USE OF SOCIAL ATTRACTION TO RESTORE ASHY STORM-PETRELS *OCEANODROMA HOMOCHROA* AT ORIZABA ROCK, SANTA CRUZ ISLAND, CALIFORNIA

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SUMMARY

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In 2008–2011, social attraction (i.e. provision of artificial nests and nocturnal vocalization broadcasting) was used to restore a small colony of Ashy Storm-Petrels *Oceanodroma homochroa* at Orizaba Rock off Santa Cruz Island, California, United States. This colony had declined 74.1% from 27 nests (1996) to 7 (2005), or -17.5% per year (1995–2004) using a colony size index. In contrast, a nearby reference colony, Cave of the Birds' Eggs, increased 72.7% from 11 (1995) to 19 nests (2005) but colony size index trend (1995–2004) was non-significant. With social attraction, number of nests at Orizaba Rock almost tripled from the baseline mean of 12 (2005–2007) to 33 (2011), reflecting increases of 22.4% per year using the colony size index (2005–2011) or 26.5% per year based on colony size (2005–2011). In 2008, four eggs were laid in artificial nests; by 2011, petrels laid eggs at 11 of 30 (36.7%) artificial nests and visited nine more (30.0%). In comparison, reference colony size increased from the baseline mean of 22 nests (2005–2007) to 24 nests (2011) or 9.3% per year using the colony size index (1995–2011). Relatively high breeding success at both colonies in 2005–2011 apparently reflected reduced organochlorine pollutants, adequate prey resources, relatively low avian predation, and low or no impacts from squid-fishing lights. In 2010, Common Ravens *Corvus corax* discovered and dismantled 12 artificial nests; modifications were made in 2011 to prevent raven access. Social attraction resulted in restoration of the Orizaba Rock colony to its 1996 size, demonstrating the technique's effectiveness in increasing colony size and encouraging storm-petrel use of artificial sites.

Key words: artificial nest sites, Ashy Storm-Petrel, Cave of the Birds' Eggs, *Oceanodroma homochroa*, Orizaba Rock, restoration, Santa Cruz Island, social attraction, vocalization broadcasting

INTRODUCTION

Large amounts of organochlorine pollutants were discharged into the marine environment in the Southern California Bight (SCB) from the 1940s to 1970, resulting in serious long-term impacts to seabirds and other wildlife. Although discharge ceased in 1970 and impacts have decreased over time, polluted marine sediments have remained and continue to affect fish and wildlife (MSRP 2005, 2012). In 1990–2001, the US Department of Justice and California State Attorney General's Office, on behalf of six federal and state agencies, sought and received monetary damages from the Montrose Chemical Corporation and other defendants to restore natural resources injured by these pollutants. The Montrose Settlements Trustee Council (MSTC) used a portion of funds obtained to develop a seabird restoration plan in the California Channel Islands (CCI) within the SCB, focused mainly on Santa Barbara and Santa Cruz islands (SCZ; 34°00′N, 119°43′W). One restoration project targeted the breeding population of Ashy Storm-Petrels *Oceanodroma homochroa* (hereafter ASSP) at SCZ. By 2005, the need for restoration of this ASSP population was clear, given results of surveys, research and monitoring from 1992–2005. Those studies mainly took place at five breeding locations (hereafter "colonies": Orizaba Rock [OR], Bat Cave, Cavern Point Cove Caves, Cave of the Birds' Eggs [CBE], and Dry Sandy Beach Cave) (McIver 2002, Carter *et al.* 2008a, McIver *et al.* 2009; W.R. McIver & H.R. Carter, unpubl. data). Three major issues were known to affect these five colonies:

(1) Organochlorine pollutants — relatively high levels and resulting eggshell thinning were documented in ASSP eggs collected at OR, CBE and Bat Cave in 1992, 1996 and 1997, consistent with relatively low hatching success in 1995–1998 (Fry 1994; Kiff 1994; Carter *et al*. 2008a, b; McIver 2002; McIver *et al*. 2009);

(2) A decrease in numbers of ASSP nests at the OR colony — by 2005, only seven nests remained, compared with 27 in 1996 (McIver 2002, Carter *et al*. 2008a); and

(3) Decimation and complete reproductive failure of the Bat Cave colony — in 2005, island spotted skunks *Spilogale gracilis amphiala* heavily depredated ASSP adults and eggs (Carter *et al*. 2008a, McIver *et al.* 2009).

The MSTC and the restoration team placed most initial focus on OR. The four SCZ sea cave colonies were also examined as potential reference colonies for comparison with OR, and for possible implementation of additional restoration actions. Social attraction (defined as providing artificial nests in association with vocalization broadcasting) was targeted to encourage colony recovery to historic levels and encourage use of protected artificial nest sites. Various forms of social attraction have been used widely for seabird conservation actions, including for storm-petrels (Jones & Kress 2012). ASSP have also nested successfully in artificial nests at the South Farallon Islands (hereafter "Farallones"), which were placed over previously existing nests to facilitate nest monitoring (*cf.* James-Veitch 1970, Ainley *et al.* 1990). At the Farallones, relatively large numbers of ASSP have also nested in gaps within man-made rock walls since the late 19th century, reflecting use of another form of artificial habitat (Ainley *et al.* 1990, Carter *et al.* 2008a, 2016). In other storm-petrel species, the provision of artificial sites without vocalization broadcasting has led to increased numbers of nesting pairs (Bolton 1996, De León & Mínguez 2003, Bried *et al.* 2009). Vocalization broadcasting has also been effective at encouraging storm-petrel re-colonization and colony growth (e.g. Podolsky & Kress 1989, Bolton *et al.* 2004, Libois *et al.* 2012).

Restoration goals for the OR colony were: (1) to return this colony to its 1996 level of 27 nests or more; and (2) to encourage use of artificial nests to reduce potential future impacts from human disturbance, avian predators or bright boat lights (particularly from squid-fishing boats). In this paper, we summarize the results of the first phase of this project (2008–2011), including: (1) social attraction efforts at OR; (2) comparison of numbers of nests and reproductive success at OR and CBE in the decline period (1995–2004), baseline period (2005–2007) and restoration period (2008–2011); and (3) an assessment of the success of this phase of the project through 2011. Common Ravens *Corvus corax* (CORA) caused severe damage to artificial nests in 2010, resulting in major changes to the project in 2012–2015. We have thus also summarized relevant information from 2012–2015, where appropriate, for assessment of project success through 2011.

METHODS

Study area

SCZ is jointly owned and managed by The Nature Conservancy (west portion, including CBE) and Channel Islands National Park (east portion and offshore rocks, including OR) (Fig. 1). The north coast of the island is composed largely of sheer cliffs and bluffs, with at least 110 sea caves (Bunnell 1988) and many offshore rocks. ASSP are confirmed breeders at 11 locations at SCZ, including 6 sea caves and 5 nearshore rocks (Carter *et al*. 2008a). OR (previously referred to as "Sppit" Rock; Sowls *et al.* 1980, Hunt *et al.* 1981, Carter *et al.* 1992) is < 0.5 ha in size, located on the central north coast of SCZ (34°02′49″N, 119°43′22″W), about 50 m from the main island. Large boulders formed by the collapse of the western third of the rock provide the majority of suitable crevices within three small (~10 m^3 to 25 m^3) caverns: Upper West Cavern, Upper East Cavern and Lower Cavern.

CBE is a sea cave located ~14 km west of OR, near the west end of the north coast of SCZ (34°04′24″N, 119°52′26″W), and adjacent waters are included within the Painted Cave Marine Conservation Area, a Marine Protected Area designated in 2003 (CDFG *et al*. 2008). CBE is ~130 m long with a 15 m^2 entrance, containing numerous rock piles and boulders with crevices suitable for nesting by ASSP (McIver 2002). The cave floor remains free of standing water throughout most of the year; however, the front portion is occasionally flooded by very high tides, large waves and storm surges.

Nest monitoring

Monitoring trips to OR and CBE from 1995 to 2011 were conducted monthly between May/June and October/November (1995–1997, 2005–2011), or as single trips in late summer, either July or August (1999–2002, 2004), after most eggs had been laid. In 1998, CBE was checked monthly, but OR was checked only in late summer. In 2003, neither CBE nor OR were checked. With monthly trips, we could determine reproductive success (i.e. hatching, fledging, and breeding success), total nests with an egg laid and the number of nests with an egg laid by late summer (Table 1). With single trips, we could determine only the number of nests with an egg laid by late summer. Late summer nest counts served as a colony size index, and data were available for most years between 1995 and 2011.

Details of monitoring and data-handling methods are provided elsewhere (McIver 2002, McIver *et al.* 2009; also see 2006–2011 annual reports available at www.montroserestoration.noaa.gov), but we summarize important aspects below. All accessible habitats and tagged sites at OR (including artificial sites) and CBE were examined with small flashlights to search for and assess ASSP activity at nests on each monitoring trip. An "active nest" in a given year was defined as a nest containing an egg, chick or eggshell fragments from an egg laid in that year. To minimize disturbance, adults in nests were not handled. If a nest site contained an adult without an egg on certain trips and an egg was not detected over the season, or if obvious signs of digging were evident, it was considered "visited only." Such nest sites were of special interest as they represented potential for future nesting. "Occupied nests" were defined as having evidence either of egg laying or visitation. Within a nesting season, if only one egg was laid in a nest site, it was referred to as a "single" egg. On several occasions, a second egg was laid after the first egg failed. We assumed they were "replacement" eggs laid by the same breeding pair (Ainley *et al.* 1990, McIver *et al.* 2009). To assess differences in reproductive

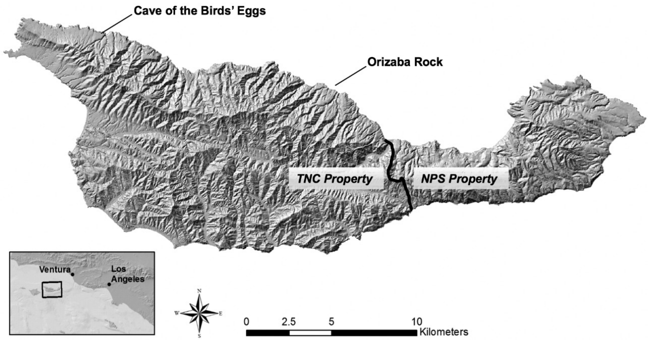

Fig. 1: Locations of Orizaba Rock and Cave of the Birds' Eggs on the north side of Santa Cruz Island, California, United States. The current boundary between the National Park Service (NPS) and The Nature Conservancy (TNC) properties is demarcated by the bold black line; all offshore rocks (including Orizaba Rock) are NPS property.

success between years and colonies, we examined breeding success, defined as the percentage of active nest sites that fledged a chick. In 1995–1998 and 2006–2011, we also recorded and removed all ASSP carcasses and feather piles found at OR and CBE on monthly monitoring trips, allowing documentation of the total number of predation events each year.

Social attraction efforts

Roof tile artificial nests

In 2008–2010, each artificial nest at OR was formed using affordable and easily available concave cement roofing tiles (A.L.L. Roofing and Building Materials Corporation, Ventura, CA; Figs. 2, 3). Each tile measured 36 cm long, 20 cm wide, and 18 cm high (all inside dimensions). Each artificial nest provided sufficient space for one pair of ASSP to nest. Fine pumice gravel (depth 2–3 cm) was spread under each tile to form a floor. Rocks were placed at tile entrances to reduce entrance sizes to generally match those of natural crevices used for nesting and to prevent entry by crevice-nesting alcids, which can evict ASSP (Ainley *et al*. 1990). One end of each tile was blocked completely by rocks or pieces of cement tile backer boards to mimic a natural nest crevice and protect the interior from wind. Fine sand was placed around tile sites to detect storm-petrel footprints and to reduce wind inside sites. Small mirrors (13 cm wide × 6 cm high; Educational Innovations, Inc., Norwalk, CT) also were taped to the outside of all artificial nests to encourage visiting storm-petrels to stay longer and to increase opportunities for interactions with other storm-petrels. In 2008, small bags filled with ASSP feathers gathered during monitoring in past years were placed inside each tile site to provide an olfactory cue to further encourage use. However, we removed feather bags in 2009–2010 to increase space in artificial nests. A total of 30 nests were deployed in the Upper West Cavern (n = 22) and Upper East Cavern (n = 8). Most (70%) nests were deployed on 1 April 2008, but five were deployed on 28 March 2009 and four on 12 March and 14 April 2010. All nests were placed near natural nest crevices, on portions of cavern floors or ledges without natural crevices. No natural crevices were physically replaced by artificial nests. Except for two nests in the Upper East Cavern, all artificial nests were within about 50 cm of at least one other artificial nest.

Ceramic artificial nests

In response to CORA impacts to several tile-based artificial nests at OR in 2010, we replaced 13 tile nests with 13 ceramic nests on 31 March 2011 (Fig. 4), in time to avoid having a year without artificial nests. Each ceramic nest was handmade of clay fired at

TABLE 1
Monitoring of Ashy Storm-Petrels at Orizaba Rock (OR) and Cave of the Birds' Eggs (CBE) 1995–2011

Colony	Metric[a]	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
OR	BS	•[b]	•	•								•	•	•	•	•	•	•
	TN	•	•	•								•	•	•	•	•	•	•
	LSN	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•
CBE	BS	•	•	•	•							•	•	•	•	•	•	•
	TN	•	•	•	•							•	•	•	•	•	•	•
	LSN	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•

[a] BS = breeding success, TN = total nests, LSN = late-summer nests.

[b] Dot indicates data were obtained during that year.

Fig. 2: Artificial nest site constructed from concrete roof tile on Orizaba Rock on 1 April 2008, showing pumice gravel pad of artificial nest site before the cement tile is placed over the pad (photo by W. McIver).

Fig. 3: Artificial nest sites at Orizaba Rock on 1 April 2008, showing mirrors on the sides of the sites, backer boards and fine sand around site sides (photo by W. McIver).

high temperatures for durability. The single entrance allowed a storm-petrel to enter the front of the nest chamber before turning around a small wall to reach the back of the chamber where the egg usually was incubated. This internal wall concealed nest contents from direct CORA viewing and prevented CORA bill access. Removable lids allowed researchers to view and access nest contents. Each lid was secured to the chamber body by metal flanges glued with epoxy to the inside of each lid, which fit into slots in the top of the nest box. The lid could be rotated slightly to lock or unlock it. Small amounts of fine pumice gravel and sand were placed as nesting substrate that would reduce egg rolling and possible breakage. For the remaining tile nests located on the ledge in the Upper West Cavern (n = 16), two handmade ceramic pieces were attached with Velcro strips to the front of each tile nest to reduce direct viewing and prevent bill access by CORA (Fig. 5). Ceramic nests were placed on the floors of the Upper West Cavern (n = 5) and Upper East Cavern (n = 7), and on a ledge in the northeastern portion of the Upper West Cavern (n = 1).

Vocalization broadcasting

At OR in 2008–2011, we used a single vocalization broadcast system, as developed by the National Audubon Society and widely used for social attraction (e.g. Parker *et al.* 2007). This system involved use of a MP3 player for continuous play of ASSP vocalizations during night hours to encourage storm-petrels to attend the colony and visit artificial nests for longer periods of time. On nights without wind, vocalizations could be heard up to about 300 m from the rock. These vocalizations were originally recorded by D.G. Ainley at the Farallones and included many typical ASSP calls (e.g. sky-call, rasp, duetting; Ainley 1995). The MP3 player, marine batteries, light sensor and amplification system were placed in a locked plastic tote box, and batteries were recharged with a 0.9 m × 1.5 m solar panel (Fig. 6). The solar panel and tote box were securely placed at an inconspicuous location on the west side of OR that received adequate sunlight. Vocalizations were broadcast by two small speakers, one in the Upper West Cavern near all artificial nests and many natural crevices, and one in the Lower West Cavern without artificial nests but with some natural crevices. In April 2008, the amplitude of the playback was 80–90 dB as measured 1 m from the speaker with a sound meter. Vocalization broadcasting was initiated each year in late March or early April, on the same dates that artificial nests were deployed, with the exception of 2010 when vocalization broadcasting was not initiated until 14 April. Broadcasting was stopped in September 2008, but was halted in August 2009–2011 to avoid any possible impacts (i.e. disorientation or predation) to chicks at fledging.

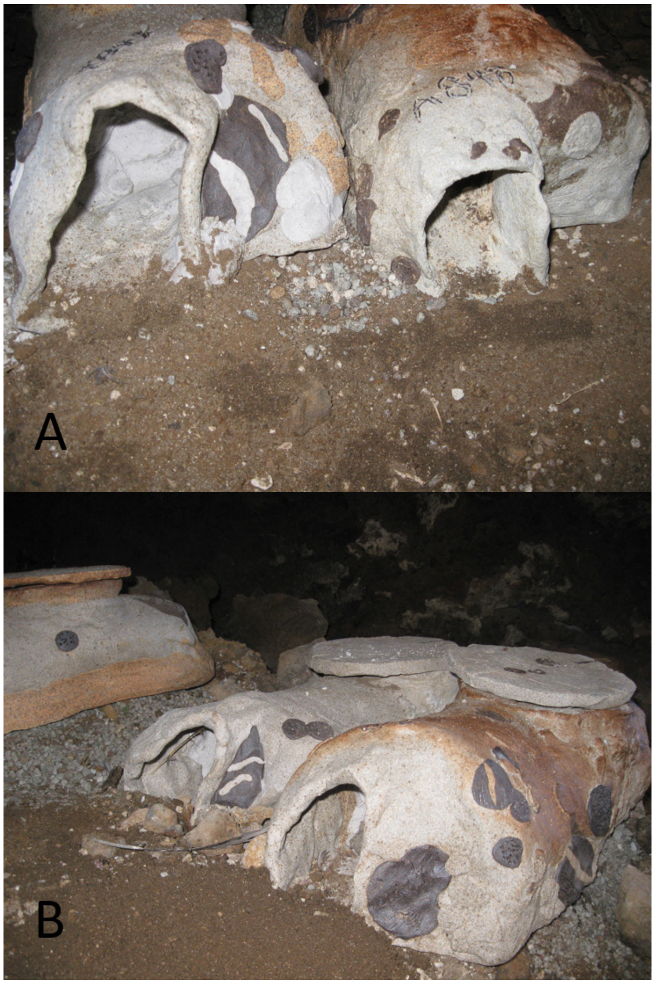

Fig. 4: Ceramic nest chambers at Orizaba Rock on 31 March 2011, showing (A) interior wall obstructing direct views of nest contents and (B) removable lids (photos by W. McIver).

Monitoring avian predators

In September 2010 and April 2011, three reconnaissance cameras (model HC500 Hyperfire, Reconyx Inc., Holmen, WI) were deployed in the upper caverns at OR to capture images of avian predators visiting the caverns, altering artificial nests or depredating storm-petrels. The cameras were active day and night, and images were taken when cameras were motion-activated within the field of view. They were programmed to take three images within three consecutive seconds before stopping for 10 min and re-setting. Two cameras were deployed in the Upper West Cavern, where most artificial nests were deployed, and one camera was deployed in the Upper East Cavern with the remainder of the artificial sites.

Data analysis

For examining changes in the OR population in the restoration period (2008–2011; n = 4 years), we designated 2005–2007 (n = 3

Fig. 5: Ceramic pieces attached to front end of concrete roof tiles at Orizaba Rock, 31 March 2011 (photo by L. Harvey).

years) as the project baseline period, because (1) data in 1999–2004 did not include total nest numbers or reproductive success; and (2) data from the 2005–2007 baseline period indicated some changes or variation before restoration actions that needed to be considered in comparisons. We also selected CBE as the best reference colony for comparison with OR because skunk predation had greatly affected Bat Cave (2005) and Cavern Point Coves Caves (2008) and less extensive data had been collected at Dry Sandy Beach Cave in 2011. In addition to restoration and baseline periods, we also compared changes in colony size at OR and CBE with the decline period (1995–2004), which informed us about the status of these colonies before the baseline period.

At OR and CBE, we examined changes in four population parameters between 1995 and 2011: colony size (total number of active nests), colony size index (number of active nests by late summer), breeding success (number of chicks fledged per active nest) and timing of breeding (estimated mean date of laying of single or first eggs).

To examine trends in colony size index, we conducted linear regression analyses over the full period of 1995–2011 (n = 16 years), the decline period of 1995–2004 (n = 9), and the baseline and restoration periods of 2005–2011 (n = 7). To examine trends in colony size, we conducted linear regression analyses for only the baseline and restoration periods of 2005–2011 (n = 7 years). We focused mainly on examining trends in the colony size index, because of the larger sample available for the 1995–2004 decline period (i.e. 9 years compared with only 3–4 years for colony size; see Table 1). This allowed for a comparison of regression trends between 1995–2004 and 2005–2011. To assess temporal trends, simple linear regression analyses of natural log-transformed numbers of active nests in July were conducted for OR and CBE. Special data handling was required to include data from certain years. In 1998, July data were not available at OR and August data were substituted. In 2005, when early and late July data were available, we used only late July data to better match the timing of July data in other years. In 1995–1997 and 2005–2011, we included in colony index counts certain nests that only had evidence of breeding before late summer trips. We assumed that evidence of breeding in these nests would have persisted until late summer if not removed by us earlier.

Fig. 6: Vocalization broadcast system on Orizaba Rock, 2011: (A) tote box containing MP3 player and other equipment and (B) close-up of solar panel and tote box (photos by L. Harvey).

To examine breeding success trends during baseline and restoration periods (2005–2011), we conducted simple linear regression analyses against year on the percentage of active nests that fledged a chick for CBE and OR. Data for breeding success in 1995–1998 were not examined due to effects from organochlorine pollutants (McIver 2002, McIver *et al.* 2009, Carter *et al.* 2008a, b). We also compared: (1) annual breeding success at CBE and OR for 2005–2011 (n = 7 years); (2) average annual breeding success at CBE and OR from 2005–2011; (3) number of nests with fledged chicks from natural and artificial nests at OR from 2008–2011 (n = 4 years); and (4) average annual success (n = 4 years) at natural and artificial nests at OR from 2008–2011. Because of non-normal data, non-parametric *t*-tests were used for all comparisons.

To examine trends in timing of breeding, we used simple linear regression analyses to assess mean lay dates against year at OR and CBE for the 2005–2011 baseline and restoration periods. As with breeding success data, data on timing of breeding from 1995–1998 were not examined due to possible effects from organochlorine pollutants. Using two-factor ANOVAs, we also compared (1) mean lay dates at natural versus artificial sites at OR from 2008–2011, (2) average annual mean lay dates (n = 4 years) for natural versus artificial sites from 2008–2011, and (3) overall averages for natural versus artificial sites at OR from 2008–2011 (years collapsed due to low sample sizes of nests at artificial sites). Nests inside and outside artificial sites were lumped for the analyses.

All data were subjected to assessments of normality and equal variance before statistical analyses were performed. Normality was assessed using histograms and the Shapiro-Wilk normality test ($P < 0.05$). Equal variances were assessed using a Levene's test with significance at $P < 0.05$. Normally distributed data with equal variances were analyzed using parametric analyses.

RESULTS

Artificial nest use

In 2008–2011, ASSP laid eggs at 36.7% of artificial nests, while 30.0% were visited only and 33.3% did not have evidence of egg laying or visitation (n = 30) (Appendix 1 [available on the website], Table 2). Overall, ASSP occupied 20 nests (66.7%; i.e. egg laying or visiting in one or more years). Usually only one egg was laid in association with each artificial nest (inside seven nests and outside four nests); however, at nest A-863, an egg was laid inside and another was laid outside about 1 m away. Egg laying occurred in more than one year at eight nests, and two nests (A-868, A-847B) were used or visited in all four years. Fourteen single/first eggs (60.9%; n = 23) were laid inside artificial nests and nine (39.1%) were laid outside nests (Table 2). Only one second egg was laid inside an artificial nest (A-869), in 2009. All artificial nests were situated on a broad ledge and cavern floors near the call playback speaker, where natural sites did not occur before deployment. We were careful to avoid disturbing active nests outside of artificial nests during nest monitoring. Most (75.0%, n = 20) occupied artificial nests were found in the Upper West Cavern, within 1–4 m of the upper speaker, where most (73.3%, n = 30) artificial nests were deployed.

Natural nest use

At OR, numbers of natural nests increased from 7 to 15 in the 2005–2007 baseline period and then from 22 to 29 in the 2008–2011 restoration period (Table 2). Many nest sites were tagged before 2005, with tags lost between 2005 and 2008 and others added in 2005–2011; by 2011, 42 tagged sites remained (Table 2). Nine replacement eggs were laid at natural sites: in 2008 (n = 3), 2009 (n = 1), 2010 (n = 3) and 2011 (n = 2). Cassin's Auklets *Ptychoramphus aleuticus* (CAAU) also were documented nesting at OR in 2005–2011 (range: 0–4 nests). Two marked natural crevice sites, used intermittently by ASSP, were occupied by CAAU in at least one year during the 2008–2011 restoration period. We did not observe direct impacts of high water events on storm-petrel nesting habitats at OR during the breeding seasons from 2008–2011.

At CBE, the number of nests increased from 19 to 30 in the 2005–2007 baseline period, remained stable at 28 and 31 in 2008 and 2009, respectively, and then decreased to 25 in both 2010 and 2011. High water (i.e. a relatively large amount of water into portions of sea cave nesting habitats that are typically dry during the breeding season) entered CBE during the breeding season in 2008, 2010 and 2011, killing at least one chick in fall 2008 and two adults in spring 2010 that likely were inside crevices and did not escape. The event in early 2010 removed clay and cobble habitat associated with three tagged nest sites from the front of the sea cave. In addition, this event may have killed additional unidentified adults at these lost sites and other sites, and caused changes of nest locations and mates by surviving adults. It occurred in the spring before many ASSP were incubating, but reduced numbers of active nests and lower breeding success in 2010 (65%), compared with 2008, 2009 and 2011 (range 71%–86%) (Table 3), may have been related to this high water event. Smaller high water events each winter also altered some natural crevice sites and caused loss of some nest tags in CBE, making it impossible to count the total numbers of previously used and visited nest sites. Four replacement eggs were laid: in 2008 (n = 2), 2009 (n = 1) and 2011 (n = 1).

TABLE 2
Numbers of active nests and visited locations for Ashy Storm-Petrels at Orizaba Rock and Cave of the Birds' Eggs 2005–2011

	Number (late-summer nest count)											
	Artificial nests				Natural crevices				Combined			
Colony/ year	Usable	Active	Visited only[a]	Total used	Tagged nests[b]	Active	Visited only	Total used	Usable/ found	Active	Visited only	Total used
Orizaba Rock												
2005	–	–	–	–	31	7 (7)	0	7	–	–	–	–
2006	–	–	–	–	26	15 (14)	0	15	–	–	–	–
2007	–	–	–	–	29	14 (14)	0	14	–	–	–	–
2008	21	4 (3)	4	8	31	20 (16)	2	22	52	24 (19)	6	30
2009	26	6 (7)	1	7	36	22 (16)	3	25	62	28 (23)	4	32
2010	30	6 (5)	2	8	40	22 (17)	7	29	70	28 (22)	9	37
2011	30	7 (7)	7	14	42	26 (22)	0	26	72	33 (29)	7	40
Cave of the Birds' Eggs												
2005	–	–	–	–	28	19 (17)	0	19	–	–	–	–
2006	–	–	–	–	36	20 (19)	3	23	–	–	–	–
2007	–	–	–	–	40	27 (26)	2	29	–	–	–	–
2008	–	–	–	–	48	28 (24)	2	30	–	–	–	–
2009	–	–	–	–	51	29 (25)	2	31	–	–	–	–
2010	–	–	–	–	45	21 (18)	4	25	–	–	–	–
2011	–	–	–	–	44	24 (18)	1	25	–	–	–	–

[a] Includes birds observed in sites with no evidence of egg laying, and no birds observed but evidence of visitation.

[b] Includes previously tagged sites found and newly tagged sites.

Pigeon Guillemots *Cepphus columba* (PIGU) also were documented nesting in CBE in 2005–2011 (range 7–21 nests), and one instance of PIGU apparently usurping an ASSP nest site was noted (i.e. an ASSP egg was ejected from a site with a PIGU chick nearby) in 2005. At least two large crevices used by PIGU also contained ASSP nests in side crevices.

TABLE 3
Breeding success (percent of nests fledging chicks) of Ashy Storm-Petrels at Orizaba Rock and Cave of the Birds' Eggs 2005–2011

Nest type	Year(s)	Breeding success[a]	n
Orizaba Rock			
Natural	2005	57.1	7
	2006	66.7	15
	2007	53.8	13
	2008	31.6	19
	2009	45.0	20
	2010	61.9	21
	2011	54.5	22
	2005–2007	60.0	35
	2008–2011	48.8	82
	2005–2011	52.1	117
Artificial	2008	50.0	4
	2009	66.7	6
	2010	33.3	6
	2011	57.1	7
	2008–2011	52.2	23
Both	2008	34.8	23
	2009	50.0	26
	2010	55.6	27
	2011	55.2	29
	2008–2011	49.5	105
Cave of the Birds' Eggs			
Natural	2005	55.6	18
	2006	61.1	18
	2007	74.1	27
	2008	78.6	28
	2009	70.8	24
	2010	65.0	20
	2011	85.7	21
	2005–2007	65.1	63
	2008–2011	75.3	93
	2005–2011	71.2	156

[a] Percentage of chicks that fledged per breeding pair, including replacement eggs.

Avian predation

Adult ASSP feather piles left by avian predators were observed at OR in 2008 (n = 1 adult), 2010 (n = 1 adult) and 2011 (n = 1 adult), but none was noted during the baseline period in 2005–2007 or in 2009. In addition, single piles of adult CAAU feathers were observed in 2010 and 2011. In 2006–2011, we also observed several large guano droppings on the west side of OR near a cavern entrance. We suspect that the primary avian predators at OR were Barn Owls *Tyto alba* and CORA, based on 1995–1998 monitoring (McIver 2002) and single owl pellets collected in 2002, 2004 and 2010. We also recorded CORA with reconnaissance cameras placed in the caverns in 2010–2011. CORA, in particular, were commonly observed at OR and elsewhere at SCZ in 1995–2011. A few pairs (<10) of Western Gulls *Larus occidentalis*, a known predator of ASSP at the Farallones (Ainley *et al*. 1974), breed at OR (Carter *et al*. 1992), but no evidence of Western Gull predation on ASSP was found in 1995–1998 (McIver 2002) or 2005–2011.

At CBE, ASSP feather piles or carcasses were observed during the baseline period in 2005 (n = 1 adult, and 1 adult or fully-feathered chick), 2006 (n = 2 adults and 1 chick), and 2007 (n = 2 adults). Feather piles also were noted at CBE in 2008 (n = 3 adults), but none in 2009–2011. In addition, PIGU feather piles and carcasses were observed during the baseline period in 2005 (n = 7 adults), 2006 (n = 1 adult) and 2007 (n = 6 adults and 1 chick). PIGU mortalities also were noted in 2008 (n = 6 adults and 1 chick) and 2011 (n = 5 adults and 2 chicks, as well as 1 depredated egg) but none in 2009 and 2010. In 2009–2011, we also noted guano streaks on a rock near the cave entrance. Based on the types of predation noted (i.e. feather piles, headless carcasses, carcasses with "clean" sternum without bite marks) and the locations of most carcasses well inside CBE, we suspect that most or all were caused by owls or CORA.

During baseline and restoration periods in 2005–2011, more ASSP were recorded killed by avian predators at CBE (n = 10) than at OR (n = 3). For other crevice-nesting seabirds, avian predation also was more prevalent at CBE (n = 29) than at OR (n = 2) in 2005–2011.

Raven impacts to artificial nests

Between July and November 2010, we noted that 12 artificial nests at OR had been physically altered, primarily by the removal of backer boards and rocks that enclosed one end of each artificial tile nest. Only artificial nests on the floors of the caverns were altered, and we re-assembled them during each monthly field trip. Images from a reconnaissance camera deployed on 15 September 2010 showed a CORA within the Upper East Cavern on 22 October and 15 November. After ceramic pieces were attached (with Velcro; see Methods) to some tile nests on the Upper West Cavern in spring 2011, we noted that ceramic pieces had been detached from four of these nests between 30 June and 30 July 2011. All ceramic pieces were then re-secured to tile nests with thicker and sturdier Velcro pieces. Further detachment of ceramic pieces from roof tiles nests was not observed in 2011 after 30 July.

Following the study period, CORA continued to dismantle artificial nests, leading us to remove affected nests and discontinue vocalization broadcasting during 2012.

Trends in colony size index

For the full period 1995–2011, the colony size index at CBE showed an increase of 9.3% per year ($P < 0.001$) (Table 4, Fig. 7). However, when the decline period 1995–2004 and the baseline and restoration periods 2005–2011 were considered separately, trends at CBE were not significant but reflected much variation. In detail, index values were similar through 1995–1998 (n = 8–10), dipped in 1999–2000 (n = 3 and 5, respectively), returned to previous levels in 2001–2002 (n = 9 in each year) and increased in 2004 (n = 13). In the baseline and restoration periods, the index continued to increase in 2005–2006 (n = 17 and 19, respectively), higher numbers were recorded in 2007–2009 (n = 24–26), and a return to lower numbers was apparent in 2010–2011 (n = 18 in both years).

At OR, during the decline period, the colony size index declined 17.5% per year from 1995 to 2004 ($P = 0.001$), then increased by 22.4% per year from 2005 to 2011 ($P = 0.002$) during baseline and restoration periods, with the estimated slope for OR being greater than that for CBE but not significantly ($P = 0.982$). A decreasing trend was evident throughout the 1995 to 2004 period, but the greatest decrease occurred between 1996 and 1997, with a lesser change in values between 1997 and 2004.

Changes in colony size

Between 1996 and 2005, at OR colony size declined 74.1% from 27 to seven nests, with a relatively large drop in nest numbers between 1996 and 1997 (n = 8), as noted for the colony size index; a lesser decline was apparent between 1997 and 2005. At CBE between 1995 and 2005, colony size increased 72.7% from 11 to 19 nests. However, numbers dropped from 12 in 1996 to nine in both 1997 and 1998, before the next colony size survey in 2005 (n = 19 nests). Thus, CBE colony size also decreased during the 1995–1998 period but then increased after 2000 (approximate timing based on index values) to 2005. Decline in 1995–1997 was less evident in index values than in colony size at OR and CBE, partly because fewer birds laid eggs after July in 1996–1998 (n = 0–2) than in 1995 (n = 4). Both colonies experienced the greatest decrease in 1995–1998, but, while the CBE colony recovered rather quickly after 2000, the colony at OR did not begin to recover until after 2004.

During the 2005–2007 baseline period, the greatest numbers of nests occurred at OR (n = 15) in 2006 and at CBE (n = 27) in 2007. At OR, numbers increased from seven to 15 nests between 2005 and 2006, but only 14 nests were found in 2007. However, some OR nests may not have been detected in 2005, as a result of a lower monitoring effort in effect before MSTC funding. At CBE, numbers were similar in 2005 (n = 19) and 2006 (n = 20) but increased to 28 in 2007.

The first season of social attraction efforts at OR resulted in a 71.4% increase in nest numbers between 2007 (n = 14 nests) and

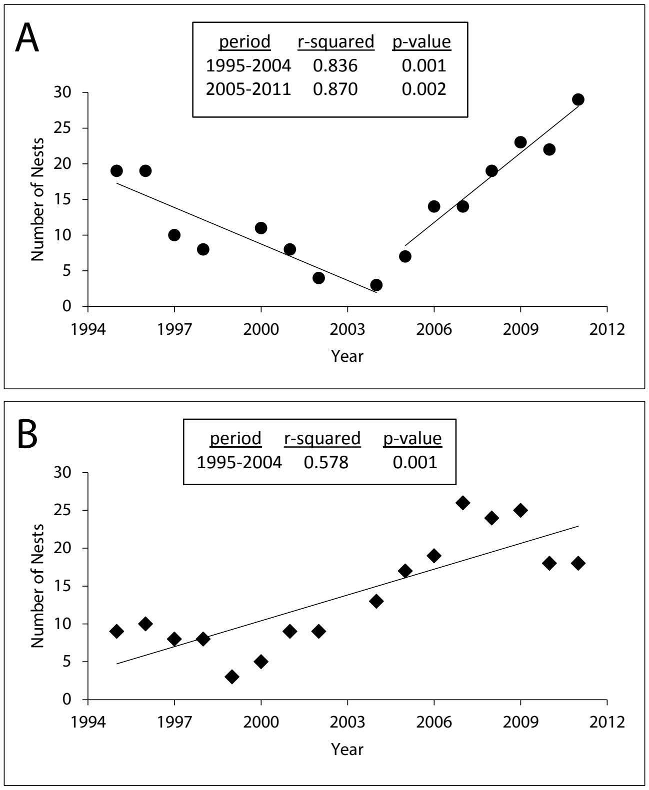

Fig. 7: Trends in colony size index (defined in text) at (A) Orizaba Rock and (B) Cave of the Birds' Eggs 1995–2011.

TABLE 4
Trends in numbers of active nests of Ashy Storm-Petrels at Orizaba Rock (OR) and Cave of the Birds' Eggs (CBE) between 1995 and 2011, regression analyses

				Slope estimates					**Percent per year change**		
Colony	**Period**	**Count**	**R^2**	**Estimate**	**SE**	**95% CI lower**	**95% CI upper**	**P value**	**Estimate**	**95% CI lower**	**95% CI upper**
OR	1995–2011	July	0.090	0.037	0.033	-0.034	0.108	0.277	3.77	-3.34	11.40
	1995–2004	July	0.836	-0.192	0.035	-0.277	-0.107	0.001	-17.5	-24.2	-10.15
	2005–2011	July	0.870	0.202	0.035	0.112	0.292	0.002	22.38	11.85	33.91
	2005–2011	Total	0.860	0.235	0.043	0.126	0.345	0.003	26.49	13.43	41.20
CBE	1995–2011	July	0.578	0.089	0.020	0.045	0.132	0.001	9.31	4.60	14.11
	1995–2004	July	0.020	0.021	0.055	-0.109	0.151	0.714	2.02	-10.3	16.30
	2005–2011	July	<0.001	0.001	0.037	-0.095	0.097	0.982	0.01	-9.06	10.19
	2005–2011	Total	0.152	0.031	0.033	-0.053	0.115	0.388	3.14	-5.16	12.19

2008 (n = 24 nests). Subsequent increases also occurred, but were relatively smaller: 2008 to 2009 (16.7%), 2009 to 2010 (0%), and 2010 to 2011 (21.4%). OR reached a high value of 33 nests by 2011 (including seven [21.2%] in artificial sites and 27 [81.8%] in natural crevices), which was 22.2% higher than in 1996 (n = 27), 135.7% higher than in 2007 (n = 14), and 175% higher than the baseline mean of 12 nests (2005–2007). Colony size grew rapidly (26.5% per year, *P* = 0.003) between 2005 and 2011 (Table 4). At CBE, colony size underwent much variation between 2005 and 2011 (n = 19–29), with highest numbers in 2007–2009 (n = 27–29), as noted for the colony size index. Using the baseline mean of 22 nests (2005–2007), CBE colony size increased only slightly to 24 nests in 2011. In 2005–2011, colony size at CBE was 46.2%–123.1% higher than in 1995 (n =13).

Timing of breeding and breeding success

Linear regressions of mean timing of egg laying in 2005–2011 were not significant for either CBE (*P* = 0.932) or OR (*P* = 0.576; Table 5). Friedman tests comparing mean lay dates for the sites also indicated no significant difference between colonies (*P* = 0.706). Timing of egg laying in artificial and natural nests at OR in 2008–2011 (all nests combined) also were not significantly different (*P* = 0.655).

Considering natural nests only from 2005–2011 (Table 3), breeding success was lower at OR (52.1%) than at CBE (71.2%) (*P* < 0.001). However, from 2005–2007, breeding success at OR (60.0%) was only slightly lower than at CBE (65.1%). Also, success was slightly higher at OR in 2005–2007 than in 2008–2011 (artificial and natural nests combined; 50%), but this difference was not significant (*P* = 0.453). Linear regression analyses for breeding success in 2005–2011 indicated a significant increase at OR (*P* = 0.005) but no change at CBE (*P* = 0.349; Table 5, Fig. 8). CBE had greater breeding success than OR in 2005–2011 overall (*P* < 0.001). No differences in breeding success were found between artificial and natural nests (*P* = 0.90; Table 5) at OR in 2008–2011 (all nests combined).

TABLE 5
Mean egg-laying dates for Ashy Storm-Petrels at Orizaba Rock (OR) and Cave of the Birds' Eggs (CBE) 2005–2011

Colony	Year(s)	Mean lay date	SD	n
OR	2005	19 June	11.4	6
	2006	16 June	7.9	15
	2007	29 May	3.2	10
	2008	15 June	5.1	24
	2009	22 June	5.9	27
	2010	6 June	8.4	17
	2011	24 June	5.1	28
	2005–2007	10 June	4.7	31
	2008–2011	17 June	3.0	96
	2005–2011	16 June	2.5	127
CBE	2005	19 June	6.6	14
	2006	5 June	4.1	17
	2007	30 May	2.8	24
	2008	28 May	5.6	28
	2009	11 June	4.2	29
	2010	6 June	5.5	19
	2011	15 June	7.4	22
	2005–2007	5 June	2.6	55
	2008–2011	7 June	2.9	98
	2005–2011	6 June	2.1	153

In 2008–2011, mean breeding success was lower at OR (49.9%, range 31.6%–61.9%) than at CBE (75.3%, range 65.0%–85.7%) (Table 3). The relatively low mean at OR was partly related to a very low value for natural sites in 2008 (31.6%). However, when 2008 was excluded, mean success at OR in 2009–2011 (53.6%, range 50.0%–55.6%) was still lower than at CBE during the same period (73.8%, range 65.0%–85.7%).

DISCUSSION

Decline of the Orizaba Rock colony, 1995–2004

ASSP have been recorded nesting at SCZ since 1912 (Appendix 2, available on the website). However, before standardized nest monitoring began in 1995, little was known about the history of the ASSP colony at OR, although nesting was documented in 1976, 1992 and 1994. OR has likely been a long-established small colony, with colony size limited by the relatively small amount of suitable nesting habitat. Given the documentation of breeding in 1976, the OR colony apparently did not disappear during the period of heavy organochlorine pollution in the SCB in the 1940s to 1970s. However, between 1995 and 2004, a major decrease in nest numbers at OR occurred, mainly between 1996 and 1997. At CBE, a much smaller decrease occurred in 1995–1997, followed by natural recovery in 2000–2005. Since these colonies are only ~14 km apart, ASSP at OR and CBE likely forage at similar locations at sea, at least during the pre-breeding and breeding seasons from about February to October when most birds attend colonies. At this time, they would be exposed to similar at-sea factors far from colonies (e.g. prey availability, organochlorine pollutants, 1998 El Niño, 1999–2001 La Niña, oil spills; see Ainley *et al.* 1990, Carter *et al.* 2008b) that may influence breeding success or mortality. Thus, some factor or combination of factors at the

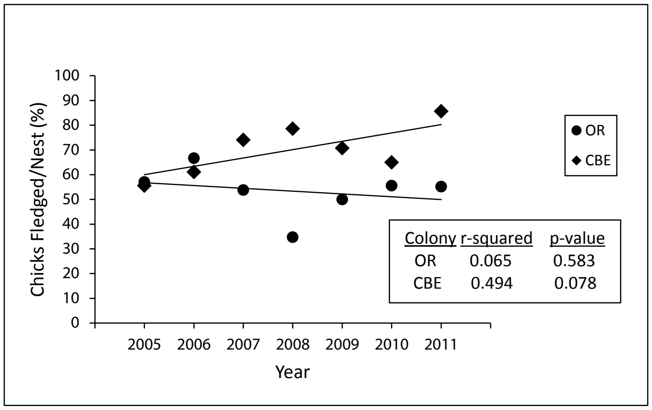

Fig. 8: Trends in breeding success of Ashy Storm-Petrels at Orizaba Rock (OR) and Cave of the Birds' Eggs (CBE) 2005–2011.

breeding colony apparently affected both OR and CBE between 1995 and 1997, causing a short-lived decrease at CBE but a greater and longer decrease at OR. Avian predation did not appear to be one of these factors, as only low levels of avian predation were recorded at OR and CBE in 1995–1998 (McIver 2002, McIver *et al.* 2009).

Three known anthropogenic activities at OR may have had large enough impacts between 1995 and 1998 to have caused or contributed to long-lasting decline at OR: (1) bright lights from squid fishing boats (1992–1996), (2) egg collecting for organochlorine pollution studies (1992), and (3) extensive mist-net captures (1994–1996). Beginning in 1992, intense market squid *Doryteuthis opalescens* harvesting using bright lights at night was carried out near SCZ. Very high levels of fishing effort in southern California (including off the north coast of SCZ) occurred between April 1995 and March 1996, and between July 1996 and September 1997 (CDFG 1996, 1997, 2005; Vojkovich 1998, Maxwell *et al.* 2004). On 24 October 1995, W.R. McIver and H.R. Carter (pers. obs.) witnessed squid-fishing boats with bright lights west and east of OR and, on 7 August 1996, W.R. McIver (pers. obs.) observed a squid boat with bright lights about 300 m off OR from 21h35 to 23h30. In each instance, the north side of OR was fully illuminated at night and the south side also was partly illuminated. Most ASSP nest site entrances at OR (especially those within caverns) were not directly exposed to these lights, but light levels likely were increased throughout the Upper West and Upper East caverns, where most natural nests are located. Nesting areas at CBE were less exposed to squid-fishing lights because most nests occur over 20 m inside the cave entrance, and the cave has only one major entrance that faces southwest, away from squid-fishing areas. Bright lights are well known to affect various species of Procellariiformes, causing increased predation rate, direct collisions with lights (especially by fledglings), decreased nest attendance, and nest abandonment (*c.f.* Reed *et al.* 1985, Weimerskirch *et al*. 2000, Rojek 2001, Le Corre *et al*. 2002, CDFG 2005). No direct observations of such impacts to ASSP at OR or CBE were obtained in 1995–1998, but we did not examine nests at night and observations of birds were not conducted at these bright light sources. However, given decreases in the number of nests in 1995–1997 during intense squid fishing, we consider that at least some impacts from squid lights (e.g. nest/colony abandonment, reduced recruitment, or predation), mainly to adults, likely occurred at both colonies. Greater exposure to squid-fishing lights at OR may have led to greater impacts to this colony than at CBE.

Nightly squid-fishing effort (estimated number of vessels) in southern California was reduced to low levels by October 1997 in response to the 1997–1998 El Niño, and did not return to previous levels due to fishery management changes (CDFG 1998, 2005; Maxwell *et al.* 2004). Light shields and wattage restrictions also were required in May 2000, and this may have reduced the amount of light emitted by squid boats. However, shifts in fishing areas also resulted in reduced fishing effort off the north side of SCZ (CDFG 2005). Reduced colony size and reduced production of fledglings in 1995–1997 likely led to lower recruitment in 2002–2004, assuming that most birds recruited at ages of 6–7 (as in Leach's Storm-Petrel *O. leucorhoa*; Huntington *et al.* 1996). Lower impacts at CBE in 1995–1997 likely accounted for less reduction in colony size and more rapid natural recovery by 2005, although breeding success was similar at OR and CBE in 1995–1997 (McIver 2002, McIver *et al.* 2009; Table 6).

In 1992, 11 viable eggs (i.e. equivalent to 41% of the 27 nests found in 1996) were collected at OR and three viable eggs (i.e. equivalent to 25%–33% of the 9–12 nests found in 1995–1998) were collected at CBE for pollutant and eggshell thickness analyses (Fry 1994, Kiff 1994, Carter *et al.* 2008b, Appendix 2). Reduced numbers of fledglings would have resulted from these collections at OR and CBE in 1992, although breeding success was not measured that year. Fewer than half of the 11 chicks that did not fledge at OR could be expected to survive to the age of first breeding, possibly leading to the loss of one or two nesting pairs at OR in 1995–1999. Overall, similar small impacts may have resulted from egg collections at both OR and CBE, whereas only OR experienced an extended decrease in numbers, so this factor alone did not cause the extended decrease at OR.

ASSP also were monitored using mist nets at OR in 1994–1996 (H.R. Carter, unpubl. data). In July–August 1994, 103 were netted on two nights; in June–October 1995, 209 were netted on nine nights; and in July-September 1996, 31 were netted on four nights. As well, 53 more were netted in June 1996 aboard the anchored support vessel near OR. Clearly, the 363 birds captured in 1994–1996 far exceeded the number of adults and associated subadults breeding on OR (maximum of 27 nests in 1996). These birds likely originated from both OR and 10 other colonies on the NW and NE coasts of SCZ (Carter *et al.* 2008a). Some birds likely fly along the shore of the main island at night to reach these colonies, passing OR in the process. Some of these passing birds may have been attracted to OR by head lamps or broadcast vocalizations during netting. Only one mortality occurred during netting on the boat and no other injuries or mortalities were noted. We consider that handling of ASSP in mist nets may have caused sufficient stress for a few OR-breeding individuals to abandon their nests or possibly make them more susceptible to predation, but we consider that this level of impact would not have been a major factor causing the observed decrease.

Increase in the Orizaba Rock colony, 2005–2011

Numbers of ASSP nests at OR increased rapidly in 2005–2011. Early signs of natural recovery at OR during the baseline period of 2005–2007 indicated improved recruitment. Improved breeding success was first documented at all SCZ colonies in 2005; this likely began earlier but success was not measured in 1999–2004 (Table 1). Decreased impacts from organochlorine pollutants and avian predation likely led to improved success (McIver *et al.* 2009). In addition, none of the three known anthropogenic activities noted above were occurring in 2005–2011.

Total numbers of ASSP nests at OR in 2009–2011 were similar to or greater than the 1996 level (McIver *et al.* 2009). This result demonstrated that one of the major project goals of restoring the colony to its former level or higher was achieved. After removal of artificial nests and cessation of vocalization broadcasting in 2012, numbers of natural nests at OR in 2012–2014 also continued to increase above 2009–2011 levels. Future monitoring will allow for the best long-term interpretation of colony growth after 2011.

Breeding success and timing of breeding in 2005–2011

Mean breeding success in natural sites at OR was higher in 2005–2011 than in 1995–1998), likely due to lower pollutant levels and lower avian predation (McIver 2002, Carter *et al*. 2008b, McIver *et al*. 2009). However, only a small increase in mean success was shown at CBE between 2005–2011 and 1995–1998. Overall, mean success still was higher at CBE than at OR in 2005–2011. Some of this difference appears to be natural and related to higher egg loss on OR from eggs rolling out of small and inadequate crevices between and under large boulders. Future monitoring will determine if breeding success continues to improve at OR over time or remains below that of CBE. Mean breeding success at CBE in 2005–2011 was comparable to that at the Farallones in 1971–1983 (Ainley *et al.* 1990).

At OR in 2008–2011, mean breeding success in all nests and artificial nests only was comparable to breeding success observed in artificial nests for Band-rumped Storm-Petrels *O. castro* (BRSP) (Bolton *et al.* 2004). In that study, breeding success in artificial nest chambers was higher than in natural cavities, due to higher egg loss in natural nests from structural characteristics (e.g. small stones that punctured eggs). At OR, we did not observe a statistical difference in mean breeding success in 2008–2011 between artificial and natural sites. High water events did not appear to explain years of relatively low breeding success at OR (2008) and CBE (2005 and 2006). Avian predation did not appear to contribute to lower breeding success at OR, but may have at CBE in 2005 and 2006, when two to three dead ASSP were found in each year. Reduced breeding success at OR in 2008 and CBE in 2005 was affected primarily by failures during the chick stage; at CBE in 2006, failures occurred during the egg and chick stages. We could not determine if the first year of nightly vocalization broadcasting at OR in 2008 had any kind of negative effect leading to relatively low breeding success, but if so, any impacts did not carry over to 2009–2011. The causes of these poor years are not known, but reduced food availability likely does not explain many failures because poor years happened in different years at different colonies. Greater undetected avian predation possibly occurred in these years, but we detected little change in predation rate among years.

Potential source of birds using artificial nests

At OR, we monitored all natural nest sites in accessible areas from 2005–2011. A few nests were known to exist in deep inaccessible cracks, based on the occasional eggshell that fell out of these habitats, but these could not be monitored. Potential sources for new recruits in 2005–2011 included: (1) subadults that had fledged from OR, (2) subadults or adults from other colonies, and (3) return of adults that previously bred at OR but had temporarily not done so. Bolton *et al*. (2004) considered that the majority of BRSP breeding in nest boxes probably represented additional pairs entering the population (i.e. either first-time breeders from the colony or from other colonies), since Procellariiformes exhibit high site fidelity (Warham 1990). Without the benefit of information from banded individuals, we assumed that additional nesting birds had entered the OR breeding population and laid eggs in both artificial nests and natural crevices. Given the rapid initial response of storm-petrels to social attraction in 2008, we suspect that new nesters in 2008 were mainly first-time breeders. This rapid response may have resulted from an initial response by older subadults already attending the colony, along with high breeding stimulation caused by vocalization broadcasting beside these sites. These individuals may have bred at a younger age, especially in artificial nests without nest holders to contest nest use. Rapid use of artificial nests, especially with broadcast vocalizations (i.e. within 1–2 years), is increasingly well known among petrels under many different circumstances (Carlisle *et al*. 2003, Bolton *et al*. 2004, Jones & Kress 2012). However, given relatively low numbers of nests (<12 per year) on OR in 1997–2005, insufficient chicks from OR would be expected to survive to breeding age to account for the 20 new nests (natural and artificial) established between 2007 and 2011. Mist-net captures in 1994–1996 suggested that some birds from other colonies pass by OR and could be attracted to OR by vocalization broadcasting. Subadults from other colonies are more likely to be attracted and choose to stay or breed at OR than are breeding adults from other colonies which are already tied to a nest site and mate. Any adults that had left OR in the past due to disturbance from squid-fishing lights or avian predators in 1995–1997, when most impacts occurred, likely remained at their new location or died before 2005.

Use of artificial nests

At OR, ASSP laid eggs in artificial nests each year from 2008–2011, and chicks fledged from each type of artificial nest (i.e. roof tile and ceramic). Nocturnal broadcasting of ASSP vocalizations from one or two speakers was implemented during the pre-laying, incubation and early chick portions of the breeding season in each year in 2008–2011; this was the first time this method had been used to encourage nesting by ASSP at specific nesting habitats. Podolsky & Kress (1989) suggested that prospecting storm-petrels are most attracted to artificial burrows when stimulated with the complete set of sounds typical of an active colony. Higher occupancy rates of storm-petrels in artificial sites at OR occurred close to speakers, as also found in other studies (Podolsky & Kress 1989, Bolton *et al.* 2004). In 2010, a nocturnal video camera also captured images of ASSP interacting directly with or displaying at speakers which confirmed direct attraction of ASSP to broadcast vocalizations (L. Halpin, unpubl. data). We suspect strongly that vocalization broadcasting and clustered placement of artificial nests encouraged the rapid and continued use of artificial sites by ASSP at OR in 2008–2011.

Vocalization broadcasting was not employed in several other studies providing artificial sites for storm-petrels. Bolton *et al*. (2004) reported a large increase in the number of breeding pairs of BRSP from the first to the second breeding season, without vocalization broadcasting, and they suggested that a small number of successfully breeding storm-petrels can attract prospecting birds to artificial sites in subsequent years. De León & Mínguez (2003) and Libois *et al*. (2012) showed that providing artificial nests in the absence of vocalization broadcasting can result in increased use of artificial nests for nesting, but it may take longer. Bried *et al*. (2009) reported an almost fourfold increase in numbers of BRSP nests in nest boxes over six years (without vocalization broadcasting), and that use of natural nests did not vary significantly between years. They also thought that nest boxes offered more protection than natural nests from inclement weather and excavation by Cory's Shearwaters *Calonectris diomedea* and resulted in higher breeding success. BRSP may have chosen nest boxes over natural nests in response to inter-specific competition with shearwaters for nest sites.

Impacts of raven predation

In past studies involving storm-petrel use of artificial nests, disruption of nests or breeding activities by avian predators was not reported (Bolton *et al*. 2004, Bried *et al.* 2009, Libois *et al*. 2012). At OR, CORA dismantled artificial nests in 2010, and this encouraged a design change for artificial nests used in 2011. These modified nests provided additional protection to storm-petrels from CORA and other avian predators, so that in 2011 impacts to artificial nests by CORA were much reduced. Reasons for higher CORA visitation to OR in 2010–2011 over 2005–2009 may have partly reflected: (1) attraction to restoration equipment (i.e. solar panel, artificial nests, cameras, broadcast vocalizations); (2) increased CORA populations at SCZ; and (3) increased CORA use of areas near OR, especially for feeding or scavenging at Scorpion Ranch Campground (31 sites) at the east end of SCZ, ~15 km east of OR.

Harriman & Berger (1986) suggested that CORA also can use olfactory cues to find food. Like other species of storm-petrel, ASSP have a distinct musky odor that is detectable at nest sites, and adults and chicks occasionally vocalize from nests during the day. At least two CORA became experienced with opening artificial sites at OR in 2010–2011. We may have under-detected CORA before this period but, with no alterations of artificial nests in 2008–2009, we suspect that CORA most likely did not enter caverns on OR before 2010, or entered caverns infrequently.

Conclusion

Using social attraction in 2008–2011, we met our two main restoration goals: (1) the recovery of colony size at OR; and (2) the annual and sustained use of artificial nest sites. Following this study, in 2012–2015, colony size also was maintained at or exceeded recovered higher levels, even without vocalization broadcasting (after mid-July 2012) and after re-deployment of artificial nests in 2014. Colony regrowth in 2005–2011 likely reflected: (1) improved reproductive success (due mainly to reduced impacts from organochlorine pollution, relatively low levels of predation, and adequate prey availability); (2) few or no impacts from squid-fishing lights near OR after 1997; (3) some natural recovery in 2005–2007; and (4) use of artificial sites and vocalization broadcasting to encourage greater nesting in 2008–2011. The immediate and continued response over these four years by ASSP to the presence of artificial nests and vocalization broadcasting indicated the value of this method of social attraction for rapidly increasing colony size, under conditions conducive to colony growth. Absent substantial continued impacts by CORA, we expect that ASSP will continue to occupy more chambers over time without vocalization broadcasting.

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