AT-SEA DISTRIBUTION OF RADIO-MARKED ASHY STORM-PETRELS *OCEANODROMA HOMOCHROA* CAPTURED ON THE CALIFORNIA CHANNEL ISLANDS

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SUMMARY

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Small, rare and wide-ranging pelagic birds are difficult to locate and observe at sea; little is therefore known regarding individual movements and habitat affinities among many of the world's storm-petrels (Family Hydrobatidae). We re-located 57 of 70 radio-marked Ashy Storm-Petrels *Oceanodroma homochroa* captured at three colonies in the California Channel Islands: Scorpion Rocks (2004, 2005), Santa Barbara Island (2004) and Prince Island (2005). Between 23 July and 22 September 2004, and 5 July and 4 August 2005, we flew 29 telemetry surveys, covered more than 65 000 km^2 (2004) and 43 000 km^2 (2005) of open ocean from San Nicolas Island north to the Farallon Islands and obtained 215 locations from 57 storm-petrels at sea. In both years, radio-marked storm-petrels were aggregated over the continental slope from Point Conception to Point Buchon, within the western Santa Barbara Channel, and over the Santa Cruz Basin between Santa Cruz, San Nicolas and Santa Barbara islands. Individuals captured in the Channel Islands ranged more than 600 km and were located as far north as Gulf of the Farallones National Marine Sanctuary. This is the first study to use radiotelemetry to determine the at-sea distribution and movements for any storm-petrel species.

Key words: Ashy Storm-Petrel, *Ocanodroma homochroa,* radiotelemetry, Channel Islands, at-sea distribution, use areas

INTRODUCTION

> "From the day that I saw my first Petrel dancing over the waves of the Pacific none of the birds of southern California so thoroughly interested me or so completely baffled all attempts at a more intimate acquaintance."
> —A.W. Anthony 1898

The Ashy Storm-Petrel *Oceanodroma homochroa* is endemic to the southern California Current System (CCS) and breeds only on Californian islands (including northern Baja California, Mexico) and a few mainland sites (Carter *et al.* 1992, Ainley 1995, McChesney *et al.* 2000, Spear & Ainley 2007, Carter *et al.* 2008). Storm-petrels are long-lived (*c.* 30 years), exhibit delayed first breeding and have low reproductive output [one egg annually (Warham 1990)]. These life history traits are associated with populations that may experience rapid declines and slow recoveries. In 1991, the total world breeding population of Ashy Storm-Petrels was estimated at 7200 birds (Carter *et al.* 1992). The Ashy Storm-Petrel is designated by the California Department of Fish and Game (CDFG) as a Bird Species of Special Concern (Remsen 1978, CDFG 1992, Carter *et al.* in press) and also is recognized by the IUCN as Endangered (Birdlife International 2004).

In the Channel Islands National Park (CINP), Ashy Storm-Petrels nest at scattered locations on San Miguel, Santa Cruz and Santa Barbara islands and on islets and offshore rocks. Ashy Storm-Petrels do not excavate burrows; they usually nest in crevices of talus slopes, rock walls, sea caves, cliffs and driftwood (Hunt *et al.* 1981, Carter *et al.* 1992, McIver 2002). Laying dates at Santa Cruz Island range from late March through late October, with mean hatching dates in late July (McIver 2002).

Unlike most other storm-petrels, Ashy Storm-Petrels are non-migratory and reside entirely within the California Current System (CCS) (Ainley 1995, Spear & Ainley 2007). The species' distribution at sea is generally confined to the area just seaward from the continental shelf break (i.e. continental slope domain, 200- to 2000-m depth) and within the pelagic (>2000-m depth) waters of the offshore CCS from northern Baja California, Mexico, to central California. Within this restricted range, they are patchily distributed at sea (Ainley & Lewis 1974, Spear & Ainley 2007).

Off southern California, Ashy Storm-Petrels were most numerous during April through June near San Miguel Island, from the Santa Rosa Ridge to 50 km south of the island; birds in that area were associated with the shelf break and the warm (i.e. more than 13°C) sides of thermal upwelling fronts (Briggs *et al.* 1987). Densities were greatest off southern California in May and September (1999–2001), with aggregations in the western Santa Barbara Channel, over the Santa Cruz Basin and from 10 km to 70 km offshore from San Miguel Island to Point Buchon (Mason *et al.* 2007).

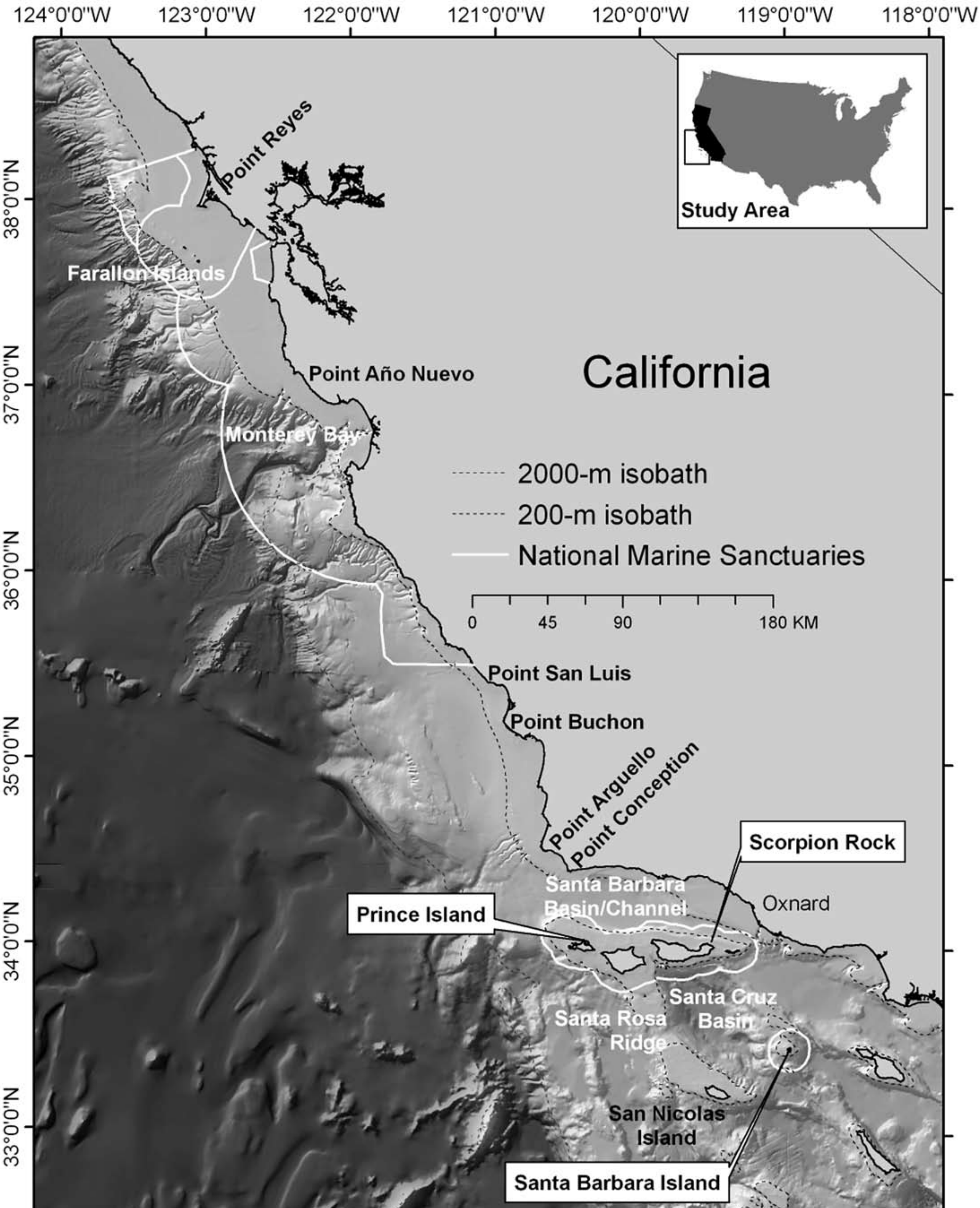

Fig. 1. Southern California study area, the California Channel Islands, major bathymetric features, and Ashy Storm-Petrel capture sites: Prince Island, Scorpion Rocks and Santa Barbara Island. Thin dotted lines demarcate the 200-m and 2000-m isobaths.

Our primary objective here is to describe the at-sea distribution of Ashy Storm-Petrels off southern California during the late incubation through early chick-rearing periods (July through September). This study focuses on birds captured and fitted with small radio transmitters at three widely-separated breeding areas in CINP during 2004 and 2005. Radiotelemetry has been used previously to locate nest sites of storm-petrels on Heimøya Island, Norway (see Nygård & Einåvik 1991); and in an unsuccessful effort to locate breeding sites, other researchers attached three transmitters to recently rediscovered New Zealand Storm-Petrels *Oceanites maorianus* captured at sea (B. Stephanson pers. comm.). To our knowledge, this study is the first to use radiotelemetry to assess the at-sea distribution of any of the world's hydrobatids.

STUDY AREA AND METHODS

We studied Ashy Storm-Petrels captured at three sites in the California Channel Islands (Fig. 1): Prince Island (34°05′N, 120°20′W; 16 ha; 90 m elevation), Scorpion Rocks (34°05′N, 119°30′W; less than 1 ha; 15 m elevation), and Santa Barbara Island (33°28′N, 119°02′W; 259 ha; 193 m elevation). The Channel Islands are located within the Southern California Bight (SCB), a geo- and oceanographic region demarcated by an abrupt change in the orientation of the coastline south of Point Conception from north–south to east–west trending. During the spring and summer, the surrounding waters are seasonally enriched by coastal upwelling, primarily north of Point Conception. Flow is partially directed into and recirculated within the western Santa Barbara Channel, which overlies the Santa Barbara Basin (500 m in depth; Harms & Winant 1998; Fig. 1).

Prince Island, located 2 km north of San Miguel Island, is a steep-sided island whose flanks exhibit loose soils, boulders and many rocky crevices.

Scorpion Rocks, a cluster of four small islets, is adjacent to the Anacapa Passage, less than 1 km north of eastern Santa Cruz Island. The larger two islets are composed of volcanic rock topped with a mixture of loamy soil and guano, containing numerous cracks, crevices and rocky pockets. The southernmost islet (adjacent to our capture site and separated from it by a narrow wash channel) provides nesting habitat for Ashy Storm-Petrels.

Ashy Storm-Petrels also nest to the west of Scorpion Rocks in nearby sea caves and on small islets along the north side of Santa Cruz Island (McIver 2002). Extensive nesting habitat is available on cliffs along the north side of Santa Cruz Island, but because those areas are inaccessible, the number of nesting birds is unknown.

Scorpion Rocks and the eastern Santa Barbara Channel are sheltered by mainland California from the prevailing northwesterly winds during the spring and summer, and the influence of upwelling is more variable than at Prince Island. Santa Barbara Island is situated in the SCB, 80 km southeast of Anacapa Island. The dominant bathymetric feature adjacent to Santa Barbara Island is the Santa Cruz Basin (1670 m in depth) bounded to the west by the Santa Rosa Ridge, and separating Santa Cruz and Anacapa islands from Santa Barbara and San Nicolas islands (Fig. 1). During the spring and summer, ocean conditions near Scorpion Rocks and Santa Barbara Island are generally warmer, more saline and more stratified than the waters off Prince Island, which are directly downstream from the Point Conception upwelling center and thus are cooler, of lower salinity, more mixed, and of greater primary productivity [i.e. greater surface chlorophyll *a* concentrations (Lynn *et al.* 2003)]. In 1991, an estimated 1150 breeding Ashy Storm-Petrels were present at Prince Island, 140 at Scorpion Rocks, and 874 at Santa Barbara Island (Carter *et al.* 1992).

Capture and marking

During 2004 and 2005, we captured and radio-marked (Fig. 1, Table 1) 70 Ashy Storm-Petrels at Scorpion Rocks (n = 28 in 2004, n = 17 in 2005), Santa Barbara Island (n = 15 in 2004), and Prince Island (n = 10 in 2005). We captured birds at night using nylon mist nets (four-tier, 50/2 38-mm 2.6×12 m denier and thread: Avinet, Dryden, New York) and vocal attraction techniques (Grubb 1971, Ainley *et al.* 1990, Brown *et al.* 2003).

During late incubation to early chick rearing, we used glue (Loctite 422) and two subcutaneous, 4-0 monofilament sutures (Ethicon Prolene, modified after Newman *et al.* 1999) to attach miniature radio transmitters [model A1030 in 2004, A2445 in 2005: Advanced Telemetry Systems (ATS), Isanti, Minnesota] dorsally to skin and feathers between the scapulae. Transmitters weighed less than 1.3 g [3% of mean petrel mass: 36.7 ± 2.0 g (standard deviation); n = 70) and had battery life expectancies of 50 days (model A1030) and 32 days (model A2445). We banded storm-petrels with US Fish and Wildlife Service size 1B leg bands and weighed them with a 100-g Pesola spring scale to the nearest 1 g. Marked birds were released approximately 5 m from the capture site.

TABLE 1
Survey effort and locations of 70 radio-marked Ashy Storm-Petrels in 2004 and 2005 for each area subset

Colony area	Year	Marked birds (n)	Sex (M:F:U)	Release dates	Surveys	Locations	Birds detected [n (%)]	Max. poss. locations (% achieved)
Scorpion Rocks	2004	15	1:13:1	21–22 Jul.	15[a]	50	12 (80)	180 (28)
	2004	13	5:8:0	18–19 Aug.	8[a]	13	11 (85)	88 (15)
Santa Barbara I.	2004	15	3:12:0	15–16 Aug.	8[a]	20	10 (67)	80 (25)
Scorpion Rocks	2005	17	0:4:13	7–8 Jul.	12[b]	79	15 (88)	180 (44)
Prince I.	2005	10	1:8:1	2–3 Jul.	14[b]	52	8 (80)	112 (46)
TOTAL		70	10:45:15		29	215	57 (81)	640 (34)

[a] 2004 radio-tracking surveys (15 surveys): 23, 24, 26 July; 2–5, 21–24 August; 2, 8, 22, 23 September.
[b] 2005 radio-tracking surveys (14 surveys): 5, 6, 11–21 July; 4 August.
M:F:U = male:female:unknown.

Determining the breeding status of storm-petrels captured in mist nets is problematic (Ainley *et al.* 1990, Warham 1996), but we maximized the likelihood of marking breeders by assessing brood-patch (bp) development (after Ainley *et al.* 1990, Carter *et al.* 1992) and noting regurgitation of stomach oil or other partially digested prey intended for chicks. Birds with bare (bp score = 2), bare and vascularized (bp score = 3), or refeathering (bp score = 3.5 and 4) brood patches were considered more likely to be breeders (Ainley *et al.* 1990). However, non-breeders may also develop bare brood patches (Warham 1996).

To determine sex, we collected a drop of blood on a Whatman FTA card (Whatman, Brentford, UK) by pricking the petrel's tarsal vein with a sterile 26-gauge needle. Archived blood was stored dry and analyzed in a lab (CL Baduini, Claremont Colleges, CA) using molecular techniques (following Fridolfsson & Ellegren 1999, Dawson *et al.* 2001; A. Patel & C.L. Baduini pers. comm.).

Telemetry

We surveyed for radio-marked petrels at sea on 23, 24 and 26 July; 2–5, 21–24 August; and 2, 8, 22, and 23 September 2004 (15 surveys total) and on 5, 6, 11–21 July and 4 August 2005 (14 surveys total). Surveys were conducted between 08h00 and 18h00 from fixed-wing, twin-engine Partenavia P-68 aircraft. To locate radio transmitters a maximum of once per flight, we equipped survey aircraft with a receiver (Model R4500: ATS) connected through a switch box to two wing-mounted, three-element, directional antennae (Gilmer *et al.* 1981). We scanned each radio frequency for 3 s, determined detection locations using a global positioning system (GPS), and noted time of day, signal strength and signal direction. Surveys were flown at 1200 m above sea level at 220–260 km h^{-1}. At that altitude, maximum lateral detection range based on reference transmitters placed at the colonies was 7–11 km. Survey patterns consisted of parallel lines spaced 7–20 km apart.

A single experienced observer estimated storm-petrel locations at sea by simultaneously recording the location of the airplane (GPS), signal direction relative to the airplane and signal strength at detection. For each signal detection, we used MATLAB (MathWorks, Natnik, MA) to generate an estimated petrel location (function *reckon.m*), which calculated a location based on the position of the airplane, the bearing toward the signal (nearest 45 degrees) and the range as estimated by signal strength. If we recorded multiple detections for an individual storm-petrel, we used MATLAB (function *meanm.m*) to calculate the geographic mean position from the set of estimated locations. If signal strength was recorded as "extra-strong" and detected on both sides of the plane, the petrel's location was estimated as equivalent to the geographic position (over the water) of the airplane at the time of detection. Similar methods have previously been used off southern California with similar transmitters and tracking equipment for surveys of Cassin's Auklets (Adams *et al.* 2004a, 2004b), and Xantus's Murrelets (Whitworth *et al.* 2000, Hamilton *et al.* 2006).

Tracklines from all surveys were imported to geographic information system software (ArcMAP 9.2: ESRI, Redlands, CA), in which we also created an 11-km buffer (22-km swath) around each trackline. We intersected the buffered tracklines for each survey with a 9- by 9-km pixel grid to create a raster surface of survey effort. This raster was then intersected with the subset-specific locations (e.g. Scorpion Rocks, 21–22 July 2004; Table 1) to generate a raster surface of number of locations per 9- by 9-km pixel. We calculated a gridded "locations per unit effort" (LPUE) for each subset of radio-marked storm-petrels released:

$$\mathrm{LPUE} = (n_{\mathrm{det}} / N_{\mathrm{max}}) / E \times 1000, \qquad (1)$$

where n_{det} is the number of detections per 9- by 9-km pixel, N_{max} is the maximum number of locations possible given the number of surveys and the total number of radio transmitters relocated, and E is the number of surveys per pixel. The resulting small quotient was scaled up by multiplying by 1000. Subset LPUE values were summed to graphically represent annual distributions that accounted for variable effort. Although this method essentially reduces the weighting of detections where survey effort was abundant (i.e. the Santa Barbara Channel), LPUE values for cells where radio-marked storm-petrels were located become relatively greater where survey effort was scarcer (i.e. Santa Cruz Basin and Monterey Bay in 2004). Values are presented as mean ± standard deviation unless otherwise noted.

RESULTS

Aerial telemetry and at-sea distribution

Our sample of radio-marked storm-petrels was biased toward females (Table 1). In 2004, 33 of 42 individuals (79%) sexed were female, and in 2005, 12 of 13 (92%) sexed were female. In 2005, 14 individuals could not be sexed because reagent problems prevented polymerase chain reaction amplification (C.L. Baduini pers. comm.). The main survey coverage (more than 65 000 km^2 in 2004, more than 43 000 km^2 in 2005; Fig. 2) ranged throughout southern-central California, but in both years was concentrated over the Santa Barbara Channel because flights originated from and returned to Oxnard, California. To search for missing birds, we flew wide-ranging surveys encompassing offshore waters from San Nicolas Island (33°30′N, 119°30′W) to Point Reyes (38°00′N, 123°00′W) in 2004 and to Point Buchon (35°26′N, 120°56′W) in 2005 (Fig. 2). In 2004, we located 77% (33 of 43) of marked birds (15 survey flights; Table 1). In 2005, we located 85% (23 of 27) of marked birds (14 survey flights; Table 1). In 2004, we achieved from 15% to 28% of the maximum possible locations for each subset of radio-marked petrels released (Table 1). In 2005, we achieved from 44% to 46% of the maximum possible locations for each subset of radio-marked petrels released (Table 1).

In 2004, storm-petrels were located over waters with a mean depth of 810 ± 547 m (n = 83 locations for 33 birds), an average of 38 ± 20 km from land (nearest island or mainland). Of all locations in that year, 92% occurred over the continental slope domain (i.e. 200–2000 m depth). In 2005, storm-petrels were located over waters with a mean depth of 1066 ± 561 m (n = 131 locations), an average of 32 ± 13 km from land (island or mainland). Of all locations in that year, 98% occurred over the continental slope domain.

In 2004, principal aggregation areas (i.e. clusters of relatively greater LPUE) were located approximately 70 km from shore between Point Buchon and Point Arguello and over the Santa Barbara Basin underlying the Santa Barbara Channel [Fig. 2(A)]. The Buchon–Arguello offshore area comprised individuals marked on both Scorpion Rocks (nine birds, 15 locations) and Santa Barbara Island (six birds, eight locations). The Santa Barbara Basin area was used solely by birds marked at Scorpion Rocks. In 2005, principal aggregation areas were the Santa Barbara Basin and Channel, and west of the Channel to approximately 45 km southwest of Point

Arguello [Fig. 2(B)]. The Santa Barbara Basin area was used by birds marked at Prince Island (three birds, nine locations) and Scorpion Rocks (seven birds, 12 locations). A third aggregation area in 2005 was centered over the Santa Cruz Basin [Fig. 2(B)]. The Santa Cruz Basin area was used primarily by birds marked at Scorpion Rocks (15 birds, 39 locations) and much less frequently by birds marked at Prince Island (three birds, four locations).

Although military training activities at San Nicolas Island during 2004 largely prevented us from surveying south of the northern Channel Islands, we detected radio-marked storm-petrels on several occasions over the Santa Cruz Basin [Fig. 2(A)]. During surveys from Point Sur to the Farallon Islands on 2 and 8 August 2004, we recorded a total of 20 locations from five of 10 individuals marked at Santa Barbara Island and relocated during surveys and 12 of 23 individuals marked at Scorpion Rocks and relocated during surveys. The LPUE from these two surveys off central California were aggregated over deep waters of the Monterey Canyon, near steep bathymetric relief and near submarine canyons off Point Año Nuevo [Fig. 2(A)]. The farthest-ranging individual was marked on Scorpion Rocks and located 21 km north of Southeast Farallon Island, more than 750 km from its capture site [Fig. 2(A)].

DISCUSSION

Using telemetry to track small far-ranging storm-petrels is difficult in comparison with studies of nearshore foragers (e.g. Adams *et al.* 2004a). Logistic constraints in 2004 prevented us from deploying all transmitters before we initiated survey flights; we therefore used an extended period of surveys to maximize the number of surveys for the complete set of radio-marked individuals. An unfortunate result was the overall low percentages of total possible locations achieved in 2004 (15%–28%). Lower success that year was partly the result of marking a subset of birds on Santa Barbara Island, combined with severe flight restrictions in the adjacent waters (i.e. Santa Cruz Basin). We were able to double our success (44%–46% total possible locations) the following year, when transmitters were deployed over a shorter interval and tracked more continuously immediately after deployment. Also, flights over the Santa Cruz Basin were less restricted in 2005, and we showed persistent use of that area by birds from Scorpion Rocks and Prince Island. Another factor limiting our success may be that we were tracking mostly non-breeding individuals (females) who were lured to mist nets using vocalizations. Female sample bias, small sample sizes, unequal tracking effort per subset of radio-marked birds and a relatively small number of tracking flights precluded meaningful statistical comparisons across seasons and years, or by sex. Despite such difficulties, our data contribute substantially to what is known about the at-sea distribution and habitat use of Ashy Storm-Petrels off southern California.

Results from this study are consistent with several previous investigations at sea; and being centered off southern California, they complement more detailed descriptions existing for the central-northern California region (i.e. Monterey Bay and the Gulf of the Farallones: Ainley & Lewis 1974, Briggs *et al.* 1987, Spear & Ainley 2007). Studies to date (including this one) off southern California reveal three main aggregation areas for Ashy Storm-

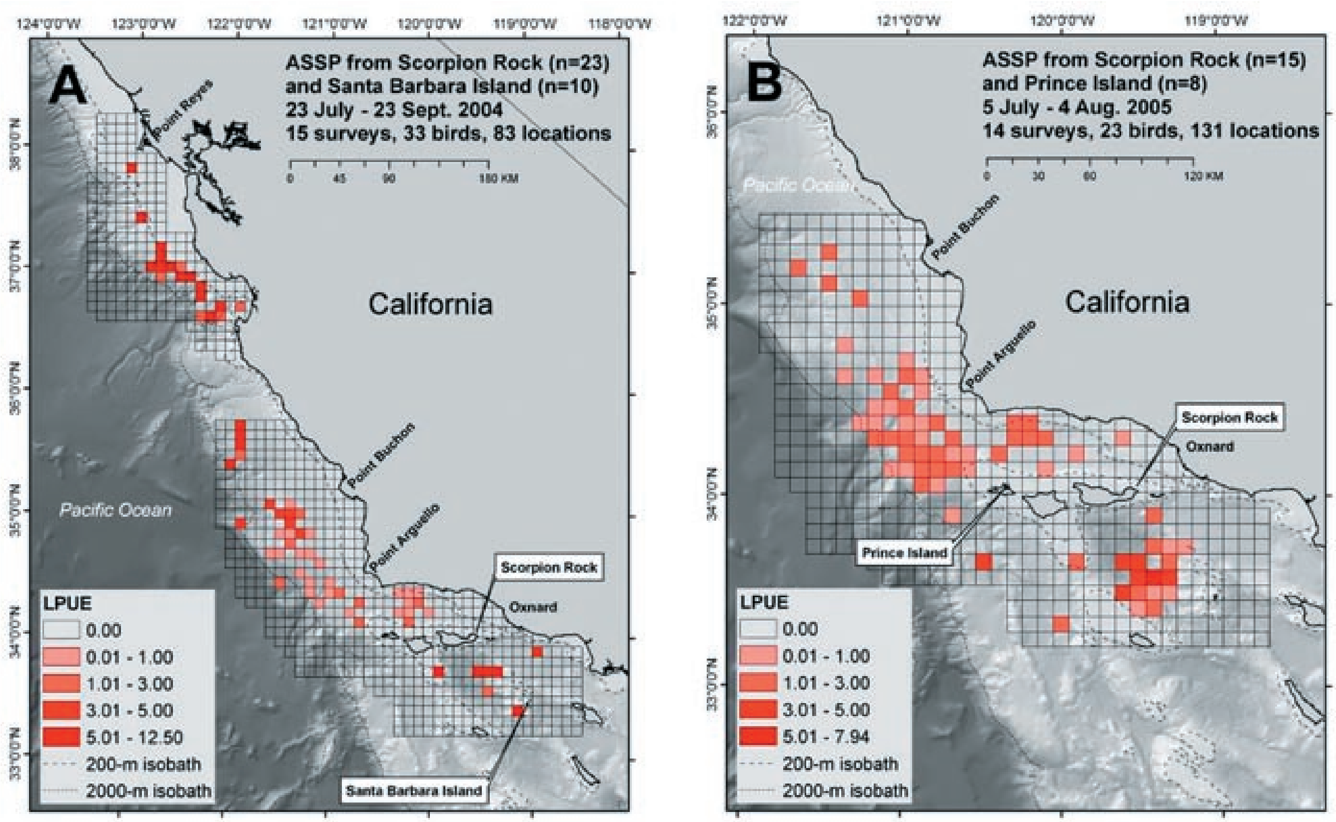

Fig. 2. Distribution of gridded (9- by 9-km pixel) "locations per unit effort" (LPUEs) for Ashy Storm-Petrels marked with radio transmitters and tracked off southern California. (A) Birds captured and marked at Scorpion Rocks and Santa Barbara Island in 2004. (B) Birds captured and marked at Scorpion Rocks and Prince Island in 2005. All grid-cells present were surveyed, and the calculated LPUEs adjust for unequal survey area coverage and changing numbers of radio-marked individuals across the survey period in each year (see Study Area and Methods).

Petrels: Santa Cruz Basin, western Santa Barbara Channel and the continental slope southwest of Point Buchon. Ashy Storm-Petrel locations (215 locations from 57 birds during two summers) from radiotelemetry are consistent with 194 sightings of the species during three years of aerial surveys off southern California [January, May and September of 1999–2002 (Mason *et al.* 2007)]. During aerial surveys in May and September 1999–2001, Mason *et al.* (2007) observed Ashy Storm-Petrels in greatest densities in the same areas where we documented aggregations using radiotelemetry and LPUE. Average May densities (one to four birds per kilometer) on aerial strip transects were greatest over the Santa Barbara Basin and Channel and the Santa Cruz Basin, with scattered sightings along the continental slope off Point Buchon south to 33°N and west of San Nicolas Island. During September 1999–2001, average densities were greatest over the western Santa Barbara Channel (fewer than 2 birds km^{-1}) and approximately 60 km west-southwest from Point Buchon (maximum recorded density: 18 birds km^{-1}; Mason *et al.* 2007). This pattern also is consistent with data compiled by the National Oceanic and Atmospheric Administration's National Centers for Coastal Ocean Science (NCCOS 2005), but unlike the data from our study and that of Mason *et al.* (2007), the NCCOS data do not indicate use of the Santa Cruz Basin area by Ashy Storm-Petrels, despite survey effort in that region. Off central to northern California, Ashy Storm-Petrels were more abundant over the continental slope and deep pelagic waters, and densities increased with SST, salinity and thermocline strength, but decreased with wind speed (Spear & Ainley 2007). It is likely that many potential locations that we failed to detect were farther offshore (i.e. depths in excess of 2000 m), beyond our survey capability.

Radiotelemetry allowed us some insight into colony-specific distributions at sea. In 2004, birds marked at Santa Barbara Island were not detected in the western Santa Barbara Basin and Channel, which was occupied exclusively by birds marked on Scorpion Rocks. Birds from Santa Barbara Island instead were located over the Santa Cruz Basin and in the area southwest of Point Buchon. Our ability to document use of the Santa Cruz Basin in 2004 (especially by petrels marked at Santa Barbara Island) was compromised, however, because of flight restrictions throughout the area. In 2005, the Santa Cruz Basin was used by birds from Prince Island, but to a greater degree by birds from Scorpion Rocks. Collectively, observations in both years showed that birds captured at all three colony areas at night used the Santa Cruz Basin by day.

In 2004, we documented a northward movement of individuals captured in the Channel Islands to Monterey Bay and the Gulf of the Farallones. That finding supports Ainley's (1976) suggestion that during the late summer through fall, large mixed flocks of storm-petrels, dominated by Ashy Storm-Petrels, include individuals from southern California and thus may constitute a significant portion of the world population. In 2004, large mixed-species flocks of storm-petrels were observed in Monterey Bay—"thousands" on 29 August 2004 and 4000 Ashy-Storm Petrels on 11 September 2004 over a cool (13.8°C) "bubble" of water (D. Shearwater unpubl. data).

The principal areas of aggregation we describe likely coincide with areas of increased food availability, as inferred from prey life history patterns (i.e. spawning phenology), prey behavior (i.e. diel vertical migration), effects on prey distribution of ocean features such as convergences or fronts, or combinations of such factors. Although the diet of Ashy Storm-Petrels has not been adequately described or quantified, it is thought to consist of "small fish" (perhaps myctophids), euphausiids (e.g. *Thysanoessa spinifera*) and other crustaceans, and young squid (Ainley 1995, G. McChesney pers. comm.). Potential food items that dominate the spring–summer neuston off California include fish eggs and larvae, copepods, euphausiids and decapods.

Eddies and their convergent margins associated with storm-petrel aggregation may enhance the availability of certain prey items important to foraging Ashy Storm-Petrels. For example, the western Santa Barbara Channel aggregation area also is an important summer foraging habitat for other planktivores including Cassin's Auklet *Ptychoramphus aleuticus* (Adams *et al.* 2004a, 2004b) and blue whales *Balaenoptera musculus* (Fiedler *et al.* 1998). The area functions as an "upwelling shadow" (Graham & Largier 1997) where relatively cool, nutrient-rich waters upwelled along the coast north of Point Conception recirculate and stimulate a relatively stable and closed system with enhanced local primary production. Stable (i.e. days to week-long) mesoscale cyclonic eddies imaged by coastal radar (Beckenbach & Washburn 2004) were present during July 2004 and 2005 [data from the University of California–Santa Barbara Institute for Computational Earth System Science (current data available online at www.icess.ucsb.edu/iog/codar_realtime.htm)]. In previous years, such features contained marked concentrations of larval and juvenile fish, including rockfishes *Sebastes* spp., California Smoothtongue *Leuroglossus stilbius* and myctophids near the surface within eddy centers (Nishimoto & Washburn 2002). Similar features and strong thermal fronts in the vicinity of Santa Barbara Island and the Santa Cruz Basin (DiGiacomo & Holt 2001) have been shown to facilitate feeding by other surface-foraging birds (DiGiacomo *et al.* 2002).

The ichthyoneuston of the southern CCS is dominated by two species: Pacific Sardine *Sardinops sagax* and Northern Anchovy *Engraulis mordax,* with lesser numbers of Pacific Saury *Cololabis saira* and rockfishes *Sebastes* spp. (Moser *et al.* 2002). Storm-petrel aggregation coincides spatially and seasonally with the spawning aggregations of sardines and anchovies. In spring and summer, sardines spawn buoyant spherical eggs [1.3–2.1 mm diameter (Watson & Sandknop 1996)] generally offshore where warm (12–14°C) waters of the inner California Current abut cool waters upwelled along the central to southern California coast (Checkley *et al.* 2000, Lo *et al.* 2005). Coincident with Ashy Storm-Petrel chick rearing, maximal larval sardine abundances off southern California occur in April and July through August (Moser *et al.* 2002). Checkley *et al.* (2000) documented the highest concentrations of sardine eggs (more than 30 eggs m^{-3}) during spring in water at 13–14°C southwest of Point Buchon and extending south and westward from the Santa Rosa Ridge. In contrast, anchovy eggs [1.3 mm diameter (DiGiacomo *et al.* 2002)] and larvae were most abundant in cooler and more saline upwelled water masses closer to the coast, with the greatest concentrations within the Southern California Bight (Moser *et al.* 2002) and near mesoscale thermal fronts over the Santa Cruz Basin (Checkley *et al.* 2000). Maximum density of anchovy eggs throughout the water column was found at the surface [i.e. neuston (Moser & Pommeranz 1990)].

Although generally one to two orders of magnitude less abundant than anchovy, saury eggs and larvae also may be of value to foraging storm-petrels. Saury eggs float and may stick to each other and to floating objects, thereby providing a readily exploitable food source. Coincident with the storm-petrel chick-rearing period, neustonic larvae reach peak abundance in May and July through August, generally in warmer waters beyond the inner California Current transition zone (Moser *et al.* 2002). Dietary importance of saury for Ashy Storm-Petrels in more nearshore areas may increase during relaxation of upwelling, when warm offshore waters encroach on the coast.

The aggregation of storm-petrels in the western Santa Barbara Channel was in close proximity (most locations fewer than 10 km) to four active oil production platforms on the northern rim of the Santa Barbara Basin. Such structures provide by far the most significant vertical, hard substrate habitat in the region, especially for numerous rockfishes *Sebastes* spp., other fishes and invertebrates (Love *et al.* 2003). Currently, 26 oil and gas platforms are active off southern California. Storm-petrels may be attracted to platforms because of relative prey abundance or because of light, sound and olfactory cues (Hutchison & Wenzel 1980, Reed *et al.* 1985, Ainley *et al.* 1990, Scofield 1990, Warham 1996, Nevitt 1999, Carter *et al.* 2000, Keenan *et al.* 2007). In the Bering Sea, Baird (1990) found storm-petrels in greater densities closer to an offshore drilling rig, and densities reached six times that level after the rig initiated drilling operations.

Future studies should investigate oceanographic features associated with Ashy Storm-Petrel foraging—sensed remotely from satellites, derived from oceanographic models or measured *in situ.* Dietary information, especially in the context of ocean habitats, will enhance our understanding of contaminant pathways (Spear *et al.* 1995, Mato *et al.* 2001), toxicologic threats (Coulter & Risebrough 1973, Boersma 1986), and species habitat-restoration monitoring (MSRP 2005) relevant to Ashy Storm-Petrels. Additional efforts should seek to understand this species' response to artificial nocturnal lighting [e.g. oil platforms (Wiese *et al.* 2001) and recreational and commercial vessels near colonies] and the significance of future energy infrastructure, including natural gas facilities and offshore wind turbines.

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