ASHY STORM-PETREL *OCEANODROMA HOMOCHROA* MIST-NETTING AND CAPTURE RATES IN THE CALIFORNIA CHANNEL ISLANDS, 2004–2007

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SUMMARY

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The California Channel Islands (CCI) provide essential nesting habitat for a significant portion of the world's Ashy Storm-Petrel *Oceanodroma homochroa* (ASSP) breeding population, but true abundance at this locality is not well known. Land-based nocturnal mist-netting has been conducted sporadically in the CCI since 1976, with variation in techniques and methods. Using a standardized catch-per-unit-effort (CPUE) is one of the few methods available to monitor trends in relative abundance, but there currently are no guidelines for a standardized, repeatable approach for the CCI. During 2004–2007, I conducted mist-netting for ASSP at three colony sites within the CCI: Scorpion Rock (SR), Santa Barbara Island (SBI), and Prince Island (PI). During 47 site-nights (22 sessions), I obtained 1 177 unique captures, including 34 recaptures (2.9%) of previously banded individuals. ASSP captured at all three islands showed peak proportions of fully developed incubation patches in July and August. ASSP captured in the CCI had 5%–9% lower body mass than individuals captured off central California during the early 1970s; it is not known whether this difference reflects natural inter-annual variation or differences in body condition. ASSP from SBI had the lowest body condition index (BCI) compared with those from PI and SR, indicating different foraging environments. Overall, 22 netting-sessions at three islands yielded a power of 84% to detect a 30% lesser CPUE; 19 sessions would be required in a future effort to evaluate this level of change. Evaluation of additional factors that affect CPUE and other independent measures of abundance or attendance should be included in future mist-netting efforts.

Keywords: Ashy Storm-Petrel, *Oceanodroma homochroa*, mist-netting, Channel Islands, catch-per-unit-effort, standardized monitoring, population trends

INTRODUCTION

The Ashy Storm-Petrel *Oceanodroma homochroa* (ASSP) is endemic to the California Current System (CCS) and nests only on Californian islands, islets and rocks (including the Pacific coast of northern Baja California, Mexico) and a few mainland sites (Ainley 1995, Carter *et al*. 2015a). Most breeding birds off southern California nest in the northernmost California Channel Islands (CCI). Here, as elsewhere, ASSP are extremely cryptic and nest among rocks on talus slopes, within rocky crevices, in sea caves and on steep inaccessible cliffs (summarized in Ainley 1995, Carter *et al*. 2008). Storm-petrels are long-lived (*circa* 30 years), exhibit delayed first breeding and have low reproductive output (Warham 1996). ASSP females lay a single egg, generally from late March through late October, including re-lays, with mean hatching dates in late July (McIver 2002).

The true abundance of ASSP remains poorly known. Most recent estimates tabulated by the US Fish and Wildlife Service (USFWS 2013) indicate a world breeding population of 10 215 individuals, with 38% nesting in the CCI and 56% nesting at the largest colony on southeast Farallon Island (SEFI; approximately 600 km north of the CCI; see also Carter *et al.* 2016). At-sea derived population estimates off central California (1980–1995) indicate noticeably more ASSP occurring off central California than southern California (Briggs *et al.* 1987), as well as a greater average estimated number of individuals during spring (7 287) than during autumn (4 207), possibly reflecting annual movement of southern California breeders out of central Californian waters during summer–autumn (Spear & Ainley 2007). At-sea densities off southern California increased between 1975–1983 and 1999–2002. Consistent with the seasonality described by Spear & Ainley (2007), numbers were greatest in May and September, then declined by January (Mason *et al.* 2007), presumably when southern California breeders disperse to at-sea areas off central California (*cf.* Adams & Takekawa 2008). Breeding season mark-recapture analyses on SEFI indicated that ASSP there declined 30%–40% from 1972 to 1992 (Sydeman *et al.* 1998), but the authors suggest caution when interpreting these data because of assumptions with mark-recapture analyses and lack of understanding of inter-annual attendance patterns at SEFI related to ocean climate variability. Due to variable and low population size estimates, small range and numerous unabated threats, the California Department of Fish and Game (CDFG, now Department of Fish and Game) designated ASSP as a Bird Species of Special Concern (breeding), Priority 2 (Carter *et al*. 2008); the species was included on both prior special concern lists (Remsen 1978, Priority 3; CDFG 1992). The USFWS considered listing the species under the Endangered Species Act in 2009 with further status review in 2013, but concluded listing was not warranted because the species is currently undergoing natural population fluctuations, there is no change in historic range, and available data (from SEFI; see Bradley *et al*. 2011) did not indicate long-term decline (Federal Register 2013).

ASSP has been identified as a preferred species for management and restoration to mitigate negative effects suffered from exposure to DDT/DDE in the Southern California Bight marine ecosystem (MSRP 2005, Carter *et al*. 2016). Given its life-history traits, cryptic breeding ecology (e.g. nocturnal attendance, remote island colonies

and inaccessible crevice nesting), poorly understood population status, threats both at colonies and at sea, and active restoration efforts, a better understanding of population size and techniques for evaluating trends in abundance within the CCI will be essential to help inform actions to protect, enhance or monitor populations.

Capture of storm-petrels using mist-nets combined with vocal attraction can provide useful information at known and potential breeding locations (Carter *et al*. 1992, Buxton & Jones 2012, Buxton *et al*. 2013, Rayner *et al*. 2013, Ismar *et al*. 2015). Information gained includes species presence as well as inter-colony seasonal and inter-annual variability in attendance (Bradley *et al*. 2011), population structure (Ismar *et al*. 2015), timing of migration (Medieros *et al.* 2012), breeding phenology, morphology, molt (Ainley *et al*. 1976, Rayner *et al*. 2013) and diet (Croxall *et al*. 1988, Quillfeldt *et al*. 2005, García-Gados *et al*. 2002). The first efforts to estimate ASSP population size using mist-netting and mark-recapture analyses were carried out at SEFI in 1972–1973 (Ainley *et al.* 1974) and in the CCI in 1989–1991 (Carter *et al*. 1992), following original mist-netting efforts in the CCI during 1976–1977 (summarized in Hunt *et al*. 1979). Since 1992, researchers at SEFI have measured ASSP catch-per-unit-effort (CPUE) using mist-nets annually (Bradley *et al*. 2011), but in the CCI, logistical constraints (i.e. less-frequent sampling, inability to modify effort based on conditions) and the dispersed nature of multiple breeding sites necessitate a different approach. CPUE is recognized in population ecology as a simple, indirect measure of the relative abundance (i.e. in time or among locations) of a target species. However, it is unknown how well it can serve as a proxy for relative abundance of ASSP. Changes in CPUE are hypothesized to reflect changes in *true abundance*, but it can be used for this purpose only if certain assumptions (e.g. closed population, equitable and constant probability of capture) are accepted (DeLury 1947). Despite problems meeting these assumptions and recognized biases precluding estimation of *true abundance*, standardized CPUE of ASSP may be the only available technique for tracking relative changes in abundance and colony visitation (Ainley 1995, Bradley *et al*. 2011).

To evaluate CPUE, during 2004–2007, I conducted mist-netting sessions targeting ASSPs at three widely separated (~80–135 km) colony sites located within the CCI: Scorpion Rock off Santa Cruz Island, Santa Barbara Island and Prince Island off San Miguel Island (Carter *et al*. 1992). Data presented herein were used to quantify sex differences in morphometrics, evaluate body condition and assess seasonal and nocturnal patterns in captures according to incubation patch status (used as a proxy for breeding status). Additionally, I evaluated factors (moon, wind, cumulative effort) that may be associated with variability in CPUE. Finally, to address future monitoring with a hypothetical example, I estimated the level of standardized effort required to detect a 30% reduction in CPUE at $\alpha = 0.15$ and power = 80%, and I present a standardized mist-netting approach to measure CPUE in the CCI.

STUDY AREA AND METHODS

Scorpion Rocks (SR; 34°05′N, 119°30′W, <1 ha, 15 m elevation) consist of two small islets (Scorpion Rock and Little Scorpion Rock) and two small rock pinnacles located off the northeast end of Santa Cruz Island (SCI; Fig. 1). The two islets provide nesting habitat for seven seabird species, including an estimated 140 breeding ASSPs in 1989–1991 (Carter *et al*. 1992). Scorpion Rock is saddle-shaped and slopes upward from the southeast to a high point above cliff-edges along the west to northwest sides. Portions of the southern slope as well as the top and middle portion of SR have a substantial layer of loamy, ornithogenic soil where invasive plants, dominated by crystalline ice plant *Mesembrianthimum cristalinum*, have been replaced since 2007 with a diverse native plant assemblage (Adams *et al*. 2014). Scorpion Rock is sheltered from prevailing northwesterly winds by SCI during the spring and summer. Located along the south side of the eastern Santa Barbara Channel, SR is surrounded by waters that are variably influenced by the effects of upwelling near Point Conception (Harms & Winant 1998). I used one primary and two adjacent mist-netting locations on the central–southern margin atop SR.

Prince Island (PI; 34°05′N, 120°20′W; 16 ha, 90 m elevation; Fig. 1), located 2 km north of San Miguel Island, is a steep-sided island flanked with loose rubbly soils, boulders and many rocky crevices. Carter *et al*. (1992) estimated 1 154 breeding ASSPs in 1991. PI is the westernmost of the study locations, and during the summer waters surrounding the island are strongly influenced by a cold upwelling plume generated off Point Conception (Harms & Winant 1998). I used one mist-netting site on the southeast (leeward) side of PI, approximately parallel to the rocky shoreline (~5 m elevation).

Santa Barbara Island (SBI; 33°28N, 119°02′W; 260 ha, 193 m elevation; Fig. 1), located 80 km southeast of SCI, is bounded by steep cliff habitat, especially along the west- and north-facing perimeter. Carter *et al*. (1992) estimated 874 breeding ASSPs in

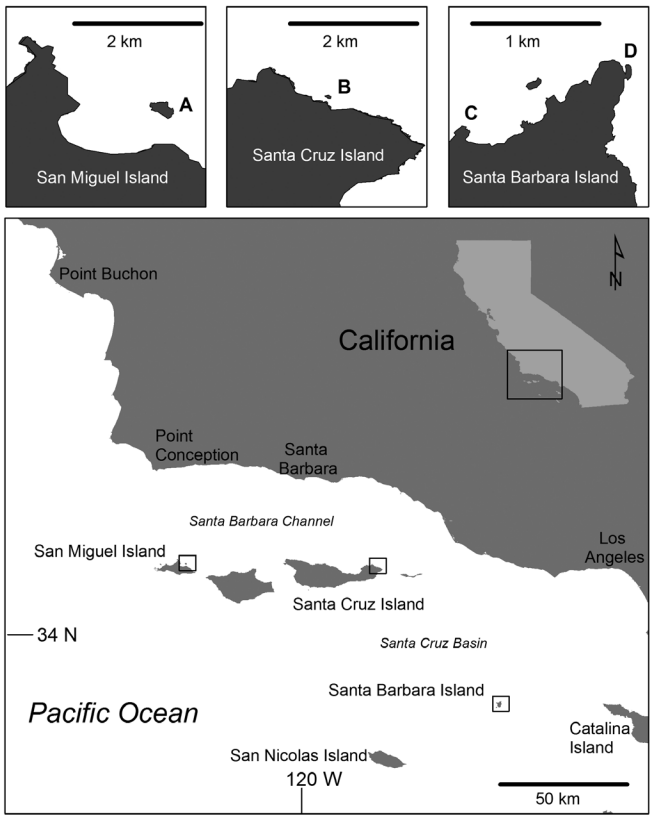

Fig. 1: California Channel Islands study area depicting locations of Prince Island (PI), Scorpion Rocks (SR) and Santa Barbara Island (SBI; sub-panels). Ashy Storm-Petrel mist-netting sites are shown for PI (A), SR (B) and SBI (C, D).

1991. SBI is somewhat isolated from the northern Channel Islands; bathymetry in this area is relatively more complex, and SBI is surrounded by several deepwater basins (>1 000 m depth). The sea here is farther from the influence of upwelled waters off Point Conception and more influenced, especially during late summer, by the Southern California Counter Current, a persistent eddy-feature of the southern extent of the California Current (Hickey 1979, Checkley & Barth 2009). I used two mist-netting sites on SBI: Arch Point (see site #05 in Fig. 11 of Carter *et al*. 1992), and Elephant Seal Point (see site #02 in Fig. 11 of Carter *et al*. 1992).

I employed mist-netting techniques during consecutive one- to three-night sessions, approximately monthly, during dark nights near the new moon in April through August 2004 (SR, SBI), 2005 (SR, SBI, PI), 2006 (SR), and once in August 2007 (PI). To maintain consistency with previous efforts, sites chosen were pre-established mist-netting locations, generally parallel to the shoreline and in the vicinity of nesting habitat, frequented by ornithologists (e.g. Carter *et al.* 1992, Martin & Sydeman 1998, Wolf *et al*. 1999).

A team of two to three biologists captured storm-petrels that were attracted to mist-nets by continuously broadcasted ASSP vocalizations (original recording from SEFI by D. Ainley and provided by Point Reyes Bird Observatory [now Point Blue Conservation Science]; see Bradley *et al*. 2011). Teams used a Lohman Predator Master 2560, 15W CD player with a horn loudspeaker (Saint 12V DC, 8Ω, 20W, 10 cm diameter × 10 cm long) to broadcast vocalizations at ~100 dB from the ground below the middle of the mist-nets (Avinet: 12 m wide, 2.6 m high, four shelves, 75/2 denier polyester, 38 mm mesh). Nets were supported on either end by 3 m telescoping painter poles spray-painted flat black, deployed at sunset and oriented in-line with the direction of the predominant wind (WNW) or parallel to the coast line (PI); nets were not realigned if the wind shifted during the netting effort. Nightly duration of netting effort ranged 2.8–7.7 h after apparent sunset (mean ± SD: 6.2 ± 0.9 h). Biologists recorded effort (min) during periods when the net was unfurled and vocalizations were broadcast; they did not include time when broadcasting was paused (e.g. to change batteries) or time during re-setting a net (e.g. after being knocked down). I calculated catch-per-unit-effort (CPUE) as storm-petrels captured per minute during a standardized period from apparent sunset to 5.3 h post-sunset. This period includes the onset of captures (~1 h after sunset) and the period of consistent and maximal captures (~2–4 h after sunset) throughout the night (see also Fig. 4.4 in Ainley *et al*. 1990). In addition, this 5.3 h period accounts for the seasonally shifting time of sunset. In the rare event (occurred 12 times) that biologists recaptured the same individual during the same night, usually following release, these events were excluded from calculations of CPUE. All birds captured were marked with unique, numbered, US Geological Survey hard-metal leg-bands (size 1B, USGS BBL; https://www.pwrc.usgs.gov/bbl/). Because others have suggested potential for net habituation (Sydeman *et al*. 1998) leading to decreasing CPUE with cumulative netting effort (Wiancko *et al*. 2011), I examined trends in CPUE between sequential nights (n = 24 occurrences) and chose to avoid autocorrelation among sequential site-nights by evaluating CPUE according to multi-night "sessions" (n = 22). I evaluated habituation effects using linear regression comparing CPUE with cumulative time spent netting. Small sample sizes (e.g. sessions) and unbalanced effort among years and islands precluded statistical evaluation of these effects on CPUE. I evaluated the effect of ocean winds (meters per second using data from offshore marine buoys located near mist-netting locations [National Data Buoy Center {NDBC} Buoy 46053, East Santa Barbara Channel for SR; NDBC Buoy 46069 South Santa Rosa Island for SBI; NDBC Buoy 46054 West Santa Barbara Channel for PI; http://www.ndbc.noaa.gov/]) on CPUE using linear regression. Mist-netting was conducted on dates targeting dark phases of the moon (e.g. small fraction of the moon's illuminated disc; mean ± SD fraction = 0.14 ± 0.16, n = 47). I used linear regression to evaluate the effect of a "moon index" on CPUE. I calculated "moon index" as the fraction of the moon's illuminated disc multiplied by number of minutes during the 5.3 h period that the moon was above the horizon. For example, a full moon with standardized effort (sunset to 5.3 h post-sunset) would yield a moon index = 1.0 × 318 min = 318. The mean moon index was ascribed to sessions >1 night. Most of the netting effort occurred on nights with a moon index <50 (mean ± SD = 16 ± 34, n = 47). I obtained apparent sunset time, moon rise and set time (http://aa.usno.navy.mil/data/docs/RS_OneYear.php), and fraction of the moon illuminated (http://aa.usno.navy.mil/data/docs/MoonFraction.php) for Santa Barbara, California. To evaluate hypothetical changes in CPUE based on similar effort in the future, I conducted a simple *post hoc* power analysis for a two-sample *t*-test (one-tailed, 30% lesser mean, $\alpha = 0.15$) using log-transformed CPUE to reduce effects of heteroscedasticity among untransformed CPUE values.

TABLE 1
Descriptive classification score for assessing Ashy Storm-Petrel incubation-patches

IP score[a]	Description
0	Completely covered with down (no incubation patch)
1	5%–50% defeathered (partially downy)
1.5	51%–95% defeathered (partially downy)
2	96%–100% bare (unvascularized)
3	96%–100% bare (vascularized, reddish, thickened)
4	5%–50% refeathered (note pins present)
4.5	51%–95% refeathered (note pins present)
5	96%–100% refeathered (no incubation patch, can be hard to separate from score = 0)

[a] Incubation patch score (IP) based on Carter *et al.* (1992)

Biologists identified captured storm-petrels to species (Ashy, Leach's, Black) and obtained morphometrics (reported here for ASSP) using Vernier calipers (± 0.05 mm) for bill length (exposed culmen; tip to feather insertion), skull length (culmen tip to posterior perietal) and tibiotarsus length (diagonal, cnemial crest to condyle); mass (100 g Pescola spring scale [± 1.0 g]) and maximum flattened outer wing length (stopped wing ruler, ± 1.0 mm) also were measured. I estimated an adult body condition index (BCI) among ASSP following Le Corre *et al*. (2003). Because principal component 1 among morphometric components accounted for only 46% of the total variance among weakly correlated variables, I chose the relationship between wing length and mass to account for partial variance in mass explained by size. As defined by Le Corre *et al*. (2003), BCI = 1 – (TM – OM)/TM, where OM is the observed mass (g), TM is the theoretical mass (g) calculated using the linear regression equation between mass and wing length (both sexes combined: mass = 0.280 × outer wing length – 4.076; $R^2 = 0.133$, n = 1 117). With this equation, a BCI of 1 indicates normal mass according to wing length; BCI <1 indicates a bird that is lighter than expected (negative body condition) and a

BCI >1 indicates a bird that is heavier than expected (positive body condition; Le Corre *et al*. 2003).

To determine sex among a sub-sample (n = 165) of captured birds, one drop of blood was collected by aseptic venipuncture from the medial tarsal vein using a 26-gauge needle and a Whatman FTA nucleic acid collection card (GE Healthcare, Brentford, UK). Sex was determined using molecular techniques (Dr. C. Baduini & A. Patel, Keck Science Center, Claremont College, California, following Fridolfsson & Ellegren 1999 and Dawson *et al.* 2001). In addition, I compared morphometrics between male and female storm-petrels using multivariate analysis of variance (MANOVA).

Determining breeding status among storm-petrels captured in mist-nets is problematic (Ainley *et al*. 1990, Warham 1996, Rayner *et al*. 2013); therefore, to classify "likely breeders," biologists assessed ASSP incubation patch (IP) (after Ainley *et al*. 1990, Carter *et al*. 1992); IP was scored following Carter *et al*. (1992) from 0 (all downy) to 5 (fully refeathered; Table 1). Birds captured after 30 April with bare (IP score = 2), bare and vascularized (IP score = 3), or refeathering (IP score = 4–5) incubation patches were classified as "likely breeders" (Carter *et al*. 1992, Adams & Takekawa 2008, Rayner *et al*. 2013). All statistical analyses were performed using SYSTAT 13 (Systat Software, Inc., San Jose, California).

RESULTS

Mist-net captures

During 2004–2007, biologists captured 1 177 individual ASSPs (34 were banded previously; Table 2). First captures occurred 1.2 h after apparent sunset, and the proportion of the total captured increased rapidly and remained relatively constant throughout the first six hours of the night (Fig. 2). During 24 occasions when mist-netting was conducted on consecutive nights, 17 (71%) occasions showed a decrease in CPUE, six (25%) occasions showed an increase, and on one occasion CPUE remained the same. When all mist-netting sessions (assumed to be independent) were evaluated, CPUE was negatively related to cumulative netting effort (min; $P = 0.003$, $R^2 = 0.07$; Fig. 3).

We recorded 34 recaptures (2.9%) of previously banded ASSP (not including same-night recaptures). Among recaptures, on SBI 11 of 15 (73%) were originally banded at SBI; on SR, 10 of 13 (77%) were originally banded at SR; at PI, six of six (100%) were originally banded at PI (Appendix 1, available online). The following five of 34 (15%) recaptured storm-petrels were originally

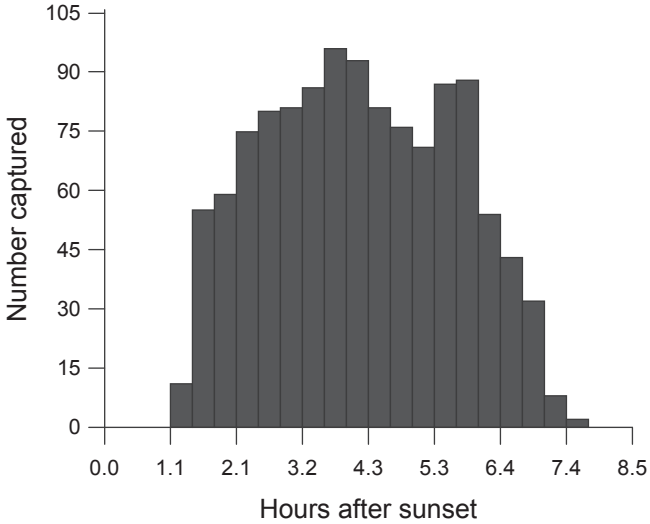

Fig. 2: Capture of Ashy Storm-Petrels (n = 1 177) from apparent sunset to 8 h post sunset at mist-netting sites in the California Channel Islands, 2004–2007. The standardized period of mist-netting effort (used to calculate CPUE) terminated 5.3 h after apparent sunset (0 on the x-axis).

TABLE 2
Summary of Ashy Storm-Petrel mist-netting during 2004–2007 on three California Channel Islands: Scorpion Rock (SR), Santa Barbara Island (SBI) and Prince Island (PI)

Island	Year	Netting dates	Total effort (min)	Total number ASSP	Standardized effort (min)	Standardized number ASSP	Site-nights (n)	Sessions (n)	Session CPUE[a] (±SD)
SR	2004	22, 23, 24 June; 21, 22 July; 18, 19 August	2 167	222	1 683	155	7	3	0.101 ± 0.048
	2005	31 May; 1, 2 June; 7, 8, 9 July; 9, 10 August	2 425	238	1 871	175	8	3	0.091 ± 0.050
	2006	29, 30 April; 2, 3 June; 28, 29 June; 26, 27 July	2 119	165	1 667	118	8	4	0.066 ± 0.043
SBI	2004	17, 18, 19 July; 14, 15, 16 August	2 527	195	1 912	141	9	4	0.080 ± 0.053
	2005	8, 9, 31 July; 1, 2 August	2 057	165	1 560	108	7	4	0.066 ± 0.015
PI	2005	28, 29 May; 1, 2, 3 July; 6, 7 August	1 815	153	1 370	128	7	3	0.113 ± 0.099
	2007	18 June	240	39	235	39	1	1	0.166
Total			13 350	1 177	10 298	864	47	22	0.088 ± 0.052

[a] Session-based catch-per-unit-effort (CPUE) during the standardized period.

banded at other islands (Appendix 1, available online): (1) banded 3 July 2005 at PI, recaptured on 8 July 2005 on SR; (2) banded 24 June 2004 at SR, recaptured 15 August 2004 at SBI; (3) banded 1 June 2005 at SR, recaptured 1 August 2005 at SBI; (4) banded 1 July 2005 at PI, recaptured 1 August 2005 at SBI and (5) banded 24 July 2003 at SEFI (R. Bradley, pers. comm.), recaptured 8 July 2005 at SBI.

Among relatively dark mist-netting sessions (average moon index <80), moon index did not significantly affect CPUE (linear regression, $R^2 = 0.02$, $P = 0.929$, n = 22; Fig. 4). The single greatest capture rate (CPUE = 0.38 birds min^{-1}, moon index = 0) was recorded on PI on 28 May 2005, when the moon's illuminated disc was 63% but the moon was entirely below the horizon; buoy wind speed on this night was not available, but wind speed off PI was estimated at 15–20 knots. Whereas average ocean winds during mist-netting sessions ranged from <5 to 12 m per second (<9.7 to 23.3 knots), proxy wind speeds (measured at adjacent NDBC buoys stations) were not correlated with CPUE (linear regression, $R^2 = 0.01$, $P = 0.88$; n = 19; Fig. 4).

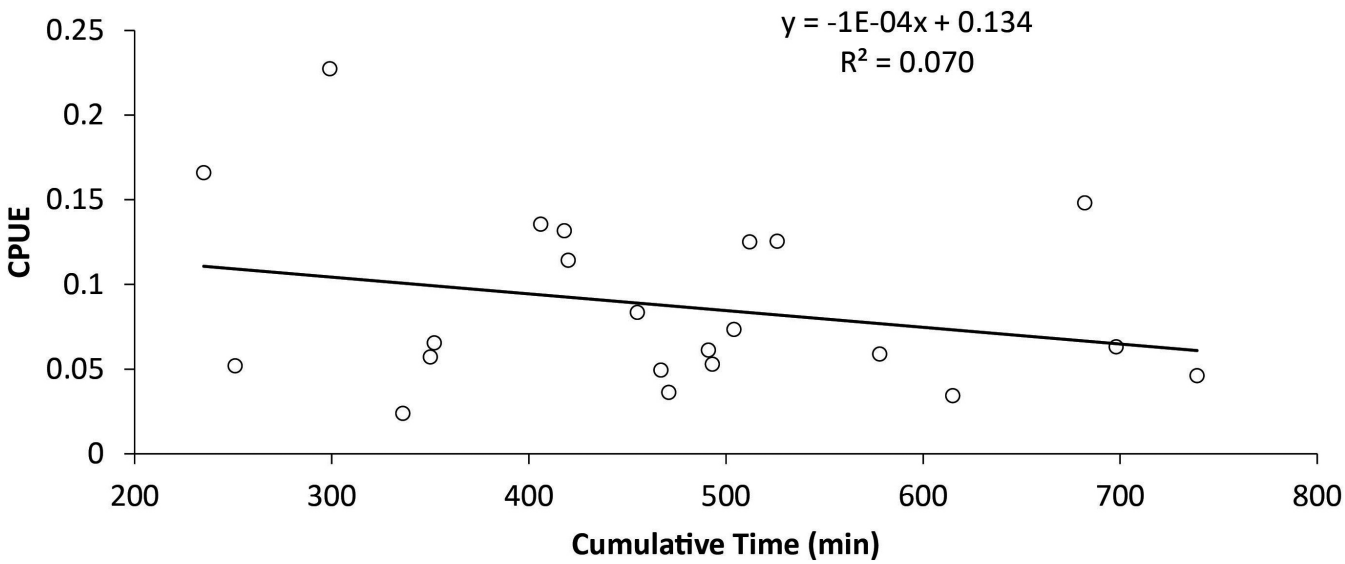

Fig. 3: Ashy Storm-Petrel catch-per-unit-effort (CPUE) in the California Channel Islands, 2004–2007 as a function of cumulative time (minutes) spent mist-netting during consecutive nights (open circles; n = 22 sessions). Line indicates linear regression; negative trend in catch-per-unit-effort (CPUE) with cumulative time indicates possible net habituation.

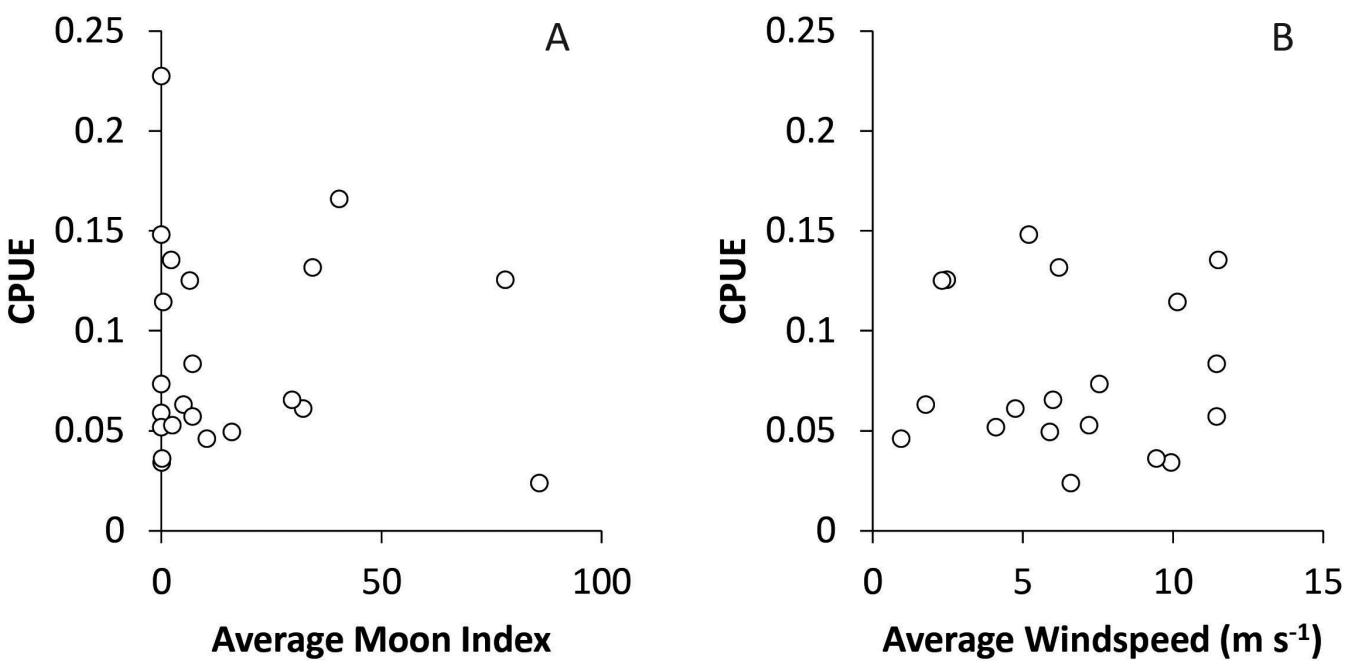

Fig. 4: The effects of average moon index (A) and average midnight wind speed (B; m s^{-1}, measured at oceanographic buoys) on standardized Ashy Storm-Petrel mist-net catch-per-unit-effort (CPUE) during mist-netting sessions (n = 22) in the California Channel Islands, 2004–2007.

Power and CPUE

Power was 84% (*post hoc*, two-sample *t*-test, one-tailed) to detect a 30% lesser mean CPUE with equivalent sample sizes and $\alpha = 0.15$ (85% CI), based on measured standard deviation and a sample size of 22 sessions from 2004 through 2007 combined. Based on these parameters, to achieve 80% power to detect a 30% lesser CPUE in the future, a minimum 19 sessions would be required (Fig. 5).

Sex, incubation patch and morphometrics

Based on a subset of 111 ASSPs sampled haphazardly during this study, we observed nearly twice the number of females (72) as of males (39) (Table 3). Although biologists did not sample for sex uniformly throughout the season or during site-nights, results from two nights were dominated by female captures: 17 July 2004 on SBI (24:2) and 28 May 2005 on PI (14:5; Table 3).

All sites showed a seasonal progression in incubation patch defeathering to refeathering, with peak proportions of fully developed incubation patches (IP = 3, 4) in July and August at all three locations (Fig. 6). At SR, 18% of birds in May and 40% in June were classified as likely breeders. At PI, 60% in May and 18% in June were classified as likely breeders. The relative proportion of petrels classified as likely breeders increased to 75% in August at SR, 84% in July and 94% in August at SBI, and 76% in July and 96% in August at PI (Fig. 7). Pooling data from all islands, the average proportion of likely breeders increased from 34% in May–June to 79% in July–August. Statistically different timing of capture (mean hours after sunset ± SE) among birds with variable incubation patch scores (ANOVA; $F_{7,1154} = 2.958$, $P = 0.004$) was driven by the difference between IP = 0 (3.9 ± 0.08 h versus IP = 3, 4.5 ± 0.17 h; Tukey's honestly significant difference [HSD] multiple comparison test, difference = 0.51 h, $P = 0.002$).

Among a subset of likely breeders (IP >1.5 and <5; i.e. bare and refeathering), ASSPs at PI were captured significantly earlier in the evening (mean ± SD; 3.69 ± 0.15 h after sunset) than at SR (4.32 ± 0.09 h after sunset) and SBI (4.44 ± 0.10 h after sunset; ANOVA, $F_{2,601} = 9.004$, $P < 0.001$); Tukey's HSD multiple comparison test indicated no significant difference in capture times between SR and SBI ($P = 0.643$).

ASSPs exhibited sexual dimorphism in body measurements (MANOVA: Wilks' lambda = 0.844, $F_{5,93} = 3.442$, $P = 0.007$). Univariate *F*-tests revealed statistically significant sex differences in mass, bill length and maximum flattened wing length (Table 4). Pearson product-moment correlations among skeletal measurements were relatively low (0.12–0.39; Table 5). BCI differed among petrels from the three islands (ANOVA; $F_{2,\ 1114} = 17.9935$, $P < 0.001$); petrels from SBI had the lowest BCI (mean ± SE, 0.966 ± 0.006) compared with PI (1.021 ± 0.008) and SR (1.00 ± 0.004).

DISCUSSION

Mist-net captures and inter-island exchange

During 223 h effort among three islands in the CCI in 2004–2007, biologists using mist-nets with vocal attraction captured 1 177 ASSPs (1 143 individuals). The significant negative effect of cumulative time spent netting (effort) on CPUE during consecutive nights (sessions) at fixed netting sites in this study indicates that the probability of capture decreases with effort during each session. Although their study had different objectives (mark-recapture population estimation), Sydeman *et al*. (1998) recognized the potential for 'trap shyness' and avoided netting at the same site on adjacent nights. Ainley (1995), however, acknowledged the potential for large nightly variation in catch rates, and suggested

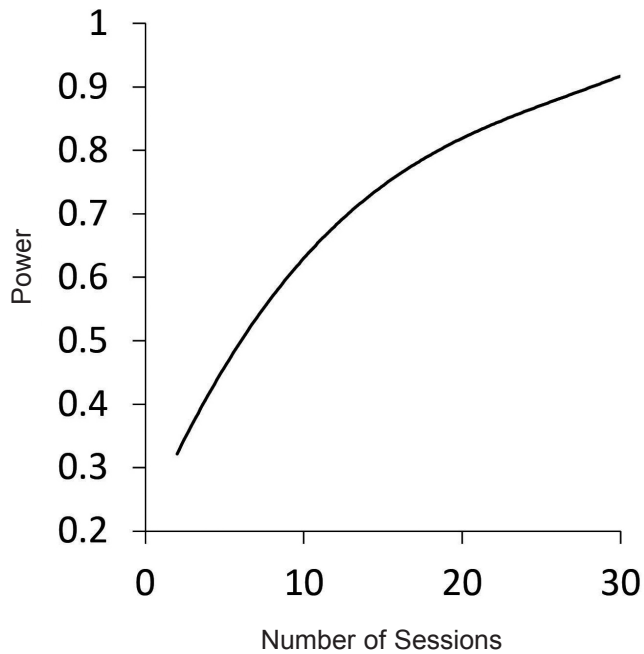

Fig. 5: Power curve showing estimated power according to sample size (number of mist-netting sessions throughout the California Channel Islands) to detect 30% lesser CPUE at $\alpha = 0.15$.

TABLE 3
Observed sex ratios (female:male) among Ashy Storm-Petrels captured using vocal broadcast and mist-netting in the Channel Islands during 2004–2007[a]

Island	Date								
	17 July 2004	28 May 2005	29 May 2005	31 May 2005	1 June 2005	2 August 2005	10 August 2005	26 July 2006	27 July 2006
PI		14:5	8:7						
SR				7:5	3:2		3:5	10:6	0:3
SBI	24:2					3:4			

[a] Total observed female:male was 72:39.

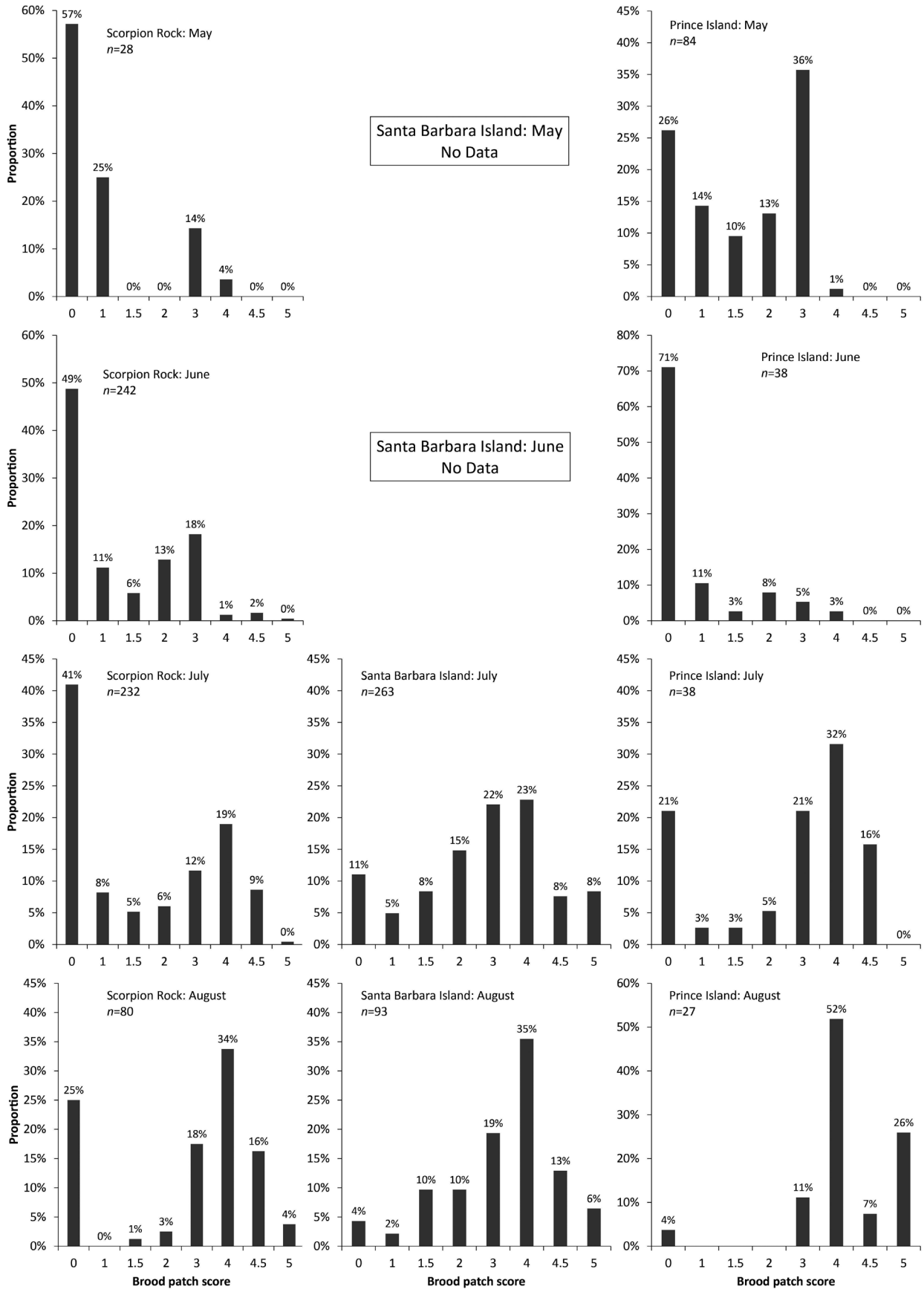

Fig. 6: Proportion of Ashy Storm-Petrels mist-net captured at three study sites in the California Channel Islands and during May, June, July and August 2004–2007 (April data from SR not shown) according to incubation patch (IP) score (after Carter *et al*. 1992).

that if standardized efforts are undertaken in the future to estimate population size, researchers should attempt mist-netting according to equal per-unit periods (e.g. five consecutive nights). Previous mist-netting in the CCI used a combination of single-night effort combined with sessions lasting multiple nights (Carter *et al*. 1992). In their study evaluating relative abundance among Cuban land birds using mist-net CPUE, Wiancko *et al*. (2011) also measured decreasing CPUE as a function of netting effort (cumulative minutes). Care should be taken to evaluate this trend in future comparisons (i.e. by site or year) and, if significant and consistent, cumulative minutes of netting effort should be used as a model covariate to control for the effect of net habituation (Wiancko *et al*. 2011). Consecutive site-nights cannot be considered independent.

Although it is not yet known whether CPUE correlates with the number of individuals actually breeding or relative abundance, mean (± SD) island-based CPUE at the largest colony, PI (0.13 ± 0.09), was greater than at SR (0.08 ± 0.04) and SBI (0.07 ± 0.04). Similar CPUE at SR (estimated to be a smaller colony than SBI, see Study Area and Methods) may reflect the proximity of SR to additional breeding birds affiliated with eastern Santa Cruz Island sea caves, abundant inaccessible cliff habitat nearby, or greater visitation by non-breeders (i.e. greater relative proportion of IP = 0 captured at SR; Fig. 6).

The relatively low effort in this study (i.e. single nets deployed infrequently at only a few fixed sites at three islands), coupled with a relatively low overall recapture rate (2.9% of banded individuals), indicates that ASSPs may be more abundant off southern California than recent estimates of nesting birds suggest (i.e. 7416 individuals or 36% of the total population; USFWS 2013). Given our limited effort and low recapture rate (2.9% of banded individuals), it seems unlikely that we captured the equivalent of 15% (1143) of the 7416 unique individuals (USFWS 2013) estimated for the southern California population. For comparison, annual recapture rates at two netting sites on SEFI, which supports an estimated 58% of the total population (USFWS 2013) during 1971, 1972, and 1992, were three to five times greater than recapture rates in the CCI, at 8.9%, 14.2%, and 15.4%, respectively (Sydeman *et al*. 1998). Perhaps ASSP at SEFI display a greater degree of site fidelity, are nesting at greater densities near netting sites, or include fewer wide-ranging prospecting non-breeders. Harris (1974) also reported relatively low recapture rates (6%–15%) among previously banded Leach's Storm-Petrels *O. leucorhoa* off northern California and surmised that low recapture rates may have resulted from many captures in the spring of non-breeding prospecting petrels that may visit additional widespread colony sites later in the season. Recaptures in the CCI during 2004–2007 reflect some degree of inter-island exchange within the CCI; however, most of our recaptures (73%–100%) represented individuals originally captured at the same netting site. Coupled with IP status (especially in July–August), this indicates capture-site fidelity that might be expected from breeding

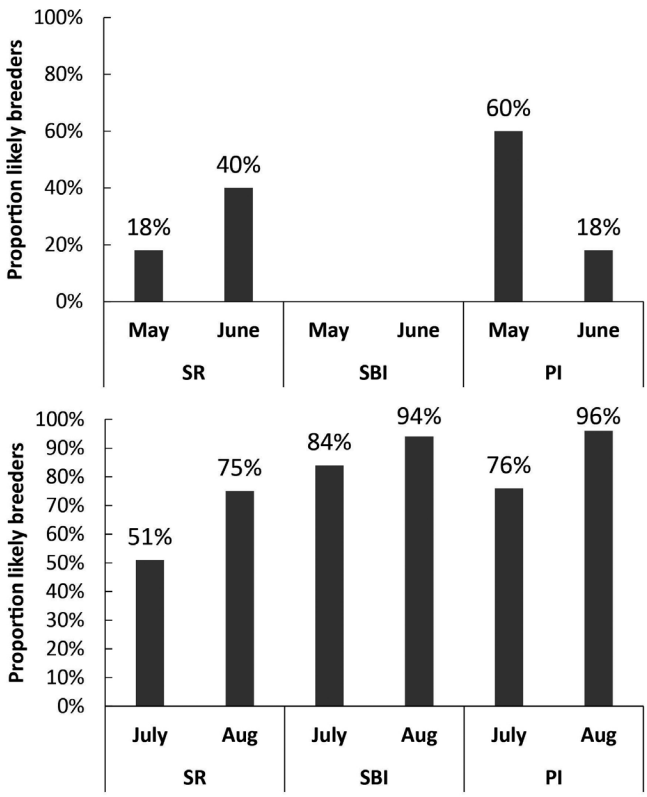

Fig. 7: Proportion of likely breeders (see Methods) among Ashy Storm-Petrels captured in mist-nets during May and June in the California Channel Islands 2004–2007 on SR (n = 28, 242) and PI (n = 84, 38) and during July and August on SR (n = 232, 80), SBI (n = 263, 93) and PI (n = 38, 27).

TABLE 4
Morphometric comparisons between female (n = 71) and male (n = 28) Ashy Storm-Petrels (n = 99) captured in mist-nets in the CCI during 2004–2006 [a]

Morphometric parameter	Mean (± SD)		Univariate F-tests
	Females	Males	
Mass (g)	36.1 ± 2.8	34.7 ± 2.1	$F_{1,97} = 5.77$, $P = 0.018$
Bill length (mm)	14.9 ± 0.5	14.6 ± 0.8	$F_{1,97} = 4.44$, $P = 0.022$
Skull length (mm)	38.1 ± 1.1	37.9 ± 0.8	$F_{1,97} = 1.14$, $P = 0.288$
Tarsus length (mm)	23.2 ± 0.9	23.1 ± 0.8	$F_{1,97} = 0.21$, $P = 0.650$
Maximum flat wing (mm)	142.7 ± 2.8	140.4 ± 3.3	$F_{1,97} = 12.31$, $P = 0.001$

TABLE 5
Pearson correlation coefficients among Ashy Storm-Petrel morphometrics (islands and sexes combined) for Ashy Storm-Petrels captured in mist-nets in the CCI during 2004–2006

Morphometric parameter	Mass	Bill length	Skull length	Tarsus length	Maximum flat wing
Mass	1.000	–	–	–	–
Bill length	0.164	1.000	–	–	–
Skull length	0.221	0.176	1.000	–	–
Tarsus length	0.047	0.142	0.217	1.000	–
Maximum flat wing	0.275	0.261	0.392	0.121	1.000

birds attending their colonies (i.e. relatively closed populations), but perhaps factors driving recapture rates in the CCI differ from those at SEFI.

While at-sea surveys reveal large inter-annual variability in numbers of birds counted off central California, it is not yet known whether increased abundance of ASSPs at sea during El Niño-Southern Oscillation (ENSO) events (Ainley & Hyrenbach 2010) coincides with decreased CPUE at colonies (*cf.* Sydeman *et al*. 1998). For context, ocean conditions surrounding the CCI during 2004–2007 were variable, but not really consistent with any particular ENSO "state." A weak El Niño in the tropics during 2004 did not seem to lead to any significant biological responses in the CCS, and the system remained in its typical "cool" state following the pronounced transition in 1999 (Goericke *et al*. 2005). Whereas the northern CCS in 2005 was unusually warm and characterized by a later-than-usual onset of upwelling and low zooplankton biomass, ocean conditions off southern California appeared normal (Peterson *et al*. 2006). During 2006 through early 2007, upwelling winds off southern California were relatively weak and delayed, but biological response to climate forcing was not unusual (Goericke *et al*. 2007). By late spring 2007, the southern CCS returned to La Niña conditions typified by cooler waters and a rebound in zooplankton biomass (McClatchie *et al*. 2008). Bradley *et al*. (2011) did not find support for the effects of ocean climate variability (several climate indices) on ASSP CPUE at SEFI from 1992 to 2010, but they did note a marked decrease in CPUE during the strong El Niño event in 1998. Although there are no data to evaluate a trend in CPUE in the CCI, values at SEFI during the same period (2004–2007) were increasing, with a maximum value recorded in 2007 (Bradley *et al*. 2011). A much longer time-series, with pronounced inter-annual anomalies in ocean conditions, would be required to evaluate ocean-climate effects on CPUE (Bradley *et al*. 2011).

Among birds that were sexed, females outnumbered males 2:1. These differences were driven by disproportionate capture of females on three of nine nights (Table 3). Medieros *et al*. (2012) found significant female bias in mist-net captures with vocal attraction among European Storm-Petrels *Hydrobates pelagicus* captured away from breeding areas, but not at breeding colonies in the United Kingdom and France. The authors suggested that consistent female bias during pre-breeding captures away from colony areas resulted from different migration routes according to sex or different colony-prospecting behavior between the sexes during migration; they were less convinced that capture facilitated with vocal attraction influenced female capture bias measured at breeding areas (based on capture ratios). Based on a small number of at-sea captured New Zealand Storm-Petrels *Fregetta maoriana*, Rayner *et al*. (2013) found male-biased capture during February and suggested that this occurred during a female pre-laying exodus, when females would have been away from their capture area near suspected colonies. Differences in sex-biased capture using mist-netting coupled with vocal attraction are not well studied, and this study was not designed to provide sufficient data to properly address variability in sex-biased capture. Additional random sampling is required to evaluate patterns in sex-biased capture of ASSPs using vocal attraction to mist-nets.

Sex differences in morphometrics have not previously been reported for ASSP (Ainley 1995). Male and female ASSPs differ slightly in size; females were slightly heavier, with longer wings, and a longer culmen. European Storm-Petrels also display similar sexual dimorphism, with females also being slightly heavier and longer in the wing (Medieros *et al*. 2012). Morphometrics in ASSP also overlapped between sexes and, as with other storm-petrels, likely do not differ enough to reliably sex birds in the field (Medieros *et al*. 2012, Rayner *et al*. 2013).

ASSPs captured in the CCI were 5%–9% lighter than average masses reported by Ainley *et al*. (1974) from SEFI, where they measured a seasonal decline in average adult mass (39.6 g in February during the pre-breeding season decreasing to 38.1 g in April; compared with 35 g [males] or 36 g [females] in the current study). This difference in mass (i.e. lower mass at lower latitude) is consistent with Bergmann's rule (Bergmann 1847), but may also relate to interactions between physiological demands, resource availability and differences in seabird community assemblages between the two regions (Olsen *et al*. 2009), or to normal inter-annual variability in body mass for ASSP. BCI revealed small differences among ASSPs captured at the three islands. Storm-petrels captured on SBI and SR had slightly lower BCI values compared with birds captured at PI. Interestingly, storm-petrels at SBI and SR were also captured about 45 min later than birds at PI. Together, these patterns indicate storm-petrels at SBI likely experienced different foraging environments or perhaps foraged farther from their colony compared with birds visiting and captured at PI (see Fig. 1). Concurrent with this study (during 2004 and 2005), a number of mist-net captured ASSPs also were tracked at sea using radio telemetry (Adams & Takekawa 2008). In 2004, ASSPs from SBI utilized at-sea habitat over the Santa Cruz Basin (near SBI) and in the more distant shelf-slope waters southwest of Point Buchon (see Fig. 1). None of the SBI birds were located in the western Santa Barbara Channel (near PI), an area occupied exclusively by birds captured and tracked from SR and shared with birds captured and tracked from PI (Adams & Takekawa 2008). In 2005, the Santa Cruz Basin was used by birds from PI, but to a greater degree by birds originating closer, from SR (Adams & Takekawa 2008). Birds frequenting all three islands during night use the Santa Cruz Basin during day, but birds from SBI, with less access to the Santa Barbara Channel, may forage farther to the west and occasionally range north of Point Conception over more distant shelf-slope waters (Adams & Takekawa 2008).

Can we use CPUE to evaluate trends in relative abundance?

Although only 7% of the variability in the negative trend in CPUE with cumulative netting effort (minutes per session) could be explained using linear regression, the negative trend was significant. The probability of capture does not remain constant through time using mist-netting with vocal attraction; net-habituation or avoidance by petrels may affect sequential mist-netting nights at a fixed site. This is of greatest concern when conducting statistical evaluations; researchers must account for this effect and use caution when evaluating independent sample units statistically. Although determining population size using mist-netting capture-recapture data is problematic for this reason, among others (see Carter *et al.* 1992, Sydeman *et al.* 1998), standardized CPUE using mist-netting techniques has been recommended and may provide those concerned with tracking the status of ASSP abundance with an index to measure relative changes through time (Carter *et al.* 1992, Ainley 1995, Carter *et al.* 2008).

A standardized approach for future ASSP monitoring throughout the species' range (and especially at large population centers) would increase the utility of mist-netting efforts to detect trends (Ainley

1995). While ASSP CPUE data at SEFI are based on repeated, annual measures (since 1992) at two fixed netting sites, data in the CCI are from a variety of locations, across widely dispersed islands, and at different times of year. Results from this study and from work on SEFI indicate that, with attention to standardized effort (e.g. equipment, methods, net sites, seasonality and moon phase), biologists can determine periodic CPUE for the CCI. Because capture rates can vary widely across short distances (Bradley *et al*. 2011), and to be able to compare results with existing data, future effort in the CCI should use the same netting sites on each of the three islands. Bradley *et al*. (2011) conducted mist-netting April through August at SEFI and found that the date was a significant factor affecting CPUE; early July typically had the greatest capture rates at SEFI. Focusing effort in the CCI during June–September would probably target likely breeders (based on IP status) and might cause less overall disturbance to individuals because fewer would be captured in nets. Although the level of trend detection is arbitrary, as an example from this study, a goal to detect a 30% lesser CPUE between infrequent survey periods (i.e. every three to five years) might be attained by following the use of standardized methods presented in this study. Based on measured CPUE and standard deviations at each island, this goal might be achieved by first allocating 19 mist-netting sessions according to proportional standard deviation using stratified, random Neyman allocation, in which sample size for stratum *h* would be $n_h = 19 \times (S_h) / [\Sigma (S_i)]$, where n_h is the sample size for stratum *h*, n = 19 is total sample size (from power analysis), and S_h is the standard deviation of stratum *h*, and S_i is the standard deviation for each of the strata (PI = 0.09, SR = 0.04 and SBI = 0.04). In this example, for best precision using a minimum of 19 sessions, biologists would allocate 10 sessions to PI (most variable, likely largest breeding population) and four or five sessions each to SR and SBI. Based on revised estimates of variance or different trend criteria, sampling effort could be revised appropriately. During the four-month June–September period, biologists could complete eight sessions per site (e.g. 24 sessions total at three sites) during the dark phase of the lunar cycle. To complete such an effort might take two seasons across the three sites to complete; therefore, reasonable monitoring might include periodic survey efforts (i.e. every three to five years).

Annual and inter-annual variability in ASSP CPUE in the CCI remains poorly understood and warrants continued investigation. To evaluate whether nocturnal vocalizations around colonies are related to island attendance patterns, acoustic recording should be evaluated along with mist-netting-derived CPUE or other independent measures available (e.g. radar detections, photogrammetry, nest counts). Acoustic detections of nocturnal seabirds have been used as an independent measure of colony attendance activity and nesting density. For example, Opell *et al*. (2014) correlated Cory's Shearwater *Calonectris borealis* call rates on Corvo Island (Azores) with nest density to estimate an island-wide population. Among Leach's and Fork-tailed *O. furcata* storm-petrels in the Aleutian Islands, Buxton *et al*. (2013) determined that calling rates were associated with a variety of factors, including moon phase, recovery time following predator eradications and presence of appropriate nest site refugia.

If monitoring of ASSP CPUE continues in the CCI, care should be undertaken to use simple, repeatable techniques with consistent methods and equipment. If varying methods are used, meaningful comparisons over time will be compromised. Any changes in methods (e.g. vocalization parameters, mist-net dimensions, mist-net locations) should be evaluated, so that values using disparate methods can be calibrated before comparisons are made. To increase power to detect differences in regional (i.e. across three islands) CPUE, effort at fixed, referenced mist-netting sites might be allocated based on proportional standard deviation among a representational number of island sites that support known concentrations of breeding ASSPs. It remains important, however, to continue efforts to evaluate the population being sampled when quantifying CPUE. For example, do trends in CPUE correlate with population sizes or colony attendance of breeders or non-breeders (i.e. the floating population) and what additional biological or environmental parameters influence seasonal variability in CPUE?

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