Reproductive Success of the Black-crowned Night Heron at Alcatraz Island, San Francisco Bay, California, 1990-2002

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Abstract.—Nesting chronology, habitat use, subcolony use, and hatchability were documented for the Black-crowned Night Heron (*Nycticorax nycticorax*) nesting at Alcatraz Island, San Francisco Bay, California during 1990-2002. Reproductive success was estimated using the Mayfield method and compared among years. Totals of monitored nests per year ranged from 68 in 2001 to 341 in 1996, with a trend of declining numbers since 1996. An increase in numbers of the Western Gull (*Larus occidentalis*), the Black-crowned Night Heron's primary competitor, occurred during the same period. Overall reproductive success of the Black-crowned Night Heron at Alcatraz Island was below the 13-year average of 56.4% since 1996. During the study, the average number of chicks fledged per nest each year ranged from 0.46 to 1.27, which is less than the two chicks per nest suggested as a requirement for a sustained population. Embryos in five of 187 failed Black-crowned Night Heron eggs were deformed. In 1990 and 1991, eggs were analyzed for a wide range of contaminants, but none appeared to be sufficiently elevated to have caused the observed deformities. Based on these relatively low levels of contaminants, a high hatchability rate (94.5%), and relatively low levels of embryotoxicity, contaminants did not appear to significantly affect Black-crowned Night Heron reproduction at Alcatraz Island. However, predation by the Common Raven (*Corvus corax*) and Western Gull, interspecific competition with the Western Gull, habitat deterioration, and possible human disturbance are likely factors contributing to the decline in Black-crowned Night Heron reproductive success on Alcatraz Island in recent years. *Received 17 March 2003, accepted 27 October 2003.*

Key words.—Alcatraz Island, Black-crowned Night Heron, California, *Larus occidentalis*, *Nycticorax nycticorax*, reproduction, Western Gull, California.

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As a follow-up to studies conducted in the early 1980s (Hoffman *et al.* 1986; Ohlendorf *et al.* 1988), nesting by the Black-crowned Night Heron (*Nycticorax nycticorax*) and Snowy Egret (*Egretta thula*) in San Francisco Bay, California was studied during 1989-1991 to evaluate the effects of contaminants on avian reproductive success. The Black-crowned Night Heron had nested on Alcatraz Island since the early 1980s, and the Alcatraz rookery was included in this study beginning in 1990 (Hothem *et al.* 1995). Numbers of Black-crowned Night Heron nests on Alcatraz ranged from 24 in 1981 (Boarman 1989) to about 60 in 1989 (M. Alvarez and T. Thomas, Golden Gate National Recreation Area, unpubl. data), but reproductive success was not evaluated at that time. Anticipating increased numbers of visitors to Alcatraz, the National Park Service requested assistance in determining the potential effects of this increased human use on nesting by the Black-crowned Night Heron on the island. Of primary concern were the direct impacts that human disturbance might have on the breeding success of the birds and indirect impacts through increased predation or inter-specific competition.

Previous studies have identified predation as a primary limiting factor for Black-crowned Night Heron reproductive success (Wolford and Boag 1971; Tremblay and Ellison 1980; Henny *et al.* 1984; Blus *et al.* 1997). In addition, competition with other species for nesting sites or food resources has also been described for many situations, including the Common Tern (*Sterna hirundo*) (Shealer and Kress 1991; Barbour *et al.* 2000), Western Gull (*Larus occidentalis*) and Brandt's Cormorant (*Phalacrocorax penicillatus*) (Spear 1993), and Great Blue Heron (*Ardea herodias*) and Double-Crested Cormorant (*Phalacrocorax auritus*) (Skagen *et al.* 2001). Although there is little evidence of humans currently causing significant harm to herons (Ardeidae) (Nisbet 2000), human disturbance may increase the effects of predation (Ålund and Götmark 1989; Skagen *et al.* 2001) or may intensify competition with other species.

The objectives of this study were 1) to conduct baseline monitoring to describe and estimate the distribution and abundance of the Black-crowned Night Heron colony on Alcatraz Island; 2) to evaluate reproductive parameters, including nesting chronology, clutch size, hatching success, fledging success, and overall reproductive success; 3) to evaluate the distribution, abundance, productivity, and effects of disturbance on nesting Black-crowned Night Herons; and 4) to compare annual and long-term variation and trends in the numbers nesting.

METHODS

Study Area

The study site was Alcatraz Island (37°49'N, 122°25'W), a National Historic Landmark within the Golden Gate National Recreation Area. This 9.1-ha island, in the central portion of San Francisco Bay, about 1.8 km north of San Francisco, California (Fig. 1), has been managed by the National Park Service since 1973 (Howell and Pollak 1991). Since its transformation from a federal penitentiary to a tourist attraction, Alcatraz has become one of the primary nesting sites for the Black-crowned Night Heron in San Francisco Bay.

Nest Monitoring

Each year, as many Black-crowned Night Heron nests as possible were monitored at up to thirteen discrete sites on Alcatraz Island (Fig. 1). Beginning in late March, these separate locations, or subcolonies, were observed to estimate the stage of Black-crowned Night Heron reproduction. To minimize the risk of colony abandonment, initial visits to each subcolony were delayed until the earliest nesting Black-crowned Night Herons had laid and were in the early stages of incubation (Custer *et al.* 1983). The range of the earliest initial visits was 9-30 April (Table 1).

Most nest-monitoring visits were conducted in the morning, starting before the first contingent of park visitors arrived by boat (about 09.00 h) and ending by early afternoon (before 14.00 h). To reduce disruption to incubating adults and chicks, time spent within individual subcolonies was kept to a minimum, only exceeding 15 minutes at some of the larger subcolonies (Rubble, Rubble West, and Tunnel). Most nests were monitored by observers who entered the subcolonies and recorded the presence and status of eggs and chicks. Nests that were beyond the reach of the observers were examined using a mirror mounted on an aluminum pole. A ladder was used to check nests at the Shower subcolony, and binoculars were used to monitor a few nests in inaccessible locations. Each active nest (i.e., with eggs or chicks present) was assigned a unique number, marked with plastic flagging to simplify its relocation, and checked regularly to determine its success.

In most years, all nests that could be found were monitored in all subcolonies at least through mid-May. In 1991 and 1992, however, based on concern for potential adverse effects from human disturbance, the Greenhouse subcolony was not monitored. The numbers of nests in this subcolony in 1991 and 1992 were estimated, based on the presence of nesting birds each year and the average numbers of nests recorded in 1990 and 1993-94 (Table 2).

We observed an increase in aggression by the adult Western Gulls towards night herons once their chicks reached about 2-3 weeks of age. At this time, any disturbance caused by observer visits to the Black-crowned Night Heron subcolonies tended to increase the likelihood that their exposed chicks would be attacked by adult Western Gulls. Sometimes these attacks resulted in the injury or death of Black-crowned Night Heron chicks. Therefore, visits to certain subcolonies were terminated earlier in the season than others, depending on the level of disturbance caused by these visits. Monitoring was most often suspended early at those sites closest to Western Gull colonies, including the Greenhouse, Bench, Tunnel, Foghorn, Rubble, and Rubble West.

Data recorded at each nest included: subcolony name, nest height, nesting substrate, numbers of eggs and chicks, chick ages, and status of the nest (i.e., active, destroyed, abandoned). Eggs that failed to hatch were collected, and their fertility, stage of embryo development (Caldwell and Snart 1974), and embryo condition (i.e., viability and normality) were assessed. Each egg was retained and frozen for analyses of contaminants (See Hothem *et al.* 1995). In addition to failed eggs, ten eggs, one per nest, were collected at random in 1990 and 1991, and selected eggs were analyzed for contaminants both years (Hothem *et al.* 1995).

Except for 1994, comprehensive surveys of nesting Western Gulls on Alcatraz Island have been conducted since 1990 by D. Bell (1990-1991), A. Fish (1992), D. Hatch and A. Fish (1993 and 1995), M. Brown (1996-1998), J. Thayer and D. Hatch (1999), and B. Saenz (2000-2002).

Estimate of Reproductive Success

The incubation stage of nests found with incomplete clutches was estimated by backdating, based on the Black-crowned Night Heron laying one egg every other day (Tremblay and Ellison 1980). Hatching dates were predicted based on these criteria or back-calculated from the estimated ages of chicks (McVaugh 1972; Klett *et al.* 1986). Based on previous studies (Custer *et al.* 1983; Hothem *et al.* 1995), we considered the incubation period for the Black-crowned Night Heron (from first egg laid to first egg hatched) to be 25 days. Because nest initiations showed a skewed distribution, the median initiation date (date first egg was laid) was calculated for each year.

Incubation was considered successful if at least one egg hatched. Clutches that failed included those that were abandoned or that were destroyed by predators or unknown causes. Clutches with an unknown outcome included those that could not be re-located and those not revisited. We classified eggs that disappeared before the hatching date as unknown unless we found indications of the their fate. Eggs that did not hatch by the pre-

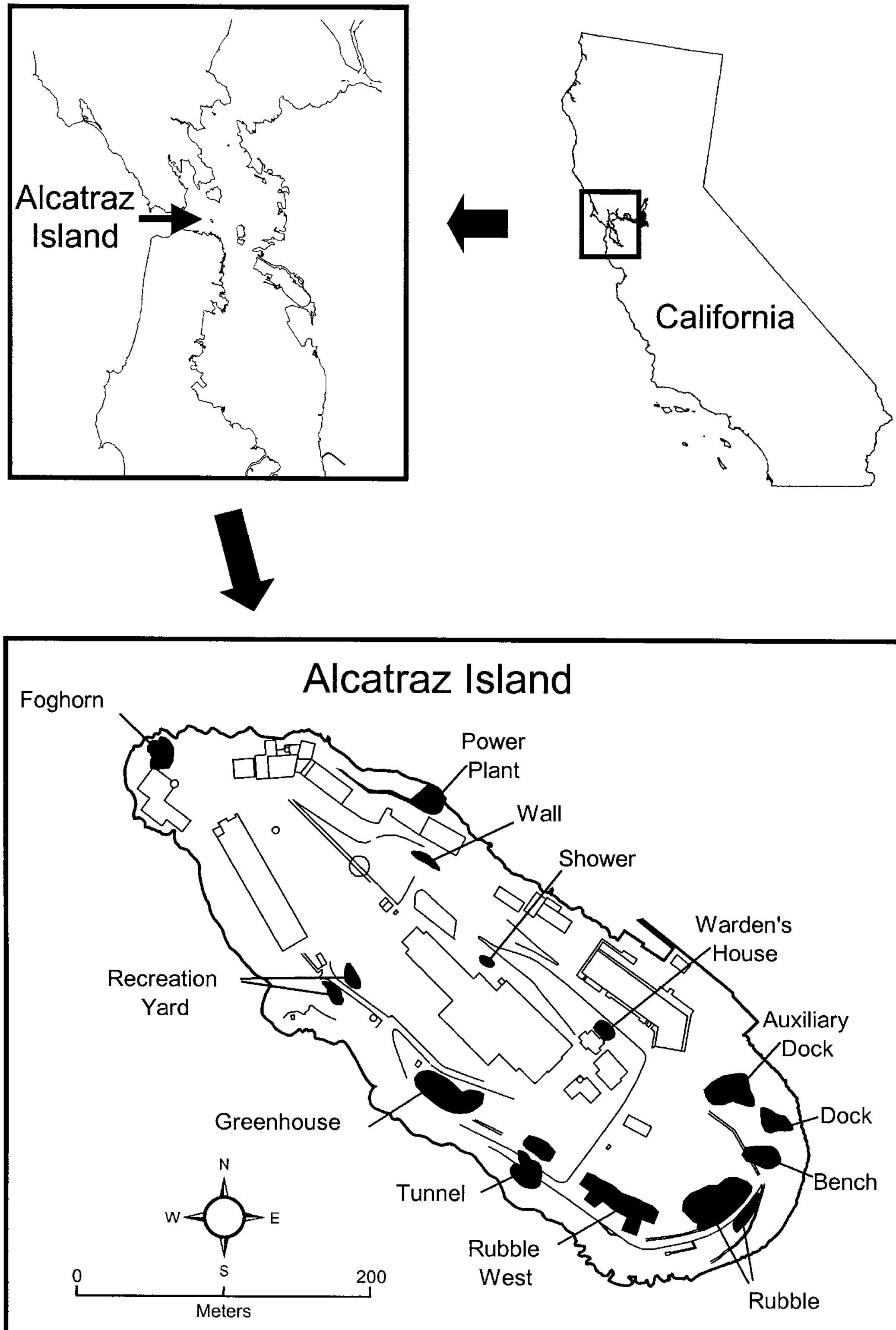

Figure 1. Black-crowned Night Heron nesting subcolonies on Alcatraz Island, San Francisco Bay, California, during 1990-2002.

Table 1. Black-crowned Night Heron reproductive chronology, Alcatraz Island, 1990-2002.

Year	Median initiation date	Range	Colony visits	Observation dates[1]
1990	28 April	24 March-11 July	16	28 April-9 August[2]
1991	8 May	26 March-4 July	14	25 April-26 July[3]
1992	13 April	20 March-28 May	3	30 April-28 May[3]
1993	23 April	16 March-24 July	15	20 April-20 August[2]
1994	6 May	25 March-18 July	8	22 April-1 August
1995	25 April	11 March-28 June	7	26 April-28 June
1996	12 April	15 March-4 June	4	29 April-28 June
1997	8 April	13 March-28 May	6	22 April-12 June
1998	7 April	15 March-21 June	14	9 April-10 July
1999	3 May	27 March-12 June	13	13 April-8 August
2000	13 May	4 April-16 July	16	18 April-8 August
2001	14 May	10 April-18 June	13	24 April-24 July
2002	14 May	16 March-23 June	10	22 April-1 July
Mean	27 April		10.7	

[1]Observations were discontinued early, normally the result of adverse competition with Western Gulls. The average final monitoring date for the Tunnel, Rubble, Rubble West, Bench, Greenhouse, and Foghorn subcolonies was 14 June; for the Dock, Recreation Yard, Shower, Warden's House, Wall, Power Plant, and Auxiliary Dock subcolonies, it was 3 July.

[2]All colonies monitored through the last monitoring date.

[3]Nesting was observed but not monitored at the Greenhouse subcolony in 1991 and 1992.

dicted hatching date and were cold were considered abandoned. Evidence of predation included partially eaten eggs in or below the nest and dead chicks with wounds attributed to predators. Because monitoring individual and unmarked chicks was difficult once they began leaving the nest, 15 days was set as the arbitrary cutoff date for successful fledging. Therefore, the nestling period began with the hatching of the first egg and extended for 15 days.

Because visits to the subcolonies were delayed until many of the birds had begun incubation, and subcolonies were not visited daily, some nests were initiated and lost between visits. To avoid overestimating reproductive success, the Mayfield method (Mayfield 1961, 1975), a less biased estimator of reproductive success, was used to calculate reproductive success (Erwin and Custer 1982). The computer program MICROMORT (Heisey and Fuller 1985; Ohlendorf *et al.* 1989) was used to calculate rates of nest and fledging success (and associated 95% confidence intervals). Exposure days were calculated following Johnson (1979) and Klett *et al.* (1986). Program CONTRAST (Hines and Sauer 1989) was used to conduct two-tailed Z-tests for comparisons of nesting and fledging success.

Mean clutch sizes were calculated for nests that we considered to have completed clutches (i.e., no increase in eggs between successive visits to an active nest), but those that failed before a full clutch was completed and those nests first found after hatching were not included. We considered that, in nests with older chicks, one or more chicks may have succumbed to predation, siblicide or other factors before the nest was found. Fisher's Least Significant Difference (LSD) Test was used to compare clutch size among years. Hatchability (egg success) was calculated by dividing the total eggs that hatched by the full clutch size for each successful nest, not including those collected, abandoned, destroyed by predators, or lost.

RESULTS

Nest Numbers, Chronology, and Distribution

Between 1990-2002, the date of the earliest nest initiation (first egg laid) ranged from 11 March to 10 April (Table 1). The annual median initiation date ranged from 7 April (1998) to 14 May (2001 and 2002); the average was 27 April. Nests were initiated during a 20-week period from 11 March through 24 July (Fig. 2), but 53% of the nests were initiated from 1 April to 5 May (weeks four through eight in Fig. 2). Only 12% of all the monitored nests were initiated after 26 May (week 11).

Between 1990-2002, 2,255 nests were found on Alcatraz Island (including an estimated 68 nests at the Greenhouse subcolony in 1991 and 1992) (Table 2). The percentage of the nests on the island monitored each year varied during the 13-year study, depending on the number of visits and the duration of the monitoring period (Fig. 3). In certain subcolonies, monitoring was curtailed early during 1992-2002, resulting in a lower percentage of the total nests being monitored. Nest numbers were most likely to be underestimated in 1992, 1998, and 1997, the three

Table 2. Number and percentage of Black-crowned Night Heron nests per subcolony, Alcatraz Island, 1990-2002.

	Year														
Subcolony	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Totals	Means
South Coast	67	57	68	60	90	129	243	240	199	136	90	51	115	1545	118.8
%	39%	46%	54%	48%	58%	64%	71%	83%	80%	83%	87%	75%	82%		67.0%
Tunnel	19	15	21	24	32	32	57	70	64	39	14	10	33	430	33.1
Bench	3	3	7	2	2	13	46	27	16	5	7	2	0	133	10.2
Rubble	11	14	17	19	17	48	85	94	88	48	30	14	34	519	39.9
Rubble West	0	0	0	0	0	0	0	0	0	27	29	21	42	119	9.2
Dock	24	15	16	7	23	15	23	21	8	3	2	1	1	159	12.2
Aux. Dock	10	10	7	8	16	21	32	28	23	14	8	3	5	185	14.2
Central	73	48	43	49	48	57	70	28	20	8	6	5	14	469	36.1
%	43%	39%	34%	39%	31%	28%	20%	10%	8%	5%	6%	7%	10%		21.6%
Greenhouse	38	34[1]	34[1]	30	34	38	36	13	7	2	1	0	11	278	21.4
Rec. Yard	7	4	3	4	7	6	13	4	4	2	1	0	0	55	4.2
Wall	24	8	5	9	4	13	20	10	8	4	2	1	0	108	8.3
Shower	4	2		6	3	0	1	1	1	0	0	0	0	19	1.5
Warden	0	0	0	0	0	0	0	0	0	0	2	4	3	9	0.7
North Coast	30	19	16	16	17	14	28	21	29	20	7	12	12	241	18.5
%	18%	15%	13%	13%	11%	7%	8%	7%	12%	12%	7%	18%	8%		11.4%
Foghorn	29	18	13	14	14	8	22	12	14	12	2	0	0	158	12.2
Power Plant	1	1	3	2	3	6	6	9	15	8	5	12	12	83	6.4
Totals	170	124	127	125	155	200	341	289	248	164	103	68	141	2255	173.5

[1]Nesting was observed in the Greenhouse subcolony, but nests were not monitored in 1991 or 1992. We estimated that there were 34 nests in the subcolony, based on an average of the numbers found there in 1990, 1993, and 1994.

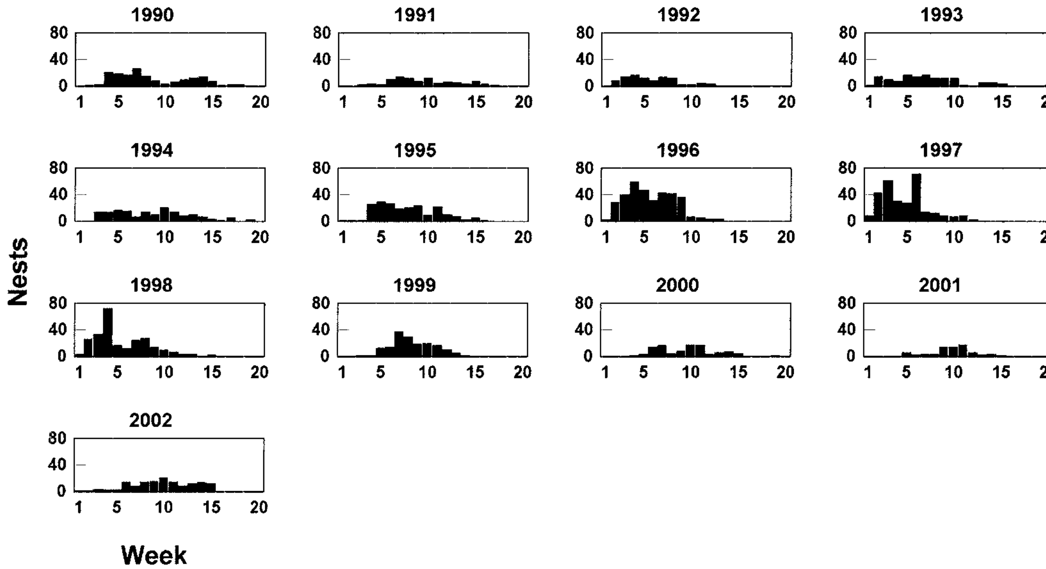

Figure 2. Weekly initiation dates (11 March-28 July) by year for Black-crowned Night Heron nests at Alcatraz Island, 1990-2002.

years that monitoring was curtailed early in the breeding season (Table 1). During the two comprehensive nest surveys, the numbers of nests declined from 170 in 1990 to 124 in 1991. After three years of relatively stable nest numbers (1991-1993), numbers increased and reached a peak of 341 in 1996 (Table 2, Fig. 3). During 1996-2002, the total numbers of nests declined significantly (r_5 = 0.90, P < 0.01), including a 13-year low of 68 nests in 2001 (Fig. 3).

The relative distribution of Black-crowned Night Heron nests at Alcatraz Island changed during the 13 years. Although nests in 1990 were generally dispersed throughout suitable habitats on the island, an apparent shift in nesting sites began in 1991. The percentage of nests found in the seven subcolonies of the South Coast Area of the island increased progressively and significantly (r_{11} = 0.92, P < 0.001) from 39% in 1990 to 82% in 2002 (Table 2; Fig. 3). Apparently, nesting areas shifted during this period from the Central Island Area, because nest numbers in that area declined during the same period from 43% to 10%. The percentage of total nests found in the North Coast Area also declined from 1990 (18%) to 2002 (8%).

In the first nine years of the study, an average of 62% of the Black-crowned Night Heron nests were in Mirrorbush (*Coprosma baueri*), the primary habitat in nine of the subcolonies. In recent years, however, other habitats have supplanted Mirrorbush as important nesting habitats, and in 2001 and 2002 fewer than 10% of the nests were found in Mirrorbush. During 1990-1998, an average of 13% of the nests were in English Ivy (*Hedera helix*), while the average during 1999-2002 increased to 25%. Likewise, the habitat clas-

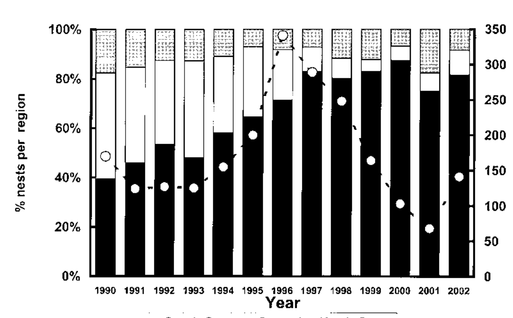

Figure 3. Total Black-crowned Night Heron nests (right y-axis) and spatial trends (left y-axis) at Alcatraz Island, 1990-2002: North Coast Area = Foghorn and Power Plant; Central Area = Wall, Shower, Greenhouse, Recreation Yard, and Warden's House; South Coast Area = Auxiliary Dock, Dock, Bench, Rubble, Rubble West, and Tunnel Bush (See Fig. 1).

sified as "rubble," which consisted primarily of the remains of demolished buildings (i.e., concrete, reinforcing rods, metal, scrap wood, and miscellaneous debris) increased from less than 0.1% of the utilized nesting habitat during 1990-1998 to an average of 30% during 1999-2002. Black-crowned Night Heron nests in "rubble" reached a peak of 44% in 2002, with 41 of 42 nests in the Rubble West subcolony and 21 of 33 nests in the Tunnel subcolony using this substrate.

Other nesting habitats, each with fewer than 10% of the total nests, included rose (*Rosa* sp.), Fig (*Ficus carica*), California Blackberry (*Rubus vitifolius*), Australian Tea Tree (*Leptospermum laevigatum*), Mimosa (*Albizia lophantha*), Victorian Boxwood Tree (*Pittosporum crassifolium*), and Monterey Cypress (*Cupressus macrocarpa*).

Competing Species

During 1990-1995, the numbers of Western Gull nests on Alcatraz Island were relatively stable, averaging 431 nests per year (D. Hatch, pers. comm.). In 1996, the same year that the Black-crowned Night Heron numbers reached a peak, the Western Gull numbers reached a peak of 541 nests. However, during 1997 to 2002, while the numbers of Black-crowned Night Heron nests were declining, the number of Western Gull nests increased significantly ($r_4 = 0.90$, $P < 0.003$), reaching a 13-year peak of 825 nests in 2002. During 1996 to 2002, numbers of nests of the Western Gull and Black-crowned Night Heron were negatively correlated ($r_5 = -0.86$, $P < 0.02$) (Fig. 4).

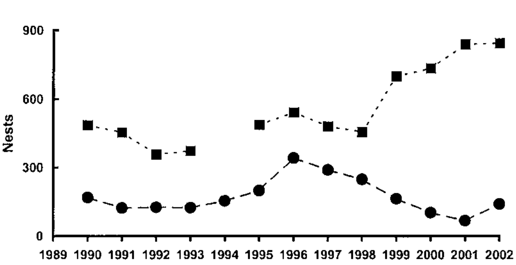

Figure 4. Trends of Western Gull (squares) and Black-crowned Night Heron (circles) nests on Alcatraz Island, 1990 -2002 (Western Gull data courtesy J. Thayer and B. Saenz, PRBO Conservation Science, pers. comm.).

Black-crowned Night Heron Reproduction

The annual mean clutch size for Black-crowned Night Herons during this study ranged from 2.78 eggs per clutch in 1995 to 3.04 eggs per clutch in 1992, with an overall mean of 2.87. Differences in clutch size were observed among years (Table 3). The means in 1990 and 1992 were higher than those in 1995 and 1998, but no overall trend was detected. Each year, the modal clutch size was three eggs, and, overall, 67.3% of the nests had three eggs, 21.6% had two, and 9.9% had four. Only seven five-egg clutches (0.4%) and 16 (0.9%) one-egg clutches were found during the study. Years were combined and mean clutch size was calculated based on nest initiation date divided into quartiles. The lack of differences in clutch size among quartiles indicated there was no seasonal effect.

The annual mean hatching success (nests that hatched at least one egg) for the Black-crowned Night Heron during this 13-year study, as measured by the Mayfield method, averaged 64% and ranged from 45% in 2001 to 81% in 1994 (Table 3). The mean fledging success (the percentage of nests with eggs that hatched in which at least one chick survived to 15 days of age) ranged from 72% in 1997 to 99% in 1993, an average of 88%. The percentage of all nests with at least one chick that fledged ranged from 36% in 1998 to 77% in 1994, an average of 56% (Table 3).

Predation was the primary limiting factor at Alcatraz. Using traditional means for calculation of success, we estimated that eggs in 12% of the nests were destroyed by predators before hatching (Table 4). Another 2% of the nests were probably destroyed by predators, but the cause was unconfirmed. Eggs in an average of 7% of the nests were destroyed by predators each year during 1990-1996, compared with an average of 23% during 1997-2002. The relatively high predation rate the first two years of the study (13% in 1990 and 19% in 1991) may have been related to observer disturbance during nest monitoring in all the subcolonies through late July or early August. Adverse interactions between the Black-crowned Night Heron and

Table 3. Estimates of clutch size and percentage nesting success (and 95% CI) of the Black-crowned Night Heron at Alcatraz Island, 1990-2002.[1]

					Nesting success		
Year	Clutch size	Nests found	Mayfield nests[2]	Exposure days	Hatching[3]	Fledging[4]	Overall[5]
1990	3.01 A[6]	170	140	1840	70 AB[7] (60-80)	90 AB (84-95)	63
1991	2.86 ABC	90	81	1230	64 ABC (52-76)	82 ABC (72-92)	52
1992	3.04 A	93	54	351	81 ABC (61-100)	88 ABC (77-99)	71
1993	2.92 ABC	125	96	1178	77 AB (66-89)	99 A (96-100)	76
1994	2.84 BC	155	117	969	81 A (70-93)	94 AB (88-100)	77
1995	2.78 C	200	142	1257	77 AB (66-88)	92 A (86-98)	71
1996	2.85 BC	341	179	1441	67 ABC (56-78)	79 BC (71-87)	53
1997	2.87 BC	289	173	1502	64 ABC (53-74)	72 C (64-80)	46
1998	2.79 C	248	203	2352	46 C (37-54)	78 BC (70-86)	36
1999	2.87 BC	164	155	2052	55 BC (45-64)	91 AB (85-97)	50
2000	2.83 BC	103	87	1073	52 ABC (39-64)	87 ABC (77-98)	45
2001	3.00 AB	68	61	576	45 BC (29-62)	95 AB (85-100)	43
2002	2.96 AB	141	125	1507	54 ABC (43-64)	93 AB (86-100)	50
Mean	2.87	168	124	1333	64	88	56

[1]Based on days of nest exposure (see Hensler and Nichols 1981).
[2]Mayfield nests are those included in the analysis. Nests that had either hatched or failed before they were found were rejected from the analysis; such nests would have no exposure days.
[3]Percent of monitored nests in which one or more eggs hatched.
[4]Percent of nests that hatched in which one or more chicks reached at least 15 days of age.
[5]Percent of monitored nests in which one or more chicks reached at least 15 days of age, calculated by multiplying Hatch Success by Fledging Success.
[6]Among years, clutch size estimates sharing a capital letter are not significantly different (Fisher's LSD Test, $P < 0.05$).
[7]Among years, survival estimates sharing a capital letter are not significantly different (z-tests; $P < 0.05$).

the Western Gull were common, especially late in the breeding season. In subsequent years, nest visits in subcolonies susceptible to Western Gull predation were curtailed early to prevent human-induced predation.

From 1992 through 1997, the clutch predation rate averaged 3%, but, in 1998, it jumped to 22%, almost ten times that observed in 1997 (Table 4). Predation on eggs exceeded 25% in each of the remaining four years of the study, despite precautions taken by observers to minimize human-induced predation. Predators also destroyed chicks in 4% of the nests with eggs that hatched before they could fledge (Table 4). Much of the predation on chicks during 1990 and 1991 (8% and 13%, respectively) was likely to be related to observer disturbance late in the breeding season.

The overall nest abandonment rates both before and after hatching were low (3% and 0.4% of the monitored nests, respectively), and no clear annual trends were observed. Nests with unknown fates, including those lost or not rechecked for other reasons, comprised 20% of the monitored nests (Table 4). The percentages of unknowns for the first two years of the study (8% and 2% in 1990 and 1991, respectively), were lower than subsequent years because nests were followed

Table 4. Nesting success of Black-crowned Night Herons at Alcatraz Island, 1990-2002.

Nesting outcome	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
Monitored nests	170	90	93	125	155	200	341	289	248	164	103	68	141	2187
Predation (%)[1]	13	19	2	7	1	2	4	3	22	27	32	28	29	12
Destroyed (other) (%)[1]	2	3	0	2	1	4	1	4	2	0	0	0	0	2
Abandoned (%)[1]	3	7	3	2	3	2	1	3	7	4	3	7	1	3
Unknown (%)[1]	8	2	23	14	37	34	23	23	10	12	17	28	20	20
Hatched[2]	127	62	67	94	88	116	239	193	146	94	50	25	71	1372
Fledged[3]	102	42	34	72	56	76	118	96	76	62	25	16	43	818
Predation (%)[4]	8	13	1	0	0	1	0	4	13	5	8	0	6	4
Destroyed (other) (%)[4]	2	2	6	1	2	3	8	13	4	2	2	4	0	5
Abandoned (%)[4]	0	3	0	0	1	1	0	0	0	0	2	0	0	0.4
Unknown (%)[4]	10	15	42	22	33	29	42	33	31	27	38	32	34	31

[1]Percentage of monitored nests.
[2]Nests observed with at least one egg that hatched.
[3]Nests observed with at least one chick that survived to age 15 days.
[4]Percentage of nests in which at least one egg hatched.

longer into the season, enabling observers to better classify clutch success.

The success of an average of 31% of the chicks was unknown, primarily because nest visits were terminated before fledging success of later-nesting Black-crowned Night Herons could be evaluated. The percentages of unknowns for the first two years of the study (10% and 15% in 1990 and 1991, respectively) were lower than subsequent years. The percentage of nests with chicks with an unknown fate was higher those years with fewer monitoring visits, and those years that monitoring was terminated early (especially 1992 and 1996) (Tables 1 and 5). For example, during the five years that subcolonies were visited from three to eight times (average = 5.6), the fate of 28% of the nests was unknown. However, in the eight years that the subcolonies were visited more than 12 times, the fate of only 14% of the breeding attempts was unknown.

During this study, 187 of 3,388 eggs (6%) which were fully incubated failed before hatching (Table 5). Hatchability ranged from 89% in 2002 to 98% in 1992 and averaged 94.5%, but some failed eggs showed signs of impaired reproduction, including crushed, cracked, or dented shells. During 1989-1991, such eggs were also found at other sites in San Francisco Bay, but teratogenesis was only observed in embryos from Alcatraz (Hothem *et al.* 1995). Two deformed embryos were collected in 1990, one was collected in 1995, and two were found in 1997. Multiple defects were found in one or more of the embryos, and they included missing or reduced mandibles, swollen joints, missing eyes, shortened neck, and encephalocele of the forebrain. Although, the five abnormal embryos collected during this study had symptoms similar to those induced by environmental contaminants, chemical analyses of random and failed eggs, and the two deformed embryos in 1990, did not confirm a chemical cause of the deformities (Hothem *et al.* 1995). Concentrations of DDE, mercury, and selenium residues in the two deformed embryos from Alcatraz Island were below concentrations associated with reproductive effects (Hothem *et al.* 1995).

Table 5. Egg and chick survival of the Black-crowned Night Heron at Alcatraz Island, 1990-2002.

	Year														
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total	Mean
Monitored nests	170	90	93	125	155	200	341	289	248	164	103	68	141	2187	168.2
Nests with hatched eggs	127	62	67	94	88	116	239	193	146	94	50	25	71	1372	105.5
Eggs observed to hatching	339	155	169	265	199	279	540	446	372	254	144	61	165	3388	260.6
Failed eggs	19	7	4	17	10	23	20	28	16	11	9	5	18	187	14.4
Nests with fledged chicks	102	42	34	72	56	76	118	96	76	62	25	16	43	818	62.9
Chicks observed to fledging	210	81	56	159	101	122	232	183	148	145	48	31	92	1608	123.7
Fledged chicks/monitored nest	1.24	0.90	0.60	1.27	0.65	0.61	0.68	0.63	0.60	0.88	0.47	0.46	0.65		0.74
Fledged chicks/hatched clutch	1.65	1.31	0.84	1.69	1.15	1.05	0.97	0.95	1.01	1.54	0.96	1.24	1.30		1.20

Mortality was also observed in chicks. Of the 3,201 eggs that were observed to have hatched, 1,608 chicks (50%) survived to at least 15 days (Table 5). During the study, 192 dead chicks were found, with 68% of them found during 1996-1998. Overall, 6% of the chicks that hatched were later found dead, but in 1996, the percentage was 14%. During the study, only one chick was found with a gross deformity (deformed upper mandible). Production averaged 0.74 fledglings per monitored nest and ranged from 0.46 in 2001 to 1.27 in 1993 (Table 5). Of the nests in which one or more eggs hatched, an average of 1.20 chicks fledged per nest. The estimated annual chick production ranged from 31 in 2001 to 232 in 1996 (Table 5).

DISCUSSION

The mean clutch size of 2.87 eggs for Black-crowned Night Herons at Alcatraz was lower than 20 other colonies assessed in recent years (Wolford and Boag 1971; Tremblay and Ellison 1980; Custer *et al.* 1983; Erwin *et al.* 1996; Blus *et al.* 1997). Mean clutch sizes of the Black-crowned Night Heron in the northeastern U.S. ranged from 3.2 eggs per nest at the southernmost colony in Delaware Bay (latitude 39°35'N) to 3.8 eggs per clutch at the northernmost colony in Boston Harbor (Parsons *et al.* 2001). All were higher than that observed at Alcatraz, a colony located at a more southern latitude (37°49'N).

The mean hatchability (94.5%) observed in this study was higher than that observed in the St. Lawrence Estuary in 1975 and 1976, where 90% egg success was considered normal (Tremblay and Ellison 1980). The mean hatchability at Alcatraz was greater than the four colonies (82-87%) included in a reproductive study in the northeastern U.S.A (Parsons *et al.* 2001), but it was similar to the 93% hatchability found by Custer *et al.* (1983) at Atlantic Coast heronries, and that found at three other San Francisco Bay nesting sites in 1989-1991 (Hothem *et al.* 1995).

The mean hatching success at Alcatraz Island (64.1%) was lower than that found at other colonies recently studied in South

Carolina, Washington, and Oregon (Post 1990; Blus *et al.* 1997) and at two colonies in San Francisco Bay (Hothem *et al.* 1995). The mean hatching success at Alcatraz, however, was higher than that at West Marin Island in 1990 (47%), Bair Island in 1989 (53%), and Brooks Island in 1990 and 1991 (56% and 38%) (Hothem *et al.* 1995). Compared with fledging success rates reported from 28 sites, only two colonies in Washington and one in Oregon (Blus *et al.* 1997) had higher fledging success than Alcatraz. Alcatraz fledging success was also higher than that at the three other islands studied in San Francisco Bay in 1989-1991 (57% to 77%) (Hothem *et al.* 1995). The percentage of all nests with at least one chick that fledged at Alcatraz was greater than most of the other colonies studied in recent years, including the Potholes Reservoir in Washington that had only 12% overall success in 1991 (Blus *et al.* 1997). Overall success at the other three San Francisco Bay sites was lower than at Alcatraz and ranged from 26% at Brooks Island in 1991 to 43% at Brooks in 1990 (Hothem *et al.* 1995).

Predation has been reported to be a major limiting factor for Black-crowned Night Heron reproductive success (Wolford and Boag 1971; Tremblay and Ellison 1980; Henny *et al.* 1984; Blus *et al.* 1997), but predation rates at Alcatraz, especially during the years 1998-2002, were among the highest reported in recent literature. During 1998-2002, the same period of time that Western Gull nests increased by 70% on Alcatraz (Fig. 4), an average of 29% of the monitored nests was destroyed by predators, or more than four times the average destroyed during 1990-1996.

The nesting chronology of the Black-crowned Night Heron relative to that of the Western Gull was especially important in determining predation intensity. Although Black-crowned Night Heron nesting initiation between years varied by about four weeks (Table 1), Western Gull nesting initiations at Alcatraz varied by only a few days (D. Hatch, pers. comm.). During 1990-2002, the Black-crowned Night Heron nests were initiated at Alcatraz Island over a 2.5- to 4-month period, but in recent years (2000-2002) the median nest initiation dates (13-14 May) have been later than the overall mean (27 April) and the medians for each of the previous ten years (Table 1, Fig. 2). As a result of this later nest initiation, Black-crowned Night Heron eggs have hatched later in the season, which has generally resulted in earlier and more intense predation by Western Gull adults.

During this study, the percentage of Black-crowned Night Herons nesting at Alcatraz increased in the South Coast Area (Fig. 3), an area closed to visitors during the breeding season. Only the Auxiliary Dock, the subcolony closest (10 m) to the point of debarkation for visitors to the island, was likely to be affected by visitor disturbance in this area. This subcolony, as well as the Bench and Dock, experienced significant declines in nest numbers from 1997 through 2002 (Table 2). These declines were likely to be related primarily to increased predator pressure from growing numbers of nesting Western Gulls, and senescence of Mirrorbush, the primary nesting habitat at these sites.

Overall, the percentage of Black-crowned Night Heron nests increased in the other three subcolonies in the South Coast area (Table 2). However, starting in 1999, nesting began to shift to the mostly unvegetated Rubble-West subcolony. Western Gull numbers began to increase in 1999, and the result was an increase in interspersion of Western Gull and Black-crowned Night Heron nests. This frequently resulted in predation by Western Gulls on the Black-crowned Night Heron eggs and chicks. Management to vegetate the barren parts of the Rubble West and Tunnel subcolonies, however, could enhance the habitat for Black-crowned Night Heron nesting, could reduce the suitability for Western Gull nesting, and could reduce the susceptibility of the Black-crowned Night Heron to gull predation.

In other parts of the island, especially in the Central Island subcolonies, adult and fledgling Common Ravens (*Corvus corax*) were frequently observed carrying Black-crowned Night Heron eggs from nesting areas to ledges on the cellhouse, where the eggs were eaten (C. Hellwig, pers. comm.). The presence of a nesting pair of Common Ravens in a Monterey Cypress near the Wall subcolony likely contributed to the severe decline in nesting in that subcolony in recent years. Common Ravens nearly eliminated the production of the Black-crowned Night Herons nesting at Summer Lake, Oregon in 1980 (Henny *et al.* 1984). Although the Norway Rat (*Rattus norvegicus*), Northern Harrier (*Circus cyaneus*), and an unidentified owl were reportedly present on Alcatraz Island at times during the study, the effects of these other predators were not assessed.

An important factor in the decline in nest numbers that began in 1997 may have been related to the major disturbance that occurred in association with the 2 June 1996 premiere on Alcatraz Island of the motion picture, "The Rock." Extensive human disturbance occurred during both day and night hours from 28 May through 5 June (Hatch 1996; Brown 1996). This disturbance occurred during a critical phase of Black-crowned Night Heron nesting, when eggs in most of the 338 nests should have hatched, but before most of the chicks would have been old enough to leave the island.

According to Brown (1996), Western Gull nesting was severely affected by the premiere, with about 23% of the Western Gull nests lost because of this disturbance. In addition, the total number of Western Gull nests declined by about 11% in 1997. Although the impacts of the movie premiere on the Black-crowned Night Heron were not assessed (Hatch 1996), there may have been long-term effects. Nest numbers in the more-remote (from the premiere) South Coast Area of the island were similar in 1997 to those seen in 1996, but nesting in the North Coast was 25% lower in 1997, while that in the Central Island subcolonies, closest to movie-premiere activities, declined by 61% in 1997 (Table 2). An island-wide decline continued through 2001 (Fig. 4).

In every year of the study, the estimated production of chicks per nesting attempt was less than the 2.0 to 2.1 young per breeding pair suggested by Henny (1972) to maintain a stable population (Table 5). The estimated number of Black-crowned Night Heron chicks that fledged per nest at Alcatraz during 1990-2002 (0.74 chicks) was on a monitored-nest basis. If chick production were calculated on a breeding-pair basis, however, because Black-crowned Night Herons may renest (Wolford and Boag 1971), the number of young fledged per pair would be higher. In addition, chicks were followed until they reached 15 days of age, about four weeks before they normally fledge; losses during this four-week period were not estimated in this study. Losses of chicks between two and six weeks of age in Alberta ranged from 10 to 15% (Wolford and Boag 1971), while 21% of the chicks were lost in the 1-7 days after age 15 in an Idaho study (Findholt and Trost 1985). Ten of the colonies studied recently (Tremblay and Ellison 1980; Custer *et al.* 1983; Henny *et al.* 1984) produced more that two chicks per nest, but none of the colonies studied in San Francisco Bay (Hothem *et al.* 1995), including Alcatraz Island, reached this level. If chick mortality from 15 days to fledging were included, chick production would have been lower than that shown in Table 5. However, even without including this mortality, we conclude that chick production in all years of the study was less than the levels normally thought to be necessary for stability.

Black-crowned Night Herons breeding in San Francisco Bay tend to disperse within the bay during winter (Gill and Mewaldt 1979) where they probably acquire contaminants by foraging in "hot spots" within the Bay. However, based on normal egg hatchability and a low incidence of reproductive impairment, it appears that contaminants did not have a significant effect on Black-crowned Night Heron reproduction at Alcatraz Island during this study.

Because we did not mark individuals, we are unable to evaluate the influence of immigration or emigration on the population structure at Alcatraz. However, it appears that the overall numbers in North San Francisco Bay have remained relatively stable, averaging 533 nests during 1991-2002 (J. P. Kelly, pers. comm.). Of the Black-crowned Night Herons nesting in North San Francisco Bay during 1990-2002 (Kelly *et al.* 1993; J. Kelly, pers. comm.), we estimate that about 33% nested at Alcatraz. The percentage nesting at Alcatraz ranged from about 12% in 2001 to about 50% during 1996-1998. In recent years, the Alcatraz Island heronry has been one of the most important for Black-crowned Night Herons in North San Francisco Bay. Management techniques that reduce predation by Common Ravens, lessen competition with and predation by Western Gulls, improve Black-crowned Night Heron nesting habitat, and minimize human disturbance will help maintain this important nesting site for the future.

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