

REPRODUCTIVE PERFORMANCE OF ASHY STORM-PETRELS (*OCEANODROMA HOMOCHROA*) AT SANTA CRUZ ISLAND, CALIFORNIA, IN 1995–2007

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Abstract—In 1995–1998 and 2005–2007, reproductive performance of the ashy storm-petrel (*Oceanodroma homochroa*) was measured at four sea caves and one offshore rock at Santa Cruz Island, California. In 1995–1998, relatively low hatching success (62.2%) occurred, with broken eggs accounting for 53% of failed eggs, consistent with documented eggshell thinning from organochlorine pollutants. Hatching success was higher in 2005–2007 (72.6%), with fewer broken eggs (32.7%), reflecting reduced pollutant levels, lower predation, and other factors. Fledging success was high in 1995–1998 (91.7%) and 2005–2007 (86.5%). Breeding success was moderate in 1995–1998 (54.9%) and 2005–2007 (63.4%). Predation by barn owls (*Tyto alba*) was prominent in 1995–1998 but not in 2005–2007. In 2005, island spotted skunks (*Spilogale gracilis amphiala*) killed at least 76 adults and caused complete reproductive failure at Bat Cave. By 2007, numbers of nests at Bat Cave had returned to about 40% of pre-2005 levels. Differences in reproductive performance between locations at Santa Cruz Island apparently were related to predation, human disturbance, and bright lights from squid-fishing boats.

INTRODUCTION

The ashy storm-petrel (*Oceanodroma homochroa*) is globally rare with a restricted breeding distribution on islands and islets off central and southern California, USA, and northwest Baja California, Mexico (Ainley 1995; Carter et al. 2008a). Largest colonies occur on the South Farallon Islands off central California; and on San Miguel, Santa Barbara, and Santa Cruz islands in the Channel Islands off southern California (Sowls et al. 1980; Ainley et al. 1990; Carter et al. 1992). World population size has been estimated at about 10,000 individuals (Sowls et al. 1980; Ainley 1995). Many aspects of reproductive biology are reasonably well known. Adults do not excavate burrows; rather, they nest in crevices of talus slopes, rock walls, sea caves, cliffs, and driftwood (James-

Veitch 1970; Ainley et al. 1990; McIver 2002). The breeding season is protracted, and breeding activities (courtship, incubation, chick-rearing) at nesting locations can occur throughout the year (James-Veitch 1970; Ainley et al. 1974). The egg-laying period extends from late April to October, peaking in June and July (James-Veitch 1970; Ainley et al. 1990; McIver 2002). Clutch size is one egg, and parents alternate incubation bouts during an average incubation period of about 44 days (James-Veitch 1970; Ainley 1995). Some pairs will lay replacement eggs after failure of a first egg (Ainley et al. 1990; McIver 2002). Nestlings are brooded for about five days, and then chicks are left alone in the nest site (except during parental feedings every 1 to 3 nights on average) until they fledge when about 66 to 85 days old (James-Veitch 1970; Ainley et al. 1990). Peak fledging occurs in

early to mid-October but latest chicks can fledge in January in some years (Ainley et al. 1990; McIver 2002). Nocturnal visits to crevice breeding sites reduce predation by diurnal predators such as western gulls (*Larus occidentalis*) and peregrine falcons (*Falco peregrinus*), although adults are preyed upon at night by burrowing owls (*Athene cunicularia*) and barn owls (*Tyto alba*) (Ainley 1995; McIver 2002). Island spotted skunks (*Spilogale gracilis amphiala*) are the only known mammalian predators of adult ashy storm-petrels, although eggs and small chicks are eaten or scavenged by house mice (*Mus musculus*) and deer mice (*Peromyscus maniculatus*) on occasion (Ainley et al. 1990; McIver 2002; McIver and Carter 2006).

Most published research on the reproductive biology of this species has been limited to Southeast Farallon Island (37°42'N, 123°00'W; hereafter SEFI), located in the northern part of the breeding range in the central portion of the California Current, where several studies and annual nest monitoring have been conducted since 1965 (James-Veitch 1970; Ainley et al. 1974, 1976, 1990; Sydeman et al. 1998b). In 1995–1998, Humboldt State University and collaborators studied reproductive biology of ashy storm-petrels at Santa Cruz Island (centered at about 34°N latitude and between 119°40' and 119°50'W longitude; hereafter SCI) to investigate possible differences in breeding biology in the southern part of the breeding range in the Channel Islands within the southern portion of the California Current (McIver 2002). In 2005–2007, U.S. Fish and Wildlife Service and collaborators continued studies of reproductive biology, mainly to provide further recent baseline data for restoration efforts at SCI which began in 2008 (McIver and Carter 2006; Carter et al. 2007; McIver et al. 2008, 2009). In this paper, reproductive performance of ashy storm-petrels at SCI in 1995–2007 is summarized and potential impacts of pollutants, predators, and other factors are discussed. Due to space limitations and analysis difficulties, statistical comparisons of reproductive performance (between SCI locations and years, and between SCI and SEFI), SCI population trends, effects of pollutants, and restoration efforts at SCI will be covered in other papers.

METHODS

SCI is located approximately 40 km south of Santa Barbara, within Santa Barbara County, California, and is the largest (249 km²) of the eight major Channel Islands (Minnich 1980). SCI is jointly managed by the Nature Conservancy (central and west parts) and the National Park Service (NPS; east end). The north coast of the island is composed largely of sheer cliffs and bluffs, with at least 110 sea caves at the base of these cliffs (Bunnell 1988). Ashy storm-petrels have been found breeding at 11 locations at SCI, including sea caves and offshore rocks (Carter et al. 2008a). In 1995–1998 and 2005–2007, reproductive performance of ashy storm-petrels was examined at four sea caves and one offshore rock along the north coast of SCI. Sea caves ranged from about 15 to 100 m in depth, with floors free of spray or standing water throughout most of the year. Cave of the Bird's Eggs (CBE) and Dry Sandy Beach Cave (DSB) were located on the remote northwest shore, while Cavern Point Cove Caves (CPC) and Bat Cave (BC) were located on the more accessible northeast shore. In these sea caves, ashy storm-petrels nested in crevices within rock piles, along the edges of cave walls, and (BC only) in driftwood piles. In addition, storm-petrels nested on occasion in open floor depressions adjacent to cave walls. At Orizaba Rock (OR), a small islet ~100 m offshore of the north central coast of SCI, storm-petrels nested in crevices occurring in rock walls, under rocks, and in floors of small caverns. These five locations were selected for this study because each location was accessible using a small inflatable boat powered by an outboard engine under most weather conditions and an adequate sample size of nests was available at each location to assess reproductive performance. In 1995–1997 and 2005, all five locations were studied. In 1998, only CBE and DSB were examined (due to lower funding) to detect any effects from intense El Niño conditions. In 1999–2003, reproductive performance was not studied due to a lack of funding, although single trips per year were made to assess changes in population size. No data were collected in 2004. In 2006–2007, only CPC, BC, OR, and CBE were included in baseline data gathered for restoration work; DSB was excluded because it was furthest from restoration sites and was the most difficult location to access and study.

To determine reproductive performance at a SCI location in each study year, all accessible habitats at each location were searched with small flashlights for active nests (i.e., with incubating adults, whole eggs, or fresh eggshell fragments) every 3–5 weeks, usually monthly, from May–June to October–November. Active nests were tagged, then checked on subsequent visits using flashlights from a distance of 0.5 to 3.0 m to briefly view nest contents. When briefly illuminated, adults usually would lift up enough to expose the egg. However, if not, adults were lightly prodded with a 30 cm wooden dowel in accessible nest sites to confirm egg presence. On each visit, nest status and chick development were recorded. In several storm-petrel studies, researcher disturbance has been demonstrated to reduce breeding success, with lower hatching success resulting from nest desertion (James-Veitch 1970; Boersma et al. 1980; Ainley et al. 1990; Blackmer et al. 2004). Researcher disturbance was minimized through infrequent nest checks every 3–5 weeks during incubation and chick periods (also necessitated by limited funds for staff and charter boats to visit these remote SCI locations), brief location visits that lasted 1–4 hours, non-handling of adults in nests, avoiding impacts to incubating adults from noise or lights, and avoiding impacts to fragile nesting habitats from trampling. To evaluate breakage of eggs and predation eggshell fragments, feather piles, carcasses, and avian pellets were collected when found to prevent double counting. Unattended eggs were left in nest sites for 2–3 months before being considered abandoned and being removed.

Within a nesting season, if only one egg was laid in a nest site, it was categorized as a “single” egg. If two eggs were found in a nest site (where a first egg had been laid but failed), the first egg was categorized as “first” and the second egg was considered a “replacement” egg presumably laid by the same breeding pair. Fates of eggs were categorized as hatched, broken, whole and did not hatch, missing, or unknown. To assess fledging with infrequent nest checks, chick ages were estimated on the basis of estimated egg laying and hatching dates, and plumage development. In almost all cases, a missing chick was assumed to have fledged, if last seen as fairly large and apparently healthy or > 66 days of age (minimum age of fledging; James-Veitch 1970). Hatching success for an SCI location

was estimated as the percentage of single and first eggs (combined) that hatched; replacement eggs were excluded from this calculation because they were not independent of first eggs and would have contributed more than one value for certain nest sites. Fledging success for an SCI location was estimated as the percentage of chicks fledged out of those hatched from single, first, and replacement eggs. Breeding success for an SCI location was estimated as the percentage of chicks that fledged per breeding pair (from eggs that were either single or replacement eggs). For general description of reproductive performance in this paper, average SCI values were calculated for hatching, fledging, and breeding success per year and for periods of years by combining all nest sites studied. However, these average values did not account for variation in locations studied per year, differences in annual sample sizes studied, and differences in success between locations within and between years. These issues potentially affected statistical analyses, and this paper focuses on summarizing information obtained rather than examining statistical differences, which will be addressed in future papers.

RESULTS

Hatching, Fledging, and Breeding Success

Totals of 749 single/first clutches and 30 replacement clutches were documented at SCI in 1995–2007 (Table 1). Largest samples of single/first clutches were found in BC ($n = 278$ in 5 years) and DSB ($n = 196$ in 5 years), with lower samples in CBE ($n = 107$ in 7 years), OR ($n = 91$ in 6 years), and CPC ($n = 77$ in 6 years). Only 8 single/first clutches and no replacement clutches had unknown fates.

Hatching success at SCI averaged 62.2% in 1995–1998 and 72.6% in 2005–2007 (Table 2). Average hatching success in 1995–2007 was lowest at OR and CPC (54.9% and 55.1%, respectively) and highest at DSB and CBE (73.7% and 74.8%, respectively; Table 2). Fledging success at SCI averaged 91.7% in 1995–1997 and 86.5% in 2005–2007 (Table 3). Average fledging success in 1995–2007 was lowest at CPC (84.6%) and highest at DSB (92.4%; Table 3). Breeding success at SCI averaged 54.9% in 1995–1998 and 63.4% in 2005–2007 (Table 4). Average breeding success in 1995–

Table 1. Numbers of ashy storm-petrel eggs monitored for reproductive performance at five locations on Santa Cruz Island, California, in 1995–2007. Codes: Clutch (1, first or single eggs; 2, replacement eggs, unknown fates in parentheses); and ND (no data). Locations are: Bat Cave (BC), Cave of the Bird's Eggs (CBE), Cavern Point Cove Caves (CPC), Dry Sandy Beach Cave (DSB), and Orizaba Rock (OR).

Location	Clutch	Year									
		1995	1996	1997	1998	2005	2006	2007	1995–1998	2005–2007	1995–2007
BC	1	64 (2)	97	70 (1)	ND	ND	19	28	231 (3)	47	278 (3)
	2	4	4	2	ND	ND	0	4	10	4	14
CBE	1	13	11	8 (1)	9	19	20	27	41 (1)	66	107 (1)
	2	1	0	0	0	2	1	1	1	4	5
CPC	1	16	11	17	ND	13	7	14	44	33	77
	2	0	2	2	ND	0	0	0	4	0	4
DSB	1	26	41	46	42	43	ND	ND	155	41	196
	2	1	2	0	0	0	ND	ND	3	0	3
OR	1	20	27	8	ND	7	15	14	55	36	91
	2	2	2	0	ND	0	0	0	4	0	4
Total	1	139 (2)	187	149 (2)	51	79	61	83	526	223	749 (4)
	2	8	10	4	0	2	1	5	22	8	30

2007 was lowest at CPC (44.4%) and highest at DSB (67.0%; Table 4).

In 1995–2007, broken and missing eggs accounted for 44.2% and 34.7% of 282 eggs that failed to hatch (Table 5). Most (76.2%) eggs that did not hatch were observed in the 1995–1998 period (Table 5).

Predation

In 1995–1997, 83 storm-petrel carcasses killed by avian predators were documented at SCI, including 76 adults and 7 chicks. Most (90.4%) were found at BC below at least two perches used by barn owls and one barn owl was observed in 1996. At OR, barn owls were observed and heard at night

Table 2. Hatching success (percentage) of ashy storm-petrels at five locations on Santa Cruz Island, California, in 1995–2007. Sample sizes in parentheses. Codes in Table 1.

Location	Year									
	1995	1996	1997	1998	2005	2006	2007	1995–1998	2005–2007	1995–2007
BC	56.3 (64)	59.8 (97)	60.0 (70)	ND	ND	89.5 (19)	67.9 (28)	58.9 (241)	76.6 (47)	61.9 (278)
CBE	61.5 (13)	81.8 (11)	75.0 (8)	88.9 (9)	63.2 (19)	70.0 (20)	85.2 (27)	75.6 (41)	74.2 (66)	74.8 (107)
CPC	31.3 (16)	18.2 (11)	52.9 (17)	ND	76.9 (13)	100 (7)	71.4 (14)	36.4 (44)	79.4 (33)	55.1 (77)
DSB	76.9 (26)	58.5 (41)	87.0 (46)	83.3 (42)	62.8 (43)	ND	ND	76.8 (155)	62.8 (41)	73.7 (196)
OR	70.0 (20)	25.9 (27)	50.0 (8)	ND	85.7 (7)	80.0 (15)	50.0 (14)	45.5 (55)	69.4 (36)	54.9 (91)
Total	59.7 (139)	53.5 (187)	67.8 (149)	84.3 (51)	67.1 (79)	82.0 (61)	71.1 (83)	62.2 (526)	72.6 (223)	65.6 (749)

Table 3. Fledging success (percentage) of ashy storm-petrels at five locations on Santa Cruz Island, California, in 1995–2007. Sample sizes in parentheses. Codes in Table 1.

Location	Year									
	1995	1996	1997	1998	2005	2006	2007	1995– 1998	2005– 2007	1995– 2007
BC	96.9 (32)	86.0 (50)	97.4 (38)	ND	ND	75.0 (16)	94.7 (19)	92.5 (120)	85.7 (35)	91.0 (155)
CBE	100 (6)	100 (8)	80.0 (5)	80.0 (5)	76.9 (13)	91.7 (12)	87.0 (23)	91.7 (24)	85.4 (48)	87.5 (72)
CPC	75.0 (4)	66.7 (3)	100 (7)	ND	80.0 (10)	100 (6)	77.8 (9)	85.7 (14)	84.0 (25)	84.6 (39)
DSB	94.7 (19)	95.2 (21)	100 (36)	78.8 (33)	95.7 (23)	ND	ND	91.7 (109)	95.7 (23)	92.4 (132)
OR	90.9 (11)	85.7 (7)	100 (3)	ND	66.7 (6)	83.3 (12)	100 (7)	90.5 (21)	84.0 (25)	87.0 (46)
Total	94.4 (72)	88.8 (89)	97.8 (89)	78.9 (38)	84.6 (52)	84.8 (46)	89.7 (58)	91.7 (288)	86.5 (156)	89.9 (444)

on several occasions during mist-netting efforts in 1995–1996 (H.R. Carter, unpublished data). In 1995–1997, owl pellets collected at BC ($n = 9$) and OR ($n = 4$) contained remains (feathers, bones) of adult ashy storm-petrels ($n = 9$), downy storm-petrel chicks ($n = 2$), and deer mice (dentary bones, hair; $n = 2$). Only eight feather piles were detected at CBE (2006: $n = 2$; 2007: $n = 3$), CPC (2005: $n = 1$; 2007: $n = 1$), and DSB (2005: $n = 1$). No evidence of avian predation of storm-petrels was detected at BC or OR in 2005–2007.

In 1995–2007, no evidence of predation of storm-petrels by western gull (e.g., gull pellets or observations of gulls inside caves) was detected at SCI. About seven gull nests were documented per year at OR, and gulls were observed flying near entrances to sea caves on several occasions. Common ravens (*Corvus corax*) were observed at the entrances of all caves on several occasions. In 1997, a raven was observed inside CBE and a dead pigeon guillemot (*Cephus columba*) chick apparently had been recently killed by ravens. Eight and one pigeon guillemot carcasses were found at

Table 4. Breeding success (percentage) of ashy storm-petrels at five locations on Santa Cruz Island, California, in 1995–2007. Sample sizes in parentheses. Codes in Table 1.

Location	Year									
	1995	1996	1997	1998	2005	2006	2007	1995– 1998	2005– 2007	1995– 2007
BC	52.5 (59)	48.9 (88)	58.7 (63)	ND	ND	66.7 (18)	66.7 (27)	52.9 (210)	66.7 (45)	55.3 (255)
CBE	54.5 (11)	80.0 (10)	57.1 (7)	66.7 (6)	55.6 (18)	61.1 (18)	74.1 (27)	64.7 (34)	65.1 (63)	64.9 (97)
CPC	20.0 (15)	10.0 (10)	46.7 (15)	ND	61.5 (13)	100 (6)	53.8 (13)	27.5 (40)	65.6 (32)	44.4 (72)
DSB	75.0 (24)	52.6 (38)	85.7 (42)	65.0 (40)	57.9 (38)	ND	ND	69.4 (144)	57.9 (38)	67.0 (182)
OR	60.0 (15)	22.2 (27)	42.9 (7)	ND	57.1 (7)	66.7 (15)	53.8 (13)	36.7 (49)	60.0 (35)	46.4 (84)
Total	54.0 (124)	45.1 (173)	64.9 (134)	65.2 (46)	57.9 (76)	68.4 (57)	65.0 (80)	54.9 (477)	63.4 (213)	57.5 (690)

Table 5. Fates of unsuccessful ashy storm-petrel eggs (percentage of failed single, first, and second clutches combined) at five locations at Santa Cruz Island, California, in 1995–2007. Fates are coded: broken (B), whole but did not hatch (DNH), and missing (M). Sample sizes in parentheses. Other codes in Table 1.

Location	Failed egg fate	Year									
		1995	1996	1997	1998	2005	2006	2007	1995–1998	2005–2007	1995–2007
BC	B	74.2 (23)	54.8 (23)	48.3 (14)	ND	ND	100 (2)	8.3 (1)	59.1 (60)	54.2 (3)	57.1 (63)
	DNH	0 (0)	4.8 (2)	41.4 (12)	ND	ND	0 (0)	83.3 (10)	15.4 (14)	41.7 (10)	25.9 (24)
	M	25.8 (8)	40.5 (17)	10.3 (3)	ND	ND	0 (0)	8.3 (1)	25.5 (28)	4.2 (1)	17.0 (29)
CBE	B	16.7 (1)	50.0 (1)	0 (0)	100 (1)	0 (0)	42.9 (3)	60.0 (3)	41.7 (3)	34.3 (6)	38.5 (9)
	DNH	16.7 (1)	0 (0)	50.0 (1)	0 (0)	57.1 (4)	42.9 (3)	0 (0)	16.7 (2)	33.3 (7)	23.8 (9)
	M	66.7 (4)	50.0 (1)	50.0 (1)	0 (0)	42.9 (3)	14.3 (1)	40.0 (2)	41.7 (6)	32.4 (6)	37.7 (12)
CPC	B	45.5 (5)	60.0 (6)	30.0 (3)	ND	0 (0)	0 (0)	25.0 (1)	45.2 (14)	8.3 (1)	26.8 (15)
	DNH	0 (0)	0 (0)	60.0 (6)	ND	0 (0)	0 (0)	25.0 (1)	20.0 (6)	8.3 (1)	14.2 (7)
	M	54.5 (6)	40.0 (4)	10.0 (1)	ND	100 (3)	0 (0)	50.0 (2)	34.8 (11)	50.0 (5)	42.4 (16)
DSB	B	50.0 (3)	31.6 (6)	33.3 (2)	57.7 (4)	25.0 (4)	ND	ND	43.2 (15)	25.0 (4)	39.5 (19)
	DNH	0 (0)	0 (0)	50.0 (3)	0 (0)	0 (0)	ND	ND	12.5 (3)	0 (0)	10.0 (3)
	M	50.0 (3)	68.4 (13)	16.7 (1)	42.9 (3)	75.0 (12)	ND	ND	44.5 (20)	75.0 (12)	50.6 (32)
OR	B	14.3 (1)	50.0 (11)	100 (4)	ND	100 (1)	66.7 (2)	14.3 (1)	54.8 (16)	60.3 (4)	57.6 (20)
	DNH	42.9 (3)	27.3 (6)	0 (0)	ND	0 (0)	0 (0)	42.9 (3)	23.4 (9)	14.3 (3)	18.9 (12)
	M	42.9 (3)	22.7 (5)	0 (0)	ND	0 (0)	33.3 (1)	42.9 (3)	21.9 (8)	25.4 (4)	23.6 (12)
Total	B	54.1 (33)	49.5 (47)	45.1 (23)	62.5 (5)	18.5 (5)	58.3 (7)	21.4 (6)	52.8 (108)	32.7 (18)	44.2 (126)
	DNH	6.6 (4)	8.4 (8)	43.1 (22)	0 (0)	14.8 (4)	25.0 (3)	50.0 (14)	14.5 (34)	29.9 (21)	21.1 (55)
	M	39.3 (24)	42.1 (40)	11.8 (6)	37.5 (3)	66.7 (18)	16.7 (2)	29.0 (8)	32.7 (73)	37.5 (28)	34.7 (101)

CBE and DSB, respectively, in 1996–1997, which also may have been raven predations. No evidence of predation on storm-petrels by peregrine falcons was found, although falcons were observed perched on cliffs, and flying near all sea caves on several occasions.

In 2005, evidence of predation of storm-petrels by island spotted skunks was detected at BC. On June 2, 60 storm-petrel carcasses, no active storm-petrel nests, and faint skunk odor were found. NPS personnel live-trapped and removed a single island spotted skunk from the cave on June 11. On July 28, 13 active storm-petrel nests were found, indicating

that temporary skunk-free conditions had allowed remaining adults to lay eggs. However, on September 15, no active nests and 16 more dead adult storm-petrels were present, following further predation by at least one other skunk. No further effort was made to remove skunks in 2005. In March 2006, NPS personnel set live traps at BC to test for the presence of skunks and none were detected. Nineteen and 28 active storm-petrel nests were observed in BC in 2006 and 2007, respectively, indicating no continuing skunk predation (Table 1).

DISCUSSION

Organochlorine Contaminants and Broken Eggshells

Between 1995–1998 and 2005–2007, hatching and breeding success at SCI apparently increased, although mainly at CPC, BC, and OR. Lower egg breakage in 2005–2007 than in 1995–1998 likely resulted to a great extent from decreased levels of organochlorine contaminants in ashy storm-petrels by 2008 compared to levels observed in 1992–1997 (Fry 1994; Kiff 1994; Carter et al. 2008b, unpublished data). In 1995–1998, 53% of unsuccessful eggs at SCI were found broken, in marked contrast to SEFI where only 4%–9% were broken in the 1965–1983 period (James-Veitch 1970; Ainley et al. 1990). These SEFI studies did not determine causes for broken eggs or eggs that were whole but did not hatch, although eggshell thinning was demonstrated in ashy storm-petrel eggs at SEFI in 1969–1970 (Coulter and Risebrough 1973). Approximately 30% of broken eggs found in nests at SCI in 1995–2007 were whole eggs with visible breaks, cracks, and dents; the other 70% were eggshell fragments only. Even with reduced contaminants, a slightly higher level of egg breakage may still occur at SCI than at SEFI. Egg neglect is well known in storm-petrels but was not quantified at SCI, due to the infrequency of our visitations. Some neglected or abandoned eggs at SCI may have been: a) cracked or broken by other storm-petrels in relatively dense sea cave and offshore rock colonies with several open nest sites; or b) in some locations (i.e., BC and CPC), eaten by small numbers of deer mice. Comparisons of natural levels of egg breakage at SCI and SEFI are confused by different study methods (which may lead to

different percentages of broken, missing, abandoned, and unknown fate eggs), and different rates and causes of egg neglect and egg abandonment may exist between colonies and time periods of study. Only introduced house mice occur at SEFI but have not been documented to eat ashy storm-petrel eggs (Ainley et al. 1990). Few apparently viable eggs (i.e., whole non-cracked eggs) were not incubated by adults during our nest visits which might have been available for predation by small numbers of deer mice. Most broken eggs at SCI appeared to result from eggshell thinning.

Levels of chlorinated hydrocarbons are generally high in storm-petrels for reasons that are unclear (Boersma and Groom 1993). Eggshell thinning and egg breakage have been related to elevated levels of chlorinated hydrocarbons (Hickey and Anderson 1968; Anderson et al. 1969; Blus 1982). Based on ashy storm-petrel eggs collected at SCI in 1992, Kiff (1994) reported significant eggshell thinning (8.3%), in comparison to eggshells collected before 1947 (i.e., pre-DDT era), with 27.8% of eggs exhibiting > 15% thinning. Fry (1994) further reported relatively high levels (11.36 ppm) of DDT residues in these eggs. Based on eggs sampled in 1992, 1996–1997, and 2008, Carter et al. (2008b) reported significant declines in levels of both p,p-DDE (-8.8% per annum) and Total PCBs (-8.4% per annum) from 1992 to 2008. In 1992–1997, relatively high contaminant levels, and associated eggshell thinning and premature embryo deaths, likely contributed to relatively low hatching success and relatively high levels of broken eggs at SCI during this period and likely for decades beforehand. By 2008, contaminant levels were much lower, likely with much less remaining effect on reproductive performance. However, even with lower contaminant levels, broken eggs continued to occur in 2005–2007, likely reflecting continuing contaminant effects on certain individuals plus other factors causing continuing egg breakage.

Predation by Barn Owls

At SCI, the barn owl was the primary avian predator of storm-petrels, based on feather remains and contents of collected pellets (McIver 2002). Numbers of owl-killed storm-petrel carcasses recovered increased from 1995 to 1997, with 90% at BC, the location with the largest numbers of nests

(Table 1). Evidence of owl predation at OR remained low in 1995–1997, with two kills per year (McIver 2002). Avian predation at SCI was much reduced during 2005–2007, coincident with higher breeding success. James-Veitch (1970) observed ashy storm-petrels circling, hovering or fluttering over crevices as they returned to nesting areas. In addition, storm-petrels were seen at entrances of nest sites at dusk, apparently waiting to leave. Storm-petrel chicks older than 20 days also will leave nest sites and walk and flap their wings on the surface of the ground at night before returning to nest sites (James-Veitch 1970; Scott 1970; Mínguez 1997). These behaviors of adults and older chicks likely increase their detection by barn owls, which have excellent low-light vision (Dice 1945; Marti 1992) and hearing (Konishi 1973), and can discriminate sounds of appropriate prey by memorizing prey noises (Konishi and Kenuk 1975). At SEFI, western gulls and burrowing owls are significant predators of ashy storm-petrels, and may be largely responsible for a 30%–40% decline in population size of ashy storm-petrels between 1972 and 1992 (Sydeman et al. 1998a, 1998b).

Predation by Skunks

Large-scale predation of adults by island spotted skunks at BC in 2005 at first seemed to be an unusual event, with skunks apparently falling or jumping off nearby bluffs or cliffs and swimming into the otherwise inaccessible cave (McIver and Carter 2006). However, in 2008, skunks also entered CPC and killed at least 30 adults (McIver et al. 2009). Like other sea caves in which ashy storm-petrels nest at SCI, BC occurs at the base of sheer cliffs, which do not afford regular access to small mammals, except for small numbers of deer mice in certain caves (McIver 2002). Skunk populations on SCI have increased in recent years (Jones et al. 2008), which may somehow relate to greater potential for skunks to enter sea caves than in the recent past. The lack of skunk presence in sea caves from 1995 to 2004 was likely preceded by decades of skunk-free conditions to account for the large numbers of nesting storm-petrels first found in these sea caves in 1994 (Carter et al. 2007). Prior to 2005, BC had the largest number of nests of ashy storm-petrels at SCI (McIver 2002; Carter et al. 2007). By 2007, numbers of storm-petrel nests at BC were about 40% of pre-2005 levels, reflecting apparent

return of some adults and past progeny that escaped skunk predation.

Night Lights

At OR, the number of active storm-petrel nests was 60% and 75% lower in 1997 than in 1995 and 1996, respectively (Table 1). Beginning in 1992, intense market squid harvesting using bright night lights occurred near SCI, and squid fishing activity was relatively high along the north coast from the west end to OR during October 1995, 1996, and 1997 (Maxwell et al. 2004). No direct observations or evidence of mortality of ashy storm-petrels through attraction to squid fishery lights were noted. However, ashy storm-petrels and related species are attracted to bright night lights, putting them at risk of light-related mortality or nest abandonment at or near breeding colonies (James-Veitch 1970; Reed et al. 1985; Ainley et al. 1990; Ainley 1995; Carter et al. 2000; Le Corre et al. 2002). Ashy storm-petrels likely first breed at 4–5 years of age as found for Leach's storm-petrels (Morse and Buchheister 1977; Huntington et al. 1996). Reduced breeding success and some adult mortality due to night lights at OR is consistent with population reduction in 1995–1997 (Carter et al. 2008a). A similar reduction in numbers of nests was not found at CBE and DSB in 1995–1998, apparently due to nesting in deep caves with few or no nesting gulls or owls nearby. Reasons for increases in numbers of ashy storm-petrel nests at OR in 2006–2007 are not fully understood and may reflect reduced night lights, movements of some adults from BC after skunk predation in 2005, or other factors.

Park Visitor Disturbance

Between 1995 and 2007, breeding success was lowest at CPC, which was easy to access by kayak and located approximately 0.75 km from Scorpion Anchorage, a popular SCI destination for camping and sea kayaking on NPS lands. In contrast, breeding success was greatest at DSB, which is difficult to access by kayak and located on Nature Conservancy lands at least 20 km from Prisoner's Harbor, the nearest SCI area on NPS lands with relatively high park visitor use. Human disturbance to seabird colonies during the breeding season can cause lowered breeding success, breeding failure, colony abandonment, destruction of nesting habitat, and deaths of adults, chicks, and eggs (Carney and

Sydeman 1999; also see Nisbet 2000). A few instances of non-researcher human visitation to CPC and BC were documented in 1995–2007 but our infrequent visits (often on weekdays) prevented measurement of non-researcher visitation rate. Incubating ashy storm-petrels are vulnerable to disruption of nesting activities by human visitations, especially at nests in open habitats at SCI sea caves. No specific instances of egg breakage or nest failure from non-researcher visitations were noted. However, peak numbers of kayakers occur during the incubation and early-chick periods in June–September. Non-researcher human visitation to CPC, which is the most accessible location closest to high visitor use areas, may have contributed to lower breeding success in 1995–2007.

Oceanographic Conditions and Breeding Success

As also found at SEFI (Ainley et al. 1990; Sydeman et al. 2001), reproductive performance of ashy storm-petrels at SCI showed limited inter-annual variability, with no clear correlation between warm-water years and reduced breeding success. In 1995–1998, breeding success at SCI was lowest in 1996, when weak to moderate La Niña (cool water) conditions prevailed (Schwing et al. 1997), and greatest in 1997 (65.2%), a year of transition from La Niña to El Niño (warm water) conditions (Lynn et al. 1998).

Competition for Nest Sites

Competition for nest sites can result in reduced breeding success in storm-petrels (Harris 1969; Ramos et al. 1997). At SEFI, ashy storm-petrels nested in shallower crevices than Leach's storm-petrels and did not excavate nesting burrows as Leach's did on occasion (Ainley et al. 1990). Leach's storm-petrels do not nest at SCI (Sowls et al. 1980; Carter et al. 1992), but some ashy storm-petrels likely compete for limited nest sites in dense-breeding conditions in sea caves with conspecifics along with small numbers of crevice-nesting pigeon guillemots, Xantus's murrelets (*Synthliboramphus hypoleucus*), and Cassin's auklets (*Ptychoramphus aleuticus*). Dense breeding in sea caves likely reflected unusual availability of many suitable nest sites in a relatively small area, limited suitable nesting habitat in adjacent steep cliffs, and strong attraction of conspecifics. Murrelets and auklets tend to nest earlier than ashy storm-petrels, and

guillemots tend to use larger crevices than storm-petrels. Despite dense-nesting conditions, availability of suitable nest sites does not currently limit nesting storm-petrels at BC, CBE, and DSB but may be a factor at CPC and OR.

Management

Continued monitoring of ashy storm-petrels at SCI will be conducted to evaluate restoration efforts begun in 2008 that aim to reduce potential impacts of avian and mammalian predators, night lights, and human disturbance through the use of artificial nesting habitat, social attraction techniques, and greater protection of nesting areas (McIver et al. 2008, 2009). Long-term monitoring also is needed to determine how this globally rare species, petitioned for listing in 2007 under the U.S. Endangered Species Act, responds to various factors that influence reproductive performance. Future research, greater statistical analysis of existing data, and statistical comparisons to SEFI are needed to further explore certain factors affecting reproductive performance at SCI, especially pollutants, predation, and climate change.

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