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Assessing the susceptibility of female black-footed albatross (*Phoebastria nigripes*) to longline fisheries during their post-breeding dispersal: an integrated approach

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Abstract

Albatross movements and foraging grounds during the post-breeding dispersal are poorly understood, despite their important conservation implications. We tracked four female black-footed albatrosses (*Phoebastria nigripes*) for 100 days during their summer (July–September, 1997–1999) post-breeding dispersal off California, and compared their movements to the distribution of fishing effort from the Japanese Eastern Pacific Ocean (EPO) longline fishery. The tracked birds foraged largely along the transition zone between the California Current and the Central Pacific Gyre, and spent 25, 24, and 51% of their time at sea within the 200-mile exclusive economic zones (EEZs) of the USA and Mexico, and the high seas (international waters) respectively. The satellite-tracked birds occupied subtropical waters (18–20 °C) targeted by longline fisheries for tuna (*Thunnus* spp.) and broad-bill swordfish (*Xiphias gladius*), and ranged disproportionately farther during daylight hours, when tuna fisheries operate. The available data suggest that albatrosses overlap temporally and spatially with longline fisheries in the northeast Pacific Ocean. However, this research cannot directly evaluate whether black-footed albatross bycatch occurs in these fisheries. The coarse temporal (monthly) and spatial (1°×1°) resolution of the fisheries data, and the dynamic nature of the fishing effort inhibited a fine-scale analysis of albatross overlap with longline fisheries. While we documented substantial spatial overlap between albatross distributions and the Japanese EPO longline fishing effort during the 1980s, we found no co-occurrence during the 1990s. This study illustrates the value of satellite telemetry to assess national conservation responsibilities, and to identify potential interactions of protected species with fisheries not currently monitored by observer programs. Furthermore, our results underscore the need to exercise caution when interpreting satellite telemetry data for conservation purposes, because of the highly dynamic nature of pelagic fisheries.

Keywords: Black-footed albatross; Longline fisheries; *Phoebastria nigripes*; Post-breeding dispersal; Satellite telemetry; Seabird bycatch

1. Introduction

Fisheries impact seabird populations globally (Tasker et al., 2000). In particular, because albatrosses are long-lived species with low reproductive rates, they are heavily impacted by fisheries bycatch (Wooller et al., 1992). Thousands of albatrosses from 21 of the 24 recognized species are incidentally killed by longlines targeting pelagic and demersal fish in subarctic, subtropical, and subantarctic regions (Croxall and Gales, 1998; Gales, 1998). Elevated mortality rates and declining population sizes of far-ranging Southern Ocean species, like the wandering (*Diomedea exulans*) and the southern Buller's (*Thalassarche bulleri bulleri*) albatross, have been attributed to incidental mortality in distant longline fisheries operating within their vast marine ranges (Prince et al., 1992; Weimerskirch et al., 1997; Sagar et al., 2000). In the North Pacific Ocean, three species are susceptible to longline fisheries bycatch: the short-tailed (*Phoebastria albatrus*), the Laysan (*P. immutabilis*) and the black-footed (*P. nigripes*) albatross (Gales, 1998; Stehn et al., 2001).

The black-footed albatross is considered a vulnerable species, according to International Union for the Conservation of Nature (IUCN) criteria, due to a projected population decline of 20% over the next three generations (approximately 45 years) (Croxall and Gales,

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1998). Black-footed albatrosses sustain substantial bycatch in the Hawaiian longline fishery, where an estimated 6827–11,622 birds were killed between 1994 and 1998 (Cousins and Cooper, 2000). In addition to the mortality in the Hawaii-based fishery (average of 1831 birds per year), an estimated 31 and 611 individuals were taken yearly by demersal longline fisheries operating in the Bering Sea and the Gulf of Alaska during 1993–1997 (Stehn et al., 2001). In conjunction, these data are cause for concern, since they suggest that approximately 1% of the worldwide black-footed albatross population (300,000 birds) were killed yearly during the 1990s (Cousins and Cooper, 2000). Additionally, albatrosses may also be taken by unobserved and unregulated fisheries operating within their vast marine range. Determining the overlap between longline fishing effort and albatross distributions is an important first step to identify potential sources of additional bycatch (Cousins et al., 2000).

The understanding of black-footed albatross dispersion is derived from vessel-based surveys, the recovery of banded birds, and the analysis of fisheries bycatch (Wahl et al., 1989; McDermon and Morgan, 1993; Cousins and Cooper, 2000). The range of this species extends from the Bering Sea to the tropics and from the west coast of North America to Japan, enlarging and contracting throughout the annual reproductive cycle. Black-footed albatrosses breed on islands in the central and western North Pacific from late October to mid June. During the brooding season (January–February), they forage over tropical (sea surface temperature, SST >20 °C) and subtropical (SST: 18–20 °C) waters in the vicinity of the breeding colonies. The foraging range expands and shifts to the northeast during the chick rearing stage (February–June), when birds venture into cooler (SST: 15–10 °C) and more productive waters off the west coast of North America (Fernández et al., 2001; Hyrenbach et al., 2002). With the onset of the post-breeding period (late June), black-footed albatrosses disperse across a vast expanse of the North Pacific Ocean (20–58°N, 117°W–160°E), where they inhabit tropical, subtropical, transition domain and subarctic waters defined by a broad range of sea surface temperatures (7.1–24.9 °C) (Favorite et al., 1976; Wahl et al., 1989; McKinnell and Waddell, 1993). Gradually, the population returns to the breeding colonies during fall (October–November) (McDermon and Morgan, 1993; Cousins and Cooper, 2000).

Traditionally, observer programs have been used to document seabird fisheries bycatch. In particular, the recovery of banded individuals has helped to establish direct links between population dynamics at specific breeding colonies and mortality in distant fisheries (Brothers et al., 1997; Gales et al., 1998). However, because observers can rarely determine the origin, gender, and breeding status of bycaught birds, it is often difficult to assess the population-level effects of the mortality rates observed at sea (Moloney et al., 1994; Brothers et al., 1997; Cousins and Cooper, 2000). The advent of satellite telemetry has improved our ability to assess the susceptibility of far-ranging seabirds to anthropogenic threats (Prince et al., 1992; Weimerskirch et al., 1999; Nicholls et al., 2001). However, quantifying fishing activities within the vast foraging ranges of threatened albatross populations remains a high conservation priority (Croxall and Gales, 1998).

The objective of this research was to assess the susceptibility of black-footed albatrosses to pelagic longline fisheries during their post-breeding dispersal in the northeast Pacific, from 20–40°N and from the west coast of North America to 135°W. Because bycatch is influenced by multiple factors, we adopted an interdisciplinary approach to: (1) quantify the spatial overlap between satellite-tracked albatrosses and longline fishing effort, (2) characterize diel cycles in albatross ranging behavior to assess the temporal overlap between diurnal fishing operations and albatross foraging activities, and (3) compare the water masses where albatrosses forage and longline fisheries operate. Moreover, to place these results in perspective, we compared bycatch estimates resulting from the summertime (July–September) fishing effort deployed within the study area with albatross population size estimates off southern California. Finally, we characterized albatross movements with respect to the 200-mile Economic Exclusive Zones (EEZs) of Mexico and the USA.

Currently, it is unknown whether albatrosses are taken in the Korean, Taiwanese, and Japanese pelagic longline fisheries operating in the North Pacific Ocean (Cousins and Cooper, 2000). However, based on the available effort statistics and the bycatch rates for tuna sets in the Hawaiian-based longline fleet, these unobserved fisheries may be taking a substantial number of albatrosses (Cousins et al., 2000). We focused our research on the Japanese Eastern Pacific Ocean (EPO) longline fishery because the National Research Institute of Far Seas Fisheries (NRIFSF) graciously provided the necessary fishing effort data. We hope that this paper will serve as a template for future studies of albatross susceptibility to longline fisheries operating within their marine ranges.

2. Methods

2.1. Satellite telemetry

We fitted six breeding-age black-footed albatross females with Telonics ST-10 (Telonics Inc., Mesa, Arizona) platform transmitter terminals (PTTs) off southern California during the summers of 1997–1999 (Table 1). All individuals were adult females with

Table 1
Summary of satellite telemetry data analyzed during this study

Bird #	Start date	Tagging location	Deployment duration (days)	Number of fixes	Maximum linear range (km)	Range of latitude occupied (°N)	Range of longitude occupied (°W)	SST occupied (median) (°C)
1	7/10/97	High seas	11	46	430	32.6 30.2	127.9 122.0	18.2–17.2 (17.2)
2	7/10/97	High seas	1[a]	6	11	31.3 31.2	123.8 123.7	–
3	7/11/97	US EEZ	12	48	149	32.7 31.4	123.2 121.8	19.7–18.5 (19.3)
4	7/17/98	US EEZ	43	148	814	33.3 28.6	128.8 113.2	21.2–17.7 (21.1)
5	8/17/99	US EEZ	34	285	1050	27.6 23.3	125.3 123.0	21.2–20.4 (21.0)
6	8/17/99	US EEZ	81[a]	–	853	32.6 28.2	122.8 115.5	–

High seas refers to waters beyond the EEZs of Mexico and the USA. Ocean habitats are depicted using the range and median sea surface temperature (SST) occupied by the satellite-tracked birds.

[a] Transmitter failure. Bird 6 was captured alive on 6 November 1999 off Baja California, Mexico (28.2°N, 115.5°W) by Dan Sansome from the "*American Angler*" sport-fishing boat.

breeding-age plumage, characterized by an overall grayish-brown appearance, extensive whitening around the face, and white tail coverts (Harrison, 1985). We determined the gender of the satellite-tracked birds using DNA extracted from feathers (Longmire et al., 1993), but had no way to determine their reproductive status. Thus, the post-breeding habitats and distributions presented in this paper likely include individuals that had bred during the previous breeding season, as well as resting birds that skipped breeding.

The PTTs operated continuously on a 90-s repeat cycle for up to 66 days. We attached the transmitters with cable ties to a plastic base plate, which had been previously glued directly to the mid-dorsal feathers using quick-set marine epoxy (Prince et al., 1992). This is the procedure recommended for long-term PTT deployments (Fraser and Trivelpiece, 1993). We could not assess detrimental instrument effects by comparing the behavior of tagged and control birds. It is unlikely, however, that the 90-g package affected the birds' flight performance because it amounted to approximately 3% of their body mass, within the recommended specifications (Gaunt et al., 1997).

Argos assigns satellite fixes to one of six possible location quality classes (LQCs) according to their accuracy (Argos, 1989). We tested the performance of the transmitters by contrasting the quality of the satellite fixes reported by Argos with a known stationary location determined using a global position system (GPS). We used satellite fixes from all quality classes because their spatial resolution, within 10 km (Table 2), was appropriate to study large-scale movements. Due to the premature failure of two PTTS, our telemetry data entail four birds and 100 tracking days (Table 1).

2.2. *Albatross diel activity patterns*

The rate of movement (speed) of satellite-tracked albatrosses can be used to characterize their foraging behavior during different periods of the day (Jouventin and Weimerskirch, 1990; Hyrenbach and Dotson, 2001). In particular, previous studies have revealed that slow movement rates are correlated with area-restricted searching (Hyrenbach et al., 2002), and with increased frequency of landings (Fernández and Anderson, 2000) in this species. Conversely, we assumed that birds that cover large expanses in search of prey are more likely to encounter longlines. Therefore, we equated rapid movements and far-ranging displacements with an increased susceptibility to bycatch.

Diel cycles in foraging behavior likely influence albatross susceptibility to fisheries that preferentially operate during the day (i.e. target tuna, *Thunnus* spp.) or at night (i.e. target swordfish *Xiphias gladius*) (Gales et al.,

Table 2
Accuracy of the telemetry data used in this study calculated by comparing ARGOS satellite locations with a global positioning system (GPS)

Argos location quality class	Sample size of accuracy test	Median error (km)	Satellite fixes obtained during this study
3	32	0.3	(5.1%)
2	36	0.5	(11.2%)
1	32	0.8	(20.5%)
0	32	1.5	(26.6%)
A	31	1.8	(19.5%)
B	31	7.3	(17.1%)
Total	194		(100.0%)

1998; Brothers et al., 1999; Cousins et al., 2000). In particular, because the Japanese EPO fishery targets tunas during daytime (Uosaki and Bayliff, 1999; K. Uosaki, NRIFSF, 7-1 Orido 5 Chome, Shizuoka, 424-8633, Japan, personal communication), nocturnally feeding albatrosses would not overlap temporally with fishing activities. To assess the differential susceptibility of albatrosses to daytime and nighttime longline sets, we determined whether the satellite-tracked birds modified their ranging behavior during different periods of the day.

To obtain a more accurate representation of albatross movements, we excluded satellite fixes less than 1 h and more than 12 h from the previous location. We calculated the net movement rate (speed) of the satellite-tracked birds using great-circle distances, and rejected satellite fixes requiring unrealistic flying speeds in excess of 80 km h^{-1} (Hyrenbach et al., 2002).

We used astronomical data publicly available from the US Naval Observatory web-site (http://riemann.usno.navy.mil/AA/) to calculate the duration of the daytime and nighttime periods experienced by the satellite-tracked birds. We classified the telemetry tracks as diurnal and nocturnal, according to the timing of civil twilight, and defined those displacements that spanned sunset or sunrise as crepuscular (Hyrenbach and Dotson, 2001). We determined whether the movement rates varied significantly during different periods of the day and among individuals using a two-way Kruskal–Wallis (Zar, 1984). Because this nonparametric test revealed significant differences across individuals, we analyzed the data from each satellite-tracked bird separately to avoid pseudo-replication (Hurlbert, 1984).

For each bird, we determined whether the movement rates varied significantly during different periods of the day using Kruskal–Wallis tests (Table 3). Additionally, we compared the proportional distance traveled during the day and at night by each individual, with the relative duration of the day and nigh periods using G tests (Zar, 1984). Under a null hypothesis of no diel behavioral cycles, we would expect no differences between the nocturnal, crepuscular, and diurnal flight speeds. Moreover, the total distances traveled by the satellite-tracked birds during the day and at night would be proportional to the duration of the nocturnal and diurnal periods they spent at sea.

2.3. Analysis of albatross distributions

We characterized albatross distributions using the amount of time the tracked birds spent at sea (“albatross hours”) over a grid of $1^\circ \times 1^\circ$ latitude/longitude cells. Additionally, we calculated the amount of time the birds spent within the 200-mile economic exclusive economic zones (EEZs) of Mexico and the USA, and within the high seas beyond national jurisdiction. We compared the distributions of the four tracked birds by contrasting their time budgets. These tests revealed individual differences in the use of water masses (*G* test, *G*: 563.182, df: 6, $P<0.001$) and jurisdictional waters (*G* test, *G*: 708.508, df: 6, $P<0.001$). Thus, instead of

Table 3
Diel cycles in black-footed albatross ranging behavior (bold font denotes significant results)

Bird (No.)	Period of the day	Movement rate (km h^{-1})		Relative diurnal activity			
		Median	Range	Sample size (*n*)	*H* statistic (*P* value)	Distance traveled (day length)	*G* statistic (*P* value)
1	Diurnal	2.87	9.80–1.63	21	2.45	73.2	5.84
	Crepuscular	4.76	36.83–0.61	18	(0.294)	(62.7)	**($0.01<P<0.025$)**
	Nocturnal	11.06	18.02–3.46	6			
	Total		36.83–0.61	45			
3	Diurnal	9.38	63.29–1.64	27	6.33	96.1	89.15
	Crepuscular	2.73	18.99–0.71	12	**(0.042)**	(62.5)	**($P<0.001$)**
	Nocturnal	2.52	17.31–0.20	4			
	Total		63.29–0.20	43			
4	Diurnal	10.29	46.79–0.90	36	14.58	70.1	6.11
	Crepuscular	2.10	55.68–0.58	35	**(<0.0001)**	(59.1)	**($0.01<P<0.025$)**
	Nocturnal	3.88	30.45–0.46	28			
	Total		55.68–0.46	99			
5	Diurnal	3.37	61.41–0.08	115	63.63	89.3	69.53
	Crepuscular	1.31	12.74–0.32	40	**(<0.0001)**	(55.5)	**($P<0.001$)**
	Nocturnal	0.87	5.31–0.12	70			
	Total		61.41–0.08	225			

pooling the "albatross hours" across individuals, we stratified these estimates and calculated a mean "time at sea" budget.

2.4. Analysis of fishing effort distributions

The Inter-American Tropical Tuna Commission (IATTC) periodically publishes quarterly summaries of fishing effort by the Japanese EPO longline fishery (Nakano and Bayliff, 1992; Uosaki and Bayliff, 1999). We used published data from 1981 to 1987 and unpublished monthly averages from 1991 to 1997, graciously furnished by Japan's National Research Institute of Far Seas Fisheries, in our analyses. Both datasets have a spatial resolution of 1°×1°latitude/longitude.

Disparities in fishing gear (e.g. mainline material) and practices (e.g. diurnal versus nocturnal sets), and environmental conditions (e.g. sea state) influence the magnitude of albatross longline bycatch (Cherel et al., 1996; Brothers et al., 1999; Melvin et al., 2001). In particular, mitigation measures such as bird-scaring "Tori" lines, the weighting of longlines, and the dyeing of bait have been successfully used to mitigate black-footed albatross interactions with the Hawaiian longline fishery (Boggs, 2001). However, because no ancillary data on gear configuration and the timing of longline sets were available, we could not account for temporal and spatial disparities in fishing gear and practices across the Japanese EPO fishery. Instead, we assumed that all fishing effort had targeted tunas during daylight hours, and that no mitigation measures had been used. Moreover, because albatrosses interact with longlines during the deployment and retrieval of the gear, we included deep, intermediate and shallow sets in our analyses.

To assess the spatio-temporal variability of fishing distributions, we compared the magnitude (hooks set) and the extent (1°×1° cells occupied) of the Japanese EPO fishing effort across months (July–September), years (1991–1997), and decades (1991–1997 and 1981–1987). For the decadal comparison, we aggregated the unpublished monthly data into seasonal composites equivalent to those in the published reports (Nakano and Bayliff, 1992; Uosaki and Bayliff, 1999).

2.5. Spatial overlap between albatross and fishing effort distributions

We used the movements of the satellite-tracked birds to delineate the extent of our study area. Using those 1°×1° cells that fell within 500 km of an albatross satellite location, we defined the black-footed post-breeding range as the area extending from 21 to 38°N and 111 to 131°W. We quantified the spatial association between the satellite-tracked albatrosses and summertime longline fishing effort within this restricted range using two metrics: proportional overlap and rank correlation. First, we estimated the proportion of time that the satellite-tracked albatrosses spent in cells containing any fishing effort. Proportional overlap ranges from 0 to 100%, corresponding to scenarios where albatrosses spend none to all of their time at sea within cells with fishing effort. We also used Spearman rank correlations to quantify the association between albatross "time at sea" and fishing effort distributions. This nonparametric statistic ranges from +1 (attraction) to −1 (repulsion) (Zar, 1984). Both analyses were performed using multi-year summertime (July–September) fishing effort composites from 1981 to 1987 and from 1991 to 1997 separately. Because the Japanese EPO fishery did not deploy any effort within the study area during the summer of 1997, we could not analyze the telemetry tracks with respect to concurrent fishing effort distributions.

2.6. Analysis of water mass preferences

Another approach to assess bycatch susceptibility is to determine the similarity of the habitats of target and non-target species (Mikol, 1997; Polovina et al., 2001). Sea surface temperature is a useful proxy to delineate oceanic habitats, and has long been used to characterize seabird and tuna distributions (Sund et al., 1981; Wahl et al., 1989).

We characterized the ocean temperature structure using weekly and monthly averages of filtered sea surface temperature imagery from the Advanced Very High Resolution Radiometer (AVHRR), publicly available at the Pacific Marine Environmental Laboratory web-site (http://www.ferret.noaa.gov/). These data have a spatial resolution of 1°×1° latitude/longitude (Reynolds and Smith, 1994), and are 0.3–0.4 °C lower than concurrent vessel-based observations, with cross-correlations between 0.3 and 0.7 (McClain et al., 1985). We integrated the satellite imagery, fishing effort and telemetry data using the Arc View 3.1 geographic information system (ESRI Inc., Redlands, CA).

We overlapped the telemetry tracks over concurrent maps of weekly SST, and calculated the amount of time the tracked birds spent over six distinct water masses defined in terms of sea surface temperature: tropical waters (>20 °C), subtropical frontal zone (20–18 °C), subtropical water mass (18–15 °C), transition domain (15–12 °C), subarctic frontal zone (12–10 °C), and subarctic domain (<10 °C) (Roden, 1971; Favorite et al., 1976; Lynn, 1986). We allocated fishing effort by the Japanese EPO fishery (total hooks set) between 1991–1997 to the same water masses using monthly SST imagery. This coarser temporal resolution was imposed by the scale of the available fisheries data composites.

2.7. Estimating potential population-level bycatch

To place our telemetry research in perspective, we assessed the potential impact of the longline fisheries operating within the eastern North Pacific on the black-footed albatross population. We estimated the potential albatrosses bycatch within the study area using the summertime (July–September) fishing effort (hooks deployed) by longline fisheries within the range of the satellite-tracked albatrosses between 1991–1997, and published hooking rates (albatross hooked per 1000 hooks set) from the Northeast Pacific Ocean (PFMC, 2001). Preliminary analyses of six fishing trips by Hawaii-based longliners between 1994 and 2000, revealed black-footed albatross bycatch rates of 0.251 birds per 1000 hooks and 0.095 birds per 1000 hooks east and west of 135°W respectively. These estimates are based on 43,847 observed hooks during 51 sets and 6 trips, and 42,198 observed hooks during 51 sets and 5 trips respectively. The overall bycatch rate obtained by combining observations east and west of 135°W for vessels that fished between Hawaii and California was 0.174 birds per 1000 hooks set (PFMC, 2001). Given the inherent variability of the data, an additional 33 observed trips are needed to lower the coefficient of variation of these estimates by 10%. However, these preliminary data give an indication of potential spatial trends in bycatch rates (S. Smith, NOAA-NMFS, SWFSC, PO Box 271, La Jolla, CA 92038, personal communication).

We first estimated bycatch in the Japanese EPO fishery separately using 1°×1° fishing effort data between 21 and 38°N, 111 and 131°W. We also estimated longline bycatch using total 5°×5° fishing effort statistics between 20 and 40°N, 115 and 135°W, including effort by Hawaiian, Korean, Taiwanese and Japanese fleets, compiled by the Oceanic Fisheries Program (http://www.spc.org.nc/OceanFish/). To place this bycatch in perspective, we compared these mortality rates with albatross population estimates off southern California.

2.8. Albatross abundance estimates

One of us (KDH) surveyed albatross distributions using standardized 300-m strip transects (Tasker et al., 1984) during six summertime California Cooperative of Oceanographic Fisheries Investigations (CalCOFI) cruises between 1996 and 1999. Because albatrosses aggregate and otherwise follow survey vessels, line transects frequently overestimate their density. To obtain more conservative albatross density estimates, we discounted sightings of birds attracted to the survey vessel and repeated counts of ship-following individuals using the "index of attraction" and the "time to independence" corrections described in-depth elsewhere (Hyrenbach, 2001).

3. Results

In this paper we advocate an integrated approach to the conservation of far-ranging marine species. We urge the readers to view this paper as an example of this inter-disciplinary approach, and to interpret any specific result with caution due to the small sample sizes of our telemetry study.

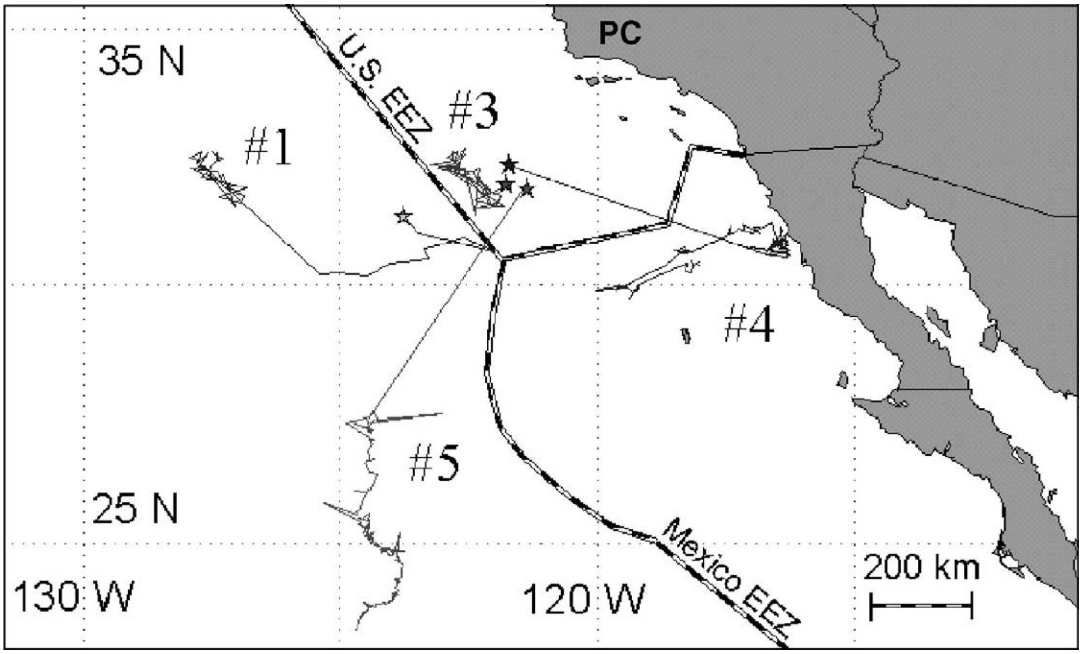

Fig. 1. Movements of four satellite-tracked black-footed albatross females off southern California (July–September 1997–1999) with respect to the 200-mile exclusive economic zones (EEZs) of the United States and Mexico, and the Point Conception upwelling center (PC). Deployment locations are labeled with stars and telemetry tracks are numbered (see Table 1).

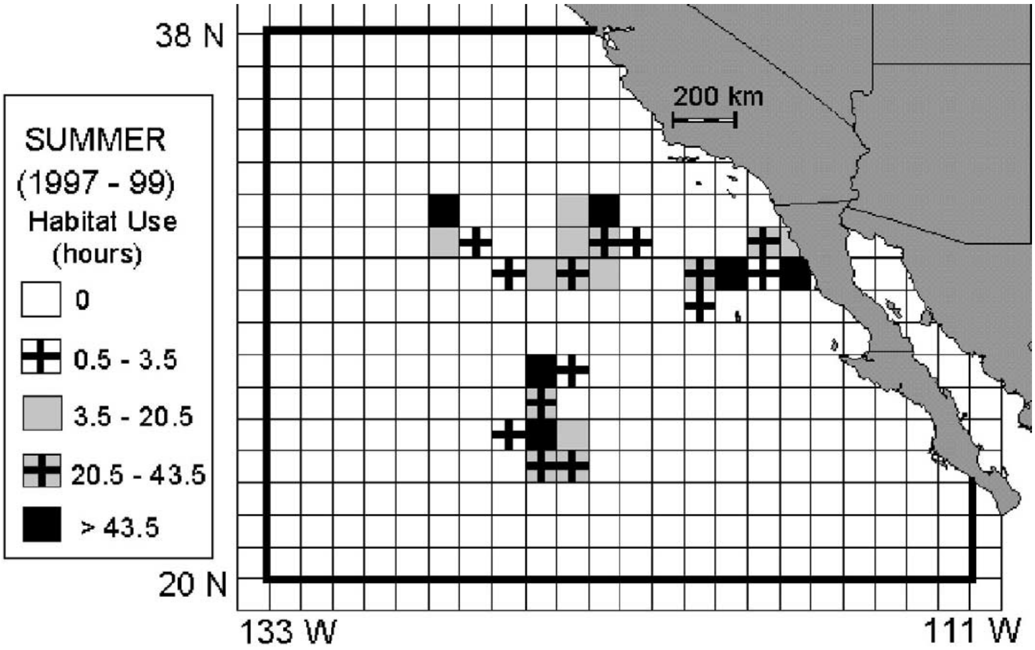

Fig. 2. Spatial distribution of black-footed albatross females tracked during their summertime (July–September, 1997–1999) post-breeding dispersal off southern California.

3.1. *Albatross foraging range and national jurisdictions*

The satellite-tracked albatrosses ranged over a vast area, spanning 262 1°×1° cells (approximately 655,000 km^2), between 23 and 33°N, and from the coast of Baja California to offshore waters beyond the extent of the California Current (113 and 129°W) (Figs. 1 and 2). The tagged birds ranged across national boundaries, and spent considerable time in the high seas beyond the US and Mexican territorial waters (Table 4).

3.2. *Diel cycle of albatross activity pattern*

The two-way non-parametric ANOVA revealed that the rate of movement (flight speed) of the tracked albatrosses varied significantly during different periods of the day (H: 5.991; df: 2, 400; $P<0.001$), and across individuals (H: 7.815; df: 3, 400; $P<0.001$). However, we did not detect a significant Period×Individual interaction (H: 12.592; df: 6, 400; $0.10<P<0.05$). Three of the four tracked albatrosses moved significantly faster during daylight hours than during crepuscular and nocturnal periods. The fourth albatross (bird 1) behaved differently: moving faster at night, and slower during daytime and crepuscular periods. However, these differences were not significant (Table 3). Moreover, all four satellite-tracked birds traveled disproportionately farther during daylight hours. Overall, the tracked birds covered 82.17% (±12.53 S.D.) of the total distance traveled between dawn and sunset, while daylight hours

Table 4
Waters inhabited by post-breeding black-footed albatrosses during summer (July–September, 1997–1999), expressed as the proportion of time the satellite-tracked birds spent within different regions defined by political and sea surface temperature categories

Individual bird (No.)	National jurisdiction (200-mile EEZ)			Water masses (sea surface temperature, °C)			
	USA	Mexico	High seas	TRW (>20)	SFZ (20–18)	STW (18–15)	TRD (15–12)
1	93	0	7	0	29	71	0
3	0	0	100	0	100	0	0
4	5	95	0	55	44	1	0
5	3	0	97	100	0	0	0
Average	25%	24%	51%	39%	43%	18%	0%

High seas refers to waters beyond the 200-mile EEZs of Mexico and the USA. We considered four oceanographic domains defined on the basis of satellite-derived sea surface temperature imagery: tropical waters (TRW), subtropical frontal zone (STFZ), subtropical waters (STW), and transition domain (TRD).

accounted for merely 59.95% (±3.39 S.D.) of the total time spent at sea. These differences were statistically significant for all birds (Table 3).

3.3. Variability of fishing effort distributions

The analysis of the available fishery data revealed substantial variability in the extent and the magnitude of fishing effort within and across decades. Summertime (July–September) fishing effort distributions varied significantly across months during 1991–1997. The magnitude (hooks set) (Kruskal–Wallis Test; *H*: 10.297; *n*: 21; *P*: 0.006) and the areal extent (1°×1° cells occupied) (Kruskal–Wallis Test; *H*: 10.297; *n*: 21; *P*: 0.006) of the Japanese EPO fishing effort within the albatross post-breeding foraging grounds (21–38°N, 111–131°W) varied

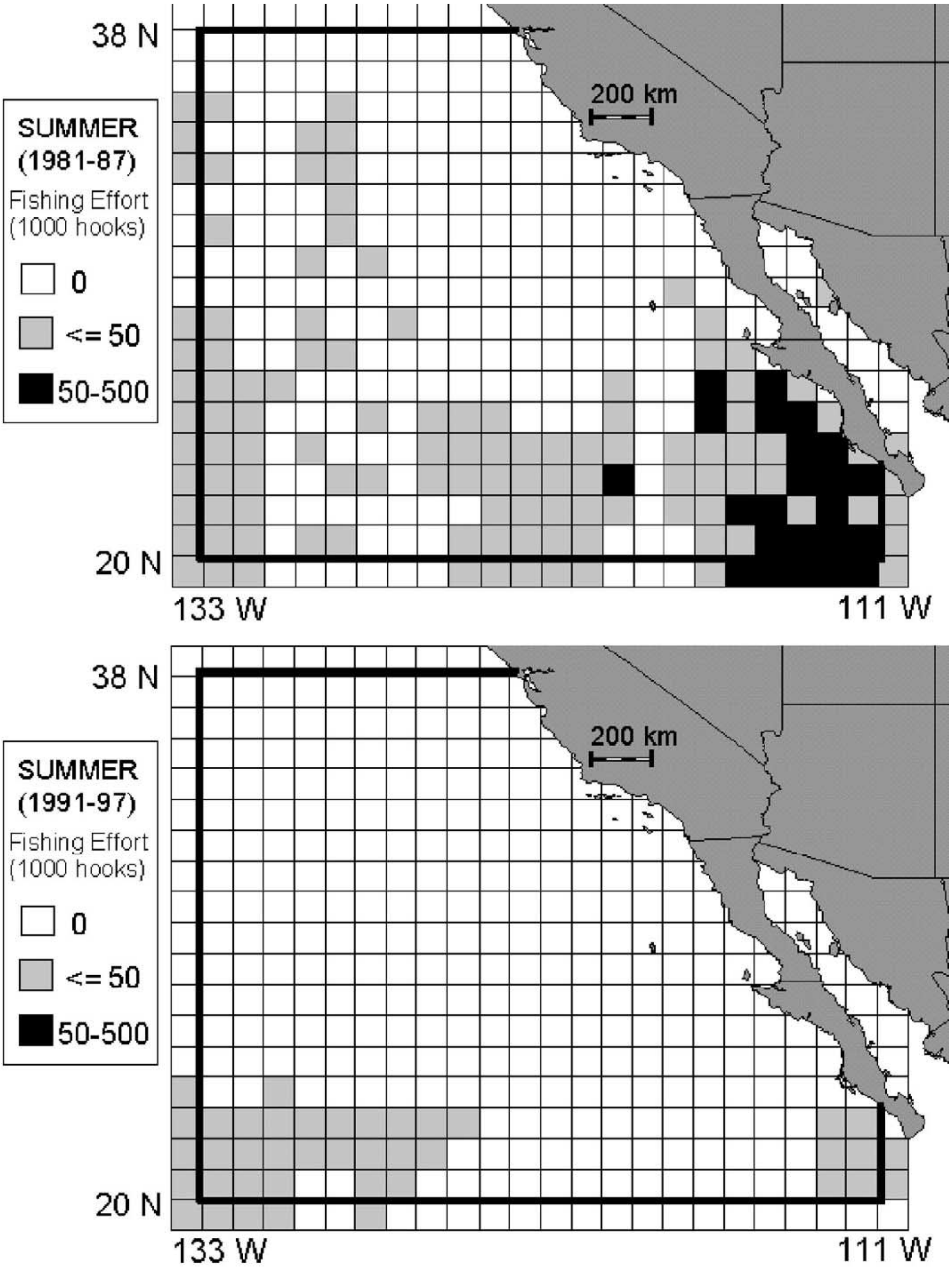

Fig. 3. Spatial distribution of summertime (July–September) fishing effort by the Japanese EPO longline fishery. Data from the 1980s (1981–1987) were published by the Inter-Tropical Tuna Commission (Nakano and Bayliff, 1992). Data from the 1990s (1991–1997) were compiled by Japan's National Research Institute of Far Seas Fisheries (NRIFSF).

significantly from month to month. Over 99% of the fishing effort was deployed during September (median: 24,860 hooks, *n*: 7 years), while little effort was deployed in July and August (median: 0 hooks, *n*: 7 years).

There was also substantial interannual variability in the extent of the fishing grounds (*G* test; *G*: 61.086; df: 6; $P<0.001$) and the magnitude of fishing effort (*G* test; *G*: 67.476; df: 6; $P<0.001$) during September (1991–97). Moreover, we detected changes in summertime fishing effort distributions within our study area across decades. The Japanese EPO longline fishery deployed 285,000 and 6,825,000 hooks during 1991–1997 and 1981–1987 respectively. Overall, the cumulative magnitude of fishing effort and the areal extent of the fishing grounds decreased by 93 and 79% respectively, between 1981–1987 and 1991–1997. During the 1990s, the fishing effort was concentrated in the southern part of the study area, within 19 of the 227 1°×1° cells outside of the US EEZ. In comparison, fishing effort during the 1980s was distributed more evenly across the study area, within 93 of the 227 1°×1° cells outside of the US EEZ (Fig. 3). The spatial distributions of effort were not significantly correlated across the two time periods (Spearman rank correlation; r_s:−0.089; *n*: 277; $0.20<P<0.10$), suggesting that the fishing grounds have shifted through time. Additionally, overall fishing effort within our study area has declined significantly between 1981–1987 and 1991–1997 (Kolmogorov–Smirnov; max_diff: 0.396; *n*: 277; $P<0.0001$).

3.4. Overlap between satellite-tracked albatrosses and longline fishing effort

The Japanese EPO longline fishery operates between 40°N and 35°S, and from 150°W to the west coast of the Americas (Nakano and Bayliff, 1992; Uosaki and Bayliff, 1999). These vast fishing grounds overlap the marine ranges of breeding and non-breeding black-footed albatrosses (Wahl et al., 1989; McDermon and Morgan, 1993; Cousins et al., 2000). The degree of overlap between the birds tracked during this study and summertime longline effort varied, depending on whether we considered fishing distributions during 1991–1997 or 1981–1987. There was no overlap between the satellite-tracked albatrosses and the longline fishing effort during 1991–1997. The birds spent no time within 1°×1° cells where fishing effort had been deployed. Moreover, albatross time at-sea and fishing effort distributions were not significantly correlated (Spearman rank correlation; r_s:−0.095; *n*: 262; *P*: 0.10). In comparison, the tagged albatrosses spent 31.8% of their time at sea in 1°×1° cells where fishing effort had been deployed during 1981–1987, though the spatial distributions were not significantly correlated (Spearman rank correlation; r_s:−0.076; *n*: 262; $0.20<P<0.10$).

3.5. Water mass preferences

The Japanese EPO longline fishery largely targets bigeye tuna (*Thunnus obesus*), and secondarily yellowfin (*T. albacares*) and albacore (*T. alalunga*), within tropical and subtropical waters of the eastern Pacific Ocean south of the Subarctic Boundary (Nakano and Bayliff, 1992; Uosaki and Bayliff, 1999). During 1991–1997, this fishery exclusively targeted warm tropical waters (SST > 20 °C) where bigeye tuna are most abundant (Calkins et al., 1993; Uosaki and Bayliff, 1999)

Conversely, only two of the four satellite-tracked albatrosses ranged within the tropical waters targeted by the EPO longline fishery. Overall, the post-breeding black-footed albatrosses spent 18, 43, and 39% of their time at sea within subtropical (SST: 18–15 °C), subtropical frontal zone (SST: 20–18 °C) and tropical waters (SST > 20 °C) respectively (Table 4).

3.6. Estimates of albatross abundance and potential bycatch

Based on our vessel-based surveys, we estimate that approximately 2000 black-footed albatrosses occurred off southern California (29–35°N, 117–124°W) in summer (July–September) during the late 1990s (Table 5). This number greatly exceeds the potential level of bycatch associated with summertime (July–September) longline fishing effort within the range of the birds tracked as part of this study (21–38°N, 111–133°W). We estimated an annual bycatch of 6–10 and 20–31 black-footed albatrosses within our study area, for the Japanese EPO fishery and for all longline fisheries combined (Table 6). These estimates should be interpreted with caution, however, because hooking rates are likely influenced by temporal and spatial variability in albatross numbers. In particular, albatross abundance varies seasonally, interannually, and spatially across the northeast Pacific Ocean (Briggs et al., 1987; Wahl et al.,

Table 5
Summertime (July–September) black-footed albatross abundance off southern California

Survey cruise	Survey effort (km)	Observed density (No. 100 km^{-2})	Estimated abundance
July 1997	1790	0.42	1260
July 1998	1781	0.52	1560
August 1996	1824	0.56	1680
August 1999	1470	0.83	2490
September 1997	1536	0.76	2280
September 1998	1499	0.83	2490
Mean		0.65	1960
S.D.		0.18	527

Table 6
Estimates of summertime (July–September) black-footed albatross population abundance (Table 5), and potential bycatch off southern California

Month	Albatross abundance (mean±S.E.)	Japanese EPO Fishery			Oceanic Fisheries Program		
		Hooks set (mean±S.E.)	Potential bycatch (east)	Potential bycatch (east/west)	Hooks set (mean±S.E.)	Potential bycatch (east)	Potential bycatch (east/west)
July	1410±150	353±353	0.08	0.05	6303±5,887	1.57	1.01
August	2085±405	0±0	0	0	7918±7,918	1.98	1.27
September	2385±105	40,371±17,324	10.09	6.46	111,485±43,351	27.87	17.83
Summer total	–	40,724	10	6	125,706	31	20

Albatross bycatch for 1991–1997 was calculated separately for the Japanese EPO longline fishery data (21–38°N, 111–131°W), and using total longline effort (20–40°N, 115–135°W) compiled by the Oceanic Fisheries Program (http://www.spc.org.nc/OceanFish/) including data from the Hawaiian, Korean, Taiwanese, and Japanese fleets. Bycatch was estimated using NMFS hooking rates for Hawaiian longline vessels operating within the northeast Pacific Ocean (1994–2000). Estimates based on observed hooking rates east of 135°W (0.25 birds per 1000 hooks), and east and west of 135°W (0.17 birds per 1000 hooks) were calculated separately (PFMC, 2001).

1989; Hyrenbach, 2001). Even though the hooking rates used in this study originate from the northeast Pacific, these estimates are based on observations collected throughout the year. Furthermore, these hooking rates originate from Hawaiian-based longline vessels, which may have been targeting mixed-sets, swordfish, and tuna (Xi et al., 1997). Albatross hooking rates from the Hawaii longline fishery observer program (1994–1998) differ as a function of the target species, with bycatch rates of 0.758, 0.499, and 0.013 birds per set in swordfish, mixed and tuna sets respectively (Cousins et al., 2000). Conversely, the Japanese EPO fishery largely targets bigeye tuna (Nakano and Bayliff, 1992; Uosaki and Bayliff, 1999). Thus, the hooking rates used in this study may have overestimated potential albatross longline bycatch.

4. Discussion

The magnitude of fisheries bycatch (B) is a function of the fishing intensity (F), the abundance of non-target species (N), and the "availability" (r) of those species to the fishing gear: ($B = F \times N \times r$) (Marr, 1951). Disparities in fishing practices and natural history characteristics influence the species-specific availability to different gear (Yatsu et al., 1995; Brothers et al., 1999; Boggs, 2001). In particular, the diving ability, the diel activity patterns, and the reliance on fisheries discards influence the susceptibility of seabirds to fisheries bycatch (Cherel et al., 1996; Gould et al., 1997; Melvin et al., 2001). Mitigation measures have diminished bycatch using an understanding of the natural history of the non-target species. For instance, "Tori" lines, line-weighting, and bait-dyeing deter shallow-diving albatrosses from taking baited hooks (Boggs, 2001; Melvin et al., 2001), and night-setting reduces takes of species that forage diurnally (Cherel et al., 1996; Brothers et al., 1999).

In this paper we evaluated three factors that likely influence the magnitude of black-footed albatross longline bycatch during their post-breeding dispersal off southern California. We quantified the summertime intensity of longline fishing effort and black-footed albatross abundance, and assessed albatross availability to the Japanese EPO longline fishery. More specifically, we calculated the degree of spatial co-occurrence of the longline fishing effort and the satellite-tracked birds, and assessed the diel overlap between albatross foraging activities and fishing operations.

4.1. Albatross ranging patterns and oceanographic habitats

The four birds tracked during this study concentrated their foraging between the coast of southern California and 129°W (Table 2, Fig. 2). This region corresponds to the broad transition zone where the cool and fresh waters of the southern-flowing California current mix with warmer and saltier subtropical waters to the south and west (Tables 1 and 4; Roden, 1971; Pelaez and McGowan, 1986). The telemetry data confirm our understanding of albatross basin-wide distributions. Previously, vessel-based surveys across the North Pacific revealed that post-breeding black-footed albatrosses aggregate at water mass boundaries and frontal systems (Wahl et al., 1989). However, the telemetry tracks contradict previous analyses of black-footed albatross ranging patterns off southern California. Marking experiments during the 1930s and 1940s suggested that albatrosses occupy foraging ranges in the order of 40–60 nautical miles, within the cold water (14–16 °C) "tongue" influenced by upwelling at Point Conception (Miller, 1942). Conversely, the birds we tracked ranged over hundreds of kilometers and ventured into subtropical–tropical waters (Tables 1 and 4).

4.2. Albatross activity patterns

All tracked albatrosses travelled disproportionately farther during daylight hours, and three of the four individuals moved significantly faster during daytime, and slower during crepuscular and nocturnal periods (Table 3). Our findings suggest that daytime foraging is prevalent in female albatross, corroborating previous telemetry studies of male birds. Diurnal movement rates were significantly faster during the day that during crepuscular and nocturnal periods (Hyrenbach and Dotson, 2001). Additionally, birds equipped with immersion monitors landed on the water more frequently during daytime than at night (Fernández and Anderson, 2000). These results support the notion that black-footed albatrosses forage diurnally by scavenging and seizing non-bioluminescent prey at the surface (e.g. flying fish eggs) (Harrison et al., 1983; Gould et al., 1997).

4.3. *Albatross overlap with the Japanese EPO longline fishery*

Presently, we cannot directly evaluate whether bycatch of post-breeding black-footed albatrosses occurs in the Japanese EPO longline fishery. The satellite telemetry data suggest that albatross post-breeding ranges overlapped spatially with longline fisheries off southern California, between 1981 and 1987. On the other hand, we detected no overlap during 1991–1997. Nevertheless, these results must be interpreted with caution because they are based on four satellite-tracked albatrosses tagged off southern California (1997–1999) and fisheries distributions (1991–1997) from slightly different time periods. Conceivably, albatrosses other than those tracked in this study forage within these vast fishing grounds; even though the limitations of our telemetry data may have obscured this overlap.

4.4. *Implications for black-footed albatross conservation*

This study revealed little spatial overlap between the Japanese EPO longline fishery and female black-footed albatrosses tracked during their post-breeding dispersal off southern California. Moreover, analyses of albatross and fishing effort distributions with respect to sea surface temperature, revealed that the longline fishery and the satellite-tracked birds occurred in different water masses. The EPO fishery is restricted to tropical waters (SST > 20 °C), while the tracked albatrosses foraged within the broad oceanographic transition zone off the west coast of North America (SST: 20–18 °C) (Table 4). The spatial segregation of albatrosses and longline fishing effort distributions is underscored by our low bycatch estimates. The EPO fishery has potentially taken an estimated 6–10 individuals within the range of the satellite-tracked birds (Table 6).

It is likely that little black-footed albatross bycatch occurs in the EPO fishery. This fishery targets bigeye tuna west of 120°W and between the equator and 10°S and 5 °N throughout the year, NE of Hawaii between 20–33°N and 122–140°W from October to March, and off Peru and Chile between June–December (Miyabe and Bayliff, 1987; Nakano and Bayliff, 1992; Calkins et al., 1993; Uosaki and Bayliff, 1999). Though most of this fishing effort is deployed south of the black-footed albatross range, potential fishery interactions may take place NE of Hawaii (150–125°W, 20–35°N) during winter (January–February), when breeding birds forage over topical waters (SST: > 20 °C) close to their colonies (Fernández et al., 2001; Hyrenbach et al., 2002).

Conversely, rearing and post-breeding albatrosses likely overlap with longline fisheries targeting albacore tuna within the North Pacific Ocean (Cousins and Cooper, 2000). Chick-rearing birds (February–June) forage within cool (SST: 15–10 °C) and productive waters off the west coast of North America (Fernández et al., 2001; Hyrenbach et al., 2002). Furthermore, during their post-breeding dispersal (July–November), black-footed albatrosses aggregate in the Transition Domain between subtropical and subarctic waters in the central North Pacific (Wahl et al., 1989), and along the warm (SST > 15 °C) side of coastal upwelling plumes off California (Briggs et al., 1987). These are the same habitats where albacore catches concentrate during late summer and early fall (Fiedler and Bernard, 1987; Laurs and Lynn, 1991; Polovina et al., 2001). For instance, albacore catches by the Japanese EPO fishery are particularly high during summer (July–September) off Baja California (20–35°N, 125–150°W) (Nakano and Bayliff, 1992; Uosaki and Bayliff, 1999). Because this region encompasses the range of the tracked birds, it is likely that post-breeding albatrosses interact with other fisheries targeting albacore in this area (Cousins and Cooper, 2000).

Unfortunately, there is little published information describing Korean and Taiwanese longline fishing effort in the North Pacific. However, the available data suggest that the Korean fishery operates primarily outside of the black-footed albatross foraging range, with most effort focusing on equatorial and southern hemisphere waters (Anonymous, 1990; Cousins et al., 2000). Future studies should concentrate on the Taiwanese fishery, which targets swordfish and albacore in the Transition Domain, and deployed 24 million hooks in the North Pacific during 1995–1996 (Sun et al., 1999).

4.5. *Management recommendations*

This study advocates an integrated approach to assess the susceptibility of wide-ranging seabirds to longline fisheries operating within their vast marine ranges. A starting point entails describing the population ranges and assessing the national responsibilities for their conservation (Prince et al., 1992; Morgan et al., 2000; Nicholls et al., 2001). Currently, Japan and the USA have jurisdiction over the black-footed albatross, on the basis of known breeding colonies (Gales, 1998). However, our study revealed that female albatrosses range within US and Mexican territorial waters during their post-breeding dispersal off California (Table 4). This result highlights the need to re-assess national conservation responsibilities using information on marine distributions. Moreover, because the satellite-tracked birds spent a substantial amount of time in the high seas, this study underscores the need for international cooperation in the conservation of wide-ranging species.

Once important foraging grounds have been identified, vessel-based surveys may be used to quantify seasonal and interannual patterns of albatross abundance within these areas. In particular, abundance estimates are essential to extrapolate population-level impacts from observed bycatch rates. However, shipboard data are constrained by limited areal coverage and by the inability to determine the origin, gender, and reproductive status of birds sighted at sea (Morgan et al., 2000).

The next step involves delineating times and areas of potential high bycatch risk on the basis of fishing effort and albatross distributions. Multi-year shipboard surveys, satellite telemetry studies, and fishery reports could be used to characterize albatross and fishing effort distributions within specific areas of interest (Prince et al., 1998; Veit and Prince, 1997; Morgan et al., 2000). Ideally, these studies would rely on concurrent telemetry and fishing effort data with a fine spatio-temporal resolution (e.g. Brothers et al., 1998; Weimerskirch, 1998). In reality, however, most analyses may be constrained to using coarse-scale published summaries of fishing effort summaries that did not overlap temporally with the telemetry tracks (Anderson et al., 1998; this study). Thus, it is essential that, whenever possible, investigators assess the temporal variability of fishing effort distributions.

In instances where substantial fishing effort is consistently deployed within the ranges of threatened albatross populations, questionnaire and logbook programs could be used to assess the incidence of bycatch (Brothers et al., 1997; Jahncke et al., 2001). Once these low-cost techniques have provided conclusive evidence of albatross mortality in a fishery, we suggest implementing exploratory observer programs to assess the magnitude of this bycatch (Brothers et al., 1999; Stehn et al., 2001). Ship-based surveys and telemetry data could also help focus limited observer coverage on those times and areas with a high bycatch risk (Morgan et al., 2000). Furthermore, movement data could help mitigate bycatch by modifying fishing practices and by minimizing the overlap between fisheries and protected species (Fernández and Anderson, 2000; Polovina et al., 2001).

Interdisciplinary studies are needed to assess the susceptibility of far-ranging seabirds to fisheries bycatch (McKinnell and Waddell, 1993; Weimerskirch et al., 1997). Satellite telemetry can play an integral role in this integrated management by delineating the nations with jurisdiction over the ranges of threatened species, identifying potential threats from distant fisheries, and providing the necessary behavioral and habitat use information to design bycatch mitigation measures.

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