Deterring cliff-swallow nesting on highway structures using bioacoustics and surface modifications

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Abstract: Cliff swallows (*Petrochelidon pyrrhonota*) are migratory birds that breed in colonies and frequently nest on highway structures. Protected by the Migratory Bird Treaty Act of 1918, swallows in their active nests cannot be harmed by nesting-control methods. This causes problems and delays in maintenance of structures by divisions of many departments of transportation. We evaluated 2 aversion strategies, bioacoustic deterrents and surface modifications, for their effect on cliff swallow nesting behavior. The bioacoustic deterrents consisted of sonic devices that broadcast 8 unique recordings of alarm and distress calls of cliff swallows. We made surface modifications, mounting high-density polyethylene sheeting on the vertical surfaces at typical bridge-nesting locations. We used 28 bridges in the Sacramento Valley of California to test the aversion strategies. Both the broadcast calls and polyethylene sheeting treatments significantly reduced the number of nests built at a site, but neither treatment nor the combination of treatments completely stopped nesting, as would be required by transportation departments.

Key Words: alarm call, bioacoustics, bridge, cliff swallow, distress call, human–wildlife conflicts, nest, *Petrochelidon pyrrhonota*

Cliff swallows (*Petrochelidon pyrrhonota*) are protected by state and federal laws. The U.S. Migratory Bird Treaty Act (MBTA; 16 U.S.C. 703-712; Ch. 128; July 13, 1918; 40 Stat. 755) specifies that completed nests cannot be disturbed during the breeding season, which in California is generally February 15 to September 1 (Gorenzel et al. 2006*a*). Construction, maintenance, and repair of bridges and buildings cannot be performed during the breeding season. According to a survey of the U.S. state department of transportation (DOT), cliff swallows build nests under bridges in more than half the states (Gorenzel et al. 2006*a*). Respondents reported problems, such as delays in bridge maintenance, construction, or demolition, as well as aesthetic and public relations problems.

The generally accepted method to prevent cliff swallows from nesting is exclusion by netting, which is installed prior to the nesting season and denies birds physical access to sites (Salmon and Gorenzel 2005, Gorenzel et al. 2006a). However, netting has resulted in the occasional trapping and inadvertent killing of swallows. This is termed an "unintentional take" by the U.S. Fish and Wildlife Service (FWS) and does not comply with the MBTA. Concerns related to netting techniques on bridges provide impetus for alternative solutions.

Bioacoustic devices use auditory deterrents to repel species by reproducing biologically meaningful sounds, such as recordings of alarm and distress calls (Bomford and O'Brien 1990). Alarm calls are given in response to perceived danger when a predator is sighted. Distress calls are vocalized when birds are captured, restrained, or injured (Boudreau 1972). Experiments demonstrating efficacy of bioacoustics have been conducted in almond orchards (Delwiche et al. 2007), roosts (Gorenzel and Salmon 1993), vineyards (Berge et al. 2007*a*), and aquaculture ponds (Spanier 1980).

Habitat modification for bird control often involves eliminating roosting or nesting locations. For cliff swallow control, the habitat of interest is the nest location. Cliff swallows demonstrate preferences for rough and

unpainted surfaces for nesting (Brown and Brown 1995). Gorenzel and Salmon (1982) and Salmon and Gorenzel (2005) described methods to modify surfaces to deter swallows from nesting on them. Such methods include surface modifications such as anti-perching spines, smooth strips mounted at an angle of at least 45°, panels of glass, sheet metal, or paint to create a surface unfavorable for cliff swallow nesting.

The existing literature focuses on preventing cliff-swallow nesting on buildings (Gorenzel and Salmon 1982, Salmon and Gorenzel 2005), but does not discuss highway structures, nor does it provide an experimental analysis of alternative control methods. To address this gap, we tested whether bioacoustic deterrents and habitat modification of the nesting location prevent swallows from nesting under bridges.

Materials and methods
Bridge selection

In Northern California there are many different types of transportation structures, including bridges, overpasses, culverts, pedestrian overpasses, viaducts, and tunnels.
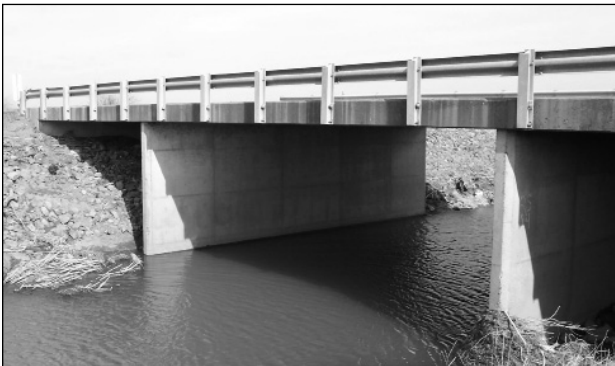

Figure 1. Concrete-slab bridge types used in study: pier-supported (top), pile-supported (bottom).

During screening to identify a preliminary set of candidate sites, we considered only concrete-slab bridges <40 m in length, extending over water, and supported by piers or piles (Figure 1). Bridges longer than 40 m tended to be too high for us to treat from ladders and would have been more expensive to treat based on cost of material. From the preliminary set, we selected bridges that showed evidence of previous colonies (nests or mud remnants from previous years), were located >0.1 km from the nearest residential property, were not adjacent to an alternate test site, and were within 40 km of the University of California at Davis to enable weekly site monitoring.

Surface modifications

We considered 6 polymers for surface modification. Delrin and polycarbonate were rejected for their stiffness. Low density polyethylene was eliminated for its higher coefficient of friction, an indicator that mud was more likely to stick. Polytetrafluoroethylene (Teflon) and ultra-high molecular weight polyethylene stood out as the best candidates, with high density polyethylene (PE) following closely. Ultimately, we selected PE sheeting to test because it was the least expensive.

Bridge portions typically requiring surface modification were determined by inspecting sites in Yolo and Solano counties, California. Nests were observed most frequently at junctures between vertical supports and ceilings that were >1.5 m above ground or water, similar to previous observations (Brown and Brown 1995). At heavily-colonized sites, nests could be located on non-juncture surfaces, sharing walls with adjacent nests.

Brown and Brown (1995) reported that nests are built from the bottom up, starting 10–12 cm below the horizontal surface (or the lowest tier of existing nests). To be conservative, we assumed that nest building starts as low as 20 cm below the horizontal surface. Plastic sheeting dimensions were chosen to provide >50% excess vertical coverage beyond the 20-cm height. We purchased PE sheeting in 150-m-length rolls, 0.51

mm thick, and 38 cm wide (Plastics International, Eden Prairie, Minn.). The natural color of the PE sheeting was opaque light-beige and matched the concrete color of the bridge. We used butyl-based sealant tape (Panlastic Bead Sealant with Nylon Cubes, Butler Manufacturing Company, Kansas City, Mo.), 0.64 cm wide, to attach the PE to the bridges. To simplify nomenclature, this surface modification treatment was referred to as PE treatment.

We removed old nests prior to the nesting season using plastic and metal scrapers attached to extension poles and swept the surfaces for dust and cobwebs. All bridges showed evidence of previous nesting, but the amount of nest removal varied by site. We applied PE sheeting to piers and piles at typical nest locations (Figure 2). The top edge of the sheeting was placed as close as possible to the juncture of the vertical bridge support and the horizontal bridge slab. Sheets were cut into 1.7-m lengths, allowing about 15-cm overlap between sections. Overlapping was done to provide maximum coverage and to add adhesive support (the butyl tape adhered well between 2 PE sheets). The butyl tape was approximately 3 mm thick, which created a gap between overlapped sheets. We considered wind direction during installation, and we oriented the sheet overlap to reduce the wind force at the gaps.
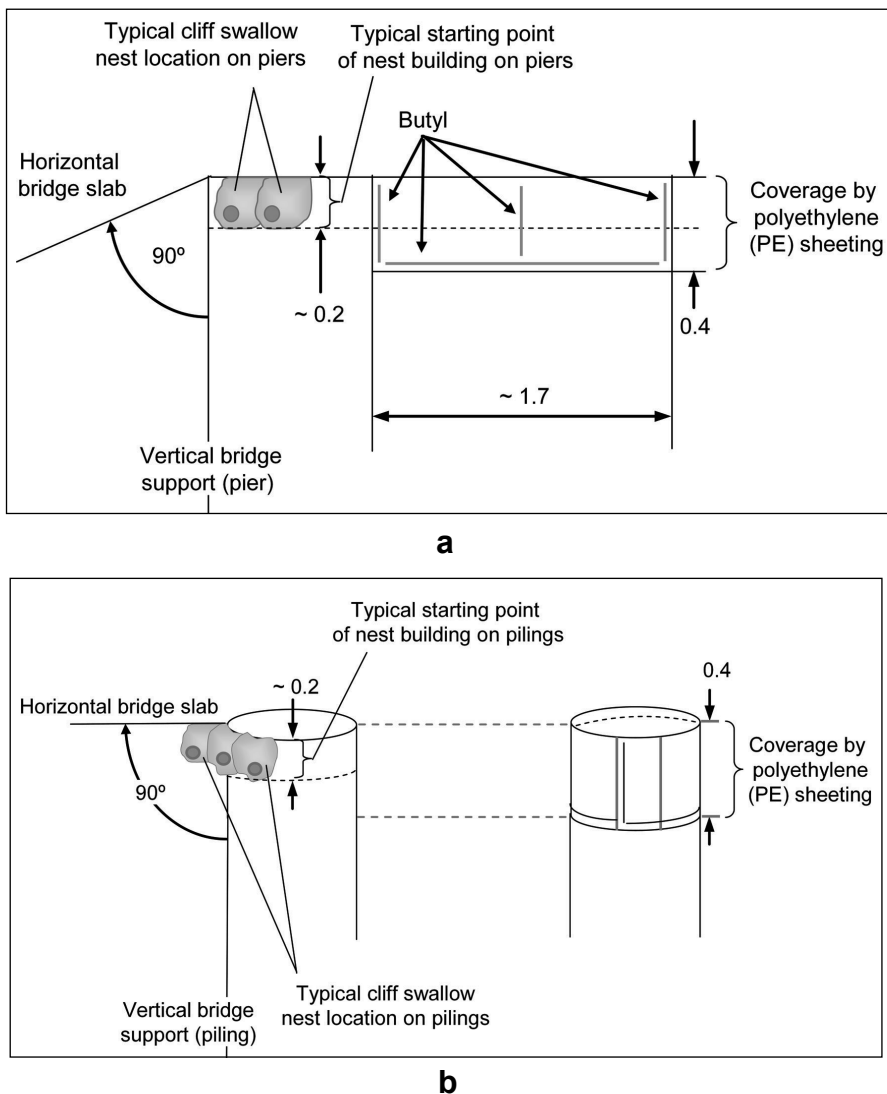

Figure 2. Typical initial nesting location on (a) pier-supported concrete bridges and (b) pile-supported concrete bridges, and the placement of PE sheeting. (All dimensions in meters unless otherwise noted.)

Broadcast units

Twenty acoustical broadcast units used in vineyards for controlling passerines (Berge et al. 2007*a*) were available for use in this study (Figure 3). These units incorporated a digital audio circuit to control playback frequency and
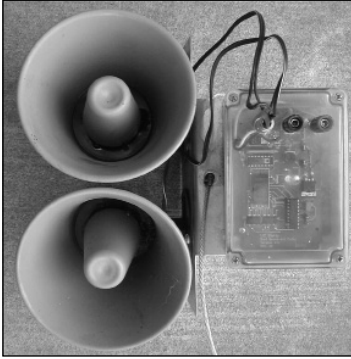

Figure 3. Broadcast unit with speakers pointed upward for use under bridges.

Figure 4. Top view of the broadcast unit and mounting system components.

playback schedule, and a 4-MiB flash memory with 8-bit resolution to allow 8 26-second call sequences to be broadcast. Random playback order and variability in calls were used to delay habituation by swallows. The audio frequencies of cliff swallow calls have been reported to range from 1.5 kHz to 7 kHz (Brown 1985). Our frequency analysis of a cliff swallow alarm call, received from Borror Laboratory of Bioacoustics (BLB #28435), fell in the same frequency range, indicating that the calls could be reproduced at a sampling frequency of 20 kHz with minimal distortion. We fitted the broadcast unit with 2 trumpet-horn speakers. The unit was powered by a 12-V lead-acid battery, which lasted several months without recharging (Berge et al. 2007*b*).

We programmed the broadcast units to play calls during nest building, when cliff swallows are most communicative (Conklin 2007). Each broadcast unit turned on at sunrise, was silent for 1 minute, played all 8 calls with 2 seconds of silence between calls, and then switched to play 1 call every 6 minutes. After 5 hours of play time, which was around 1100 hours, the frequency was reduced to 1 call every 12 minutes for another 5 hours until about 1600 hours, after which the call frequency of 1 call every 6 minutes was resumed until sundown. At sundown, the system turned off. We based this schedule of calls on cliff swallow behavior during the breeding season (Withers 1977).

The broadcast units were originally designed to treat an area of 0.6 ha for vineyard applications (Berge et al. 2007*a*). Because the bridges in this study were between 0.03 ha to 0.4 ha in size, 1 broadcast unit per bridge provided sufficient coverage. Preliminary tests on rainy, overcast days verified that the broadcast unit would get sufficient light in the morning to activate the circuit.

For mounting at a bridge site, we placed each broadcast unit inside a 19-liter bucket (Figure 4). We sand-blasted and then spray-painted the buckets grey and rust colors to reduce the appearance of value to potential vandals. We drilled 4 holes in the bottom of the bucket to allow drainage and positioned the 2 trumpet-speakers face upward. We tension-mounted galvanized straps to the pile or pier and attached the bucket using interlinked cables and a latching hook. We referred to broadcast call treatment as BC.

Alarm and distress calls

We obtained swallow call recordings from the Borror Laboratory of Bioacoustics at the Ohio State University Lab of Ornithology (Columbus, Oh.) and from the Macaulay Library of Natural Sounds at the Cornell Laboratory of Ornithology (Ithaca, N.Y.). The files, previously digitized, were downloaded in wave-file format. We selected 8 of the 14 cliff swallow sound files to create playback calls (Table 1). Files contained multiple individuals within a colony giving alarm calls, which we assumed provided a random representative sample of vocal variation.

Table 1. Playback calls created using audio editing software to cut, filter, and mix digitized raw field recordings of cliff swallow alarm and distress calls.

Call	Description[a]	Filter	Mix
1	Cliff swallow distress call (LNS-8077)		
2	Multiple cliff swallow alarm calls (BLB-28435)		
3	Colony of cliff swallows giving alarm calls (LNS-118832)	x	
4	Colony of cliff swallows giving multiple calls (LNS-118832) + 2 cliff swallow alarm call sequences (LNS-73817)	x	
5	Cliff swallow distress call with alarm calls in background (LNS-8077) + 4 alarm calls in foreground + 2 distant alarm calls (LNS-105668)		x
6	Colony of cliff swallows giving multiple alarm calls (LNS-118832) + cliff swallow alarm calls from a distinct colony (LNS-41138)	x	
7	Colony of cliff swallows giving multiple alarm calls (LNS-118832) + individual cliff swallows giving alarm calls (LNS-104564)		
8	1–2 cliff swallows giving alarm calls, flying by and flying away (LNS-111063)		x

[a] LNS prefix: Macaulay Library of Natural Sounds, Cornell Lab of Ornithology, Ithaca, New York. BLB prefix: Borror Laboratory of Bioacoustics, Ohio State University, Columbus, Ohio.

We edited the sound files using commercial audio software (Goldwave, St. John's, Newfoundland, Can.) to create 8 playback calls, each 26 seconds in duration. We removed file segments lacking alarm or distress calls. We mixed some segments to create sequences that sounded like multiple birds in a colony giving alarm calls. We used filtering to reduce ambient and competing sounds, such as traffic noise. We converted the final selection of calls included in the field experiment to uncompressed pulse code modulation, unsigned 8-bit, monowave files and stored them in the flash memory of the broadcast units.

Experimental design and analysis

The field test was designed as a 2^2 factorial experiment: factor BC levels, no sound versus sound; factor PE levels, no plastic versus plastic (Conklin 2007). We rejected a split-plot design because cliff swallows would move to another nesting site on the same structure when control methods were implemented (Gorenzel and Salmon 1982, Salmon and Gorenzel 2005, Gorenzel et al. 2006b) and sound from broadcast units would carry between sub-plots. The experimental unit was a bridge site. If multiple bridges were adjacent, we included only one of them.

To ensure a unique colony per site we chose bridges that were a min-

Figure 5. Comparison of incomplete cliff swallow nest (left) with wet mud still visible on rim, and completed cliff swallow nest (right).

imum distance of approximately 1 km from each other (Brown et al. 2002). To capture the temporal response, we incorporated a blocking by survey period into the experimental design. We conducted 12 field surveys on a weekly basis over a period of 90 days, starting April 2006, with 8 surveys to collect data for the experiment and 4 more surveys to verify that the experiment was complete and no new nest construction occurred. We used 7 replicates and evaluated deterrent effectiveness by the number of swallow nests that were

Figure 6. Map of study region in Solano and Yolo counties, California, showing location and treatment of each bridge. BC = broadcast alarm and distress call. PE = polyethylene sheeting.

completed. We defined a completed nest (Figure 5) as a nest having an opening of approximately 4.5 cm in diameter or having the presence of white excrement at the nest entrance (Emlen 1954, Salmon and Gorenzel 2005).

We could not randomly assign any treatment to every experimental unit because five of the bridges were either too tall to safely apply PE from ladders or were close enough to residents' houses to create the potential for residents to complain due to BC treatment. Complaints would cause the removal of the broadcast unit as stipulated in our permits). Subject to these constraints, we made a substantial effort to minimize bias in treatment assignments. Following Hurlbert's (1984) recommendation for small experiments, we assigned treatments to bridges to provide adequate interspersion. Replicate bridges were similar in construction and size, showed evidence of previous cliff swallow nesting, and were isolated from one another. A map of bridge location and treatment to document the interspersion is shown in Figure 6.

We hypothesized that the treatments would reduce the number of completed nests at a bridge site. The regression model captured
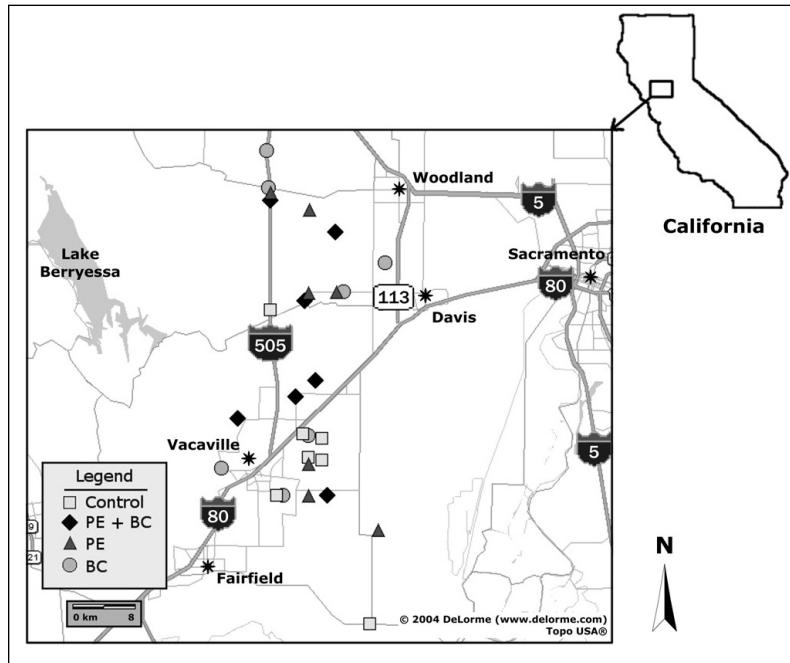
the nest count and temporal response to the treatments. This model evaluated the number of completed nests built at each of the 28 sites counted during the 8 surveys. The temporal effect was brought into the model by including a survey week block effect. We modeled number of completed nests per site per survey, Y_{ijkl} as:

$$Y_{ijkl} = \mu + \rho_i + \alpha_j + \beta_k + (\alpha\beta)_{jk} + \varepsilon_{ijkl} \; , \; (1)$$

where μ represented the overall mean, ρ_i the survey week block effect, α_j the polyethylene surface modification's main effect, β_k the broadcast alarm and distress calls' main effect, $(\alpha\beta)_{jk}$ the interaction effect of polyethylene and broadcast alarm, and ε_{jkl} the error term, assumed to be independent and normally distributed.

Before making inferences from the analysis of variance, we evaluated the appropriateness of the model by analyzing the residuals (Kutner et al. 2005). The plot of fitted values versus residuals revealed non-constancy of variance with a megaphone-shaped pattern. The normality probability plot departed substantially from linearity, suggesting that the error distribution was not normal. These results indicated that a transformation of Y was appropriate. The Box-

Cox procedure was employed using the family of transformations of the form:

$$Y' = Y^{\lambda} \quad . \tag{2}$$

To determine the parameter λ from the data, we evaluated values from –2 to 2 in increments of 0.5, and we chose λ to be –0.5, which we used to transform the raw data for statistical analysis (Conklin 2007).

Animal use and care in this project was approved by the Office of Environmental Health and Safety of the University of California, Davis, under protocol #11976.

Results

The analysis of variance of completed nests per site over the 8 survey periods (Table 2) using equation 1 with the data transformed by equation 2 showed that both broadcast call and polyethylene surface modification treatments affected nesting behavior. Five of 224 possible

Table 2. Analysis of variance for completed nest counts after Box-Cox transformation, with blocking by survey. Dependent variable: completed nest count transformed by equation (2).

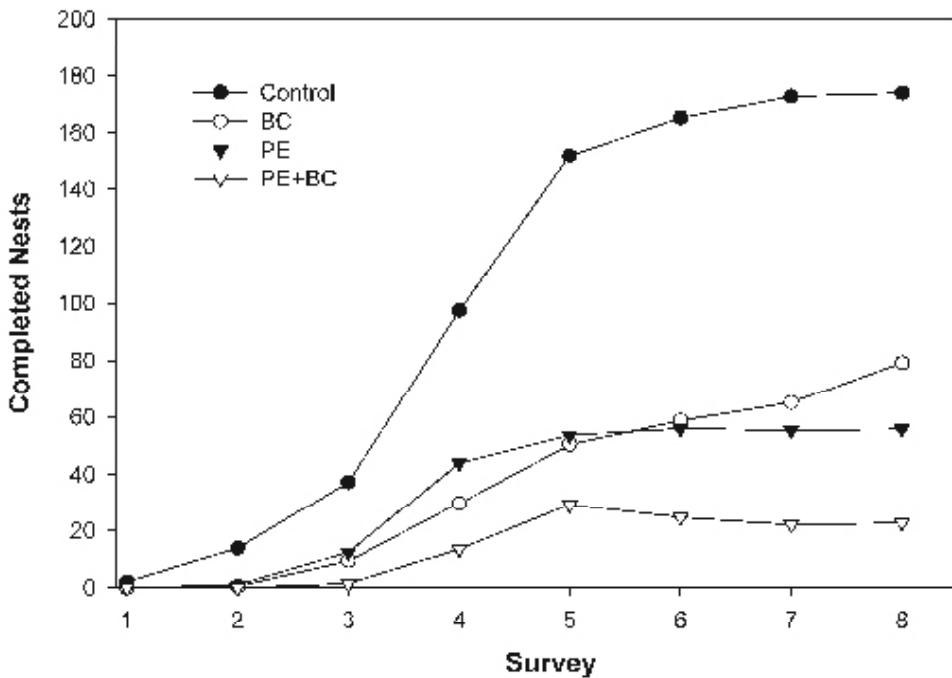| Source	DF	Type III SS	MS	F Value	P
Survey	7	5.50	0.79	6.61	<0.0001
PE	1	2.84	2.84	23.92	<0.0001
BC	1	2.02	2.02	16.99	<0.0001
PE*BC	1	0.42	0.42	3.53	0.06
Error	208	24.72	0.12		
Total	218	35.69			

Figure 7. Average number of completed nests per treatment combination ($n = 7$), by survey. PE = polyethylene sheeting. BC = broadcast alarm and distress calls. Control = absence of both treatments.

observations were missing, but the Type I and III sum of squares were virtually the same. Analysis of the factor effects showed that both PE and BC caused significant ($P < 0.0001$) reduction of completed nests over time. The interaction of PE and BC factors was not significant ($P = 0.06$), allowing consideration of the factor effects separately. The plot of average completed nests over time (Figure 7) shows a similar response to each of the treatments. Figure 7 also shows the additive effects of PE and BC treatments, with the treatment combination of both yielding the lowest count of completed nests.

The maximum number of completed nests averaged 181 for no treatment, 56 for PE treatment, 85 for BC treatment, and 31 for the combined treatment (Conklin 2007). Because some nests fell off between surveys, the average maxima were slightly higher than the data in Figure 7, which were averages at the same survey time. All of the control sites were colonized.

Discussion

Cliff swallow nesting on bridges can be reduced by the use of bioacoustics and surface modifications. Treatments applied in combination showed a greater deterrent effect than either treatment alone, supporting the premise that deterrents function best as part of an integrated strategy. Our data in Figure 7 also suggest a gradual habituation to the broadcast calls from the steadily increasing nest counts (Figure 7).

At the start of this experiment, we had to choose between limiting the final set of bridges to those that could have any treatment or increasing the number of bridges by including some that could not be treated either with plastic (too tall for ladders) or broadcast calls (potential for residents' complaints). We chose the latter to give us more replications and followed Hurlbert's (1984) suggestion for interspersion. All of the bridges were of the same material, approximate size, and general design. The sites subject to restricted-treatment assignment were not substantially different from the unrestricted sites; none of the bridges was >5 m over water and none was <0.1 km from the nearest residence. We did not expect any difference in cliff swallow nesting behavior between the restricted-treatment and unrestricted sites

due to bridge height or presence of people. All sites had been previously occupied by swallows, with nest counts ranging from 10 to 100, although exact counts could not be made during the nest removal phase prior to the start of the experiment because flooding at some sites removed whole nests, leaving only mud remnants. Based on the similarity of bridge construction and the evidence of previous nesting, we think the experimental replications were reasonably independent and unbiased; we believe the effects of broadcast calls and surface modification were real.

The field tests provided several insights to possible improvements for the aversion strategies. One potential enhancement to the broadcast unit design would be to include a sound-activated sensor for swallow call recognition. The advantage would be that calls would be broadcast only when swallows are in the vicinity of the bridge, thus lengthening the time to habituation. Cliff swallows are particularly suited for this technology because of their frequent communication and the limited repertoire of their calls. Additional experiments should be conducted to evaluate the efficacy of the distress calls we recorded (but that were too late in the test period to use) from restrained cliff swallows.

Deterrent effectiveness seemed to be influenced by the presence or absence of alternate structures suitable for nesting. Sites with combined treatments near an alternate site were the most effective. One speculative treatment approach would be to transport nesting structures to the vicinity of a bridge scheduled for maintenance, thereby reducing the pressure on deterrent strategies to combat site fidelity. However, the microclimate under a bridge is a factor in colony site selection, and it might be difficult to replicate, short of building a second bridge as an alternate site. Because swallows demonstrate a tendency to nest directly on the remains or scars of old nests, adding mud from previous nests at the alternate nesting structure might aid in swallow adoption of the alternate site.

Management implications

Cliff swallow nesting on bridges can be reduced by the use of alarm and distress calls and surface modification with plastic sheeting.

These treatments, applied in combination, show a greater deterrent effect than either treatment alone. However, the treatments did not cause complete deterrence of cliff swallow nesting at all treated sites and, therefore, do not fully solve the problem faced by departments of transportation.

Acknowledgments

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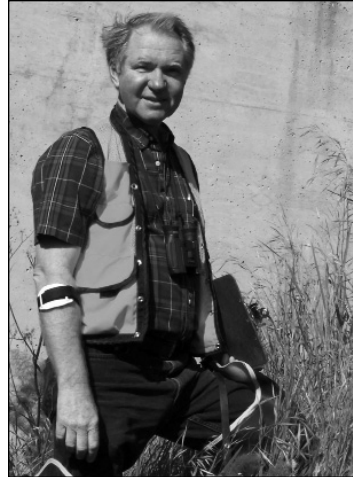
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