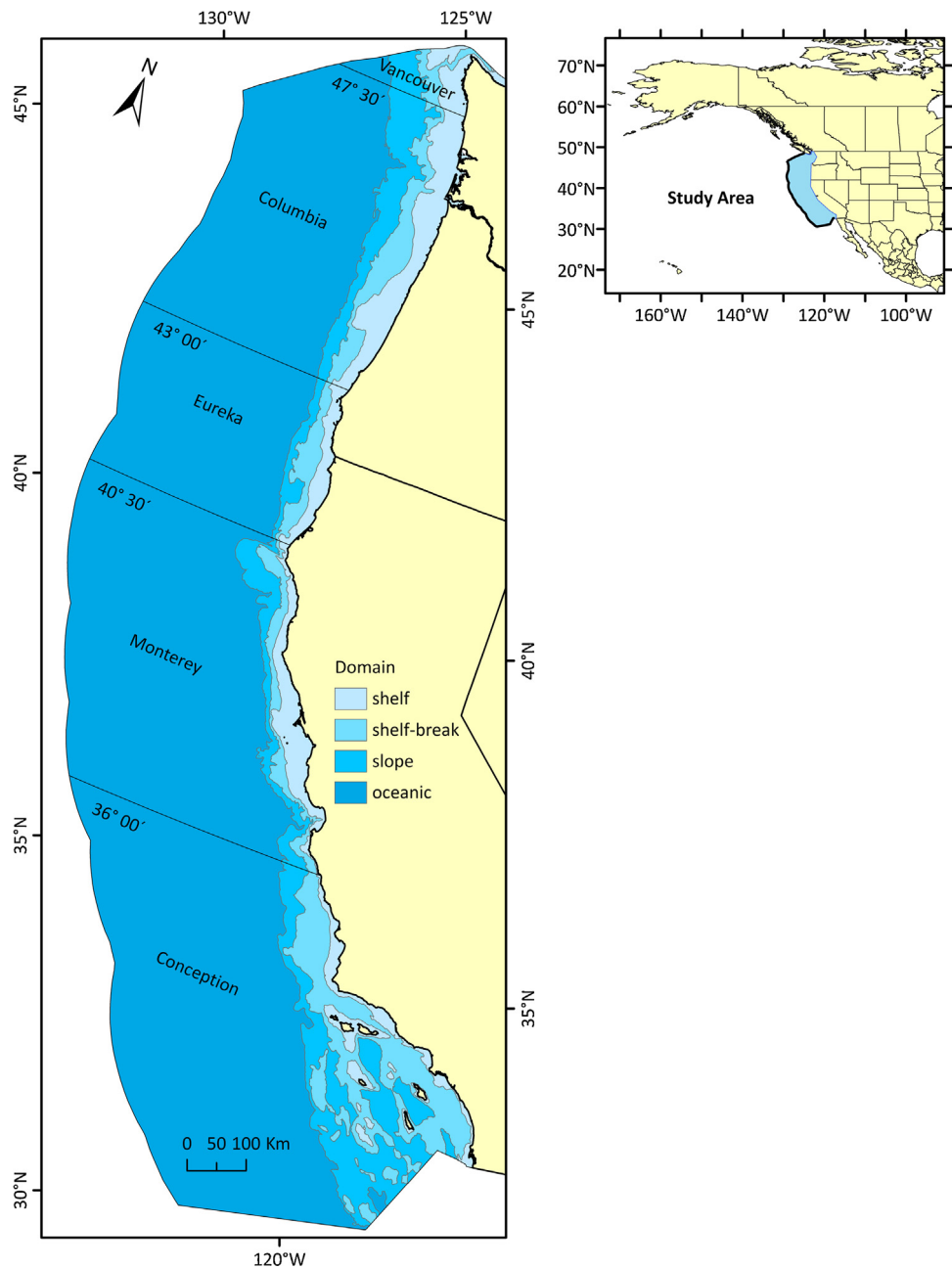


Fig. 1. Map of the study area showing the International North Pacific Fisheries Commission (INPFC) management areas and ocean bathymetric domains No groundfish fishing effort was observed in the oceanic domain in the study period.

Conception (south of 36° N). We subdivided each management area into four bathymetric domains: continental shelf (the shelf; 0–200 m), continental shelf-break (the shelf-break; 201–1000 m), continental slope (the slope; 1001–2000 m), and oceanic (>2000 m) to represent bathymetric categories of biological significance (Briggs et al., 1987; Yen et al., 2004; Suryan et al., 2007). We refer to each of the resulting management area-bathymetric domain units as analysis regions.

2.2. Fishery-independent data

We used two types of fishery-independent seabird data: at-sea distributions from vessel-based surveys and individual tracks from satellite tracking. Although at-sea surveys sampled the study area extensively, sightings of Laysan and short-tailed albatrosses were few. Including available telemetry tracks in our analysis allowed us to obtain insight on species-specific habitat use and residence time in any given area, yielding a more robust comparison among species. Because telemetry data were limited, we included more years of telemetry data (14) than at-sea surveys (4 years) or fisheries effort data (8 years).

2.2.1. At-sea surveys

We compiled 64,014 km of ship-based seabird surveys collected over 4 years (2005–2008) from multiple research and monitoring programs (Table 2 and Fig. 2). All surveys determined seabird abundance by species, behavior (on water, flying, feeding, ship-following), and location in a 300 m strip off one forequarter of the ship's bow (Tasker et al., 1984). Each survey track was divided into 3 km segments to reduce the effects of spatial autocorrelation in these data (Yen et al., 2004). Bird counts (regardless of behavior category) and the total area of the strip surveyed (survey length multiplied by 0.3 km) were assigned to the midpoint of each segment and each midpoint was assigned to an analysis region using ArcGIS (version 9.3.1, ESRI, 2009). Bathymetric domain was determined using the ETOPO1, 1 arc-minute global relief model (Amante and Eakins, 2009).

2.2.2. Satellite tracking

We obtained satellite telemetry data (Argos, CLS America, Inc., Maryland) for 98 albatrosses tracked within the U.S. Pacific west coast EEZ between 1998 and 2011 from several albatross tracking programs throughout the North Pacific (Table 3). Transmitters weighing 22–90 g (<1–2% of body mass) were attached with adhesive tape (Tesa®) to dorsal body feathers of all birds except five short-tailed albatross, for which transmitters were attached using harnesses. Black-footed albatross tagged in Hawaii and Laysan albatross tagged in Mexico were tracked during incubation, brooding, or chick-rearing periods and, therefore, were conducting central-place foraging trips into the study area. Tracking durations for individuals within the study area ranged from 1 to 70 days (Table 3; see Section 3 for more details).

We standardized tracking data obtained from various transmitter duty cycles using linear interpolation with locations spaced at hourly intervals (BFAL = 14,524, LAAL = 3431, STAL = 3509 hourly locations). Position-only satellite transmitters (30–65 g) were most common, and were programmed either to transmit continuously (60 or 90 s transmission intervals) or to use duty cycles of 6–20 h on or 4–24 h off. For short-tailed albatross tagged in 2009 and 2010, solar powered, satellite-linked global positioning system (GPS) receivers (22 g, Microwave Telemetry, Inc., Columbia, MD, USA) were used. The GPS units acquired six fixes per day at 2–4 h intervals and transmitted these positions via Argos satellites every 3 days. All data were filtered using standard algorithms for Argos (Suryan et al., 2008; Suryan and Fischer, 2010) and GPS (Suryan, unpubl.

data) to remove locations with detectable positional error (<5% of all positions were removed).

2.3. Fishery-dependent data

2.3.1. Opportunistic short-tailed albatross sightings

Given their rarity in at-sea surveys, we also mapped the locations of short-tailed albatross (2001–2011) opportunistically sighted by West Coast Groundfish Observer Program fishery observers, all of whom are trained to identify and record ESA-listed species.

2.3.2. Fishery seabird surveys

We acquired systematic seabird counts conducted during annual longline and trawl surveys. These data included counts from 127 stations surveyed during the International Pacific Halibut Commission (IPHC) longline stock assessment for Pacific halibut (2005–2008), and 1597 stations surveyed by the Northwest Fisheries Science Center – Fishery Resource Analysis and Monitoring Division (FRAM) bottom trawl groundfish survey (2006–2008). In both surveys, trained fishery scientists identified and recorded all seabirds to species or species group within a 50 m radius from the vessel's stern immediately after hauling the fishing gear, following the methods of Melvin et al. (2006).

2.3.3. Fishery effort

We partitioned fishing effort information for the west coast groundfish and pink shrimp fisheries (2002–2009) into six fisheries defined by gear type (longline or trawl) and primary target species. Longline fisheries gear type included the fishery for sablefish (*Anoplopoma fimbria*) and the near-shore fishery targeting rockfish (*Sebastes* spp.). Although we broadly defined all hook-and-line (rod-and-reel, vertical longline, stick-gear) fishing gears as longline fisheries, most hooks set for sablefish and the minority of hooks set for near-shore rockfish were set using longlines (98% and 9%, respectively). Trawl fisheries included the bottom trawl fishery for a variety of non-hake groundfish species (referred to from here forward as groundfish trawl fishery), the bottom trawl fishery targeting California halibut (*Paralichthys californicus*; CA halibut trawl), the bottom trawl fishery for pink shrimp (*Pandalus jordani*; pink shrimp trawl), and the catcher-processor and catcher vessel – mothership mid-water trawl fishery for Pacific hake (*Merluccius productus*; at-sea hake). This analysis did not include longline effort data for Pacific halibut or for most Treaty groundfish fisheries (tribal effort was included only for the at-sea hake fishery).

The West Coast Groundfish Observer Program trains and deploys biologists on a spatially stratified randomized subset of vessels to monitor fishing effort, total catch, and discards on vessels targeting the groundfish species with the exception of hake (Jannot et al., 2011). The At-Sea Hake Observer Program trains and deploys biologists to monitor all vessels that process catch at-sea and sample nearly all tows at levels approaching 50%. For each fishery other than at-sea hake and groundfish trawl (see below), we estimated the fleet-wide distribution of fishing effort by linking spatially explicit catch and effort information collected by fishery observers with commercial landing records maintained by the Pacific Fisheries Information Network. To estimate total distribution of fishing effort in any given fishery, we first calculated an expansion factor by dividing the weight of target catch recorded by observers to total catch in metric tons. Second, we allocated fishing effort spatially by dividing the fishing effort (hooks or towing hour) recorded by observers in each analysis region by the expansion factor (Table 4). This allocation procedure assumed a positive linear relationship between catch and fishing effort fleet-wide. It also assumed that the stratified randomized observer selection procedures adequately reflected the actual spatial distribution of fishing effort in any

Table 2

Summary of the research program, survey years, spatial extent, and data provider and source for each at-sea survey dataset.

Program	Years	Extent	Provider	Source
California Cooperative Oceanic Fisheries Investigation Program	2005–2008	Southern CA	University of California San Diego Scripps Institute of Oceanography, NOAA National Marine Fishery Service, California Department of Fish and Game, PRBO Conservation Science, Farallon Institute for Advanced Ecosystem Research (FIAER)	William Sydeman, FIAER
Oregon–California–Washington (ORCAWA)	2005–2006	CA, OR, WA	NOAA, Southwest Fisheries Science Center	Lisa Ballance, NOAA-SWFSC
Gulf of the Farallones National Marine Sanctuary Survey	2007–2008	Central CA	Gulf of the Farallones National Marine Sanctuary	Jan Roletto, GFNMS
Olympic Coast National Marine Sanctuary Survey	2005–2007	Northern WA	Olympic Coast National Marine Sanctuary	Barbara Blackie, OCNMS
Wind to Whales	2005–2007	Monterey Bay, CA	University of California Santa Cruz, Monterey Bay Aquarium Research Program	Don Croll, UCSC
Ocean Salmon Ecosystem Survey	2005–2008	Northern CA, OR, WA	NOAA Northwest Fisheries Science Center	Jen Zamon, NOAA-NWFSC
Juvenile Rockfish Survey	2005–2007	Central CA	NOAA Southwest Fisheries Science Center, PRBO Conservation Science, Farallon Institute	William Sydeman, FIAER
Sardine Survey	2006	CA, OR, WA	NOAA Southwest Fisheries Science Center, NOAA Northwest Fisheries Science Center, Farallon Institute	William Sydeman, FIAER

Table 3

Summary of the data provider, number of albatross tagged by species, tagging location, tagging years and months, tracking duration (days) within the U.S. west coast Exclusive Economic Zone (EEZ), and citation for each telemetry data set.

Provider	Number/species	Tagging location	Tagging years and months in EEZ	Mean (range) days in EEZ	Citation
Wake Forest University/Tagging of Pacific Predators	12 black-footed ^a , 1 Laysan ^a	Hawaii	1998–2006 (January–July, Dec)	15 (2–70)	Fernández et al. (2001) ; Kappes et al. (2010)
Oikonus – Ecosystem Knowledge	36 black-footed ^b	California	2004–2008 (July–October)	19 (4–50)	Hyrenbach (2008) ; Hester (unpubl. data)
Tagging of Pacific Predators/Grupo de Ecología y Conservación de Islas	41 Laysan ^a	Mexico	2003–2006 (January–April)	5 (1–11)	Henry (2011)
Oregon State University/Yamashina Institute of Ornithology	8 short-tailed ^b	Alaska, Japan	2003–2010 (January–June, September–December)	23 (4–65)	Suryan et al. (2007) ; Suryan and Fischer (2010) ; Suryan and Ozaki (unpubl. data)

^a Tracked during breeding period (i.e., central place trips returning to a colony).^b Tracked during non-breeding period (i.e., not returning to a colony).

given fishery. The expansion factor for sablefish longline fishery was adjusted to account for the differing rates of observer coverage among three sub-fishery permit levels ([Appendix A](#)). Additionally, because the near-shore longline fishery was not observed in 2002, and the pink shrimp trawl fishery was not observed in 2002, 2003, and 2006, we assumed the available observer data represented the entire study period for these fisheries.

The at-sea hake trawl fishery is made up of two types of vessels: (1) catcher-vessels that deliver fish to shoreside plants or mother-ships for processing and (2) catcher-processors that both catch and process fish at sea. Unlike catcher-processors, catcher-vessels are

not monitored at-sea by fishery observers; however, their catch is monitored by fisheries observers on mother-ships or at shore-side processing plants. Effort data for those catcher vessels delivering to mother-ships was available in the form of logbooks; effort data was not available for catcher-vessels delivering to shore-side plants. We used logbook data (Pacific Fisheries Information Network) to characterize fishing effort of the groundfish trawl fishery. These data included set and haul locations and times, and catch of target species for all hauls.

Within each fishery, fishing effort data from analysis regions with fewer than three vessels fishing were pooled and divided

Table 4

Estimated total fleet-level effort and landings over 8 years (2002–2009) for longline (hooks) and trawl (hours) fisheries. Expansion factors, fleet-wide landings, observed landings, annual observed and fleet landings (min–max and mean in parenthesis), and West Coast Groundfish Observer Program landings category are shown. The expansion factor is the ratio of catch in metric tons recorded by WCGOP fishery observers to the landed catch in metric tons from the Pacific Fisheries Information Network database for each fishery. N/A = fisheries with logbook effort information.

	Sablefish longline	Near-shore longline	Groundfish trawl	CA halibut trawl	Pink shrimp trawl	At-sea hake trawl
Fleet-wide effort	66,688,391	19,500,233	108,676	52,615	235,154	40,454
Expansion factor	17.22%	4.15%	N/A	11.12%	3.10%	N/A
Fleet landings (mt)	15,800	3493	164,789	1208	108,219	980,438
Observed landings (mt)	2596	145	N/A	134	3350	N/A
Annual observed landings (mt)	162–550 (325)	0–26 (21)	N/A	4–38 (17)	0–882 (670)	N/A
Annual fleet landings (mt)	1592–2577 (1975)	382–575 (437)	17,797–26,159 (20,599)	78–253 (151)	8400–25,375 (13,527)	72,123–180,419 (119,215)
Landings category	Groundfish	Groundfish	Groundfish	CA halibut	Shrimp	Hake

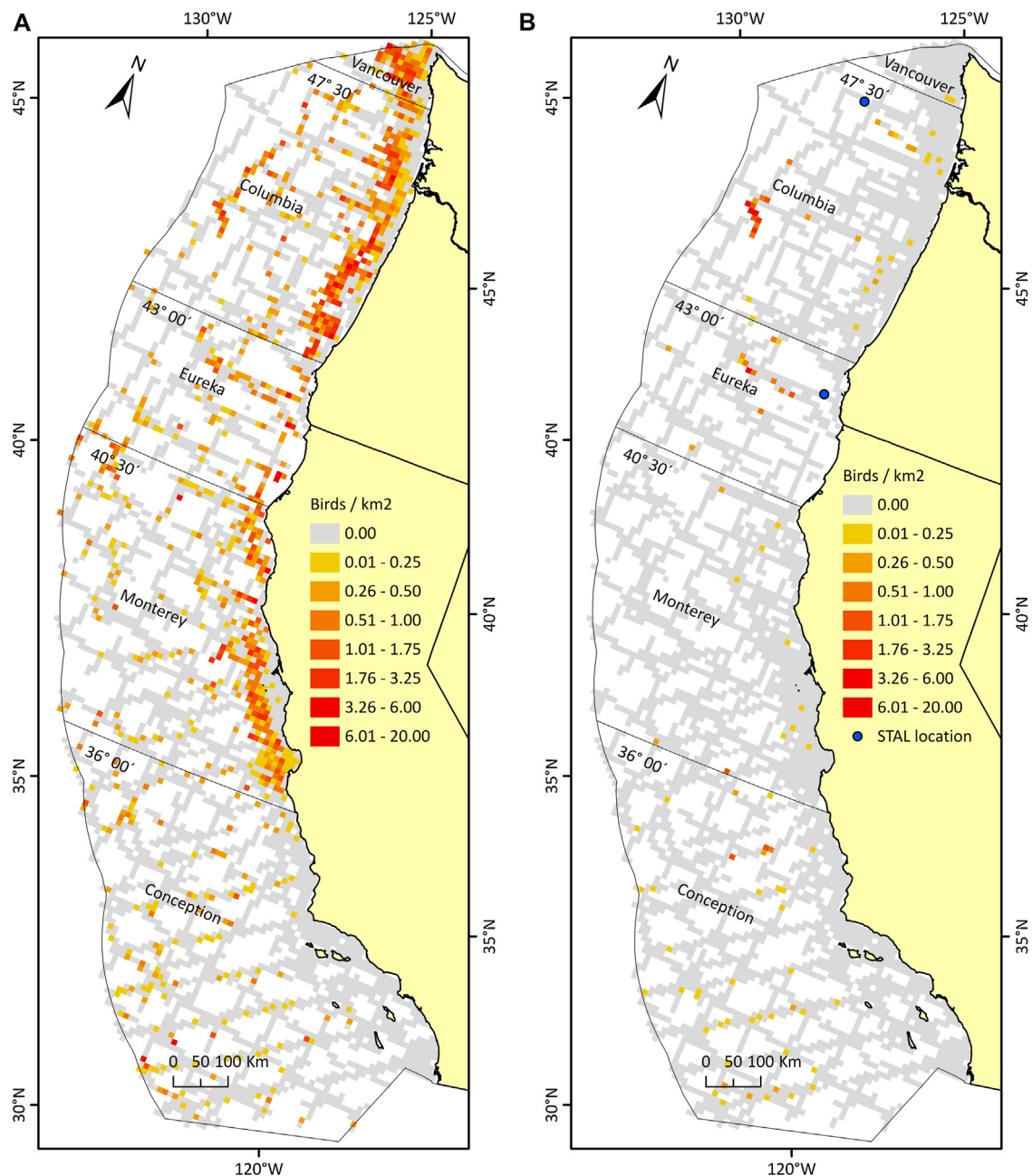


Fig. 2. Map of black-footed (A) and Laysan albatross (B) mean density (bird/km²) and the individual sighting locations of short-tailed albatross (STAL; B) from at-sea surveys (2005–2008). Density distributions are for 10 km by 10 km grid cells (display only).

equally among these regions. This step ensured adherence to legally mandated confidentiality restrictions (Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006). This confidentiality restriction was rarely encountered in data pooled over 4 years (less than 1% of all longline and 3% of all trawl fishing effort), and therefore had little effect on results.

2.4. Data analysis

2.4.1. Albatross distribution and density

We calculated the mean at-sea survey density (birds/km²) within a 100 km² grid to evaluate the spatial distribution of black-footed and Laysan albatross density across the study area. We used the mean at-sea survey density (birds/km²) of black-footed

albatross in each analysis region for computing the overlap index (see below).

We used satellite-tracking data from birds within the U.S. west coast EEZ (but tagged outside the EEZ) to compare habitat use among albatross species. First, we used kernel density estimation with a 1 km smoothing factor to visually compare core use areas (50% utilization distribution) for each species. Next, we contrasted the mean proportion of hours spent by albatrosses north and south of 36° N (Monterey and Conception management area boundary) and landward of the 2000 m depth contour. We also calculated the residence time within the U.S. west coast EEZ of non-central-place foraging albatrosses (those not returning to a breeding colony outside the study area; black-footed albatrosses tagged off central California and short-tailed albatrosses during the non-breeding

period) to determine the amount of time individuals spent within the study area (i.e., transitory vs. resident).

2.4.2. Vessel affinity

To investigate the effect of fishing vessels on albatross distributions, we compared the mean density of black-footed albatross associated with actively fishing vessels (derived from IPHC and FRAM surveys) to their mean fishery-independent density (derived from at-sea surveys) using linear regression (SPSS v. 12.0). We converted black-footed albatross count data from the IPHC and FRAM surveys into mean birds/km² by summing albatross numbers from each count and dividing the sum by the number of counts for each analysis region.

2.4.3. Temporal analyses

We summarized fishing effort for each of the six fisheries by month and ranked the totals as annual percentages (none < 5%, med = 5–10%, high = 10–15%, or peak > 15%). We also calculated several monthly temporal values for albatrosses – survey effort, albatross breeding phenology, and opportunistic short-tailed albatross sightings – and contrasted those with monthly fishing effort. The annual percentage of survey effort by month was calculated and ranked in the same way as effort.

2.4.4. Fishery-albatross overlap index

To calculate a relative index of overlap of albatrosses for each fishery, we multiplied the mean fishery-independent albatross density by the total number of hooks for each longline fishery and by the total number of hours the net was towed for each trawl fishery within each analysis region (Cuthbert et al., 2005; Tuck et al., 2011). Thus, the resulting overlap index has units of birds × hooks/km² for longline fisheries and of birds × net hours/km² for trawl fisheries.

3. Results

3.1. Fishery-independent data

3.1.1. At-sea surveys

Black-footed albatross was the most abundant albatross species in the study area; a total of 4075 were sighted in 19,951 km² of strip transect surveys within the EEZ of the west coast. Almost all black-footed albatross sightings (99%) occurred between 36° N and the U.S.–Canadian border; most were (95%) landward of the 2000 m isobath (Fig. 2A) with the highest density values occurring in the shelf-break domain (Table 5). Laysan albatross and short-tailed albatrosses were orders of magnitude less common (184 and 2 sightings, respectively). Unlike black-footed albatross, Laysan albatross occurred throughout the EEZ and were most numerous seaward of the 2000 m isobath (75% of all sightings; Fig. 2B). Two short-tailed albatross were sighted in the course of 4 years of survey effort; one in the Eureka area landward on the shelf-break and one in the Columbia area seaward of the 2000 m bathymetric contour.

3.1.2. Satellite tracking

Kernel density (50%) maps show similar distributions for black-footed and short-tailed albatrosses (Fig. 3). Both species spent most of their time (52% and 57% for black-footed and short-tailed albatrosses, respectively) landward of the 2000 m isobath and north of 36° N. Consistent with at-sea survey data, Laysan albatross spent most of their time (79%) seaward of the 2000 m isobath, beyond the observed range of groundfish and shrimp fishing effort (Table 6).

Individual, non-breeding black-footed and short-tailed albatrosses varied in the amount of time spent within the U.S. west coast EEZ, indicating both transient and resident behaviors. While both

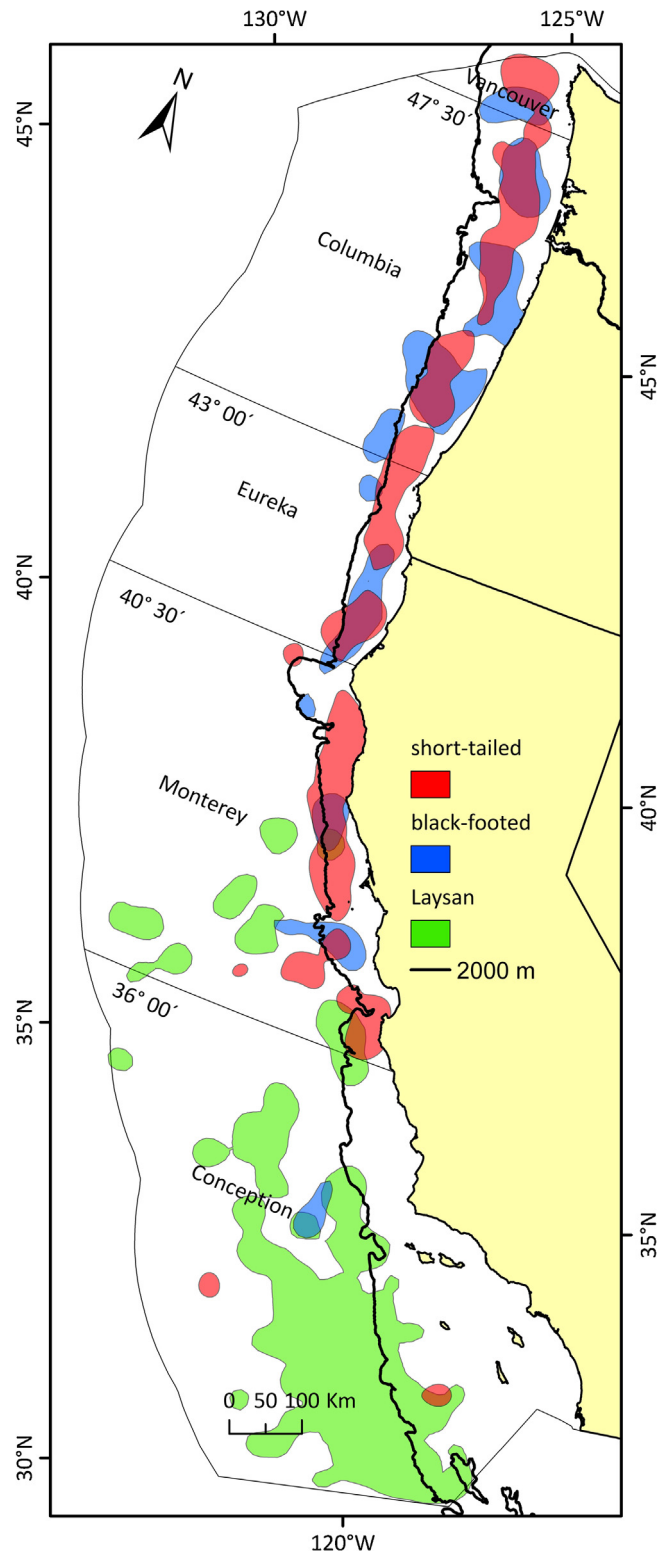


Fig. 3. 50% kernel density of satellite-tagged (1998–2010) black-footed ($n=12$), short-tailed ($n=8$), and Laysan albatrosses ($n=42$). Black-footed and short-tailed albatrosses occupied the area north of 36° N and landward of the 2000 m bathymetric contour in the U.S. Exclusive Economic Zone. Laysan albatross occupied the southern portion of the study area, especially seaward of the 2000 m contour.

species demonstrated transient behavior with individuals spending as few as 4 days total within the study area, mean residence times were 11 ± 6 SD and 8 ± 6 SD days per month for black-footed and short-tailed albatrosses, respectively. Individual black-footed

Table 5

Summary of the survey area, number of black-footed albatross sighted, and the mean and standard deviation of black-footed albatross density from at-sea surveys conducted from 2005 to 2008 by management area and bathymetric domain (see methods for definitions). No black-footed albatross were sighted in the conception-shelf region.

	Shelf (0–200 m)			Shelf-break (201–1000 m)			Slope (1001–2000 m)			Oceanic (> 2001 m)		
	Survey (km ²)	Total birds	Mean ± SD (birds/km ²)	Survey (km ²)	Total birds	Mean ± SD (birds/km ²)	Survey (km ²)	Total birds	Mean ± SD (birds/km ²)	Survey (km ²)	Total birds	Mean ± SD (birds/km ²)
Vancouver	797	480	0.60 ± 2.41	424	399	1.03 ± 3.28	101	80	0.68 ± 3.59	39	1	0.02 ± 0.16
Columbia	2204	543	0.24 ± 1.69	642	819	1.28 ± 4.08	363	143	0.39 ± 1.32	1508	150	0.10 ± 0.47
Eureka	68	4	0.05 ± 0.38	93	113	1.17 ± 4.40	63	14	0.21 ± 0.71	1095	113	0.10 ± 0.41
Monterey	1463	204	0.13 ± 0.89	656	314	0.48 ± 1.22	561	221	0.40 ± 1.15	2729	270	0.09 ± 0.45
Conception	613	0		1411	16	0.01 ± 0.11	850	4	0.00 ± 0.07	4271	187	0.05 ± 0.35

and short-tailed albatrosses spent a maximum of 22 and 29 days per month, respectively, and up to three consecutive months in the study area.

3.2. Fishery-dependent data

3.2.1. Opportunistic short-tailed albatross sightings

Fisheries observers sighted a total of 114 short-tailed albatross over 11 years starting in 2001. Short-tailed albatross sightings in this period spanned all management areas except Conception, with most sighted (76%) within the shelf-break domain (Fig. 4). Most were sighted in the Columbia area (53%), with considerably fewer in the Vancouver, Eureka, and Monterey areas (15%, 15%, and 18% of sightings, respectively).

3.2.2. Fishery seabird surveys/vessel affinity

Mean densities of black-footed albatross were 332 times higher (SE=99) near vessels longline fishing (IPHC survey, min=43.5 birds/km², max=270.9 birds/km²) and 370 times higher (SE=106) near vessels trawl fishing (FRAM survey, min=1.2 birds/km², max=157.4 birds/km²) than in the vicinity of vessels engaged only in strip-transect bird surveys (min=0 birds/km², max=1.28 birds/km²). Black-footed albatross densities derived from strip-transect surveys reflected black-footed albatross densities derived from longline ($R^2=0.88$, $F(1,4)=29.98$, $p=0.005$) and trawl ($R^2=0.59$, $F(1,13)=18.63$, $p=0.001$) vessel-based surveys (Fig. 5). The slope of the best-fit regression line was significantly >1 for both fish surveys (longline: $t(4)=5.44$, $p=0.005$) and trawl: $t(13)=4.27$, $p=0.001$).

3.2.3. Fishery effort

The sablefish longline and near-shore rockfish longline fisheries together set an estimated 86.2 million hooks from 2002 to 2009 (Table 4). The sablefish longline fishery set the majority of hooks (77%), most in the shelf-break domain (92%, Table 7). In contrast, effort in the near-shore rockfish longline fishery was confined to the shelf domain with most hooks (75%) set in the Eureka and Monterey areas.

Total estimated trawl effort from 2002 to 2009 was 436,899 tow-hours across the four trawl fisheries evaluated (Table 4). Pink shrimp and groundfish accounted for most of the west coast trawl effort (54% and 25% of hours, respectively; Table 7). CA halibut and at-sea hake accounted for 12% and 9% of tow hours, respectively.

The pink shrimp trawl fishery occurred primarily on the shelf (93% of all shrimp fishery hours), with the bulk of tow-hours (77%) occurring in the Columbia area. For groundfish trawl, the majority of tow hours (72%) were within the shelf-break domain from Monterey north. The distribution of effort in the CA halibut trawl fishery was limited, occurring exclusively on the shelf in the Monterey and Conception areas. The at-sea hake trawl fishery occurred exclusively within the three northern management areas (Eureka, Columbia, and Vancouver), with most tow-hours (87%) within the shelf-break domain.

3.2.4. Temporal analysis

All fisheries, except the at-sea hake and pink shrimp trawl, fished year round (Fig. 6). Sablefish longline and near-shore rockfish longline effort was greatest from May to November peaking in August and September. Groundfish trawl effort was greatest between January and June with no clear peak. Fishing effort for CA halibut trawl occurred throughout the year with the least effort in May and the fall months. Effort for pink shrimp occurred from April to September and was greatest in the May through August period. Effort in at-sea hake occurred from May through December, but was greatest May through June.

Albatrosses were present in the study area during all months of the year. The highest at-sea survey effort spanned the April through November period – the period of greatest fishing effort for most fisheries in this analysis (Fig. 6). Nearly all black-footed and Laysan albatross sightings were recorded during this period (96% and 94% of sightings, respectively). As in at-sea surveys, satellite-tagged albatrosses were detected in the study area throughout the year: black-footed albatross December to October; Laysan albatross January through April; and first-year short-tailed albatross September to June. Fishery observers sighted short-tailed albatross opportunistically near fishing vessels every month of the year. The two short-tailed albatross sighted in the 4 years spanned by the at-sea surveys were both in the month of April.

The phenology of North Pacific albatrosses can briefly alter the risk posed by west coast fisheries to breeding albatrosses in that most breeding birds migrate to colonies in the central to western Pacific to lay and incubate their eggs from November through February (Arata et al., 2009). However, during the chick-provisioning period, which can start as early as January, black-footed albatross make extensive foraging trips to the continental shelf of North America from central California to southern

Table 6

Mean proportion of hours spent (1998–2010) by North Pacific albatrosses (central-place foraging birds only) tracked north and south of 36° N, relative to the 2000 m bathymetric contour. Note: Because these proportions are calculated for the study area, they add up to 1.

	Black-footed n = 12		Short-tailed n = 8		Laysan n = 42	
	Landward	Seaward	Landward	Seaward	Landward	Seaward
North of 36°	0.52	0.02	0.57	0.23	0.09	0.40
South of 36°	0.22	0.24	0.09	0.12	0.12	0.39

Table 7

Summary of expanded fishery effort (2002–2009) used to calculate the overlap of albatross with longline and trawl gears by fishery, management area, and bathymetric domain (see methods for definitions). Bold values indicate effort totals that were allocated equally among adjacent analysis areas by fishery in compliance with confidentiality requirements.

Area	Longline (per 10,000 hooks)			Trawl (per 100 h)									
	Sablefish longline			Near-shore longline	Groundfish trawl			CA halibut trawl	Pink shrimp trawl		At-sea hake trawl		
	Shelf	Shelf-break	Slope		Shelf	Shelf-break	Slope		Shelf	Shelf-break	Shelf	Shelf-break	Slope
Vancouver	165.9	1529.7	4.3		43.4	89.1	2.3			72.3	13.1	86.5	12.2
Columbia	190.7	1653.0	29.5	199.6	139.6	369.3	18.7		1813.3	121.4	20.7	220.9	4.8
Eureka	4.3	429.5		1034.0	16.6	173.1	21.3		234.7		1.3	43.1	1.9
Monterey	4.9	540.6	135.1	434.1	34.7	149.1	10.0	461.9	36.6				
Conception	6.3	1970.7	4.3	282.3	0.4	18.7	0.4	64.2	36.6	36.6			

British Columbia and return to this area in their post-breeding migration (Fernández et al., 2001). Laysan albatross breeding in Hawaii provision chicks in foraging bouts as far north as the Gulf of Alaska and Aleutian Islands, and migrate to these same areas post-breeding. Short-tailed albatross forage in Western Pacific waters off Japan when provisioning chicks (Suryan et al., 2008), but migrate to US waters off western North America post-breeding (Suryan et al., 2007) and throughout the year for non-breeding birds (this study). Alaskan fishermen have reported that albatrosses are most aggressive during foraging bouts during the chick-provisioning period in the spring. Some unknown subset of older non-breeders may visit the colony; however, in general non-breeding albatrosses are likely to remain vulnerable to west coast fisheries throughout the year.

3.2.5. Fishery-albatross overlap index

In the two west coast longline groundfish fisheries, the overlap with effort in the sablefish fishery, as measured by the overlap index, was near 30 times as high as that in the near-shore fishery,

and nearly all (95%) of the overlap in the sablefish fishery was in the shelf break domain (Table 8). Albatross overlap with the near-shore rockfish fishery was low due to relatively low fishing effort in this fishery and low albatross densities within the shelf domain. We did not estimate overlap of Laysan albatross because they were sighted primarily seaward of the 2000 m isobath, a region where no groundfish or shrimp fishing effort was recorded.

Of the four west coast trawl fisheries, albatross overlap was greatest in the groundfish fishery (44% of total trawl overlap), with near all (91%) overlap occurring in the shelf-break domain from Monterey north (Table 8). Albatross overlap in the pink shrimp trawl (32% of total trawl overlap) and at-sea hake trawl (21% of total trawl overlap) fisheries was also relatively high. Most pink shrimp fishery overlap (67%) occurred in the Columbia-shelf region, while at-sea hake trawl fishery overlap occurred primarily (95%) along the shelf-break in the Vancouver, Columbia, and Eureka management areas. Albatross overlap was lowest in the CA halibut trawl fishery (3%), which occurred exclusively within the Monterey-shelf region.

Table 8

Summary of the estimated black-footed, and, by proxy, short-tailed albatross, overlap with six west coast fisheries. The overlap index is the product of the expanded fishery effort from Table 6 and the mean black-footed albatross density (birds/km²), derived from fisheries-independent seabird surveys (2005–2008). Values highlighted in gray are those greater than the mean overlap index value for each gear type (longline or trawl). Values in bold indicate regions with observed fishing effort and no recorded albatross (Conception-shelf). Null values are domain-region blocks with no observed fishing effort.

Management area	Shelf	Shelf-break	Slope	Shelf	Shelf-break	Slope
	Longline overlap (per 10,000 hooks × birds/km ²)					
	Sablefish longline			Near-shore longline		
Vancouver	99.43	1575.01	2.90			
Columbia	46.60	2118.77	11.64	48.78		
Eureka	0.23	504.06	0.00	55.37		
Monterey	0.62	261.28	53.83	55.11		
Conception	0.00	20.80	0.02	0.00		
Management area	Shelf	Shelf-break	Slope	Shelf	Shelf-break	Slope
	Trawl overlap (per 100 h × birds/km ²)					
	Groundfish trawl			CA halibut trawl		
Vancouver	26.03	91.74	1.55			
Columbia	34.11	473.35	7.38			
Eureka	0.89	203.14	4.53			
Monterey	4.41	72.08	3.99	58.65		
Conception	0.00	0.20	0.00	0.00		
Management area	Shelf	Shelf-break	Slope	Shelf	Shelf-break	Slope
	At-Sea hake trawl					
	Pink shrimp trawl					
Vancouver	7.83	89.10	8.27	43.31		
Columbia	5.06	283.16	1.90	443.10	155.59	
Eureka	0.07	50.57	0.40	12.57		
Monterey				4.65		
Conception				0.00	0.39	

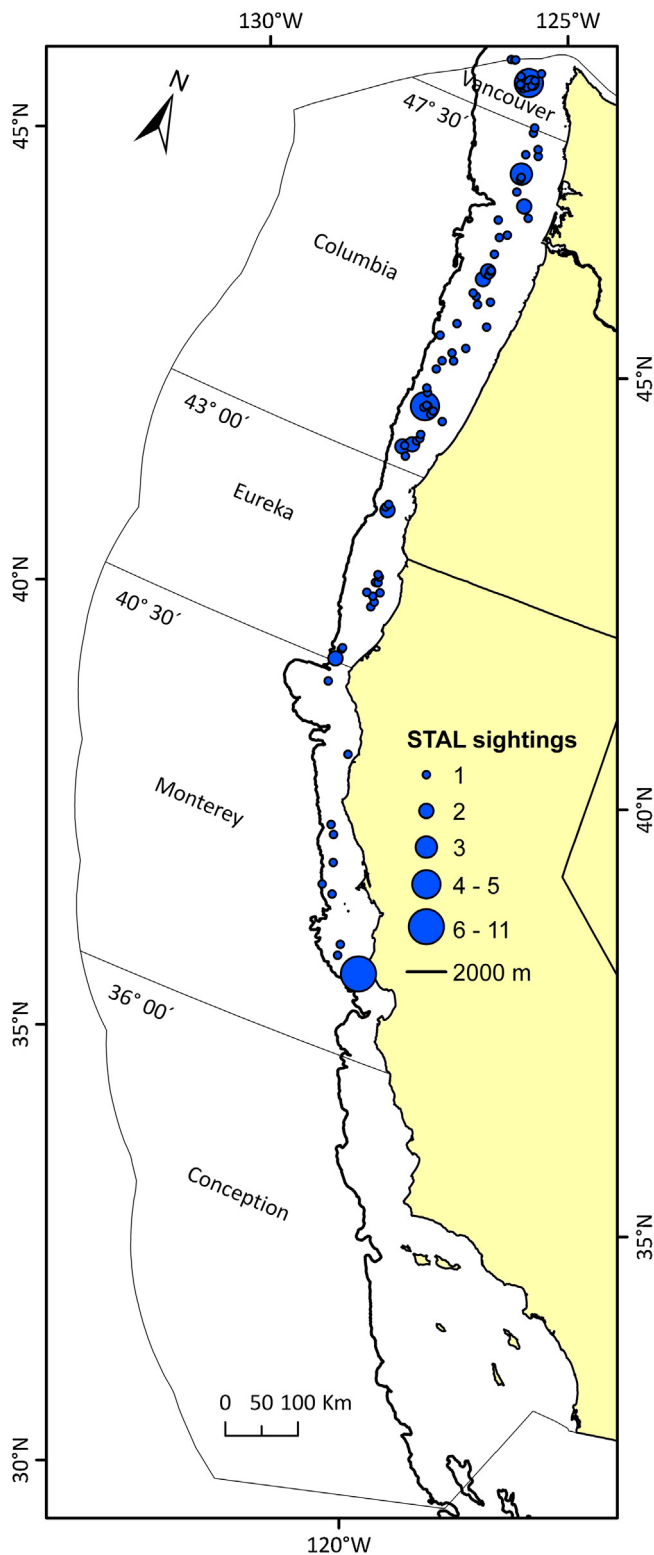


Fig. 4. Map of opportunistic short-tailed albatross ($n = 114$) sightings by West Coast Groundfish Observer Program fishery observers from fishing vessels from 2001 to 2010. For a map of the distribution of fisheries effort, see [NWFS \(2011\)](#).

4. Discussion

4.1. Overall

This study is the first to integrate data on the distribution and density of North Pacific albatrosses with fishing-effort data

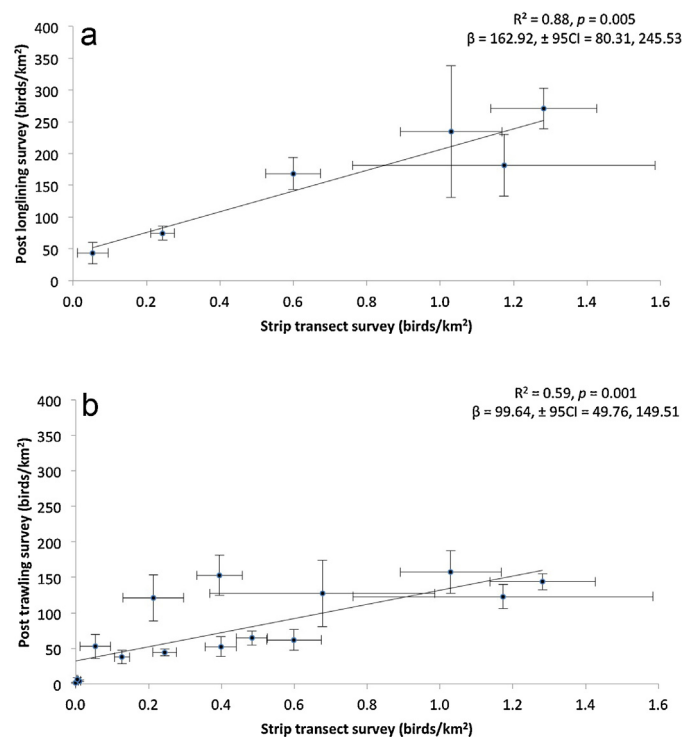


Fig. 5. Scatterplots and best-fit regression lines comparing mean black-footed albatross density from fisheries-independent strip transect surveys (2005–2008) with mean black-footed albatross density collected during (a) the International Pacific Halibut Commission (IPHC) longline surveys (2005–2008), and (b) Fishery Resources Analysis and Monitoring (FRAM) groundfish trawl surveys (2006–2008) within each analysis region. Points in each plot are mean densities with standard errors from each area-bathymetric region pair for which data were available. The slope of the best-fit regression line was significantly >1 in longline ($p = 0.005$) and trawl ($p = 0.001$) comparisons.

from multiple gear types as a means to spatially and temporally delineate potential bycatch risk to albatrosses. Ship-based seabird survey data provide an index of the density of albatross species across habitats, whereas satellite-tracking data provides additional insight into the behavior of individual birds, including their habitat use patterns and their residence time in any given area. Together, these data provide a comprehensive picture of North Pacific albatross distributions, relative density, residency patterns, and pelagic habitat use. The delineation of potential bycatch risk by management area and bathymetric domain provides a potential framework to decide which fisheries and management areas might require greater observation or bycatch mitigation, and which fisheries present little or no bycatch risk.

Within the study area, black-footed and short-tailed albatrosses primarily utilized the shelf-break domain (201–1000 m) north of 36°N ([Figs. 2 and 3](#)), a region of high fishing effort for three of the six fisheries examined. This finding is consistent with previous studies showing that black-footed and short-tailed albatrosses most frequently use continental margins at or around the shelf-break ([Suryan et al., 2006; Kappes et al., 2010; Fischer et al., 2009](#)). In contrast, Laysan albatross primarily selected oceanic habitats beyond the shelf-break, areas with little fishing effort ($>2001 \text{ m}$). These findings are consistent with those of other telemetry studies, which demonstrate intra-specific habitat partitioning of black-footed and Laysan albatrosses during incubation ([Fernández et al., 2001; Hyrenbach et al., 2002; Kappes et al., 2010](#)) and non-breeding periods ([Fischer et al., 2009](#)). Our findings are also consistent with the results of stable isotope analyses that show the pelagic habitats used by black-footed and short-tailed albatrosses to be more similar to each other than to that of Laysan albatross ([Suryan and](#)

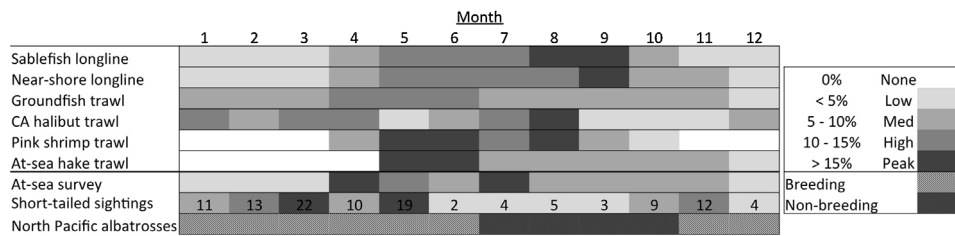


Fig. 6. The ranked annual proportion by month of observed fishing effort (2002–2009) for six west coast groundfish fisheries and at-sea seabird survey effort (2005–2008); the number of opportunistic sightings of short-tailed albatrosses from fishing vessels by month, and the generalized breeding phenology of North Pacific albatrosses by month.

Fischer, 2010). Given the habitat similarities of black-footed and short-tailed albatross, we used the distribution of black-footed albatross to evaluate the extent of fisheries overlap with the much less abundant short-tailed albatross.

Based on this analysis, the longline fishery for sablefish north of 36° N (Monterey, Eureka, Columbia, and Vancouver) showed the greatest overlap with albatrosses. This finding, coupled with fishery observer data documenting the highest annual mortality of black-footed albatross is in this fishery (Jannot et al., 2011) as well as the recent short-tailed albatross mortality in 2011, strongly suggests that, of all west coast fisheries, the sablefish longline fishery north of 36° N presents the greatest threat to albatrosses. Given that we found the mean black-footed albatross density to be over 300 times higher near actively fishing longline vessels, the risk of albatross mortality may be much higher than our overlap index indicates.

Several factors also indicate that the catcher-processor mid-water trawl fleet targeting Pacific hake may pose considerable risk to albatrosses. This fishery showed comparatively high overlap with albatrosses in the three northern management areas (Eureka, Columbia, and Vancouver). As in the longline fisheries, we found that albatross congregate around actively fishing trawl vessels, again suggesting our metric for overlap may be conservative. Moreover, albatross mortality is likely to be underreported for this fishery for a number of reasons. Although the At-Sea Hake Observer Program deploys fishery observers on nearly 100% of fishing trips and an average of 45% of the annual catch is observed (Jannot et al., 2011), monitoring is focused on the ship factory, but cable-strike related mortality is not monitored. This protocol, where only seabirds captured in the trawl's cod end can be encountered and quantified, can underestimate seabird bycatch. In similarly observed fisheries, such as the Bering Sea pollock (catcher-processor) fishery, observers underestimated seabird mortality due to net entanglements by a factor of 7 and from cable interactions by a factor of 3.5 (Melvin et al., 2011; Fitzgerald, unpubl. data).

There is also evidence from other fisheries of potential unobserved seabird mortality in the at-sea hake fishery. High volume catches typical of the hake fishery can often leave the net floating at the surface for extended periods during the haul back, increasing the risk of seabird entanglement (Bartle, 1991; Weimerskirch et al., 2000). Finally, the use of third wires or net sonar cables combined with discards of fish-processing waste in the hake mid-water trawl fishery increases the likelihood of albatross mortality due to cable strikes (Bartle, 1991; Weimerskirch et al., 2000; Melvin et al., 2011). Albatross interactions with trawl cables are limited to vessels that harvest and process fish at sea (Sullivan et al., 2006; Watkins et al., 2008). In the case of at-sea hake, the risk to albatrosses from cable interactions is likely limited to the catcher-processor sector.

Although we lacked spatial data on the fishing effort of catcher boats delivering hake to shoreside plants, it is reasonable to assume that the spatial distribution of effort was similar to that of the catcher vessels delivering to motherships and catcher-processors,

and therefore that overlap was high for all components of the hake trawl fleet. Despite high overlap and the use of net sonar cables, albatross cable interactions with catcher-vessels and related mortality are likely to be low due to the lack of offal discards. The recent implementation of video monitoring at sea in 2008 and deployment of fishery observers in 2012 provide the opportunity to better evaluate the threat to albatrosses from the shore-side fishery in the future.

The groundfish trawl fishery showed the greatest overlap with albatrosses among the four west coast trawl fisheries assessed in this study. However, fisheries observers monitored a relatively large fraction (approximately 20%) of the fleet and over eight years of monitoring (2002–2009) and no albatross mortalities were detected (Jannot et al., 2011). Albatross bycatch mortality is unlikely in the groundfish trawl fishery for a number of reasons: (1) little processing takes place on these vessels, although they do discard whole fish at sea; (2) this fleet does not use net sonar cables; and (3) bottom trawls in this fishery are weighted, making the cod end less likely to float at the surface during hauling and minimizing the risk of net entanglements. Together, these attributes suggest that the risk of albatross cable interactions in the groundfish trawl fishery is low compared to that in the Pacific hake mid-water trawl fishery.

This analysis demonstrated that fisheries focused on the shelf (<200 m), such as the CA halibut trawl and near-shore rockfish longline, have little overlap with albatrosses, and therefore pose little threat to these species. Similarly, over 90% of trawling effort for pink shrimp occurred in the shelf domain where albatross densities were low. However, a small fraction of pink shrimp trawl effort (5%) did take place in the shelf-break domain of the Columbia area, yielding 25% of its overlap score. In addition to having low overlap with albatrosses, pink shrimp trawlers typically deploy a trawl and warps to each side midway along the vessel. This mid-ship warp configuration, together with slow trawling speeds (~2 knots), weighted nets, and minimal at-sea processing, suggests that the risks of cable and net interactions with seabirds is minimal. That fishery observers detected no albatross mortality in the pink shrimp fishery over 8 years (2002–2009) supports existing evidence, although we note that observer coverage over this time was relatively low (3.8%) in this fishery compared to the other fisheries considered in this study (Jannot et al., 2011).

4.2. Fishery management options

This study clearly showed that North Pacific albatrosses are present on the fishing grounds of the west coast groundfish and pink shrimp fisheries year round, providing no opportunity to reduce albatross-fishery interactions via season-based management measures.

4.2.1. Longline fisheries

Given that our analysis found that the longline fishery for sablefish poses the greatest threat to North Pacific albatross species,

fishery managers could take action to reduce this threat by implementing proven seabird bycatch mitigation measures on longline vessels targeting sablefish north of 36° N. This management action has the greatest potential to reduce fishing impacts on albatrosses in west coast groundfish fisheries and would be consistent with Alaskan and British Columbian demersal longline fisheries and many demersal fisheries worldwide that pose mortality risk to albatrosses. Bird-scaring lines, weighting longlines to enhance sinking speed, and setting baited hooks at night are widely accepted as best-practice seabird bycatch mitigation in demersal longline fisheries (CCAMLR, 2006; Løkkeborg, 2011; ACAP, 2013). In the near term, fishery managers should consider implementing seabird bycatch avoidance measures similar to those required in Alaskan longline fisheries, which include a longline fishery targeting sablefish, until the most effective mitigation techniques and performance standards can be determined for the west coast fleet. Although the longline fishery for Pacific halibut was not analyzed in this study, the risk to albatrosses in this west coast fishery is likely to be similar to that in the sablefish longline fishery, and could merit the same management action to ensure albatross conservation. These management actions would complement ongoing efforts to protect nesting islands, restore nesting habitat, and exclude introduced terrestrial predators, and would therefore strengthen efforts to address the full range of threats to North Pacific albatrosses (Arata et al., 2009).

4.2.2. Trawl fisheries

Given the potential threat to albatrosses posed by the catcher-processor vessels targeting hake and uncertainty regarding cable and net-related mortality, we suggest fishery managers consider putting a program in place to more fully evaluate risk by monitoring hake catcher-processors' trawl cables and nets for albatross interactions. Effective mitigation options are available should mitigation be deemed necessary in this fleet. For example, studies conducted in the Eastern Bering Sea pollock catcher-processor fleet showed that warp and net sonar cable strikes can be mitigated using streamer lines flown from both sides of the vessel, and net sonar cable interactions can also be reduced significantly by drawing the cable to the water at the stern via a snatch block (Melvin et al., 2011). These results are consistent with and included in best-practice mitigation recommended for global trawl fisheries (Løkkeborg, 2011; ACAP, 2013). If high levels of interactions are found in the hake catcher-processor fishery, it may justify looking more closely at other west coast groundfish trawl fisheries with high overlap indices.

In 2011, the groundfish trawl fishery was converted to an individual fishing quota (IFQ) management system, which included a requirement for 100% observer coverage, as well as provisions for switching to longlines, pots, or other gear types (PFMC, 2011, Amendment 20). If trawl quota fishing effort transitions to longline methods, especially for sablefish, the risk to albatrosses will likely increase. Looking to the future, numbers of albatrosses, particularly short-tailed albatross, will likely increase as recovery efforts take hold. It is also likely that the distribution of albatrosses will shift as numbers increase and populations respond to changes in the ocean environment. All these factors make it imperative to track the bycatch rates of albatrosses and other seabirds in a population-level context as a function of fishing effort – in longline fisheries, as individuals per 1000 hooks, and in trawl fisheries as birds per hour or cable strikes per unit of time, to allow management to interpret the need for and success of mitigation measures. Albatross bycatch numbers alone would not account for changes in fishing effort, nor would bycatch rates alone account for potential changes in seabird abundance.

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Appendix A.

Summary of the sub-fishery observer coverage and landings used to calculate the sablefish longline fishery expansion factor (2002–2009). We multiplied the percentage of total observed hooks by the ratio of observed landings to total landings at each level to provide the percentage of hooks represented. We summed the percentage of hooks to provide the expansion factor.

Permit level	Percentage of total observed hooks (%)	Ratio of observed landings	Hooks represented (%)
Limited entry sablefish primary	64	0.23	14.74
Limited entry non-tier endorsed	32	0.07	2.35
Open access	4	0.03	0.13
Expansion factor (C) = 17.22%			

References

- ACAP (Agreement on the Conservation of Albatrosses and Petrels), 2012. Agreement on the conservation of albatrosses and petrels. In: Amended by the Fourth Session of the Meeting of the Parties, April 23–27, 2012, Lima, Peru <http://www.acap.aq/index.php/en/documents/instruments> (20.06.12).
- ACAP, 2013. Report of the Seabird Bycatch Working Group, AC7 Doc 14 Rev 1. In: Seventh Meeting of the Advisory Committee, May 6–10, 2013, La Rochelle, France <http://www.acap.aq/index.php/en/advisory-committee/doc.download/2135-ac7-doc-14-rev-1-sbwg-report> (20.06.13).
- Amante, C., Eakins, B.W., 2009. ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24, 19 pp.
- Arata, J.A., Sievert, P.R., Naughton, M.B., 2009. Status assessment of Laysan and black-footed albatrosses. In: North Pacific Ocean, 1923–2005: U.S. Geological Survey Scientific Investigations Report 2009–5131, 80 pp.
- Artyukhin, Y.B., Vinnikov, A.V., Terentiev, D.A., 2006. Seabirds and bottom longline fishery in Kamchatka region. Moscow, 50 pp. <http://www.wwf.ru/resources/publ/book/eng/177>
- Austin Jr., O.L., 1949. The status of Steller's albatross. *Pac. Sci.* 3, 283–295.
- Bartle, J.A., 1991. Incidental capture of seabirds in the New Zealand subantarctic squid trawl fishery. *Bird Conserv. Int.* 1, 351–359.
- Birdlife-International, 2004. Tracking ocean wanderers: the global distribution of albatrosses and petrels. In: Results from the Global Procellariiform Tracking Workshop, September 1–5, 2003, Gordon's Bay, South Africa. Birdlife International, Cambridge, UK.

- Briggs, K.T., Tyler, W.B., Lewis, D.B., Carlson, D.R., 1987. Bird communities at sea off California: 1975–1983. *Stud. Avian Biol.* 11, 1–74.
- Brothers, N., 1991. Albatross mortality and associated bait loss in the Japanese long-line fishery in the Southern Ocean. *Biol. Conserv.* 55, 255–268.
- CCAMLR, 2006. Report of the Twenty-Fifth Meeting of the Scientific Committee (SCCAMLRL-XXV). Annex 5. Appendix D. Commission for the Conservation of Antarctic Marine Living Resources, Hobart, Australia.
- Chiba, H., Kawakami, K., Suzuki, H., Horikoshi, K., 2007. The distribution of seabirds in the Bonin Islands, southern Japan. *J. Yamashina Inst. Ornithol.* 39, 1–17.
- Croxall, J.P., Rothery, P., Pickering, S.P., Prince, P.A., 1990. Reproductive performance, recruitment, and survival of wandering albatross *Diomedea exulans* at Bird Island, South Georgia. *J. Anim. Ecol.* 59, 775–796.
- Croxall, J.P., Rothery, P., 1991. Population regulation of seabirds: implications of their demography for conservation. In: Perrins, C.M., Le Breton, J.D., Hiron, G.M. (Eds.), *Bird Population Studies: Relevance to Conservation and Management*. Oxford Univ. Press, Oxford, pp. 272–296.
- Croxall, J.P., Gales, R., 1998. Assessment of the conservation status of albatrosses. In: Robertson, G., Gales, R. (Eds.), *Albatross Biology and Conservation*. Surrey Beatty & Sons, Chipping Norton, Australia, pp. 46–65.
- Croxall, J.P., Butchart, S.H.M., Lascelles, B., Stattersfield, A.J., Sullivan, B., Symes, A., Taylor, P., 2012. Seabird conservation status, threats and priority actions: a global assessment. *Bird Conserv. Int.* 22, 1–34.
- Cuthbert, R., Hilton, G., Ryan, P., Tuck, G.N., 2005. At-sea distribution of breeding Tristan albatross *Diomedea dabbenena* and potential interactions with pelagic longline fishing in the South Atlantic Ocean. *Biol. Conserv.* 121, 345–355.
- ESRI (Environmental Systems Resource Institute), 2009. ArcMap 9.3.1. ESRI, Redlands, CA.
- FAO, 1999. International Plan of Action for reducing incidental catch of seabirds in longline fisheries. In: International Plan of Action for the Conservation and Management of Sharks. International Plan of Action for the Management of Fishing Capacity, Rome, 26 pp. <http://www.fao.org/docrep/006/X3170E/X3170E00.HTM>
- FAO, 2009. Best Practices to Reduce Incidental Catch of Seabirds in Capture Fisheries. FAO Technical Guidelines for Responsible Fisheries. No. 1, Suppl. 2, Rome, 49 pp. <http://www.fao.org/docrep/015/i1145e/i1145e00.htm>
- Fernández, P., Anderson, D.J., Sievert, P.R., Huyvaert, K.P., 2001. Foraging destinations of three low-latitude albatross (*Phoebastria*) species. *J. Zool.* 254, 391–404.
- Fischer, K.N., Suryan, R.M., Roby, D.D., Balogh, G.R., 2009. Post-breeding season distribution of black-footed and Laysan albatrosses satellite-tagged in Alaska: inter-specific difference in spatial overlap with North Pacific fisheries. *Biol. Conserv.* 142, 751–760.
- Fitzgerald, S.M., Perez, M.A., Rivera, K.S., 2008. Summary of seabird bycatch in Alaskan groundfish fisheries, 1993 through 2006. In: Boldt, J. (Ed.), *Ecosystem Considerations 2009. Appendix C of the Bering Sea/Aleutian Islands and Gulf of Alaska Groundfish Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK, pp. 116–141.
- Hattori, T., 1889. The story of the albatross of Torishima. *Dobutsugaku Zasshi* 1, 405–411 (in Japanese; translated in Austin, O.L. Jr., 1949).
- Henry III, R.W., 2011. Consequences of Range Expansion in Laysan Albatrosses. University of California, Santa Cruz, 152 pp., PhD.
- Hobday, A.J., Smith, A.D.M., Stobutzki, I., Bulman, C., Daley, R., Dambacher, J., Deng, R., Dowdney, J., Fuller, M., Furlani, D., Griffiths, S.P., Johnson, D., Kenyon, R., Knuckey, I.A., Ling, S.D., Pitcher, R., Sainsbury, K.J., Sporcic, M., Smith, T., Walker, T., Wayte, S., Webb, H., Williams, A., Wise, B.S., Zhou, S., 2011. Ecological risk assessment for the effects of fishing. *Fish. Res.* 108, 372–384.
- Hyrenbach, K.D., Fernández, P., Anderson, D.J., 2002. Oceanographic habitats of two sympatric North Pacific albatrosses during the breeding season. *Mar. Ecol. Prog. Ser.* 233, 283–301.
- Hyrenbach, K.D., 2008. Applying spatially-explicit measures for albatross conservation. In: De Roi, T., Jones, M., Fitter, J. (Eds.), *Albatross: Their World, Their Ways*. Firefly Books, Buffalo, NY, pp. 118–120.
- IUCN, 2011. The IUCN Red List of Threatened Species, Version 2011.2. <http://www.iucnredlist.org> (downloaded 16.03.12).
- Jannot, J., Heery, E., Bellman, M.A., Majewski, J., 2011. Estimated Bycatch of Marine Mammals, Seabirds, and Sea Turtles in the US West Coast Commercial Groundfish Fishery, 2002–2009. West Coast Groundfish Observer Program, National Marine Fisheries Service, NWFSC, Seattle, WA.
- Kappes, M.A., Shaffer, S.A., Tremblay, Y., Foley, D.G., Palacios, D.M., Robinson, P.W., Bograd, S.J., Costa, D.P., 2010. Hawaiian albatrosses track interannual variability of marine habitats in the North Pacific. *Prog. Oceanogr.* 86, 246–260.
- Lewis, R.A., Crowder, L.B., 2003. Estimating fishery bycatch and effects on a vulnerable seabird population. *Ecol. Appl.* 13, 743–753.
- Løkkeborg, S., 2011. Best practices to mitigate seabird bycatch in longline, trawl and gillnet fisheries—efficiency and practical applicability. *Mar. Ecol. Prog. Ser.* 435, 285–303.
- Lebreton, J.D., Véran, S., 2012. Direct evidence of the impact of longline fishery on mortality in the Black-footed Albatross *Phoebastria nigripes*. *Bird Conserv. Int.*, <http://dx.doi.org/10.1017/S0959270912000299>, Available on CJO 2012.
- Melvin, E.F., Parrish, J.K., Dietrich, K.S., Hamel, O.S., 2001. Solutions to Seabird Bycatch in Alaska's Demersal Longline Fisheries. Washington Sea Grant Program. WSG-AS 01-01 <http://wsg.washington.edu/communications/online/seabirds/seabirdpaper.html>
- Melvin, E.F., Wainstein, M.D., Dietrich, K.S., Ames, K.L., Geernaert, T.O., Conquest, L.L., 2006. The Distribution of Seabirds of the Alaskan Longline Fishing Grounds: Implications for Seabird Avoidance Regulations. Washington Sea Grant Program. WSG-AS-06.01 <http://wsg.washington.edu/communications/online/seabirds/seabirddistrl.pdf>
- Melvin, E.F., Dietrich, K.S., Fitzgerald, S., Cardoso, T., 2011. Reducing seabird strikes with trawl cables in the Pollock catcher-processor fleet in the eastern Bering Sea. *Polar Biol.* 34, 215–226.
- Niel, C., Lebreton, J.D., 2005. Using demographic invariants to detect overharvested bird populations from incomplete data. *Conserv. Biol.* 19, 826–835.
- NMFS (National Marine Fisheries Service), 2010. Annual Report on Seabird Interactions and Mitigation Efforts in the Hawaii Longline Fisheries for 2010. NMFS Pacific Islands Regional Office, Honolulu, HI, 58 pp.
- NWFSC (Northwest Fisheries Science Center), 2008. Report on the Bycatch of Marine Mammals and Seabirds by the US West Coast Groundfish Fleet. Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA, 34 pp.
- NWFSC (Northwest Fisheries Science Center), 2011. Risk Assessment of U.S. West Coast Groundfish Fisheries to Threatened and Endangered Marine Species. Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA.
- Petersen, S.L., Phillips, R.A., Ryan, P.G., Underhill, L.G., 2008. Albatross overlap with fisheries in the Benguela Upwelling System: implications for conservation and management. *Endanger. Species Res.* 5, 117–127.
- Pacific Fishery Management Council (PFMC), 2011. Pacific Groundfish Fishery Management Plan. Pacific Fishery Management Council, Portland, OR.
- Small, C., Waugh, S.M., Phillips, R.A., 2012. The justification, design and implementation of Ecological Risk Assessments of the effects of fishing on seabirds. *Mar. Policy* 37, 192–199, <http://dx.doi.org/10.1016/j.marpol.2012.05.001>.
- Smith, J.L., Morgan, K.H., 2005. An assessment of seabird bycatch in longline and net fisheries in British Columbia. In: Technical Report Series No. 401. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia <http://www.birdsmith.ca/papers/SmithMorgan.2005.pdf>
- Sullivan, B.J., Reid, T.A., Bugoni, L., 2006. Seabird mortality on factory trawlers in the Falkland Islands and beyond. *Biol. Conserv.* 131, 495–504.
- Suryan, R.M., Sato, F., Balogh, G.R., Hyrenbach, K.D., Sievert, P.R., Ozaki, K., 2006. Foraging destinations and marine habitat use of short-tailed albatrosses: a multi-scale approach using first-passage time analysis. *Deep Sea Res. Part II* 53, 370–386.
- Suryan, R.M., Dietrich, K.S., Melvin, E.F., Balogh, G.R., Sato, F., Ozaki, K., 2007. Migratory routes of short-tailed albatrosses: use of exclusive economic zones of North Pacific Rim countries and spatial overlap with commercial fisheries in Alaska. *Biol. Conserv.* 137, 450–460.
- Suryan, R.M., Anderson, D.J., Shaffer, S.A., Roby, D.D., Tremblay, Y., Costa, D.P., Sievert, P.R., Sato, F., Ozaki, K., Balogh, G.R., Nakamura, N., 2008. Wind, waves, and wing loading: morphological specialization may limit range expansion of endangered albatrosses. *PLoS ONE* 3, e4016, <http://dx.doi.org/10.1371/journal.pone.0004016>.
- Suryan, R.M., Fischer, K.N., 2010. Stable isotope analysis and satellite tracking reveal interspecific resource partitioning of nonbreeding albatrosses off Alaska. *Can. J. Zool.* 88, 299–305.
- Tasker, M.L., Hope Jones, P., Dixon, T., Blake, B.F., 1984. Counting seabirds from ships: a review of methods employed and a suggestion for a standardized approach. *Auk* 101, 567–577.
- Tuck, G.N., Phillips, R.A., Small, C., Thomson, R.B., Klaer, N.L., Taylor, F., Wanless, R.M., Arrizabalaga, H., 2011. An assessment of seabird-fishery interactions in the Atlantic Ocean. *ICES J. Mar. Sci.* 68, 1628–1637.
- Véran, S., Gimenez, O., Flint, E., Kendall, W.L., Doherty, P.F., Lebreton, J.D., 2007. Quantifying the impact of longline fisheries on adult survival in the black-footed albatross. *J. Appl. Ecol.* 44, 942–952.
- Watkins, B.P., Petersen, S.L., Ryan, P.G., 2008. Interactions between seabirds and deep-water hake trawl gear: an assessment of impacts in South African waters. *Anim. Conserv.* 11, 247–254.
- Weimerskirch, H., Jouventin, P., 1987. Population dynamics of the wandering albatross, *Diomedea exulans*, of the Crozet islands: causes and consequences of the population decline. *Oikos* 49, 315–322.
- Weimerskirch, H., Capdeville, D., Duhamel, G., 2000. Factors affecting the number and mortality of seabirds attending trawlers and long-liners in the Kerguelen area. *Polar Biol.* 23, 236–249.
- Yen, P.P.W., Sydeman, W.J., Hyrenbach, K.D., 2004. Marine bird and cetacean associations with bathymetric habitats and shallow-water topographies: implications for trophic transfer and conservation. *J. Mar. Syst.* 50, 79–99.