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Predictable hotspots and foraging habitat of the endangered short-tailed albatross (*Phoebastria albatrus*) in the North Pacific: Implications for conservation

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Abstract

The short-tailed albatross (*Phoebastria albatrus*) is a rare and endangered seabird that ranges widely over the northern North Pacific. Populations are slowly recovering but birds face several threats at sea, in particular the incidental capture of birds in long-line fisheries. Conservation efforts are hampered by a lack of information about the at-sea distribution of this species, especially knowledge of where it may predictably co-occur with long-line fishing effort. During 18 years of transiting the Aleutian Islands Unit of the Alaska Maritime National Wildlife Refuge on a research vessel, we observed short-tailed albatross on 65 occasions. They were consistently observed near Ingenstrem Rocks (Buldir Pass) in the western Aleutians and near Seguam Pass in the central Aleutians. Based on the oceanographic characteristics of the locations where we saw most of the birds, we hypothesized that short-tailed albatross "hotspots" were located where tidal currents and steep bottom topography generate strong vertical mixing along the Aleutian Archipelago. As a test of this hypothesis, we analyzed a database containing 1432 opportunistic observations of 2463 short-tailed albatross at sea in the North Pacific. These data showed that short-tailed albatross were closely associated with shelf-edge habitats throughout the northern Gulf of Alaska and Bering Sea. In addition to Ingenstrem Rocks and Seguam Pass, important hotspots for short-tailed albatross in the Aleutians included Near Strait, Samalga Pass, and the shelf-edge south of Umnak/Unalaska islands. In the Bering Sea, hotspots were located along margins of Zhemchug, St. Matthews and Pervenets canyons. Because these short-tailed albatross hotspots are predictable, they are also protectable by regulation of threatening activities at local spatial scales.

Keywords: Short-tailed albatross; *Phoebastria albatrus*; Hotspots; Upwelling; Submarine canyon; Alaska

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1. Introduction

Little is known about the pelagic ecology of the endangered short-tailed albatross (*Phoebastria albatrus*) because populations were driven to near extinction during the early 1900s, well before the advent of systematic seabird surveys in the North Pacific (Sanger, 1972). Information on distribution at sea is vital for conservation of the species because threats at sea include mortality in long-line fisheries, oil spills, and derelict fishing gear (DeGange and Newby, 1980; McDermond and Morgan, 1993). No marine waters in the US have been identified as critical habitat because "there is currently no information to support a conclusion that any specific marine … areas … are uniquely important" (Federal Register, 2000).

In this paper, we identify some specific marine areas that appear to constitute predictable "hotspots" for the short-tailed albatross in Alaska. We also suggest some oceanographic mechanisms that likely create those hotspots (i.e. relatively small areas of ocean where marine predators tend to congregate because of high production or aggregation of food for various bio-physical reasons). A key characteristic of hotspots is that they are persistent over time, so that predators exploit them repeatedly (Irons, 1998; Etnoyer et al., 2004).

Our understanding of the pelagic ecology of short-tailed albatross has advanced slowly. Once breeding in the millions on at least nine colonies south of Japan and in the East China Sea, populations were slaughtered for their feathers until as few as 100 birds remained on Torishima Island in 1933 (Sanger, 1972). Survival of the species was in doubt after this colony site was buried under lava and ash following a major volcanic eruption in 1939. Birds were discovered nesting again in the 1950s, and by the late 1960s about 60 adults were attempting to breed on Torishima. Sanger (1972) was first to review the pelagic status of short-tailed albatross, but this was based almost entirely on anecdotal accounts of 24 sightings between 1940 and 1970. Hasegawa and DeGange (1982) updated Sanger's account, and McDermond and Morgan (1993) repeated the process to include records up to 1991. This brought the total to a scant 56 records of 68 birds over a 51-year period (Tickell, 2000).

Evidence suggests that the short-tailed albatross formerly ranged south to the coast of China, in the Japan and Okhotsk Seas, throughout the Kuril and Aleutians archipelagos, into the Bering Sea as far as Bering Strait, and throughout the NE Pacific from the Gulf of Alaska to Baja California (Hasegawa and DeGange, 1982). Birds apparently move seasonally around the North Pacific, with high densities near Japan during the breeding season (December–May), and migration of adults during the non-breeding season through Alaskan (April–September) and North American west coast (April–December) waters (McDermond and Morgan, 1993). Non-breeding sub-adults could be found in all areas at any time of year. Few birds appeared to venture south of 20° N latitude (about the Hawaiian islands). Based largely on archeological evidence from midden sites and these early observations, investigators concluded that the short-tailed albatross was "abundant in shallow waters of coastal North America" (Hasegawa and DeGange, 1982) and it is "considered to be mainly an inshore species" (McDermond and Morgan, 1993).

Here we present data on more than 1400 sightings of short-tailed albatross at sea. This 25-fold increase in sightings resulted from two important events in the 1990s: listing of the short-tailed albatross as endangered in US waters (Federal Register, 2000) by the US Fish and Wildlife Service (USFWS) and, more importantly, implementation of an observer program by the National Marine Fisheries Service (NMFS) and collection of seabird data on the International Pacific Halibut Commission (IPHC) set line surveys (Federal Register, 2004). From these data we demonstrate that the short-tailed albatross is not a "coastal" albatross, but rather is associated with upwelling in Aleutian passes and along continental shelf margins in Alaska. Further, we show that short-tailed albatross appear persistently and predictably in some marine "hotspots", offering an additional opportunity to protect this endangered species from known threats at sea.

2. Methods

2.1. Seabird observations

We compiled observations of short-tailed albatross recorded during 1988–2004 by observers on the M.V. *Tiglax*, a vessel operated by the USFWS Alaska Maritime National Wildlife Refuge. Most observations were made opportunistically as the *Tiglax* traversed the Aleutian Archipelago at least 35 times, covering 100,000s of linear km. The *Tiglax* also traveled extensively on inner-shelf waters of the northern Gulf of Alaska. As a typical example, the

Tiglax traveled 34,000 km from Cook Inlet to Attu Island, and into the Bering Sea as far north as St. Matthew Island, during 169 days in 2005, landing field crews at 58 different islands. This inevitably meant traveling through a wide variety of habitats including the broad continental shelf of the Gulf of Alaska and Bering Sea, over smaller Aleutian island shelf systems, across many shelf slopes, occasionally over deep oceanic waters, through Aleutian passes, along mainland and island shores, and inside bays, inlets and channels.

We cannot quantify the effort spent on locating and identifying short-tailed albatross from the *Tiglax*, but the ship's captain (KB) was tasked since 1992 with recording and reporting all short-tailed albatross observations, including those made by himself ($n = 32$) while driving the vessel (i.e. almost every day). It is unlikely that many short-tailed albatross flying across the bow of the *Tiglax* went un-recorded during normal running operations. We estimate conservatively that several thousand hours of observation effort occurred during daytime. This effort was distributed randomly among the habitats visited by the *Tiglax*, so we feel confident that the distribution of short-tailed albatross in the Aleutians is portrayed (Fig. 1) reasonably well in this analysis.

In addition to the *Tiglax* records, we queried, compiled and error-checked several other datasets of known short-tailed albatross sightings in the North Pacific including: incidental sightings by biologists, fishermen, seamen, fisheries observers and birdwatchers provided to the USFWS, the International Pacific Halibut Commission (IPHC) and the Alaska Natural Heritage Program (ANHP); and historical sightings documented in published literature (Sanger, 1972; Hasegawa and DeGange, 1982; Ogi and Hitoshi, 1989; Camp, 1993). We cannot vouch for the accuracy of all records in this database. However, the short-tailed albatross is the largest seabird in the northern hemisphere, adults have a golden head, and all ages have an enormous pink bill, so it is not difficult to identify under good viewing conditions (Hasegawa and DeGange, 1982). Short-tailed albatross identification guides were distributed to many biologists, observers and fishermen working in Alaska waters (Melvin and Parrish, 2001; Melvin et al., 2004). The final database was proofed to remove duplicate sightings and location errors. Unfortunately, there are no effort data associated with these observations.

We also queried the North Pacific Pelagic Seabird Database (NPPSD, 2004) for short-tailed albatross records. The NPPSD contains 57,660 pelagic strip

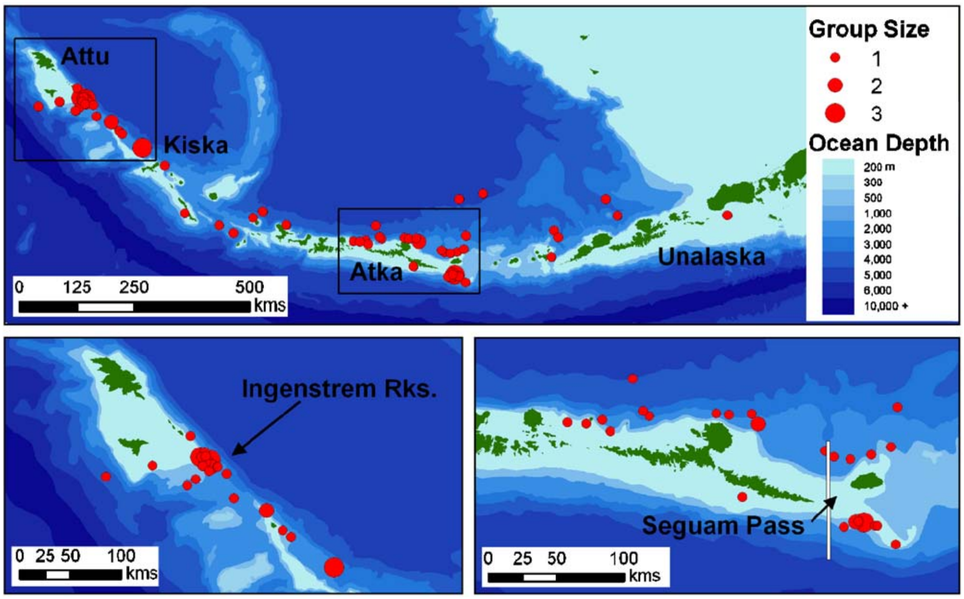

Fig. 1. Observations of short-tailed albatross made from the Alaska Maritime National Wildlife Refuge (USFWS) research vessel M.V. *Tiglax* from 1988 to 2004. A total of 79 birds were recorded on 65 occasions, most (75%) in two areas: Buldir Pass between Attu and Kiska (particularly near Ingenstrem Rocks, as shown in left inset) and north of Atka (particularly on either side of Seguam Pass, as shown in right inset). Note association of birds with shelf-edge habitats and steep slopes. White line in Seguam Pass shows location of CTD transect line used to collect data in Fig. 2.

transects (typically 300 m wide and 3–4 km long) for seabirds that were conducted mostly (85%) between 1974 and 1985. Surveys were conducted mostly in the Bering Sea and Gulf of Alaska, but also elsewhere in the North Pacific between California and Japan (for more details, see Gould et al., 1982; Springer et al., 1999; NPPSD, 2004; Piatt and Springer, 2003).

2.2. Mapping distributions

We used ArcGIS® 9.0 to categorize bottom topography from 2-min gridded global relief data (ETOPO-2) for the North Pacific (from 20° N latitude to the Chukchi Sea) into three groups with gentle, moderate and steeply sloping sea floor topography. Slope was determined for each 2-min^2 pixel with ArcGIS by calculating the maximum slope between each pixel and all adjacent pixels. Cut-points for grouping into each slope bin were determined by making each category dataset equal in size (number of pixels), i.e. dividing all the bottom terrain into thirds based on slope. We then selected a subarea of the North Pacific that contained 95% of all short-tailed albatross sightings, and calculated the slope under each bird location. The frequency of observations was tallied for each slope category previously determined. The total area containing each slope category was also calculated (and remained about equal thirds). We used χ^2 to compare the observed frequency of short-tailed albatross among slope categories with the frequency expected if birds were distributed equally among all categories.

2.3. Oceanographic profile

In addition to seabird observations, we show temperature and salinity data from Seguam Pass in the Aleutian Archipelago. These data were collected from the R.V. *Alpha Helix* as part of an interdisciplinary study of the marine environment of the eastern and central Aleutian Archipelago (Ladd et al., 2005a, b). On 10 June 2001, a total of 14 conductivity, temperature, and depth (CTD) casts to a maximum depth of ~500 m were taken on a north/south cross-section Seguam Pass. Casts were taken with a Seabird SBE-911 Plus system. Salinity calibration samples were taken on all casts and analyzed on a laboratory salinometer.

3. Results

A total of 79 short-tailed albatross were observed (Fig. 1) on 65 occasions from the USFWS M.V. *Tiglax* between 1988 and 2004, inclusive. The first and second short-tailed albatross ever recorded from the *Tiglax* were seen (*fide*, J.L. Wells) in Seguam and Buldir passes, respectively. During the following 18 years in which the *Tiglax* traversed the Aleutians, most (75%) of all short-tailed albatross sightings were located in these same two local areas, i.e., in Buldir Pass between Attu and Kiska, or along the north shore of Atka Island and east to Seguam Pass (see insets in Fig. 1).

Some relatively small locations within these areas were notable as persistent "hotspots". For example, short-tailed albatross were sighted 11 times during six different years (1995, 1998, 1999, 2001, 2003, 2004) in close proximity to Ingentrem Rocks (east of Attu Island, Fig. 1). These sightings were made during different months among years (May [$n = 2$], June [$n = 3$], July [$n = 5$], August [$n = 3$]) and within years (e.g., in June, July and August of 2003). Similarly, short-tailed albatross were sighted in close proximity to Seguam Pass 14 times (Fig. 1) from the *Tiglax* in 1988, 1994, 1997, 1998, 1999, and 2002. These sightings were made during different months among years (February [$n = 1$], May [$n = 2$], July [$n = 1$], August [$n = 5$], September [$n = 5$]) and within years (e.g., in February and July of 1998; or May and August of 1999). It is also noteworthy that 35 sightings of at least 12 different individual short-tailed albatross were made in Seguam Pass during attempts to capture birds and deploy satellite tags in August 2003 (G. Balogh, pers. obs.).

The average depth of Seguam Pass is about 150 m over its ~50 km length (Fig. 2). Well-defined fronts in temperature and salinity separate North Pacific (NP) water from Mixed Water (MW) in the pass, and MW from Bering Sea water to the north of the pass (Ladd et al., 2005a, b). The location of the surface expression of these fronts depends on the direction of tidal currents. The frontal structure is particularly evident on the south side of the pass during flood tides when strong currents flow from south to north (Fig. 2). Abrupt bathymetry along the Aleutian Archipelago causes upwelling of deeper NP water and strong vertical mixing within Seguam Pass. This accounts for the abrupt horizontal gradient in surface properties from relatively warm, low-salinity water of the NP

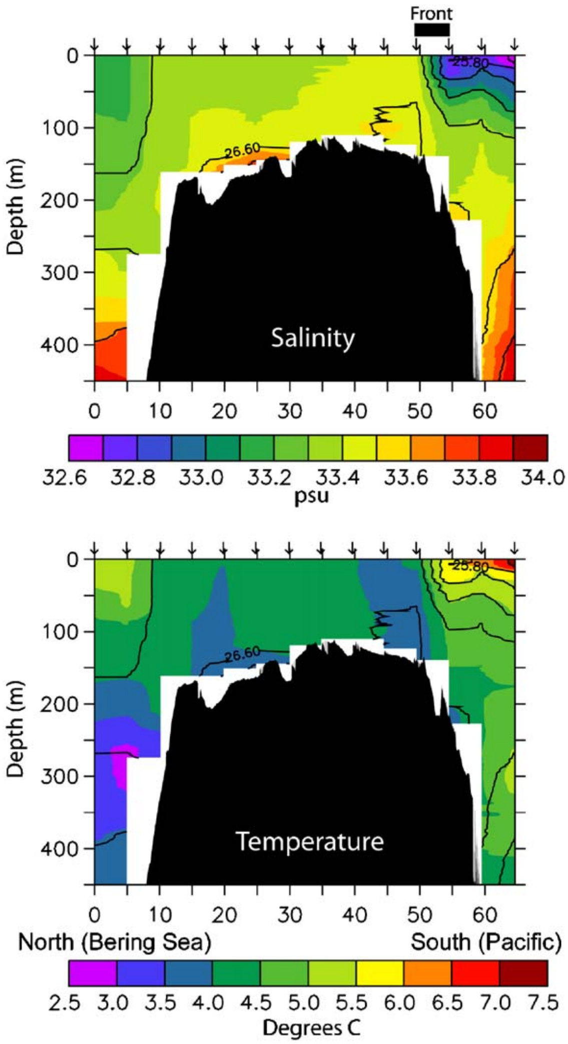

Fig. 2. Frontal structure in Seguam Pass during flood tide on 10 June 2001, when tidal currents were flowing from south to north (right to left) through the pass (distance in km given along *x*-axis). Illustrated are salinity and temperature (color) cross-sections of the pass (arrows indicate stations along the transect line shown in Fig. 1). Density (σ_t) is overlaid (black contour lines). The black areas represent the bottom topography of Seguam Pass. A strong front is found on the south side of the pass where deep Pacific waters are upwelled to the surface. After Ladd et al., 2005a.

to relatively cold, high-salinity MW in the pass. During strong ebb tides, the current flows from North to South, and upwelling occurs on the north side of Seguam Pass (Ladd et al., 2005b). We have no data on currents or upwelling near Ingenstrem Rocks.

Using data compiled from all sources, we mapped 1432 observations comprising 2463 short-tailed albatross and overlaid those observations on bathymetry of the North Pacific basin (Fig. 3). Short-tailed albatross were closely associated with shelf-break slope habitats throughout the northern Gulf of Alaska and Bering Sea. Short-tailed albatross favored steep slopes ($\chi^2 = 199.1$, $p<0.001$) by more than 2-to-1 over gentle or moderate slopes (Fig. 4). They favored steep or moderate slopes by almost 4-to-1 over gentle slopes. Larger group sizes help to indicate the location of foraging hotspots (Fig. 3). In addition to Ingenstrem Rocks and Seguam Pass, important hotspots for short-tailed albatross in the Aleutians included Near Strait, Samalga Pass, and the shelf-edge south of Umnak and Unalaska islands in the eastern Aleutians. In the Bering Sea, short-tailed albatross were distributed along the outer shelf-edge, but hotspots also were located along margins of Zhemchug, St. Matthews and Pervenets canyons. Only three short-tailed albatross were recorded on systematic bird transects archived in the North Pacific Pelagic Seabird Database (NPPSD). A total of 77,223 km^2 were surveyed, and 538,600 observations comprising 7.0 million seabirds were recorded, but short-tailed albatross were only seen once in the western Aleutians (2 in Buldir Pass) in 1975, and once more off the Alaska Peninsula in 1983.

About 3% of all observations in Alaska included sightings of more than five birds. Especially large groups (10–136 birds) were concentrated along the Bering Shelf canyons. All of these large groups were associated with fishing vessels, about 75% of these observations were made during fall (September–October), and most (85%) large flocks contained at least one bird in adult plumage. Using records where age-classes were noted ($n = 1907$ birds) and lumping them into two categories (adult versus sub-adult/juvenile), we found that large flocks (group size >5) contained a much higher proportion (43.6%) of adult-plumaged birds than smaller flocks (where group size $\leqslant 5$, 21.3%, $\chi^2 = 68.7$, $p<0.001$) or 'flocks' of individual birds (where group size $= 1$, 19.5%, $\chi^2 = 69.9$, $p<0.001$).

The largest aggregation of short-tailed albatross ever documented was observed during summer, 2004, by a crewman fishing near St. Matthews canyon (see Fig. 3). Josh Hawthorne (pers. commun.) observed *at least* 200 short-tailed albatross gathered on the water around his vessel after setting long-line gear for black cod (*Anoplopoma fimbria*). He took several photographs of birds around the

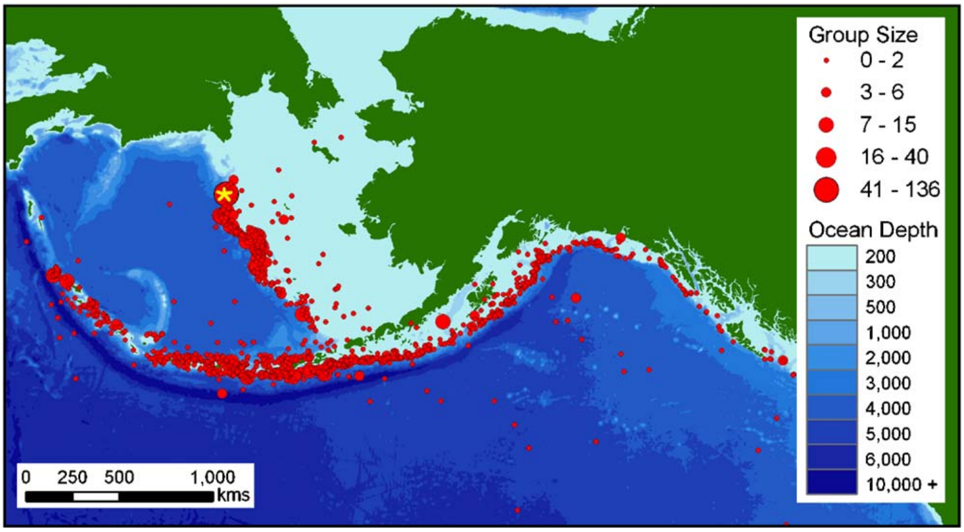

Fig. 3. Sightings ($n = 1432$) of short-tailed albatross in the North Pacific (1940–2004). See text for sources of data. Note the tight spatial association of albatrosses with the continental shelf edge in the Gulf of Alaska and Bering Sea, and on both sides of the Aleutian archipelago. The largest groups were located near the great canyons on the western Bering shelf, especially Zhemchug and St. Matthews canyons. The yellow asterisk indicates location of the large albatross flock shown in Fig. 5.

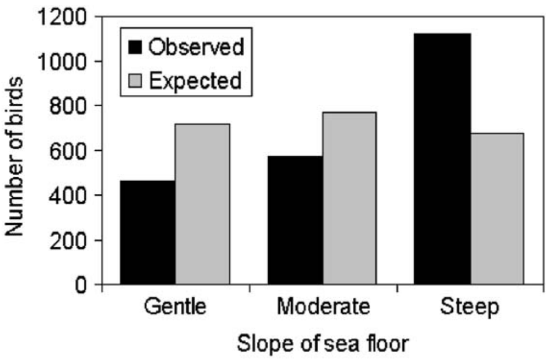

Fig. 4. Distribution of short-tailed albatross sightings over sea floors with slopes that are gentle, moderate and steep. The "expected" frequency would be found if birds were equally distributed among habitats (see Methods).

boat, including Fig. 5 (used here by permission). We systematically counted 97 short-tailed albatross in this picture. We matched cloud patterns with an adjacent picture taken shortly after Fig. 5, and counted an additional 39 short-tailed albatross on that picture, for a total count of at least 136 individuals. Not all birds surrounding the vessel could be captured in these two photographs (J. Hawthorne, pers. commun.), and so Hawthorne's minimum estimate of 200+ individuals seems reasonable.

4. Discussion

4.1. Myth of the "coastal albatross"

A long-standing mystery of 20th century ornithology has been the apparent abundance of short-tailed albatross remains in Native midden sites from southern California to St. Lawrence Island in the northern Bering Sea (Murie, 1959). How could these wanderers of the open oceans become a common diet item for coastal peoples? Early naturalists had a chance to observe short-tailed albatross under pre-harvest conditions. Nelson (1887) accurately defined its summer range from 50° N latitude northward through the Bering Sea as far as Bering Strait. Turner (1886) noted they were common in the Aleutian islands, generally far out at sea. Bean (in Nelson, 1887) reported them common at the mouth of Cook Inlet. Elliot (1898) indicated that short-tailed albatross were often seen about the Pribilof Islands in the 1850s, feeding on whale carrion associated with whaling vessels.

By the turn of the 19th century, millions of short-tailed albatross had already been harvested for the feather trade. No wonder Bent (1922) was disappointed to find not a single bird after cruising the length of the Aleutians. There are no records of short-tailed albatross at sea from that date until the 1940s (Sanger, 1972; Hasegawa and DeGange,

Fig. 5. Photograph of an aggregation of short-tailed albatrosses at sea during summer, 2004, near St. Matthews canyon on the western edge of the Bering Sea shelf. A total of 136 short-tailed albatrosses were counted on this and an adjacent photo, and many more were on the other side of the vessel (J. Hawthorne, pers. commun.). This represents about 10% of the total world population gathered into this one hotspot.

1982) despite the considerable efforts of marine ornithologists to find the bird (Murie, 1959). Since that time and up to the 1990s, only 56 records of birds at sea were available for analysis of their pelagic distribution (McDermond and Morgan, 1993).

In the absence of data on their pelagic distribution, ornithologists gleaned what they could from archeological evidence of short-tailed albatross distribution in the North Pacific. The bones of short-tailed albatross were common in midden sites at such far-flung localities as Pt. Mugu, California (Howard and Dodson, 1933), Yuquot, Vancouver Island (McAllister, 1980), and Kodiak, Umnak, Buldir and St. Lawrence islands in Alaska (Friedman, 1934; Murie, 1959; Yesner, 1976; Lefevre et al., 1997). Geist (in Murie, 1959) reported that short-tailed albatross were often caught in the pack-ice near St. Lawrence Island. Other seabirds found in these middens included nearshore species such as loons, geese, cormorants and gulls. From these records, and in the absence of many pelagic observations, Hasegawa and DeGange (1982) concluded that short-tailed albatrosses were abundant in shallow waters of coastal North America. McDermond and Morgan (1993) speculated further that the short-tailed albatross should be considered an inshore species.

4.2. Alternate explanations: coastal "hotspots" for short-tailed albatross

However, there are alternative explanations for finding short-tailed albatross in middens of coastal natives. Yesner (1976) suggested that Aleuts hunted short-tailed albatross as an adjunct to hunting for marine mammals in the island passes. He further speculated that "short-tailed albatrosses were formerly found in great numbers in such places as Samalga Pass between Umnak Island and the Islands of the Four Mountains, the site of a major nutrient-rich vertical upwelling system, associated with high densities of plankton and other marine life (Kelley et al., 1971)". Yesner noted a strong correlation in abundance of short-tailed albatross and northern fulmar (*Fulmarus glacialis*) bones in middens, but a poor correlation with coastal species such as cormorants, ducks and gulls, and offered this as further proof that short-tailed albatross were taken in the passes and at some distance from coastal village sites.

We think Yesner (1976) was correct: short-tailed albatross may have been reasonably common nearshore, but only where upwelling "hotspots" occurred in proximity to the coast. It would be more accurate to label the short-tailed albatross a continental shelf-edge specialist like the northern fulmar—which ranges to some extent over the shelf, including some coastal areas—but favors steeply sloped edges of the Gulf of Alaska continental shelf, Bering Sea shelf and Aleutian archipelago (Gould et al., 1982; Hatch and Nettleship, 1998).

Why should short-tailed albatross favor shelf-edges and areas with strong vertical mixing? Albatrosses have limited diving ability and are largely relegated to foraging at the sea surface (Hyrenbach et al., 2002). Diet of the short-tailed albatross is poorly known, but includes various squid species, flying fish, and crustaceans (Tickell, 2000). The continental shelf-edge and other areas of upwelling or vertical mixing are more productive and bring prey closer to the surface where they can be exploited by surface feeders such as albatross (Tickell, 2000; Hyrenbach et al., 2002).

Upon closer examination, most accounts of coastal "hotspots" for the short-tailed albatross based on their presence in middens can be explained in light of oceanographic processes. Pt. Mugu, California, is situated on the deep Santa Barbara Channel, and is exposed to seasonal coastal upwelling (Oey et al., 2001). Similarly, the Monterey Bay canyon is well known for its strong upwelling and localized coastal productivity (Croll et al., 2005) and short-tailed albatross were historically viewed commonly there from shore (Loomis, 1918). The Yaqout midden is situated on the west coast of Vancouver Island, where the Nootka people hunted whales and albatross in cool waters upwelled by the Juan de Fuca canyon eddy and coastal wind forcing (Burger, 2003; Hickey and Banas, 2003). Farther north, intense upwelling of west-ward flowing currents at the mouth of Cook Inlet and on the east coast of Kodiak Island accounts for shelf-edge levels of productivity found there—more than 150 km from the actual shelf-edge (Sambrotto and Lorenzen, 1987; Piatt, 1994; Speckman et al., 2005).

In the Aleutian archipelago, strong upwelling or vertical mixing may occur around relatively small island shelf systems, depending on the strength of prevailing currents and tidal influence (Kelley et al., 1971; Hunt et al., 1993; Stabeno et al., 1999; Drew et al., 2003; Ladd et al., 2005a, b). Vertical mixing is more vigorous west of (and including) Samalga pass, where relatively short, deep and wide passes allow for higher current speeds and volume transport (Swift and Aagaard, 1976; Ladd et al., 2005b, Stabeno et al., 2005). Correspondingly, short-tailed albatross are more abundant in Samalga pass, and passes to the west (Jahncke et al., 2005).

Perhaps the most paradoxical "coastal" observation is that of short-tailed albatross at St. Lawrence Island and Bering Strait, more than 1000 km from the Bering Shelf edge. Once again, this can be explained by oceanographic processes. The Anadyr Current flows north along the coast of the Chukotsk Peninsula and into Bering Strait, advecting cold, plankton-rich Bering slope water into the Chukchi Sea (Springer et al., 1989). Strong vertical mixing occurs as this oceanic water squeezes past St. Lawrence and Diomede islands, creating upwelling plumes downstream. This supports shelf-edge densities of planktivorous seabirds at great distance from the actual shelf-edge (Piatt and Springer, 2003) and, apparently, shelf-edge specialists such as the short-tailed albatross and northern fulmar.

4.3. Shelf-edge and canyon habitats: principal "hotspots" for short-tailed albatross in Alaska

The majority of short-tailed albatross sightings in our database were located on the continental shelf edge of Alaska (Fig. 3). In the eastern and northern Gulf of Alaska, the offshore shelf-break and slope domain is influenced by the Alaska Current, a broad (300 km), sluggish (<15 cm/s) counter-clockwise flow with weak horizontal and vertical gradients (Reed and Schumacher, 1986). Short-tailed albatross abundance is greatly diminished along the east gulf coast and south to SE Alaska (Fig. 3). To the west of the Kenai Peninsula, the Alaska Current is transformed into the Alaska Stream, a narrow (100 km), swift (100 cm/s) flow that creates strong vertical and horizontal gradients in the slope domain. The stream continues westward along the south side of the Alaska Peninsula and Aleutian Islands, maintaining strong flow until about 180 °W (Stabeno et al., 1999). Short-tailed albatross abundance was highest along this eastern Aleutian shelf-edge, particularly south of Unalaska and Umnak islands.

The topography of the northern Gulf of Alaska continental shelf is irregular, and cut by more than a dozen major troughs and canyons that promote the formation of eddies, induce upwelling along the shelf edge, and enhance vertical mixing over the shelves (Reed and Schumacher, 1986; Allen et al., 2001). This vertical mixing over the shelf apparently draws short-tailed albatross in from the shelf edge. For example, east and northeast of Kodiak Island are several major valleys including Amatuli Trough, Stevenson Trough, Chiniak Trough, and Kiliuda

Trough which separate four small banks including North, Middle and South Albatross banks. Short-tailed albatross were observed in small numbers over the entire area (Fig. 3).

In the Bering Sea, short-tailed albatross were concentrated along the continental shelf-edge in a tight band that corresponded to the location of the narrow, energetic shelf-break front (Coachman, 1986). This shelf-edge domain, or "green-belt", extends around the perimeter of the Bering Sea (Springer and McRoy, 1996). The interaction of strong tidal currents with the abrupt, steep shelf break promotes upwelling at the front (Coachman, 1986) and this helps bring nutrients to the euphotic zone where they support exceptionally high levels of primary production (Springer and McRoy, 1996). In turn, the shelf edge domain supports extremely high densities of zooplankton, mesopelagic fish and cephalopods (Sinclair et al., 1999), and this attracts pelagic predators such as fur seals (Robson, 2001) and seabirds (Shuntov, 1993), including short-tailed albatross.

The Bering Sea shelf edge is cut by seven major canyons (Bering, Pribilof, Zhemchug, Middle, St. Matthews, Pervenets, and Navarin canyons). Several of these canyons are larger than the Grand Canyon, and have a strong influence on the flow of water along and onto the shelf (Stabeno et al., 1999). Canyons may serve to channel water and food up onto the shelf edge, creating focused hotspots along the coast or shelf-edge (Vetter, 1994; Allen et al., 2001; Burger, 2003; Hickey and Banas, 2003; Croll et al., 2005). Canyons seem to be particularly attractive to short-tailed albatross (Figs. 3 and 5), perhaps because they may concentrate preferred shelf-edge prey in eddies (Allen et al., 2001).

A few short-tailed albatross were also seen over the southeast Bering Shelf and up to a distance of 200–300 km inwards from the shelf edge (Fig. 3). Few appeared beyond this distance, which corresponds to the location of the well-defined "middle front" between the middle and outer domains, positioned at approximately the 100 m depth contour (Coachman, 1986). Vertical mixing of waters at the front is strongly influenced by tides, and the resultant upwelling may attract seabirds to the front (e.g., Schneider, 1982).

4.4. Bias in the data sets

Most of the data presented here were collected opportunistically and we have no quantitative measure of survey effort in coastal, shelf and oceanic waters. It is prudent to ask if the results were skewed by a concentration of effort in shelf-edge habitat. Most (85%) of the data records shown in Fig. 3 were obtained after 1995, when agency concerns resulted in wide-spread efforts to document the distribution and abundance of short-tailed albatross in Alaska. Prior to this time, most of the records derived from sightings by marine ornithologists from ships of opportunity, and there is no reason to suspect a bias towards shelf-edge habitat. If anything, observers were just as likely to be traveling across the open Pacific (McDermond and Morgan, 1993, and references therein). During the 1970s and 1980s, a vast survey effort took place under the Outer Continental Shelf Environmental Assessment Program (OCSEAP) and as suggested by the name, most of the effort was focused on the Alaskan continental shelves, including coastal and nearshore habitats (Gould et al., 1982; NPPSD, 2004). Our analyses of these data turned up only three short-tailed albatross, all in shelf-edge waters. In fairness, we suspect that these early surveys were handicapped in documenting bird distribution by the rarity of short-tailed albatross in the North Pacific at that time (Hasegawa and DeGange, 1982).

During the 1990s, both survey effort and albatross populations increased in Alaska. A subset ($n = 396$) of albatross records provided to the Fish and Wildlife Service indicated that most sightings came from observers working on: (1) halibut longline surveys (54%), which were typically scattered over the entire continental shelf in the Gulf of Alaska and to a much lesser degree on the outer shelf in the Bering Sea (Melvin et al., 2004), (2) crab surveys (21%), scattered over the middle and outer shelves in the Gulf of Alaska and Bering Sea (NMFS, 2005), (3) groundfish trawler surveys (16%) conducted throughout the eastern Bering Sea shelf (NMFS, 2005), and (4) sablefish longline surveys (7%) which were concentrated along the shelf-edge (NMFS, 2005). Our picture of short-tailed albatross distribution (Fig. 3) is therefore probably biased towards shelf-edge records, but certainly not just an artifact of observation effort. Similarly, short-tailed albatross observed from the *Tiglax* (Fig. 1) were almost exclusively associated with shelf-edge habitat, while the vessel spent far more time in transit over the shallow island shelves, passes and nearshore (see Methods). We conclude that if short-tailed albatross were foraging regularly in coastal and shelf waters of Alaska, the data compiled here would have revealed that pattern.

4.5. Implications for conservation

Today, the short-tailed joins 15 other albatross species (out of 21 total) that are listed as threatened with extinction in the IUCN Red Book List (IUCN, 2004). Modern threats at sea include contamination with organochlorine, heavy metal and oil pollution, ingestion of plastic debris, entanglement in fishing gear, and most notably, bycatch in long-line fisheries for tuna, billfish and groundfish (Tickell, 2000). The latter threat is of particular concern for short-tailed albatross in marine waters of Alaska (Federal Register, 2000), and considerable effort has been directed at mitigating impact of those fisheries by the USFWS, NMFS and fishing industry (Melvin and Parrish, 2001; Federal Register, 2004). One impediment to protecting short-tailed albatross from fishery impacts has been the absence of information on where concentrations of birds are located at sea (Federal Register, 2000). Data presented in this paper help to fill this information gap, and further suggest that short-tailed albatross have fairly narrow habitat requirements.

Most other albatrosses forage widely over the world's oceans and appear to use a broader range of habitats (Tickell, 2000). For example, both Laysan (*Phoebastria immutabilis*) and black-footed (*P. nigripes*) albatross are widely dispersed over pelagic areas of the central North Pacific (Springer et al., 1999) and spend most of their time transiting or foraging over abyssal waters, occasionally foraging along the continental shelf edge (Hyrenbach et al., 2002). Unless attracted by fishing vessels, they do not appear to concentrate any more at the shelf break than they do in the oceanic domain (Gould et al., 1982). In contrast, the black-browed albatross (*Thalassarche melanophrys*) is a shelf and shelf-edge specialist almost throughout its range in the southern hemisphere (Weimerskirch et al., 1997; Tickell, 2000). Other albatross species utilize to varying degrees frontal systems, continental shelves and shelf-breaks, and it is becoming increasingly apparent that each species has unique preferences during at least part of their breeding cycle (J. Croxall, pers. commun.) related at least in part to different dietary preferences (Tickell, 2000). But aside from the Galapagos albatross (*P. irrorata*), which forages almost exclusively over a relatively small triangle between the Galapagos Islands and the continental shelf off Ecuador and Peru (Anderson et al., 1997; Tickell, 2000), no other albatross of the world has such a narrow and predictable range of foraging habitat as the short-tailed albatross in Alaska marine waters.

By definition, a marine "hotspot" is a relatively small area in which we expect to find animal aggregations repeatedly. It is precisely the elements of small-scale predictability and repeatability that make hotspots attractive for conservation purposes (Etnoyer et al., 2004; Royer et al., 2004). For example, the flock of ca. 200 short-tailed albatross observed near St. Matthews Canyon during 2004 represented about 10% of the entire world population at the time, and it appears that such aggregations are predictable at canyons on the outer shelf of the Bering Sea. Mitigation of potentially threatening activities such as oil development or fishing can be accomplished by regulating the scope of activities allowed within hotspots. In the case of short-tailed albatross, its strong link to permanent topographic features such as canyons, shelf-edges and passes makes at-sea conservation measures a realistic part of an overall strategy to restore this endangered species (Yen et al., 2004; Croll et al., 2005).

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