RESTORING AND MONITORING BALD EAGLES IN SOUTHERN CALIFORNIA: THE LEGACY OF DDT

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ABSTRACT—Bald eagles (*Haliaeetus leucocephalus*) disappeared from southern California by the mid-1960s, primarily as a result of DDT contamination in the Southern California Bight. Between 1980 and 1986, the Institute for Wildlife Studies (IWS) released 33 bald eagles from hacking towers on Santa Catalina Island, CA in an effort to restore a breeding population. Nesting began in 1987, but all the eggs broke in the nests. Analyses of egg contents indicated that DDE, a metabolite of DDT, was the likely cause of nesting failure. Beginning in 1989, IWS began an active manipulation of nests to maintain and increase the eagle population, in conjunction with further hacking of birds. Eggs removed from the nests were incubated by the Santa Cruz Predatory Bird Research Group or the San Francisco Zoo (Zoo) and chicks were fostered back into nests. Hatching success of removed eggs was about 20%, but the Zoo also provided chicks produced by their breeding eagles. Since 1989, IWS has released an additional 21 birds from hacking towers and successfully fostered 35 chicks into active nests. About 50% of released birds left the island 2–3 months after fledging and have been reported from San Diego, CA to British Columbia. Minimum first year survival is greater than 70% and there are generally 15–20 resident eagles on the island, including five breeding pairs. Thirty years after DDT was outlawed for use in the United States, DDE contamination continues to preclude successful breeding by bald eagles on Santa Catalina Island without human intervention. Only one of five active territories has had a significant decline in DDE contamination in eggs that have failed to hatch between 1989 and 2003. IWS plans to continue managing the bald eagle population until pollution levels decline to a point at which reproduction is possible, either through natural degradation or clean-up efforts being explored by the Environmental Protection Agency.

Keywords: bald eagle, DDE, Haliaeetus leucocephalus, reintroduction, survival

INTRODUCTION

Bald eagles (*Haliaeetus leucocephalus*) occurred historically on all California Channel Islands and on mainland southern California. Kiff (1980) estimated a minimum of 24 pairs nested on the Channel Islands, with 1–5 pairs nesting on each island. The southern-coast mainland population disappeared by the 1930s, probably due to habitat loss from encroaching development. Bald eagles persisted on the Channel Islands until the mid-1950s or early 1960s, but no successful nesting activity was known after 1950.

Reasons for the eventual disappearance of bald eagles on the Channel Islands are not completely understood; however, the likely cause of population declines on the Channel Islands was contamination of the marine environment with the industrial pesticide DDT (Kiff 1980). Between 1947 and 1961 an estimated 37 to 53 million liters of DDT-contaminated acid sludge, containing 348–696 metric tons of DDT, was disposed at an ocean dump site 16 km northwest of Santa Catalina Island (hereafter Catalina Island; Chartrand et al. 1985). In addition, an estimated 1,800 metric tons of DDT was discharged from the Joint Water Pollution Control Plant outfall, 3.3 km offshore of Palos Verdes Peninsula (Chartrand et al. 1985); this area was designated as a Superfund site by the U.S. Environmental Protection Agency in 1996. Levels of DDE (a metabolite of DDT) have been found to be inversely correlated with eggshell thickness and productivity in bald eagles (Hickey and Anderson 1968, Wiemeyer et al. 1984). The decline in bald eagle populations in southern California was concurrent with declines in seabird breeding success in the Southern California Bight and with continent-wide declines in bald eagle populations that were attributed to the impacts of DDT (Risebrough et al. 1971, Anderson et al. 1975, Grier 1982, Wiemeyer et al. 1984).

After DDT was banned in the U.S. in 1972, environmental levels of DDT dropped sharply. Efforts to restore bald eagles in southern California began in 1980 when the Institute for Wildlife Studies (IWS), in cooperation with the United States Fish and Wildlife Service (USFWS) and the California Department of Fish and Game, initiated a program to reintroduce bald eagles to Catalina Island. The goal of the project was to establish a breeding population on Catalina Island that would then expand to the other Channel Islands.

Between 1980 and 1986, 33 eagles were collected from wild nests in northern California, Washington, and British Columbia and released on the island from three artificial nest or "hacking" platforms (Garcelon 1988). Initial releases were successful and many of these birds matured and formed breeding pairs on the island. The first eggs were laid in 1987 and 1988, but they all broke in the nest. Analyses of egg remains removed from failed nests implicated DDE as the causal agent of the lack of productivity (Garcelon et al. 1989) because mean concentrations were twice as high as that known to cause nearly complete reproductive failure (Wiemeyer et al. 1984). Analyses of potential prey items confirmed DDE contamination in fish, gulls, and marine mammals collected around Santa Catalina Island (Garcelon et al. 1989, Garcelon 1997).

Since 1989, the reintroduced population has been maintained through manipulations of eggs and chicks at each nest site and through additional hacking of birds. Currently, a program of active manipulation and augmentation of nests is believed to be the only way to maintain the Catalina Island bald eagle population. Herein, we summarize the bald eagle restoration efforts made on Catalina Island through 2003 and the current status of those efforts.

STUDY AREA

Catalina Island is located 34 km south of Long Beach, CA. The island is 34 km long, 0.8–13.0 km wide, and covers 194 km^2 (Fig. 1). Elevations range from sea level to 648 m and there is considerable topographic relief, with numerous steep-sided canyons incising the island. Mean annual maximum temperatures range from 16.6–20.1°C near the coast, and yearly precipitation averages 30.2 cm (Western Regional Weather Center 2003).

MATERIALS AND METHODS

Nest Manipulations

Observations of adult eagles began in January of each year to determine the location of breeding pairs and their respective nest sites. Active nests were monitored every 1–2 days to determine when eggs were laid. We replaced eggs with artificial eggs (resin eggs of same general size, shape, and weight of eagle eggs) within 1–4 days of the date that eagles were confirmed incubating. The eggs were transported to the Santa Cruz Predatory Bird Research Group (SCPBRG, 1989–1991) or the Avian Conservation Center (ACC) at the San Francisco Zoo (1992 to present) for artificial incubation. After the adults had incubated for about 30 days, we fostered 1–2 healthy chicks, which hatched from eggs taken from the nests or from eggs laid by captive-breeding eagles at the ACC, back into the nests. For adults that had not successfully raised chicks previously, we also placed a broken eggshell with the chick to help the

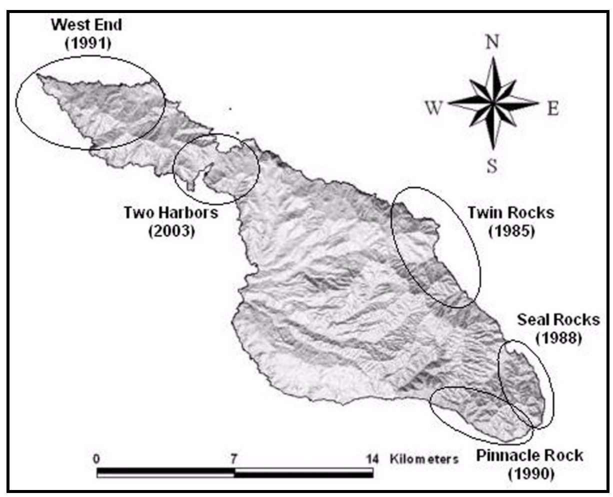

Figure 1. Santa Catalina Island, CA, one of the eight California Channel Islands off the coast of southern California. Active bald eagle territories are circled and the year they were established is indicated in parentheses.

adults make the association of egg and chick. We also placed a viable egg from a wild nest into a nest on Catalina Island twice in 1991 and once in 1995. During nest manipulations we were in view of the nest less than 20 minutes to reduce adult abandonment. This was particularly important during the initial egg switch because adults had not invested much time in nesting activities.

We returned to the nest to equip 8-week-old eaglets with USFWS metal leg bands, colored leg bands, wing markers, and a backpack-style radio-transmitter. We also collected a blood sample (~10 cc) for contaminant analyses and made morphological measurements to determine sex (Bortolotti 1984, Garcelon et al. 1985).

Bald Eagle Hacking

From 1991 to 2003 we released eagles from hacking towers when nests were not available for fostering activities. Eight week old eaglets were brought to Catalina Island, placed into a hacking tower, and marked and radiotagged as described above prior to release. Each tower consisted of a 2.44- x 3.66-m platform raised 4–5 m above the ground on four utility poles. Each platform had a box with a solid roof and was separated by a wall into two sections: a 2.44- x 2.44- x 2.10-m nest box and a 1.22- x 2.44- x 2.10-m observation area. The wall contained feeding doors and a one-way glass window. The rear half of the cage's side wall was solid, whereas the front half of each side wall and the entire front of the cage were made of vertical metal bars with a release door that was opened when the birds were about 12 weeks old.

Monitoring

Active nests were viewed from observation blinds or with solar-powered weatherproof video cameras that transmitted the video using microwave video transmitters. We monitored each nest from incubation through fledging to determine the stage of nest failure (if any) and to insure that any chicks fostered into nests remained healthy.

We used radio-telemetry to locate and observe behavior of each fledging every 2–3 days in the first month of flight and 1–3 times per week in the second month. Occasional monitoring continued year-round for all eagles remaining on the island. We also recorded reported sightings of the eagles, usually identified by their wing markers, on the Channel Islands and the mainland. From these data survival was estimated using censored survival data, where a bird was dropped from the data after its last sighting (if not a known mortality), using the Kaplan and Meier procedure (Kaplan and Meier 1958) in Graphpad Prism (Graphpad Software, Inc., San Diego, CA).

Collection of Tissue Samples

Eggs that did not hatch were stored for contaminant analyses. Eggshells were rinsed in water, air dried, and stored in aluminum foil. Shell contents were placed directly into a chemically clean jar and frozen. Frozen samples were shipped to a USFWS contract laboratory and analyzed for six DDT isomers, the 45 PCB congeners, and 10 PCB homologues using Gas Chromatography/Low Resolution Mass Spectroscopy with minimum detection levels ranging from 0.04–0.30 µg/kg. In addition, lipid and moisture content were calculated for each sample. Concentrations were converted to fresh wet weight values based on the ratio between weight of egg contents at opening and the fresh wet weight calculated from egg measurements.

RESULTS

Nest Manipulations

Adults rarely abandoned nests following introduction of artificial eggs. On the two occasions of abandonment, both laid another clutch within a month, although one pair also abandoned the second clutch after the egg switch. We removed 69 eggs from 44 nests (1–5/year) from 1989 through 2003 (Table 1). Of these eggs, 59 were known to be fertile and only 11 (18.6%) hatched (Table 1). More eggs were laid than collected (Table 1), either because an egg broke before we could remove it or an additional egg was laid after the egg switch. All eggs left in the nest broke within two weeks.

Since 1989 we fostered 42 chicks into nests and two more chicks hatched from two healthy eggs placed in nests in 1991. Thirty five of these chicks (80%) successfully fledged (Fig. 2). Three of the nine birds that did not fledge were removed from the nest prior to fledging because of injuries (one was later released from a hacking tower), two

Table 1. Summary of bald eagle egg manipulations on Santa Catalina Island, CA 1989–2003.

	Year														
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Number active nests	1	2	2	3	3	2	3	3	2	3	4	3	4	4	5
Number of eggs laid	2	2–3	3	5	5–6	3	5	5–6	6	7	8	7	8	8	9
Number of eggs collected	1	1	3	5	4	3	5	4	5	6	6	4	7	7	8
Number of eggs hatched	0	0	1	2	0	0	0	0	1	1	1	2	0	2	1

died accidental deaths, one bird was killed by a red-tailed hawk (*Buteo jamaicensis;* Perkins et al. 1996), one chick was killed by the nesting female, one chick disappeared, and one died of unknown causes. We have released an additional 21 eagles since 1991 (20 chicks and a 1-year-old bird) through continued hacking (Fig. 2).

Monitoring

Most fledglings spent about one month within their parents' territories before dispersal. About 50% of the eaglets left the island, usually 2–3 months after fledging. Of these, 32 were sighted on the mainland or other Channel Islands (59 separate reports). Six birds were reported mortalities and one was of an injured eagle that had been shot near Arvin, CA. The birds were seen from San Diego, CA to Vancouver Island, B.C. (Fig. 3). In April 1998, a female fostered into the West End nest in 1992 was found on a nest at Santa Margarita Reservoir in San Luis Obispo County, CA. This bird mated with a male released by the Ventana Wilderness Sanctuary, Monterey County, CA in 1994, but no eggs hatched. The same female mated with another male in 1998, and again her eggs did not hatch. The only known successful mainland breeding was by a female released in 1993 that nested at Bass Lake, CA (central CA) and fledged five chicks between 1999 and 2001. Estimated first year survival based on sightings on Catalina Island and reports we have received, including birds released between 1980 and 1986, was approximately 72% (Fig. 4). As the eagles aged their annual survival rate increased to 90–100%.

The initial releases from 1980–1986 and the fostering and hacking activities conducted since 1989 resulted in the formation of five active breeding territories on Catalina Island and a resident population of 15–20 eagles, as of 2003

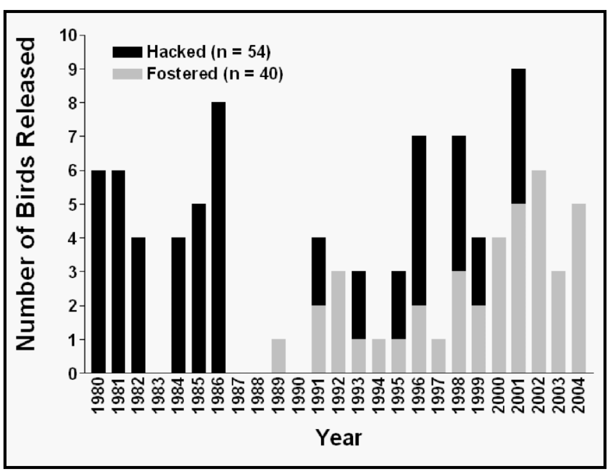

Figure 2. Bald eagles successfully released by hacking and fostering on Santa Catalina Island, CA, from 1980–2003.

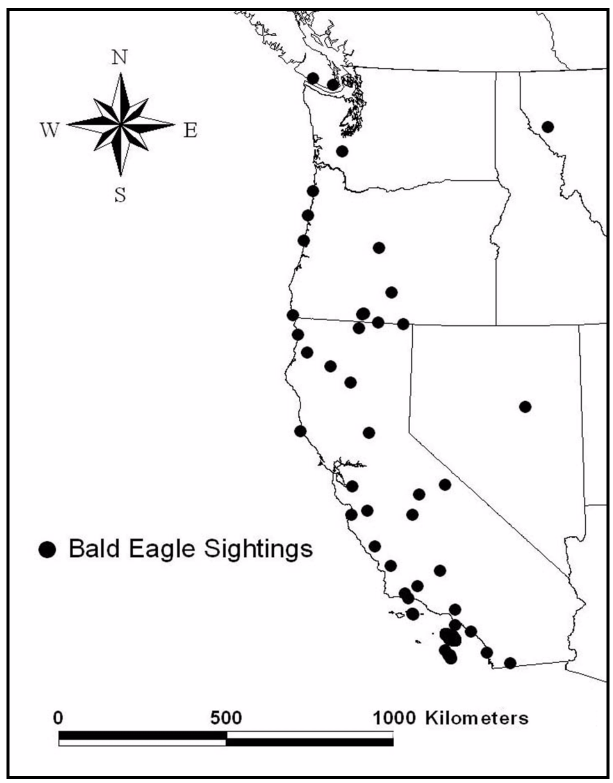

Figure 3. Sightings of bald eagles originally released on Santa Catalina Island, CA, 1980–2003.

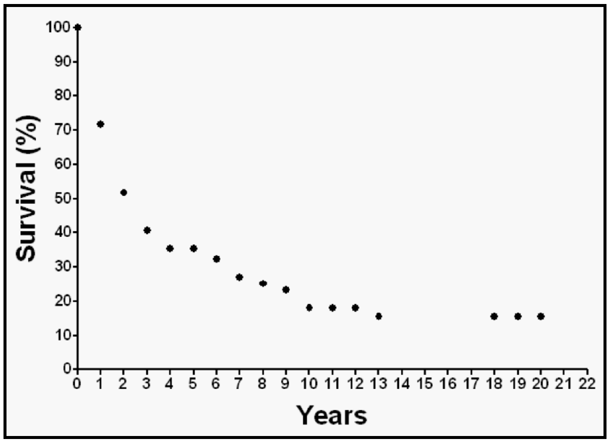

Figure 4. Survival curve for bald eagles released on Santa Catalina Island, CA, from 1980–2003. A total of 89 eagles have been successfully released.

(Fig. 1). The breeding pairs at the Pinnacle Rock, Two Harbors, and West End territories are the same birds that established the territories, except that a second female joined the West End pair in 1992. This trio has cooperatively nested through 2003. The Twin Rocks and Seal Rocks territories have had four and six different adults use the territories, respectively. Usually one adult died or disappeared and was replaced by another adult. Currently, the males in the Twin Rocks and Seal Rocks territories hatched from eggs removed from Catalina Island nests in 1993 and 1992, respectively, and the Two Harbors female hatched from a Catalina Island egg in 1998. All other breeding adults are birds from the 1980–1986 releases or birds produced by captive-bred eagles at the ACC. There are also at least three additional bald eagles on the island that are nearing breeding age (4–6 years old).

Collection of Tissue Samples

Chemical analyses were completed for 54 eggs collected from Catalina Island nests from 1989 through 2003. DDE (p,p'-DDE) generally comprised greater than 95% of the total DDT compounds in analyzed eggs. DDE concentrations did not decline significantly ($P > 0.05$) in eggs that did not hatch between 1989 and 2003 in two of four active territories based upon linear regression analyses (Fig. 5). There were significant linear declines in DDE contamination (µg/g) in unhatched eggs from the Seal Rocks (DDE = 6,882 - 3.436 (Year); $R^2 = 0.6990$; $P = 0.0097$) and Twin Rocks (DDE = 1,140 - 0.5652 (Year); $R^2 = 0.4612$; $P = 0.0442$) nests. The regression line for the Seal Rocks nest was driven largely by the egg contaminant levels in 1990 and 1992. The female that laid these eggs died in 1993 of apparent DDE poisoning (Garcelon and Thomas 1997). If this female's eggs are removed from the analyses, there was a trend towards a decline in DDE contamination in the Seal Rocks territory from 1995 through 2003, but it was not statistically significant ($P = 0.0654$).

DISCUSSION

After 24 years of restoration we have established a breeding population of bald eagles on Catalina Island and a year-round population of 15–20 eagles. DDT was last dumped into the Southern California Bight over 30 years ago, yet the eagles are still unable to hatch their eggs because of continued DDE contamination in the food chain. Eggs removed from nests on Catalina Island exhibited thinning of the shell (Garcelon 1997) and areas of gross structural abnormalities of the eggshell that resulted in rapid water loss and a weakening of the eggshell (Risebrough 1993). Even with artificial incubation, using a variety of

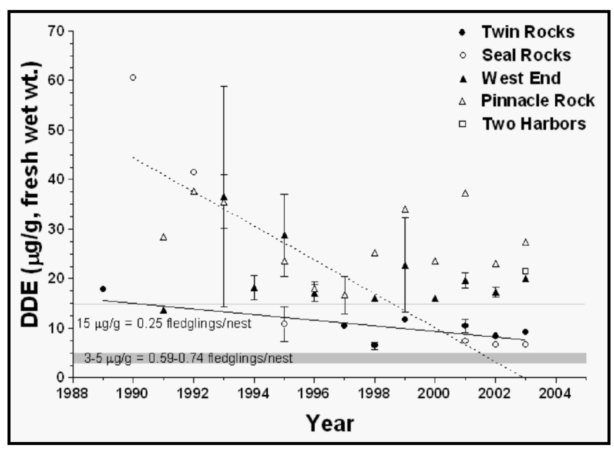

Figure 5. DDE contamination (mean ± 1 SD) in bald eagle eggs from nests on Santa Catalina Island, CA that failed to hatch, 1989–2004. Only eggs from the Twin Rocks and Seal Rocks territories have shown significant declines in DDE contamination ($P \leq 0.05$), with the regression lines shown in solid dashed lines, respectively. Calculated nest success for DDE levels of 3–5 µg/g and 15 µg/g comes from equations in Wiemeyer et al. 1984.

techniques to decrease water loss, the hatching rate is low.

Removal of eggs from bald eagle nests may cause abandonment of nests in some cases (Anthony et al. 1994), but apparently accessing nests quickly resulted in few abandoned nests following manipulations. Without the manipulations it is unlikely that any nesting activity would persist more than 2–3 weeks because of egg breakage. When eagles are not successful at breeding there is the possibility that the birds will "divorce" and search for another mate (Gerrard and Bortolotti 1988). Our egg and chick manipulations have helped maintain the pair bonds of the adults on Catalina Island and resulted in the fledging of chicks from active nests in most years.

The survival of eagles released on Catalina Island was similar to that for other studies (Wood 1992, Bowman et al. 1995, Jenkins et al. 1999) and there does not appear to be a permanent negative impact resulting from being raised in a DDE-contaminated area. Both males and females breeding on the island are fertile and, as shown by the eagle that bred on the mainland, they can breed successfully once they are no longer ingesting the highly contaminated prey items currently found in the Southern California Bight.

DDE concentrations did not decline significantly in bald eagle eggs between 1989 and 2003 in some territories and declined slowly in others, indicating that we will likely need to continue manipulating nests for the foreseeable future if we are to have "successful" bald eagle nesting on Catalina Island. Only the Seal Rocks and Twin Rocks territories have shown a significant decline in DDE contamination in the eggs analyzed. If the decrease in DDE contamination continues along the current trajectory in these two territories, we estimate that egg contamination could decrease to $\leq$ 3 µg/g (fresh wet weight), the level at which eggshell thinning is estimated to begin (Wiemeyer et al. 1984), in the next 5–10 years.

The reason for the wide variation is DDE contamination in eggs from different territories is unclear. Although it is possible that prey contamination varies widely among territories, this is unlikely. In 2003, the lowest egg contamination was found in eggs from the Seal Rocks territory and the highest was found in eggs from the Pinnacle Rock territory (Fig. 5). These territories are adjacent to each other on the southeastern portion of the island (Fig. 1) and we would not expect contaminant levels in prey to vary widely over such a short distance. A more likely explanation for egg contaminant differences is prey preference. For instance, the Seal Rocks female may have a higher proportion of fish in her diet (low DDE contamination; Garcelon et al. 1989, Garcelon 1997), whereas the Pinnacle Rock female may have a higher proportion of gulls and/or marine mammal carcasses in her diet (high DDE contamination; Garcelon et al. 1989, Garcelon 1997).

DDE levels of >15 µg/g in bald eagle eggs have been associated with reproductive failure approaching 100% (Wiemeyer et al. 1984). As of 2003, unhatched eggs from three of five nests on Santa Catalina Island exceeded 19.5 µg/g fresh wet weight. Environmental remediation, such as capping the areas of contaminated sediment, may reduce the amount of DDE entering the food chain, but remediation may be too expensive to conduct on such an extensive area of contamination as that found off the Palos Verdes Peninsula. With the estimated half-life of DDE in soil ranging from 2–16+ years (ATSDR 2002), the legacy of DDT is likely to continue in the Southern California Bight for many years.

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