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# Aversive Conditioning to Reduce Raven Predation on California Least Tern Eggs

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**Abstract.**—We examined the potential of using conditioned aversion to reduce predation by Common Ravens (*Corvus corax*) on eggs of the endangered California Least Tern (*Sterna antillarum browni*). In 1991, we placed Japanese quail (*Coturnix japonica*) eggs injected with 30 mg (active ingredient) methiocarb near eight raven nest sites at the U. S. Marine Corps Base, Camp Pendleton, CA. All raven pairs learned to avoid the treated eggs within 4-5 days, and at seven sites egg removal was minimal throughout the 4-5 week trial period. Later, we established a simulated Least Tern colony on the beach, and a pair of ravens that had previously learned to avoid quail eggs placed near their nests dominated access to the site, actively excluded neighboring ravens, and resumed taking quail eggs. This response indicated that the previously acquired aversion was site-related and not transferrable to eggs encountered in a different location. From 15 April to 4 June 1992, we placed quail eggs injected with 30 mg methiocarb at three California Least Tern colonies at Camp Pendleton. Methiocarb-treated eggs were taken by ravens at each location, but no tern eggs were lost to ravens. Ravens that nested near the Least Tern colonies actively defended their territories against intruding ravens thereby excluding them from the tern colonies as well. In contrast to 1989-1991, when up to 10 ravens had been removed yearly for predator control, none was killed in 1992. We conclude that proper deployment of eggs treated with methiocarb or a similar aversive agent can be a useful, nonlethal means of reducing raven predation at Least Tern colonies. *Received 8 February 1995, accepted 12 May 1995.*

**Key Words.**—Aversive conditioning, California Least Tern, Common Raven, *Corvus corax*, nonlethal control, predation, *Sterna antillarum browni.*

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The California Least Tern (*Sterna antillarum browni*) once nested widely along the California coast, but in recent years land use changes and human encroachment have rendered much of California's coastal habitat unsuitable for tern nesting (U.S. Fish and

Wildlife Service 1983). One of the largest and most productive California Least Tern nesting areas is at the U.S. Marine Corps Base at Camp Pendleton (Fig. 1), where the nesting biology of the Least Tern has been intensively studied since 1983 (see Belluomini 1992 and references therein). Camp Pendleton also includes extensive nesting habitat for Common Ravens (*Corvus corax*; Linz *et al.* 1992) which are among the most potentially detrimental predators on eggs of California Least Terns (Linz *et al.* 1990, Belluomini 1991).

Since 1988, Least Terns at Camp Pendleton have benefitted greatly from aggressive predator control that has emphasized lethal techniques, including poisoning and shooting (Butchko and Small 1992). Although often effective, lethal control is not always feasible or desirable. One alternative to lethal control is behavior modification through aversive conditioning and subsequent food avoidance (Barker *et al.* 1977). Previous studies suggest that egg predation by corvids can be alleviated through aversive conditioning, using eggs treated with illness-inducing compounds (Nicolaus *et al.* 1983, Nicolaus *et al.* 1989).

The use of nonlethal aversive conditioning to reduce egg predation has several advantages over lethal approaches. Because the amount of toxicant introduced into the environment is reduced, so is the risk that nontarget organisms will be poisoned. In addition, secondary poisoning of scavengers feeding on carcasses of egg predators is eliminated. Because ravens establish and maintain territories from which conspecifics are excluded (Nicolaus 1987), if allowed to remain in place, conditioned territorial ravens near Least Tern colonies would serve as deterrents to untrained conspecifics. If the resident birds are shot or poisoned, however, access to the Least Tern colony is unchecked, requiring still further lethal control of intruders.

Our study consisted of three steps. To determine if aversions could be established, we initially placed methiocarb-treated quail eggs near several raven nest sites. We treated the eggs with methiocarb, a rapidly reversible cholinesterase-inhibiting compound that induces conditioned avoidance through post-ingestional illness (Rogers 1974, Schafer 1991). Then, we evaluated the reactions of one pair of ravens to treated and untreated eggs in a nearby simulated Least Tern colony to determine if the learned egg aversion was site-dependent. Finally, we deployed methiocarb-treated eggs in actual Least Tern nesting colonies.

Thus, our objectives were:

(1) to document ravens' responses to methiocarb-treated eggs,
(2) to determine if exposure to methiocarb-treated eggs near raven nest sites would condition avoidance of untreated eggs at the same locations,
(3) to determine if egg avoidance behavior acquired near the nest site would extend to eggs placed elsewhere, and
(4) to assess the effectiveness of methiocarb-treated egg deployment at California Least Tern nesting colonies.

## STUDY AREA

The Camp Pendleton Marine Corps Base is located in the extreme northwestern corner of San Diego County in southern California. Along the Base's approximately 27 km of coast, California Least Terns nest near the mouth of Aliso Creek and the Santa Margarita River (Fig. 1). The 4 ha fenced site at Aliso Creek is known as White Beach, and in 1993 this colony included 38 Least Tern nests (Caffrey 1994).

The North Beach colony is on the north side of the Santa Margarita River, 6 km south of White Beach. The 13 ha nesting site is marked by fences and "Keep Out" signs, and contained 404 Least Tern nests in 1993 (Caffrey 1994). Approximately 1 km inland from the beach, on the south side of the Santa Margarita River, is an open, unfenced area known as Salt Flats (Fig. 1). Here, there were 84 Least Tern nests in 1993 (Caffrey 1994).

Common Ravens nest throughout Camp Pendleton in trees, on power poles, and rocky outcroppings. Raven nests are particularly dense near the beach, however, where 20 to 50 m coastal bluffs provide numerous crevices, ledges, and holes (Linz *et al.* 1992).

## METHODS

### Trapping and Marking Ravens

We captured Common Ravens using several techniques including drop-in (modified Australian crow) traps (Johnson and Altman 1983) and cannon nets (Engel and Young 1989). We marked each newly captured raven with a U.S. Fish and Wildlife Service band and tagged each with a numbered patagial marker (Young and Kochert 1987).

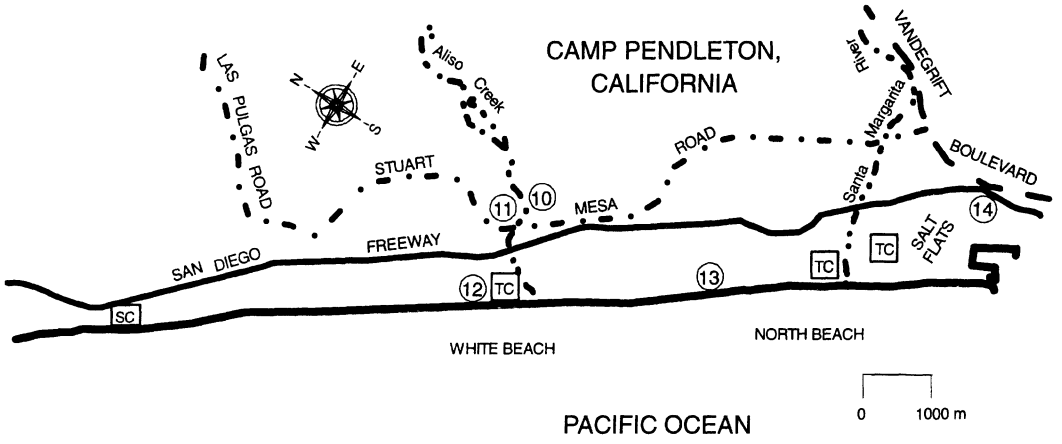


**Figure 1. California Least Tern colonies (indicated by TC), 1991 simulated experimental tern colony (SC), and 1992 raven nest locations (circled numbers) at Camp Pendleton Marine Corps Base, San Diego County, California.**

Preparation of Repellent Eggs

We purchased *Coturnix* quail eggs locally and refrigerated them until use. We chose quail eggs because they were readily available in quantity and because of their similarity in size and general patterning to tern eggs. We prepared treated eggs in batches of 18. First, we punctured a hole in the large end of each egg and removed 4 ml of the contents with a syringe. The total of 72 ml of quail egg was mixed with one chicken egg in a blender for 3 sec. We added 600 mg of methiocarb (Mesurol 75% wettable powder, Mobay Corporation, Kansas City, MO) to 10 ml of water and mixed this with 50 ml of blended egg. Then, we injected 3 ml of the egg-methiocarb mixture into each egg and sealed the opening with glue. We refrigerated the eggs until deployment. Previous research had shown this rate of treatment (30 mg methiocarb/egg) to be effective against captive Fish Crows (*Corvus ossifragus*, Avery and Decker 1994), a common egg predator.

Artificial Scrapes - 1991

We located eight active raven nests in coastal bluffs along 10.5 km of beach. On top of the bluffs, within 25 m of each nest, we created five shallow scrapes in the ground 1-2 m apart. We placed one methiocarb-treated quail egg in each scrape and surrounded each with sifted dirt to aid in identification of animal tracks.

Egg deployment commenced on either 25 April (one location), 29 April (six), or 5 May (one). During the conditioning phase, which lasted approximately 2 weeks, each location received methiocarb-treated eggs. Then, during the test phase, we randomly assigned four raven territories to receive untreated quail eggs in the scrapes, while the remaining four pairs continued to receive treated eggs. We visited each location twice daily through 16 May, after which we visited once daily through 31 May. On each visit, we recorded the status of each scrape and noted all animal tracks. We replaced broken or missing eggs during our last visit on any given day. Egg loss was evaluated between phases and groups using two-way analysis of variance. Percentages were arcsine-transformed prior to analysis.

We recorded activity at three locations with video cameras concealed within metal barrels. We filmed during randomly determined 2 h periods in the morning and afternoon at two sites during 25 April-1 May, and at one other site during 5-14 May.

Simulated Tern Colony - 1991

We selected a site on the beach that was relatively free from human disturbance, readily accessible to territorial ravens, and observable from a blind 30 m away. The 20 × 200 m study area was approximately 6 km north of White Beach, the nearest Least Tern nesting colony (Fig. 1). On three sides we marked the boundaries of the simulated colony with metal fence posts, electrical fencing wire, and "Keep Out" signs to approximate the look of an actual Least Tern colony. The simulated colony was bordered to the east by a 25 m cliff. From 25 April to 10 May, ravens whose territory encompassed the simulated colony were given treated quail eggs in scrapes near their nest site, as described previously.

We placed quail eggs in the simulated colony from 11-15 May and from 31 May to 13 June, intervals which overlapped the primary egg-laying period of California Least Terns at the Camp Pendleton colonies (Belluomini 1992). We selected 20 sites, randomly distributed throughout the simulated colony. Ten of these were then randomly chosen for placement of methiocarb-treated eggs and 10 for untreated eggs. One egg was placed at each site. During the final two weeks of the study, we deployed 10 methiocarb-treated eggs only. We marked egg locations with small, numbered wooden stakes similar to those used at actual Least Tern colonies. Each morning we checked the eggs and replaced any that were broken or missing.

From the observation blind, we watched the simulated colony for 2 h each morning and we supplemented direct observations with video camera surveillance. We reviewed videotapes to quantify aspects of raven behavior. For each complete egg-taking sequence, we recorded the date and time; the identity of the raven; the number and condition (treated, untreated) of the egg; the latency to contact the egg (time from approach to first touch of the egg); whether the bird ate, pecked, or left the egg untouched; whether the bird flew from the simulated colony with the egg or left it; and the total time the bird interacted with the egg. We assessed differ-

ences in latency and total contact time between treated and untreated eggs with one-way analyses of variance.

Egg Presentation at Tern Colonies - 1992

At the North Beach, White Beach, and Salt Flats Least Tern colonies, 10 test-egg sites were randomly selected and marked with short numbered wooden stakes. Because of the size of the North Beach colony, we worked only at the extreme north end, where an observation blind could easily be constructed.

The presentation of one methiocarb-treated egg/site began on 15 April, approximately 3 weeks before terns began to lay eggs. We checked the status of the eggs daily, recorded any tracks, and replaced eggs that were broken or missing. Every three days, all eggs were replaced with freshly treated ones. Chemical analysis showed that the methiocarb-treated eggs retained their potency for at least three days (T. Primus, Denver Wildlife Research Center, unpub. rep.). When Least Terns began to lay eggs, we shifted the treated eggs to the peripheries of the colonies to reduce disturbance caused by our daily visits.

From 15 April to 4 June, we watched Least Tern colonies during regularly scheduled 2-h observation periods. On each weekday, observations were made during 0700-0900, 1000-1200, and 1600-1800. Only morning observations were conducted on Saturdays, and no observations were made on Sundays.

## RESULTS

### Artificial Scrapes - 1991

Egg removal. Egg loss to ravens during the conditioning phase ranged from 9% to 67% (Table 1). The high percent of egg loss at nest 7 was primarily due to the shorter length of the training period there (6 days versus 12-16 days). Ravens consistently removed treated eggs from the scrapes during the first four days of presentation (Fig. 2), but few were removed thereafter. During the test phase when untreated eggs were offered at four locations, egg loss generally remained low. Four locations lost no eggs to ravens following the training phase. Egg removal during the training phase averaged 27% (SE = 7%), compared to 7% (SE = 4%) in the test phase ($F_{1,12}$ = 8.24, P = 0.014). Throughout the experiment, egg loss in the untreated group ($\bar{X}$ = 25%, SE = 8%) exceeded ($F_{1,2}$ = 5.99, P = 0.036) that of the treated group ($\bar{X}$ = 8%, SE = 3%).

Videotapes. From 25 April through 1 May, we videotaped 26 h at each of two nest scrapes. On 25 April, a raven at one scrape took two eggs, and a raven at the other took one egg. Neither raven ate eggs on site. During 5-14 May, we videotaped a third scrape site for 14 h. On three separate occasions, one raven rapidly removed all five eggs, presumably to cache them. Total elapsed time for removal of all 5 eggs averaged 4 minutes.

Visitors other than ravens. Tracks at the scrapes indicated that coyotes (*Canis latrans*), dogs (*C. familiaris*), raccoons (*Procyon lotor*), California ground squirrels (*Spermophilus beecheyi*), and unidentified birds smaller than ravens also damaged or removed test eggs. We also frequently found tracks of cats (*Felis domesticus*), rabbits (*Sylvilagus* sp. or *Lepus* sp.), mice (probably *Peromyscus maniculatus* and *Mus musculus*), lizards (probably

**Table 1. Eggs removed from experimental egg scrapes by ravens, April-May 1991, Camp Pendleton, California.**

| | Days offered[a] | | Eggs lost (%) | |
|---|---|---|---|---|
| Raven nest | Training | Test | Training | Test |
| Treated[b] | | | | |
| 1 | 12 | 21 | 17 | 0 |
| 2 | 13 | 13 | 15 | 0 |
| 3 | 11 | 20 | 9 | 0 |
| 4 | 12 | 20 | 23 | 3 |
| Untreated | | | | |
| 5 | 16 | 20 | 20 | 5 |
| 6 | 13 | 20 | 49 | 0 |
| 7 | 6 | 20 | 67 | 12 |
| 8 | 13 | 5 | 17 | 33 |

[a]5 eggs/day offered.

[b]All eggs presented to both groups were treated with 30 mg methiocarb during the training phase. During the test phase, the treated group continued to receive eggs treated with 30 mg methiocarb while the untreated group received untreated eggs.

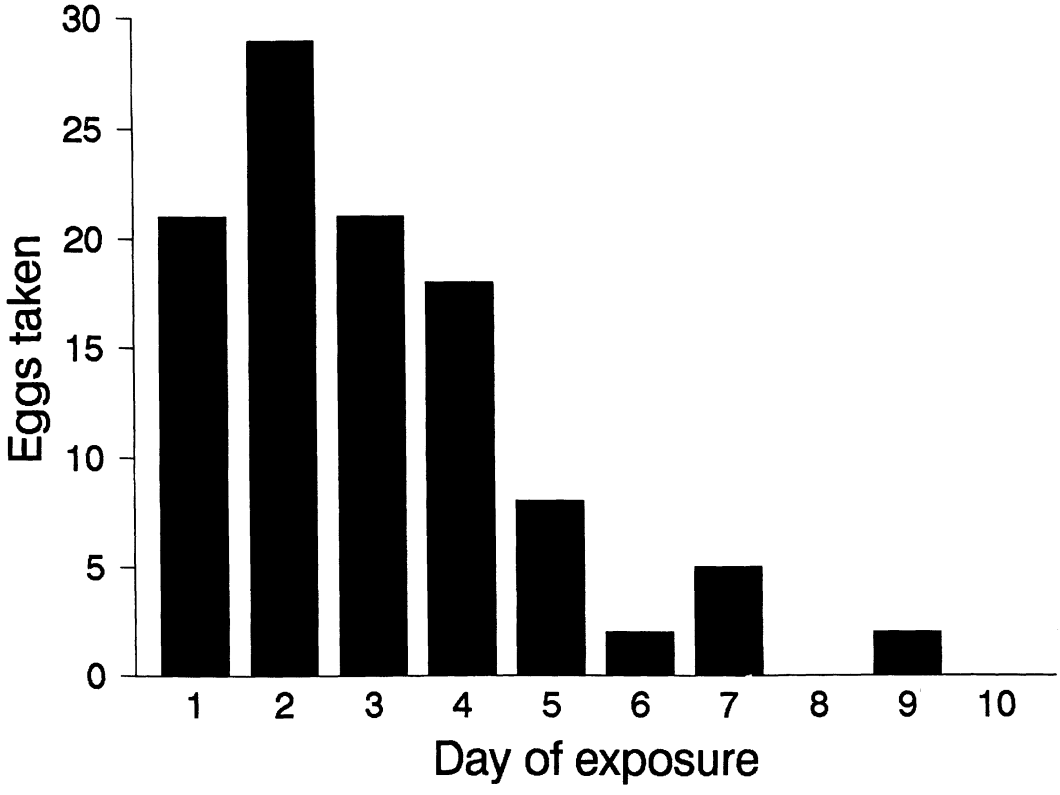


**Figure 2. Total number of methiocarb-treated eggs removed from artificial scrapes by eight pairs of Common Ravens during the first 10 days of presentation. Five eggs were presented daily to each pair of ravens.**

*Sceloporus* sp.) and greater roadrunners (*Geococcyx californianus*).

Simulated Tern Colony - 1991

Egg removal. Of 10 methiocarb-treated and 10 untreated quail eggs placed on 11 May, none was intact 24 h later. From 11-15 May, only 24% of the treated eggs and 13% of the untreated eggs were recovered intact. From 31 May to 12 June, we presented 10 methiocarb-treated eggs and no untreated eggs. During the first 5 days of this interval, 30% of the eggs remained intact. Over the entire 2 weeks, 50% of the eggs were recovered intact.

Raven behavior with eggs. We initially obtained videotape of ravens taking eggs in the simulated Least Tern colony on 14 May, the fourth day of egg presentations. Altogether, we recorded 44 complete sequences of ravens taking eggs. The birds removed the egg off-site 25 times, while on the other 19 occasions, the birds pecked or ate the egg while remaining in the simulated colony. One female raven was solely responsible for all eggs removed.

The proportion of untreated eggs taken off-site indicates an ability by ravens to discriminate good eggs from bad. Of the six treated eggs the female raven removed, five were taken on or after 31 May, when no untreated eggs were available. Overall latency to contact did not differ ($F_{1,36}$ = 1.42, P = 0.241) between treated ($\overline{X}$ = 9.2 sec, SE = 2.2) and untreated ($\overline{X}$ = 14.1 sec, SE = 3.7) eggs, suggesting that the raven had to handle the eggs to discern their condition. Although contact time with treated eggs on site was lower ($F_{1,17}$ = 18.77, P < 0.001) than with untreated eggs, the ravens handled treated eggs an average of 25 sec before abandoning them (Table 2).

Territoriality. In 78 h of direct visual observation and 16 additional hours of video

**Table 2. Latency to contact and handling time by one raven with treated and untreated eggs at a simulated Least Tern colony, Camp Pendleton, California, May-June 1991.**

| Egg removed from simulated tern colony? | *N* | Latency to contact (sec) | | Handling time (sec) | |
|---|---|---|---|---|---|
| | | $\bar{X}$ | SE | $\bar{X}$ | SE |
| Yes | | | | | |
| Treated | 6 | 8.7 | 3.5 | 6.8 | 3.1 |
| Untreated | 13 | 14.2 | 4.5 | 4.7 | 1.6 |
| No | | | | | |
| Treated | 15 | 9.4 | 2.9 | 24.7 | 5.8 |
| Untreated | 4 | 14.0 | 6.5 | 76.0 | 6.5 |

camera surveillance at the simulated colony, only two ravens from one nest (#9) landed at the site. On six occasions we saw marked ravens from the neighboring territory flying over the north end of the simulated colony; the #9 pair intercepted them each time, and the two pairs engaged in aerial displays until the neighboring birds left the vicinity.

## Egg Deployment at Least Tern Colonies - 1992

North Beach. The main Least Tern nesting colony at North Beach was approximately 1.6 km south of one raven nest and potentially accessible to other ravens via the Santa Margarita River (Fig. 1). In 98 h of direct observation and 16 h of video camera surveillance, however, only once did we see ravens land inside the colony. This was an unmarked pair that looked around for several seconds and then departed without taking a test egg. On 12 other occasions, ravens (usually tagged birds from the nearby nest) flew over the north end of the colony, but did not land in it. In one territorial interaction, ravens from the nearby nest mobbed and chased off an unmarked raven.

During 50 days that methiocarb-treated quail eggs were continuously deployed, 15 were broken or removed (Table 3). Within hours of the initial treated egg placement on 15 April, one was taken by a raven. No further predation occurred until 3-4 May when seven more eggs were removed.

The first Least Tern nest was found at North Beach on 8 May (Belluomini 1992). On 12 May, we moved the treated eggs to the north and west edges of the colony, from where seven additional treated eggs were removed through 4 June. On 15 and 27 May, raven tracks lead to eggs that were not taken.

White Beach. We initially deployed treated eggs on 15 April. On 14 May, after commencement of Least Tern nesting, we moved the treated eggs just outside the fence along the north boundary of the colony. We recorded no predation on treated eggs until 19 May, when one egg was taken and another was moved a short distance. There were raven tracks at both sites. Another egg was punctured on 24 May, but the tracks appeared to be those of a crow. On 1 June, one egg was missing, and the next day raven tracks approached the replacement egg at the same site, but the egg was not moved.

Although we did not see a raven inside the White Beach colony during 94 h of direct observation, ravens from a nest approximately 0.7 km north of the colony flew over

**Table 3. Removal of methiocarb-treated quail eggs at three California Least Tern colonies during April-May 1992, Camp Pendleton, California.**

| Colony | Days | No. of eggs | | | % Predation |
|---|---|---|---|---|---|
| | | Presented | Broken | Taken | |
| North Beach | 50 | 500 | 5 | 10 | 3.0 |
| White Beach | 50 | 500 | 1 | 2 | 0.6 |
| Salt Flats | 45 | 450 | 1 | 1 | 0.4 |

or perched within 50 m of the colony on 21 occasions. In addition, other marked ravens from nests 1.5-1.7 km to the east (Fig. 1) were observed within 100 m of the colony on 10 occasions. On four occasions, ravens from the closest nest chased intruding ravens from the vicinity of the tern colony.

Salt Flats. We initially deployed treated eggs on 15 April. One egg was missing on 19 April, with no discernible tracks in the vicinity. In response to the onset of Least Tern nesting, we moved the treated eggs outside of the colony on 12 May. On 22 May, a treated egg was found punctured, again with no tracks. No other eggs were disturbed during the study. On 24 days between 22 April and 26 May, we made 56 h of direct observations at Salt Flats and saw no ravens inside the colony.

### Predator Control and Raven Predation on Least Tern Eggs

In 1992, there was no raven predation on Least Tern eggs at the Camp Pendleton colonies (Belluomini 1992), and furthermore, no ravens were shot during the 1992 season for predation control (S. Little, USDA/Animal Damage Control, pers. comm.). This contrasts to 1989, 1990, and 1991 when 10, 8, and 6 ravens, respectively, were killed as part of the California Least Tern predator management program at Camp Pendleton (Butchko and Small 1992).

## DISCUSSION

Using repellent-treated eggs to reduce raven predation of California Least Tern eggs appears feasible. Factors governing the likelihood of success include where the treated eggs are placed, the availability of untreated eggs, and the number of times individual predators encounter repellent-treated eggs.

Our results from 1991 suggest that learned aversions to eggs are site-related. Thus, conditioning must occur at the site to be protected, and so application of repellent-treated eggs should be at the Least Tern colonies. For maximum effectiveness, repellent eggs should be deployed 2-3 weeks prior to the laying of eggs by Least Terns. This will ensure that ravens foraging at the site will encounter only treated eggs frequently enough for aversive conditioning to occur. The complete negative reinforcement is essential to discourage the ravens' exploratory behavior. Observations at the simulated Least Tern colony indicated that, if untreated eggs are present, ravens will find them. Obtaining good eggs will encourage ravens to persist even after only treated eggs are available.

High priority should be given to conditioning territorial raven pairs near Least Tern colonies and then maintaining the integrity of the established territories. In 1992, at the White Beach and North Beach colonies we observed nearby territorial ravens drive off intruding ravens. These observations confirmed previous findings (Knittle 1992) and our 1991 observations at the simulated colony that it is beneficial to maintain territorial pairs of ravens near Least Tern colonies as long as the territorial pairs have already been trained not to prey on eggs at the colonies. By maintaining the integrity of raven territories, the number of ravens that are potential depredators is minimized because the territorial birds prevent other ravens from gaining access to the colony. If possible, management strategies to protect Least Tern colonies should view killing of resident ravens as undesirable because removal of territorial birds will surely initiate intrusions by other ravens and necessitate their removal as well.

Implementation of an aversive conditioning program can be labor intensive. This might not be a serious drawback, however, as many colonies of California Least Terns and other species are already intensively managed, and implementation of a repellent egg program would necessitate only a redirection of existing predator control efforts. Aversive conditioning is likely to be most effective when egg predators are resident and territorial. If the avian egg predators at a given site are transients, then the training period will be extended and it will be difficult to expose all potential depredators to repellent-treated eggs.

Although in some situations selective killing of predators may be warranted, nonle-

thal methods such as repellent-treated eggs and corvid effigies (Caffrey 1994) should be employed whenever possible. Of course, additional evaluations are needed to define more precisely the range of situations and duration of effectiveness for repellent-treated eggs. Further research is also needed to evaluate the effectiveness of this approach against mammalian predators.

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