METHODS FOR EXCLUDING CLIFF SWALLOWS FROM NESTING ON HIGHWAY STRUCTURES

Final Report CA05-0926
August 24, 2009

Prepared for:
State of California
Department of Transportation
Division of Research and Innovation
Office of Materials and Infrastructure Research
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Sacramento, CA 95811

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STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT DOCUMENTATION PAGE

TR0003 (REV. 10/98)

1. REPORT NUMBER CA05-0926	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER

4. TITLE AND SUBTITLE Methods for Excluding Cliff Swallows from Nesting on Highway Structures	5. REPORT DATE August 24, 2009 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R.W. Coates, W.P. Coates, M.J. Delwiche, T.P. Salmon	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Biological & Agricultural Engineering University of California, Davis One Shields Avenue Davis, CA 95616	10. WORK UNIT NUMBER 11. CONTRACT OR GRANT NUMBER Contract Number 65A0220
12. SPONSORING AGENCY AND ADDRESS Department of Transportation Division of Research and Innovation 1101 R Street Sacramento, CA 95811	13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE

15. SUPPLEMENTAL NOTES

16. ABSTRACT

Cliff swallows (*Petrochelidon pyrrhonota*) are colonially breeding migratory birds that frequently nest on highway structures. Protected by the Migratory Bird Treaty Act of 1918, nesting control methods cannot harm swallows or active nests. This causes problems and delays for structures and maintenance divisions of many departments of transportation. Two aversion strategies, bioacoustic deterrents and surface modifications, were evaluated for their effect on cliff swallow nesting behavior. The bioacoustic deterrents (BC) consisted of sonic devices that broadcast 8 unique recordings of alarm and distress calls. Surface modification consisted of plastic sheeting with a low coefficient of friction. In year 1, surface modifications with high density polyethylene (HDPE) sheeting were mounted on the vertical surfaces at typical nesting locations. Twenty-eight bridges in the Sacramento Valley of California were used to test the aversion strategies, using a 2^2 factorial design with 7 replicates. In year 2, silicone-based paint and polytetrafluoroethylene (PTFE, commonly called Teflon) sheeting were evaluated as surface modifications. Nine bridges were divided into three treatment groups: control (no treatment), silicone paint, and PTFE. In year 3, 15 bridges were divided into three treatment groups: control (no treatment), PTFE, and PTFE+BC. Each year, completed nests were counted on a weekly basis for several months. In year 1, both broadcast calls and HDPE treatments reduced the number of nests built at a site, but neither treatment nor the combination completely stopped nesting. In year 2, swallows were able to complete nests on silicone paint, but did not successfully complete any nests on PTFE. Silicone paint was determined to be an ineffective surface modification. In year 3, nests were completed at all control sites, and several PTFE and PTFE+BC sites. Nests built at sites with PTFE or PTFE+BC were never started on the PTFE sheeting itself, but instead on the bare concrete and next to the sheeting or at a location where sheeting had peeled away from the surface. Altogether, these tests indicated that only PTFE was wholly effective in preventing cliff swallows from building on a treated surface, however nests were still completed at non-covered locations on the bridge surface or at locations of failed sheeting attachment. Broadcast calls (BC) reduced the number of completed nests by delaying the onset of building, but did not stop nest construction altogether.

17. KEY WORDS	18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. SECURITY CLASSIFICATION (of this report) Unclassified	20. NUMBER OF PAGES	21. PRICE

Reproduction of completed page authorized

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ACKNOWLEDGMENTS

This work was supported by the California Department of Transportation. Thank you to Jon Lea of UC Davis for advice on proper bridge terminology.

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Abstract

Cliff swallows (*Petrochelidon pyrrhonota*) are colonially breeding migratory birds that frequently nest on highway structures. Protected by the Migratory Bird Treaty Act of 1918, nesting control methods cannot harm swallows or active nests. This causes problems and delays for structures and maintenance divisions of many departments of transportation. Two aversion strategies, bioacoustic deterrents and surface modifications, were evaluated for their effect on cliff swallow nesting behavior. The bioacoustic deterrents (BC) consisted of sonic devices that broadcast 8 unique recordings of alarm and distress calls. Surface modification consisted of plastic sheeting with a low coefficient of friction. In year 1, surface modifications with high density polyethylene (HDPE) sheeting were mounted on the vertical surfaces at typical nesting locations. Twenty-eight bridges in the Sacramento Valley of California were used to test the aversion strategies, using a 2^2 factorial design with 7 replicates. In year 2, silicone-based paint and polytetrafluoroethylene (PTFE, commonly called Teflon) sheeting were evaluated as surface modifications. Nine bridges were divided into three treatment groups: control (no treatment), silicone paint, and PTFE. In year 3, 15 bridges were divided into three treatment groups: control (no treatment), PTFE, and PTFE+BC. Each year, completed nests were counted on a weekly basis for several months. In year 1, both broadcast calls and HDPE treatments reduced the number of nests built at a site, but neither treatment nor the combination completely stopped nesting. In year 2, swallows were able to complete nests on silicone paint, but did not successfully complete any nests on PTFE. Silicone paint was determined to be an ineffective surface modification. In year 3, nests were completed at all control sites, and several PTFE and PTFE+BC sites. Nests built at sites with PTFE or PTFE+BC were never started on the PTFE sheeting itself, but instead on the bare concrete and next to the sheeting or at a location where sheeting had peeled away from the surface. Altogether, these tests indicated that only PTFE was wholly effective in preventing cliff swallows from building on a treated surface, however nests were still completed at non-covered locations on the bridge surface or at locations of failed sheeting attachment. Broadcast calls (BC) reduced the number of completed nests by delaying the onset of building, but did not stop nest construction altogether.

Keywords

Alarm call, bioacoustics, bridge, cliff swallow, distress call, human-wildlife conflict, nest, *Petrochelidon pyrrhonota*, polyethylene, Teflon, transportation

Introduction

Cliff swallows (*Petrochelidon pyrrhonota*) are protected by the Migratory Bird Treaty Act (MBTA) of 1918. Completed nests cannot be disturbed during the breeding season, which is defined by the California Department of Fish and Game to be February 15 – September 1. Cliff swallows nest in colonies that often contain 200 to 400 nests or more (Brown and Brown 1995). The original nesting habitat of cliff swallows was on rocky cliffs (Emlen 1954), but their range has expanded in North America over the last half century due to the availability of suitable habitat from bridges, culverts, and buildings, which serve as surrogates for cliffs (Figure 1).

Cliff swallow nesting on man-made structures creates challenges for construction, maintenance, and repair, which cannot be performed during the breeding season. Departments of transportation (DOT) frequently struggle with this impediment and are actively seeking solutions. There have been demolition projects where unsuccessful swallow prevention has been reported to cause project delays, bird mortality, and cost increases.

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). However, netting has resulted in the occasional trapping and inadvertent killing of swallows. This is termed an “unintentional take” by the United States Fish and Wildlife Service (USFWS) and does not comply with the MBTA. Concerns related to netting techniques on bridges provide impetus for alternative solutions.

We reviewed available literature on cliff swallow behavior and control, surveyed U.S. DOTs and U.S. Fish and Wildlife Service regions, and evaluated several potential methods of cliff swallow control including chemical, visual, and auditory deterrents, habitat modification, and exclusion.

Objectives

The overall objectives of this project were to

(1) summarize existing knowledge of cliff swallow ecology, behavior, and previous control strategies,

(2) conduct field surveys of cliff swallow behavior and habitat at occupied and unoccupied sites to predict the likelihood of occupancy and to identify potential control strategies, and

(3) evaluate the most promising control strategies on selected sites and select the best approach for future implementation.

The first objective was completed in 2007 and the resulting literature review was submitted to Caltrans (Appendix A). Questionnaires were also used to obtain cliff swallow information from each U.S. DOT and USFWS region (Appendix B). The methods and results for development of a habitat selection model, part of objective 2, are presented here. Our evaluation of potential control methods and initial field study in 2006 (Appendix C, Appendix D) partially fulfilled the second and third objectives. The work presented in the body of this report builds upon the results of the initial field study.

Literature Review

Existing knowledge of cliff swallow ecology, behavior, and previous control strategies were summarized in a literature review submitted to the California Department of Transportation (Caltrans) in January of 2007. We provided a list of 234 publications or other sources of information regarding cliff swallows. We provided an abstract or summary of the contents for 2 general types of articles: 1) those which contain information pertinent to the management of cliff swallows, particularly if it applied to California, and 2) those pertinent to habitat and colony site selection as they may apply to the development of a habitat model. While extensive literature exists on cliff swallow biology and behavior (Brown and Brown 1995), published research on controlling cliff swallow nesting is scarce. The existing literature focuses on preventing 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. The complete literature review is in Appendix A.

DOT and USFWS Questionnaires

As part of our investigation of cliff swallow control techniques, we conducted a survey of the state DOTs in the continental U.S. and a Federal regulatory agency. The objectives of the survey were to determine: (1) the status of cliff swallows relative to highway structures, (2) problems caused by swallows, (3) techniques employed to deter nesting on highway structures, and (4) the legal requirements for dealing with swallow nests. We mailed a questionnaire to each state DOT, excluding Hawaii, to each of the 12 Caltrans administrative districts within California, and to each of the seven USFWS regions.

Results from the questionnaires pointed out four factors: 1) cliff swallows on highway structures are mostly a problem in the western U.S., 2) the federal permit process is not helpful in dealing with cliff swallows on highway structures, 3) most states rely on standard and sometimes less than optimal techniques to resolve swallow problems, and 4) little research or experimentation has been undertaken to develop new control techniques. The survey methods and results are in Appendix B.

Initial Field Study - 2006

We began this project by evaluating several potential methods of cliff swallow control, including chemical, visual, and auditory deterrents, habitat modification, and exclusion. We selected the most promising non-lethal methods of control - surface modification with plastic sheeting and broadcast alarm and distress calls. A field trial was conducted during the 2006 nesting season to determine the effectiveness of these two control methods. We used high-density polyethylene (HDPE) sheeting to cover bridge pier walls and pile bents where cliff swallows were likely to build nests. The hypothesis was that the HDPE's low coefficient of friction would prevent the nests from adhering to the surface. Additionally, bioacoustic devices played cliff swallow alarm and distress calls in an attempt to haze the birds and reduce their desire to nest at that location. The results of that study showed that HDPE and bioacoustic devices were able to reduce the total number of completed nests compared to control sites. HDPE was more effective than bioacoustics in reducing the number of completed nests. However, without complete deterrence, the techniques provide limited benefit to departments of transportation. Conklin et al. (2009) published the results of this study (Appendix C) and Conklin (2007) provides details on the selection of control methods, experimental plan, data analysis, and results (Appendix D). The work presented here builds upon the results of this initial field study. Since HDPE failed to completely prevent cliff swallow nest completion, we explored alternative materials and increased surface coverage for greater effectiveness.

Methods and Materials

Habitat Selection Model

Cliff swallows nest at sites that have three primary attributes: (1) a vertical surface with an overhang for nest attachment, (2) an open area for foraging, and (3) a mud supply of the proper consistency for nest building (Emlen 1954). However, many other factors play a role in determining whether a site will be selected for nesting. To determine the likelihood of cliff swallow nesting on a particular bridge structure, we developed a habitat selection model based on several site characteristics.

We first randomly selected 300 bridges from the Caltrans state bridge log. Bridges were limited to those within a 100-mile radius of UC Davis and with a length less than 500 ft. The 100 mile radius allowed multiple site analyses in single-day trips but at the same time provided geographical diversity (e.g., Coast Range, Sacramento Valley, San Joaquin Valley, Sierra Nevada foothills, and mountains). As part of this requirement, we selected bridges only within Caltrans districts 1, 3, 4, and 10. Distance to each bridge was determined by converting latitude and longitude from bridge log entries to Universal Transverse Mercator (UTM) coordinates and calculating the vector length to UTM coordinates for UC Davis. Bridges over 500 ft were considered too long to be surveyed without boats or in a reasonable amount of time. Duplicate entries in the bridge log were also eliminated from the selection list. We obtained encroachment permits from districts 1, 3, 4, and 10 for the 300 randomly selected bridges.

Since the physical characteristics of the sites did not change greatly in the short-term, the timing of the surveys was not restricted to the breeding season when birds were present. Between January and November 2007, we visited bridges to collect on-site characteristics of the bridge structure, cliff swallow nesting evidence, and surrounding habitat. Sites that were deemed unsafe or difficult to reach by car or foot were eliminated. Several sites were not surveyed due to the time constraints of our daily trips. We ultimately surveyed 206 bridges (Appendix E) which were well interspersed within the 31-thousand square-mile region of study. Prior to site visits, we printed aerial photographs of each bridge site using Google Earth (Google Inc., Mountain View, California) and created data collection sheets containing information from the Caltrans bridge log and blank spaces for data collected in the field. The aerial photographs showed the surrounding habitat within a 4 km^2 area centered on each bridge. During site visits, we annotated these maps with more detailed and current information on the habitat. The habitat classes we used were (1) fresh water, (2) salt water, (3) row crops, (4) orchards and vineyards, (5) trees and chaparral, (6) grass, fields, and bare ground, and (7) roads and buildings (Appendix F). The total area (acres) of each habitat type was measured using a dot grid. A 900-cell transparent grid corresponding to 1.08 acres per cell was overlaid on each aerial photograph. The total land area covered was 972 acres (393 ha). Each cell was assigned the habitat class that filled most of the cell. The number of cells for each habitat class was summed and divided by 900 to obtain a classification percentage. We also calculated Simpson's diversity index to test in the model (Simpson 1949).

As an alternative to our method of habitat classification, we obtained a separate set of data from the 2001 National Land Cover Database (NLCD) from the U.S. Geological Survey. The NLCD contained 21 classes, 19 of which appeared in our data (no Perennial Ice/Snow or Fallow classes were present). Cover classes did not always have one-to-one correspondence with categories used in our dot grid classification. For example, the category *roads and buildings* included three cover classes, *Developed - high intensity*, *medium intensity*, and *low intensity*. Conversely, the cover class *Cultivated crops* included two dot grid categories *row crops* and *orchards and vineyards*. The NLCD data are current as of 2001 and have a mapped resolution of approximately 1.0 acre. We obtained the total area (acres) of land for each classification within 0.5 km and 1.0 km (radii) of each bridge. These correspond to 194 acres (79 ha) and 776 acres (314 ha) around each bridge. Classification data were provided by the GIS Lab at University of California's Hopland Research and Extension Center. The advantage of using the NLCD is that classification data can be easily obtained for any bridge of Caltrans' choosing.

In addition to habitat classification, we collected data related to the bridge characteristics and cliff swallow nesting. Table 1 lists the 22 parameters and possible values we recorded at each site. Some of these data may be obtained from the Caltrans bridge list, but all data used in our analysis were recorded based on our field observations. *Latitude*, *longitude*, and *elevation* provided a broad geographic classification. Sites were later grouped into three broad geographic *regions* to simplify analysis - Central Valley, Coast Range, or Sierra/Sierra Foothills. *Material* was the primary material composing the bridge surfaces, most commonly concrete. *Undersurface* indicated the presence of I-beams, drop caps, or concrete girders with intermediate transverse diaphragms on the underside of the deck. *Vertical support* specified the presence of mid-span supports. Undersurface features and mid-span vertical supports could increase the possible nesting locations for cliff swallows. *Deck/Abutment angle* was the angle at the juncture of the deck and abutment classified as <90, 90, or >90 degrees. *Column/Deck angle* was likewise classified but included None as an option if mid-span supports were absent. *Deck Edge angle* classified the angle on the outside edge of the deck as <90, 90, >90 and <180, or >=180 degrees. The last option indicated the edge of the deck was flat or otherwise did not have an interior-angle juncture of likely interest to cliff swallows. Cliff swallows generally nest at 90 degrees junctures. *Road/Water* specified the feature over which the bridge crossed. The *opening width* and *height* were measurements of the maximum flight-path area allowing access by cliff swallows to the underside of a bridge. *Obstruction of opening* was visually estimated at 4 quadrants on each side of a bridge to indicate how much of the openings were obstructed by trees, plants, or adjacent structures within 20 ft. A value of 0% indicated no obstructions within 20 ft of an opening quadrant and 100% indicated complete obstruction. The average obstruction was calculated for each side of the bridge from the four quadrant estimates. Finally, partial and completed *nests* and *nest scars* were counted and each value recorded. Nest scars were dark outlines caused by ectoparasite excrement on the bridge surface that remains after a nest has fallen.

The habitat and bridge classifications were analyzed using logistic regression in NCSS (NCSS, Kaysville, Utah). Logistic regression is a multivariate technique appropriate for habitat use/nonuse studies employing random sampling and can be used to model the conditional probability of occupancy (Keating and Cherry 2004). Although other sampling schemes could have been used, the random design was simplest and yielded a sample that contained occupied and unoccupied structures in approximate proportion to their natural occurrence. This in turn yielded unbiased estimates of the coefficients and the conditional probability of use, or the resource selection probability function.

A binary dependent variable was used to indicate presence (1) or absence (0) of nests or scars for each site. Each habitat classification from the dot grid and NLCD data was considered an independent numerical variable. Bridge characteristics were each considered independent numerical or categorical variables. We first analyzed each independent variable separately using chi-squared and Mann-Whitney tests to determine if there was a difference in distribution across occupied and unoccupied sites. Variables with a significant difference were tested for correlation with all other variables. If two variables produced a correlation coefficient of greater than 0.6, we rejected one of variables from further consideration. The remaining variables were then analyzed using a forward selection logistic regression algorithm. The algorithm was set to use prior probabilities of 0.6 for unoccupied sites and 0.4 for the occupied sites. This was based on the approximate total percentage of sites occupied in the study. In this procedure, the model began with no variables. The model was then tested with each variable, one at a time, to determine which one produced the largest log likelihood value. Once found, this variable was added permanently to the model. The procedure was repeated to add additional variables to the equation until a maximum of 20 iterations was completed. We then evaluated the selected variables and the resulting log-likelihoods to determine how much of an effect the addition of each variable actually had on the model. If the log-likelihood increased by less than 2 from the previous iteration, we rejected it from the model. The remaining variables were used in the full model. Inclusion of additional variables in the final model would risk fitting idiosyncrasies in the data instead of the general patterns likely responsible for the differences in site occupancy. For the same reason, we did not consider interaction terms in the model.

To validate the full model, we randomly selected 90% of the data (185 sites) to create a validation model using the same logistic regression analysis as before. The remaining 10% of the data (21 sites) were evaluated using the validation model to determine whether site occupancy was correctly predicted. The procedure was repeated 10 times, each time using a different set of randomly selected data. The goal was to show model stability through consistency in variable selection and occupancy predictions.

Field Studies - 2007, 2008

Surface Modification

In the 2006 field study (Conklin et al. 2009), HDPE was shown to reduce the number of nests built at a site, but was not wholly effective at preventing cliff swallow nesting. Birds were able to stick mud to the surface after persistent attempts. We believe that the HDPE did not provide a slick enough surface to prevent nest adhesion. Based on the coefficient of friction values for other plastics (Table 2), two alternative materials were selected for consideration. Both Ultra High Molecular Weight Polyethylene (UHMW) and Polytetrafluoroethylene (PTFE) (commonly called Teflon) had coefficients of friction less than half that of HDPE.

Sample sheets of all three plastics were hung on a vertical wall in our lab. Cliff swallow nest remnants were mixed with water to create a thick mud to mimic that used by the birds. Four dabs of mud (approximately 1 cm^3) were pressed on to each of the clean sheets. After the mud had dried for about 1 day, an upward sheer force was applied to the dabs using a compression spring scale with maximum load of 23 ounces (6.4 N). Gauthier and Thomas (1993) calculated that the average mass of a completed cliff swallow nest was 652.8 g. Gravity (9.8 m/s^2) would exert a force of 6.4 N on the nest from its weight alone, which is equal to the maximum load of our scale. The scale was placed in contact with a dab and slowly compressed (about 5 seconds from zero to maximum load). In several cases, the maximum scale force was reached without dab detachment. A larger scale was not readily available, so remaining dabs were removed by hand and differences in required force were estimated.

In our material selection test, we noticed that wet dabs of mud slid down all of the plastic surfaces. The rate of sliding was greatest on PTFE, followed by UHMW and HDPE. After drying, the sheer load required to dislodge the dry dabs was measured. One of 4 mud dabs self-dislodged from the PTFE surface before measurements were made. A second dab dislodged when touched, though no measurable force was applied. The third dab on PTFE dislodged with a force of 11 ounces, and the fourth dab self-dislodged at the same time due to the abrupt dislodging of the third dab. All 4 dabs remained on the UHMW and HDPE surfaces after drying. One dab dislodged from the UHMW sheet with a force of 22 ounces. The remaining 3 dabs on UHMW and all 4 dabs on HDPE remained after applying the maximum scale force of 23 ounces. No other scale was readily available, so 2 researchers compared the force required to dislodge the remaining dabs by hand. We estimated that the dabs on UHMW took half to two-thirds as much force to dislodge as those on HDPE. Based on these results, we selected PTFE for surface modification testing. A 0.010 inch (0.254 mm) thickness, 24 inch (61 cm) wide sheet of "virgin Teflon" was selected (TFV-.01-R24, Plastics International, Eden Prairie, Minn.). The 0.010 inch thickness was chosen since it was the thinnest (i.e., lightest and least expensive) material that we felt could withstand handling during installation without tearing. The 24 inch width was selected in order to provide the option of greater surface coverage using a single sheet of material.

In addition to surface modification with PTFE sheeting, silicone-based anti-graffiti and anti-corrosion paints were tested (Si-COAT 530 and 579, CSL Silicones, Guelph, ON, Canada). The materials are described as one-part room temperature vulcanizing organosiloxane/polysiloxane coatings. Previous tests by the Texas Department of Transportation indicated that birds did not nest on surfaces painted with Si-COAT 530 (CSL Silicones, 2007). However, the tests were conducted on bridges painted in a checkerboard pattern with silicone-based paint, allowing birds to nest on unpainted portions of the same structure. This test showed that cliff swallows prefer an unpainted surface, but it did not show whether birds would attempt to nest on a fully painted structure or whether they would be able to complete nests on the painted surface.

We conducted a preliminary test similar to that for selection of the plastic material to determine whether to use Si-COAT 530 or 579 for our field study. Both paints were applied to separate faces of a concrete cinder block. Four mud dabs were pressed onto each of the two painted surfaces, and also one unpainted concrete surface. The sheer load required to dislodge the dry dabs was measured. In our silicone paint selection test, all mud dabs self-dislodged from the both painted surfaces. Mud dabs on the unpainted concrete remained on the surface and could not be removed with the maximum force from our scale. Hand-applied force was able to dislodge the dabs, but with substantial difficulty. Si-COAT 530 was ultimately selected for further testing because it had a translucent appearance which was more desirable than the Si-COAT 579 grey color.

PTFE and silicone paint were applied to portions of the bridge undersurface where nests are commonly built - at the junctures of vertical and overhead surfaces (Figure 2). For the bridges in these studies, this included the upper portion of pier walls and piles, the surface above piles and walls, and the vertical and overhead juncture of drop caps. The vertical and overhead juncture of abutments was treated in 2008, but not in 2007. We cleaned the surfaces using metal paint scrapers to remove any old nest remnants and then pressure washed with water to remove dust and debris that might reduce adhesion of the treatment materials. Control sites in the field studies were only scraped. PTFE sheets were attached to the bridge surface using the same material as our 2006 field study, a butyl sealant primarily used in roof construction (Panlastic Bead Sealant with Nylon Cubes (#25390), Butler Manufacturing Company, Kansas City, Missouri). This material acted like an adhesive putty to attach the sheeting to bridge surfaces and was removable at the end of the study, a requirement of our county bridge permits. PTFE sheets used for surfaces above pier walls and drop caps were 24 inches wide for sites in 2007 and the first few bridges in 2008. We reduced the sheet width to 12 inches for the remaining bridges and also replaced some 24 inch sheets with the 12 inch versions in 2008 (Figure 2). PTFE above piles extended about 7 inches out from the edge of each pile. Sheets on drop caps and abutments were limited to 6 ft in length. Butyl adhesive strips were applied along the edges and interior of each sheet so that any point on the sheet was no farther than 6 inches from an adhesive strip. The paper backing of the butyl strips was removed and the sheets were pressed against the bridges surfaces (Figure 3). We overlapped sheets about 1/8 to 1/4-inch to provide continuous coverage of each surface with PTFE. Silicone paint was applied at the same locations as PTFE, extending 24 inches down columns and 18 inches out on the overhead surface (Figure 4). The juncture of drop cap sides and the overhead deck were covered up to 18 inches out. The paint was stirred for 2 minutes and then applied to the surfaces using 3/4-inch nap paint rollers. Paint brushes were used apply paint in the corners that rollers could not reach. The paint cured within several hours of application.

Bioacoustics

Broadcast call treatments were shown to have a deterrent effect in our 2006 field study (Appendix C) and were tested again in our 2008 study. The selection of calls was modified to include cliff swallow distress calls that were not available for the 2006 study. Distress calls were recorded from adult cliff swallows being banded for another study. The calls were digitized, clipped to 26 seconds in duration, loaded onto broadcast call units, and operated in the field study as described for our 2006 field study (Appendix C and Appendix D). Broadcast call units were installed following the methods used in 2006, except the PTFE sheeting was installed on top of the plumbers tape to reduce the likelihood of nests being started on the tape's rough surface. A total of 8 calls were used in the 2008 study (Table 3), 4 from the 2006 study and 4 new distress calls (UCD prefix in Table 3).

Experimental Design

The 2007 and 2008 field studies were completely randomized designs with 9 bridge sites in 2007 and 15 sites in 2008 (Table 4). Bridge sites were randomly selected from state and county bridges within 40 km of UC Davis that met the criteria for bridge characteristics, bird nesting, and surrounding habitat laid out in our 2006 field study (Appendix C). We also added the criterion that sites must be capable of receiving any treatment so as to avoid bias in treatment assignments. Three treatments were randomly assigned to sites in each field study (Figure 5). Treatments for the 2007 study were PTFE surface modification, silicone paint surface modification, and control (untreated). Treatments for 2008 were PTFE surface modification, PTFE surface modification plus broadcast calls (PTFE+BC), and control (untreated). All except 4 sites used in 2007 and 2008 were used in the 2006 study. Treatments were installed shortly before or at about the same time cliff swallows arrived to nest. We visited each site on a weekly basis to count the number of cliff swallows and completed cliff swallow nests over 9 weeks in 2007 and 11 weeks in 2008. When the number of nests reached an asymptotic maximum, we considered the nest building to be finished for the season and we selected the number of completed nests from this single site visit for consideration with analysis of variance (ANOVA). Data were analyzed with SAS (SAS Institute, Cary, North Carolina).

Our hypothesis was that sites treated with PTFE, silicone paint, or broadcast calls would have fewer completed nests compared to untreated sites. The number of completed nests, Y_{ij}, was modeled as

$$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}, \tag{1}$$

where μ was the mean number of completed nests, α_i the treatment factor, and ε_{ij} the error term. This is the model for a completely randomized one-way design.

The error terms for each model were assumed to be independent, normally distributed, and to have equal error variances. However, this proved to be false due to unequal error variances across treatments. Normality was satisfied, but only marginally. Y was transformed to satisfy the model assumptions. Transformations used the form

$$Y' = (Y + k)^{\lambda}, \tag{4}$$

where Y' was the transformed dependent variable, λ was the exponent for transformation, and k was a constant added to account for instances of $Y = 0$ in the data. A typical value of $k = 1$ was selected and values of λ between to -2 and 2 in increments of 0.5 were tested and it was determined that the most improvement in error variance equality was provided by $\lambda = 0.5$ for the 2007 data and $\lambda = -1$ for 2008 data. While the transformed data appeared to meet our assumptions, we further stabilized the error variance by using a weighted least squares analysis with a weight equal to the reciprocal of the variance of each treatment level of Y'. For the transformed and weighted least squares ANOVA results, error terms did not violate the assumptions of normality or equal error variance. F-statistics and Tukey's multiple comparison procedure (Neter et al. 1996, pp.1084-1086) were used to make inferences about the treatment effects.

Animal use and care in this project was approved by Institutional Animal Care and Use Committee of the University of California, Davis, under protocol #11976.

Results

Habitat Selection Model

The independent variables selected as a result of chi-squared and Mann-Whitney tests are shown in Table 5. For the dot grid data, all habitat categories except *trees and chaparral* showed significant differences between occupied and unoccupied sites. Results for NLCD data were similar to each other except for the significance of *deciduous forest* and *pasture, hay* in the data with 1 km radius. Correlation tests between selected variables in each of the three data sets resulted in no correlation coefficients greater than 0.6, so all variables were used in the logistic regression analysis. All three data sets yielded similar regression models. The first variable selected for the model using dot grid data was *roads and buildings*. The first variable for both models using NLCD data was *Development - Medium Intensity*. The second and third variables for all three models were *undersurface* and *road/railroad or water underneath*. The log-likelihood increased more than 2 for the three steps in which these variables were added. Subsequent addition of variables to the model resulted in a log-likelihood increase less than 2, so all other variables were eliminated from consideration. The full model for each data set was the same except for variations in the multiplicative coefficients of each variable. When the data were run through each model, the occupancy predictions were similar. The model for the NLCD data with 0.5 km radius produced slightly more accurate predictions and was selected for further consideration. The full model was

$$\begin{aligned} Logit(P) &= 0.5432 - 0.0707*(DM) + 0.2301*(US = none) + 1.4092*(US = bentcap) \\ &+ 2.5840*(US = sheerbeams) - 0.77678(RW = road) \end{aligned} \tag{5}$$

where *logit(P)* is the logit of the proportion (*P*) of sites with nests, *DM* was the area (in hectares) of land cover within 0.5 km of the site classified as *Development - Medium Intensity* in the 2001 NLCD, *US* was the *undersurface* classification of the bridge and was assigned a value of 1 if categorized as none, drop cap, or girders with transverse diaphragms and 0 otherwise, and *RW* indicated whether a *road/railroad or waterway* was underneath the bridge and was assigned a 1 if categorized as road/railroad and 0 otherwise. *Logit(P)* can be converted to proportion of sites with nests *P* using the logistic transformation

$$P = \frac{e^{\log it(P)}}{1 + e^{\log it(P)}}. \tag{6}$$

Logit(P) < 0 corresponds to *P* < 0.5, indicating nests are not likely to be present, and *logit(P)* > 0 corresponds to *P* > 0.5, indicating nests are likely to be present. The model correctly predicted 87.0% (120 of 138) of unoccupied sites and 66.2% (45 of 68) of occupied sites. Ten different validation models were created and the predicted occupancies of the remaining 10% of sites for each model are in Table 6. The validation models correctly predicted 79% to 100% of the unoccupied sites and 20% to 88% of the occupied sites.

Field Studies - 2007, 2008

Completed nests were found at all but 3 sites by the end of our 9-week study in 2007 (Figure 6). No completed nests were found at 2 PTFE-treated and 1 silicone paint-treated sites. Seven nests were completed on the untreated-abutment of one PTFE-treated site. These nests were washed away by high water in the 6th week of the study. No evidence of prior nesting at this location existed, so this prompted us to include prophylactic abutment treatments in the 2008 study. No nests were completed on the PTFE surface at any site, though several attempts were made by the cliff swallows (Figure 7). One paint-treated site had 40 completed nests on the painted surfaces and another site had 214 completed nests by the end of the study (Figure 8). All control sites were occupied, with 132 completed nests at the smallest of the three colonies (Figure 9). Nest building ceased at all sites by the 7th week of study, so we used nest counts from the 7th survey for statistical analysis. The mean numbers of completed nests for surface modification treatments in 2007 were 0 for PTFE, 85.0 for silicone paint, and 347.7 for control (Figure 10). Analysis of variance of the transformed and weighted least squares data indicated that the treatment means were not equal [$P = 0.0064$], but Tukey's multiple comparison test indicated that only PTFE and control treatment means differed [$\alpha = 0.05$]. (Note that in order to accomplish weighted least squares analysis, the nest count for one PTFE site was changed from 0 to 1 in order to produce a non-zero treatment variance and allow weighted least squares calculation. This modification of the data had no appreciable effect on the conclusions.)

All control sites in the 2008 study were colonized, though 1 site had a maximum of only 7 completed nests over the 11-week period (Figure 11). After 11 weeks, 1 PTFE-treated site had 0 nests completed, 1 site had 2 nests, and the other 3 sites had greater than 80 nests each (Figure 12). Over the same period, 1 PTFE+BC-treated site had 0 nests, 2 sites had 3 or 4 nests, 1 site had 46 nests, and 1 site had 146 nests (Figure 13). We decided to do the statistical analysis on nest counts collected during the 7th survey due to technical problems with treatments at PTFE and PTFE+BC sites. Specifically, PTFE sheeting was detaching from the bridge surfaces and could not be replaced quickly enough to maintain the integrity of the treatment after the 7th week. The mean numbers of completed nests for surface modification treatments in 2008 were 0.6 for PTFE+BC, 51.6 for PTFE, and 195.6 for control (Figure 14). Analysis of variance of the transformed and weighted least squares data indicated that the treatment means were not equal [$P = 0.0015$], but Tukey's multiple comparison test indicated that only PTFE+BC and control treatment means differed [$\alpha = 0.05$].

Discussion

Habitat model

Equations 5 and 6 can be used to predict the likelihood of finding nests at a particular site based on just 3 selected factors. If $P > 0.5$, the model predicts that nests will be found at the site. However, several caveats that should be mentioned. First, the full model accuracy for predicted occupied sites was only 66.2% and the validation models ranged from 20% to 88%. Even though this represents the best our model can achieve, there is potential for incorrect classification. Correct prediction of unoccupied sites was greater for the full and validation models. This indicates that the model may be more useful for where not to find cliff swallows. The second caveat is that the model should be considered valid only for the region in which data were collected, within 100 miles of Davis, CA. Sites outside this region may introduce regional variations in cliff swallow nesting behavior or other variables not included in this study. As an example of different cliff swallow behavior, nests are frequently found on residential homes in Southern California, but rarely in Northern California (region in this study). The effect this would have on cliff swallow nesting on highway structures in Southern California is unknown. The third caveat regards our interpretation of the model. The inclusion of *undersurface* in the full model is peculiar since we observed no substantial correlation between *undersurface* classification and nest presence. We also noted that the frequency of occupied sites for each *undersurface* classification, with the exception of girders with transverse diaphragms, was not noteworthy - 21.9% for none, 52.0% for drop caps, 66.7% for girders with transverse diaphragms, and 35.7% for steel I-beams. It is not clear why the regression analysis eliminated steel I-beams from the model. Inclusion of *Development - Medium Intensity* and *Road/RR* with negative coefficients in the model seems sensible since both would be likely to reduce the habitat available for food, water, and mud, as well as increase deterrence by people, pets, and vehicular traffic. As with most animals, cliff swallow nesting behavior is not easily defined with a simple equation. Nonetheless, the model provided here can be used to predict the likelihood of cliff swallow nesting on hundreds of Caltrans highway structures and may provide insight into trends not yet evident in our data alone.

Field Studies - 2007, 2008

Preparation and installation of plastic surface modifications required substantial effort. Site scraping and washing took 1 to 2 hours per bridge. Cutting PTFE sheets to the appropriate sizes and application of butyl adhesive to these sheets for a single site took 2 people about 2 to 6 hours. Installation time for 2 people ranged from 2.5 to 5 hours. Replacement of fallen sheets required additional time. Sites with pier walls typically took longer to treat due to the greater area of coverage required compared to pile bents. The area of bridge surface covered by PTFE ranged from 190 ft^2 to 480 ft^2. The cost for PTFE sheeting was \$1.06 per ft^2 (\$2.12 per linear foot for 0.010 inch thick, 24 inch wide). The cost of butyl adhesive was \$0.067 per linear ft and when using about 6 ft butyl per 4 ft^2 PTFE, the cost of butyl was \$0.10 per ft^2. Therefore, the total cost of PTFE treatment was about \$1.16 per ft^2 of treated bridge surface. For comparison, UHMW sheeting cost \$0.87 per ft^2 (\$1.74 per ft for 0.010 inch thick, 24 inch wide), and HDPE used in 2006 cost \$0.25 per ft^2 (\$0.31 per ft for 0.020 inch thick, 15 inch wide). Silicone paint cost about \$0.50 per ft^2 based on our average coverage of 130 ft^2 per gallon of paint. Broadcast call treatments cost about \$250 each based on the costs of the components used for the call units.

The 2007 field study results showed that treatment with silicone paint reduced the mean number of nests completed at a site, but was not significantly different than control sites. In spite of our preliminary test results, mud did stick to the painted surfaces and allowed nest completion. The reason for this discrepancy is not fully known, but there are several factors that could be responsible, including differences in mud composition, pellets formation by birds versus our hand, paint thickness or adhesion to the bridge surface versus the concrete block used in preliminary tests, and surface alteration by the birds (e.g., scratching or dirtying the painted surface with repeated nest building attempts). These results were similar to those of HDPE in 2006 and we felt silicone paint did not warrant further consideration. PTFE performed well in the 2007 study. No nests were completed on the PTFE sheets, though several attempts were made by birds. The only completed nests in the study were found on an abutment with no evidence of nesting in prior years. This prompted us to treat abutments in our 2008 study. A total of 9 PTFE sheets detached from the bridge surfaces in last few weeks of the 2007 study. At the time, we felt this would not be a major problem for the 2008 study, though this ultimately proved to be untrue.

Analysis of the 2008 field study showed that only PTEF+BC treatment differed from the control treatment. However, we believe both PTFE and PTFE+BC treatments would have been more equally effective if not for problems with PTFE sheet adhesion to the bridge surface. We estimate that 192 sheets detached from the bridge surfaces (about 29% of all sheet installed) in 2008 (Figure 15). Most of these sheets (176) were installed overhead such that the weight of the sheet pulled directly away from the bridge surface. We do not believe vandalism contributed to this problem. Vandalism was clear on only one occasion, but this was for a broadcast call unit, which was smashed and partially stolen. We replaced missing sheets as quickly as possible during the first 7 weeks of study, but were soon overwhelmed by the rate of failure and stopped replacing sheets. At some sites, we were unable to replace PTFE sheets before the birds had built nests at that location. These nests were part of those counted during the study and therefore do not reflect the ability of PTFE to deter nesting (assuming it is properly attached to the surface). We were unable to determine whether the butyl adhesion failed first on the concrete bridge surface or PTFE sheet surface. Butyl detached from the concrete in half the cases and from the PTFE in half the cases. This indicates that butyl sealant is not adequate for reliable surface modification treatments as conducted in this study. Thinner or smaller sheets, or additional strips of butyl adhesive might prevent detachment from the bridge surface, but we feel that a better solution would be to find an alternative attachment method. Mechanical fasteners or semi-permanent epoxy adhesives could be used by Caltrans if not constrained by the same permit limitations encountered in our study.

Sheet attachment failure was not the only reason for completed nests at PTFE treated sites, however. We also noted that several nests were started at unusual locations on the bridges. Completed nests were found on the vertical surfaces below the edge of PTFE sheets (Figure 16) and on the overhead surfaces along seams in the concrete (Figure 17). These nests were also counted and do reflect the true ability (or lack of ability) of PTFE to deter cliff swallow nesting when used only at typical nesting locations. No nests were completed wholly on PTFE sheets at any site.

Since nests were not completed on PTFE surfaces in 2007 and 2008 studies, we feel the material would be very useful to Caltrans for cliff swallow nesting prevention. However, improved attachment methods need to be developed to ensure treatment reliability. Also, without surface modification of all bridge surfaces, this study indicates that it may be difficult to provide 100% effectiveness, since birds may nest at locations that they would not otherwise. If employing surface modification, we recommend treating all junctures of a structure (as done in this study) to provide a minimum level of deterrence. Treating all vertical surfaces to within 2 ft of the ground (level at which birds would be concerned about predators) would provide more effective deterrence. Lastly, unusual surface features such as seams, cracks, lumps, bolts, and brackets should be treated for even greater deterrence. Only complete coverage of a bridge surface with PTFE and reliable attachment methods would likely be 100% effective.

Treatment with broadcast calls and PTFE was shown to improve the deterrence of nesting compared to PTFE alone. It is difficult to say whether this effect would be evident in the absence of our PTFE surface attachment problems. Our 2006 study showed that broadcast calls delayed nesting onset and reduced the number of nest completed at a site. Because the 2006 study used HDPE on which birds successfully built nests and the 2008 study used PTFE, on which birds were not able to build nests, we would expect to see less difference between PTFE and PTFE+BC treatments compared to the difference seen between HDPE and HDPE+BC treatments. The main benefit of broadcast call at PTFE treated sites would likely be in reduced nesting on untreated, unusual nesting locations. We noticed that birds built nests on top of the broadcast call units during the 2006 and 2008 studies. This shows that habituation does occur and precludes complete deterrence of cliff swallows by broadcast calls.

Conclusions

Cliff swallows are a problem for departments of transportation since they frequently colonize highway structures and their nests cannot be disturbed until the nesting season has passed. Based on our habitat selection model, three main factors increased the likelihood of cliff swallow colonization: 1) lack of surrounding urban development, 2) an undersurface not containing steel I-beams, and 3) presence of water under the bridge. The number of nests completed at a site was reduced by using surface modification with low friction plastic sheeting and silicone-based paint at preferred nesting locations. However, HDPE and silicone paint were considered ineffective since birds could still build nests upon them. PTFE (Teflon) was more effective than HDPE, but also more expensive. PTFE could have been more effective in our field studies if we had a more effective method of attachment than butyl sealant. Broadcast calls reduced the number of completed nests by delaying the onset of nest building. Even though broadcast calls did not completely eliminate nesting, it was much easier to install than surface modifications. We recommend treatment with PTFE and broadcast calls to reduce the likelihood of cliff swallow nesting on bridge surfaces. This should be supplemented with weekly site visits to check treatment integrity and remove any partial nests not on the treated surfaces.

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Figures and Tables

Figure 1. Partial and completed cliff swallow nests on underside of highway structure.

Table 1. Information collected at each site used for habitat selection model.

Characteristic	Possible values (units) [details]
Latitude, Longitude	(degrees)
Elevation	(feet)
Material	Concrete, Concrete/Steel, Steel
Undersurface	Steel I-Beams, Concrete Girders & Transverse Diaphragms, Concrete Drop Caps, None
Vertical support	Concrete Pile/Column/Wall, Steel Column, Abutments Only
Deck/Abutment angle	< 90 , 90, > 90 (degrees)
Column/Deck angle	< 90, 90, > 90, None (degrees)
Deck Edge angle	>= 180 (exterior), < 90, 90, > 90 & < 180 (degrees)
Road/RR or Water	Road/RR, Waterway, Ground
Opening Height	(feet)
Opening Width	(feet)
Obstruction of opening	0 - 100 (percent) [4 quadrants, both openings of bridge]
Nests	[Number of complete or partial nests]
Scars	[Number of scars on bridge surface]

Table 2. Coefficient of friction of plastic materials considered for surface modifcation.

Material[1]	Dynamic Coefficient of Friction[2]
High Density Polyethylene (HDPE)	0.28
Ultra High Molecular Weight Polyethylene (UHMW-PE)	0.12
Polytetrafluoroethylene (PTFE)	0.1

[1] Data from Plastics International (www.plasticsintl.com). [2] ATSM D3702 (276 kPa, 0.25 m/s).

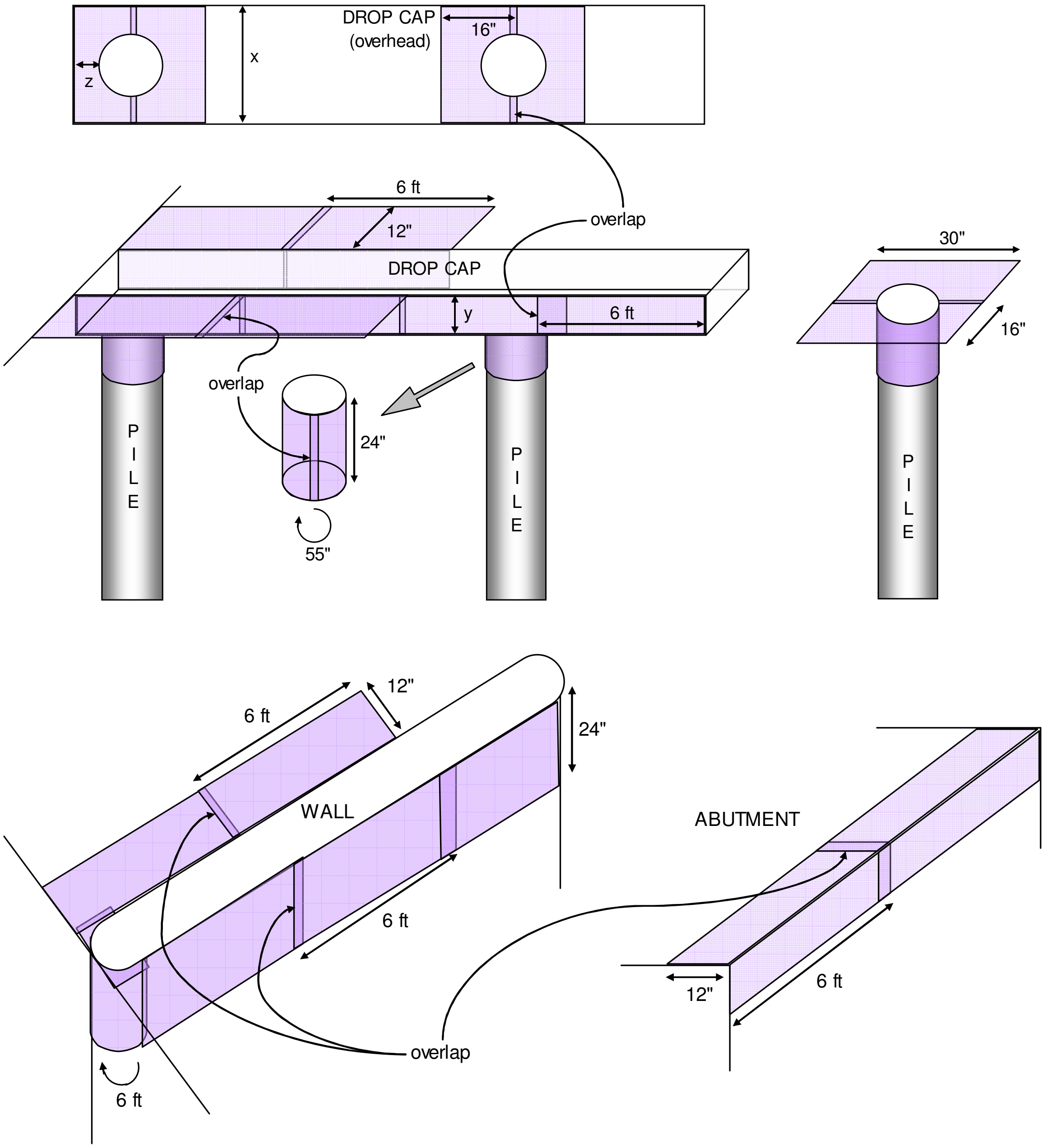

Figure 2. Locations of surface modifications on highway structures with pile bents and pier walls. Dimensions x, y, and z varied depending on the site. (Diagram not to scale)

Figure 3. Highway structures with PTFE surface modification.

Figure 4. Highway structures with paint surface modification.

Table 3. Broadcast call sequence characteristics.

Call	Description[a]
1	Cliff swallow held by legs giving distress call (UCD-4A)
2	Multiple cliff swallow alarm calls (BLB-28435)
3	Cliff swallow held by legs giving distress call (UCD-6A)
4	Colony of cliff swallows giving multiple calls (LNS-118832) + 2 cliff swallow alarm call sequences (LNS-73817)
5	Cliff swallow held by legs giving distress call (UCD-7A)
6	Cliff swallow held by legs giving distress call (UCD-9A)
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)

[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. UCD prefix - University of California, Davis, California (new distress calls for 2008).

Table 4. Characteristics of sites used in 2007 and 2008 field studies.

Br No	District	County	Bridge Name	Facility Carried	Treatment	Scraped	Washed	Installation	Primary nesting surfaces
				2007 Field Study					
22C0080	3	Yolo	DRY SLOUGH	COUNTY RD 31	Control	04/03/07	04/03/07	--	10 columns, 2 boxbeams
22C0122	3	Yolo	SOUTH FORK WILLOW SLOUGH	COUNTY RD 95	PTFE	04/03/07	04/03/07	04/04/07	5 columns
22C0045	3	Yolo	CHICKAHOMINY SLOUGH	COUNTY RD 93A	Paint	04/03/07	04/03/07	04/05/07	12 columns
22C0149	3	Yolo	SOUTH FORK WILLOW SLOUGH	COUNTY RD 93	Control	04/04/07	04/04/07	--	5 columns, 2 walls
22 0028	3	Yolo	SOUTH FORK WILLOW SLOUGH	ROUTE 16	PTFE	03/16/07*	04/10/07	04/12/07	14 columns
22C0073	3	Yolo	LONG CREEK	COUNTY RD 90A	Paint	03/16/07*	04/10/07	04/13/07	15 columns
23C0188	4	Solano	GIBSON CANYON CREEK	LEWIS RD	Control	04/06/07	04/06/07	--	5 columns, 1 boxbeam
23C0194	4	Solano	MC CUNE CREEK	SILVEYVILLE RD	PTFE	03/16/07*	04/10/07	04/12/07	8 columns
23C0125	4	Solano	GIBSON CANYON CREEK	BYRNES RD	Paint	04/05/07	04/05/07	04/09/07	5 columns, 1 boxbeam
				2008 Field Study					
22C0145	3	Yolo	SOUTH FORK WILLOW SLOUGH	COUNTY RD 89	Control	02/21/08	--	--	10 columns, 2 boxbeams
22C0037	3	Yolo	SOUTH FORK WILLOW SLOUGH	COUNTY RD 90	PTFE	03/10/08	03/10/08	03/27/08	8 columns
23C0207	4	Solano	NEW ALAMO CREEK	LEWIS RD	PTFE+BC	03/11/08	03/11/08	04/09/08	2 piers
23C0189	4	Solano	GIBSON CANYON CREEK	FOX RD	Control	02/21/08	--	--	2 piers
23C0199	4	Solano	SWEENEY CREEK	MERIDIAN RD	PTFE	02/21/08	03/07/08	04/04/08	10 columns
22C0122	3	Yolo	SOUTH FORK WILLOW SLOUGH	COUNTY RD 95	PTFE+BC	03/10/08	03/10/08	03/27/08	5 columns
22C0044	3	Yolo	DRY SLOUGH	COUNTY RD 93A	Control	03/07/08	--	--	12 columns
23C0188	4	Solano	GIBSON CANYON CREEK	LEWIS RD	PTFE	02/21/08	03/10/08	04/10/08	5 columns, 1 boxbeam
23C0169	4	Solano	NEW ALAMO CREEK	MERIDIAN RD	PTFE+BC	02/21/08	03/11/08	04/09/08	2 piers
22C0036	3	Yolo	COTTONWOOD SLOUGH	COUNTY RD 90	Control	02/21/08	--	--	8 columns, 2 boxbeams
23C0116	4	Solano	ULATIS CREEK	FOX RD	PTFE	02/21/08	03/11/08	04/02/08	2 piers
23C0194	4	Solano	MC CUNE CREEK	SILVEYVILLE RD	PTFE+BC	03/07/08	03/07/08	03/28/08	8 columns
23C0200	4	Solano	ULATIS CREEK	LEWIS RD	Control	03/10/08	--	--	2 piers
22C0080	3	Yolo	DRY SLOUGH	COUNTY RD 31	PTFE	02/21/08	03/07/08	04/01/08	10 columns, 2 boxbeams
23C0166	4	Solano	ULATIS CREEK	BYRNES RD	PTFE+BC	03/10/08	03/10/08	04/08/09	2 piers

*Site scraped multiple times thereafter until wash/installation.

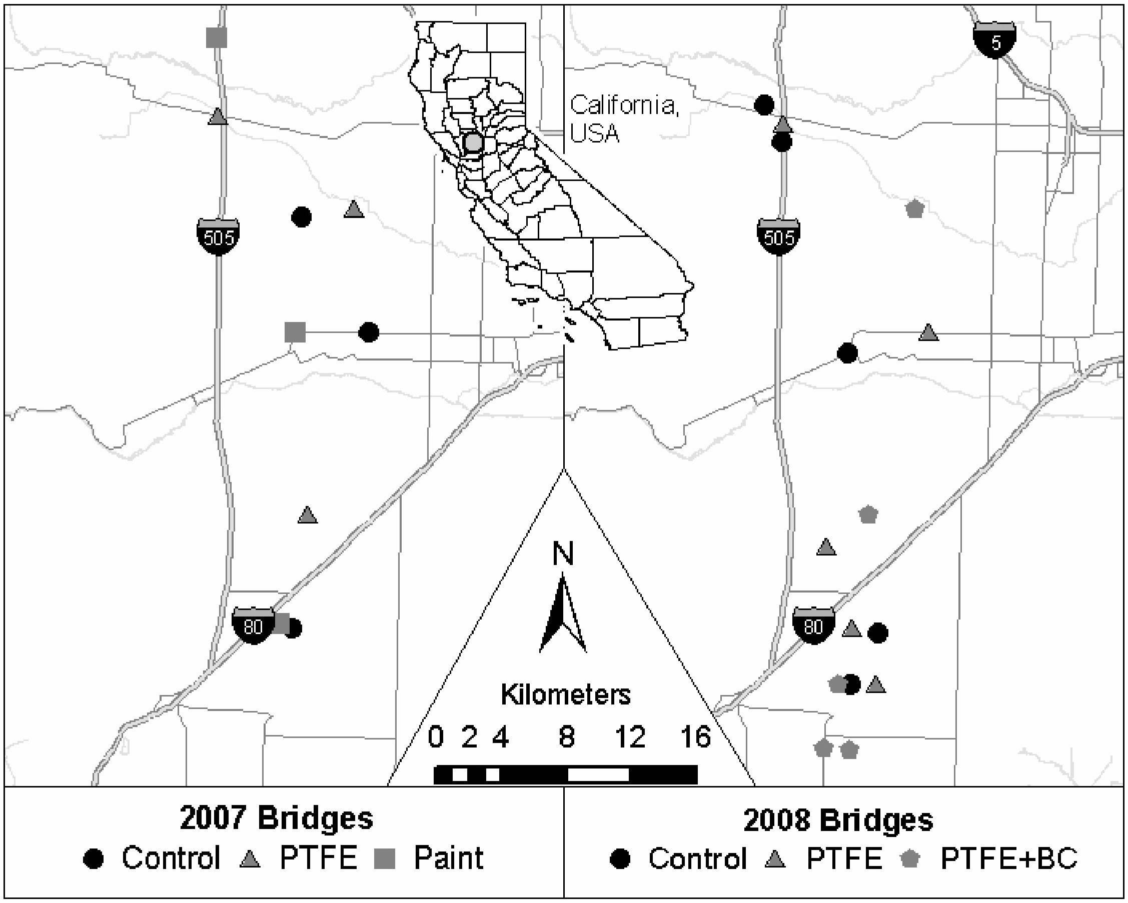

Figure 5. Map of 2008 site locations and treatment assignments.

Table 5. Numerical or categorical variables and univariate significance for inclusion in logistic regression for Dot grid data, NLCD 2001 data with 0.5 km radius, and NLCD 2001 data with 1 km radius.

Dot Grid (Google Earth maps)	NLCD 1/2 km	NLCD 1 km
	Numeric	
Grass, fields, bare ground (ha)*	Open water (ha)	Open water (ha)
Row crops (ha)*	Developed, open space (ha)	Developed, open space (ha)
Roads and buildings (ha)*	Developed, low intensity (ha)*	Developed, low intensity (ha)*
Fresh water (ha)*	Developed, medium intensity (ha)*	Developed, medium intensity (ha)*
Orchards and vineyards (ha)*	Developed, high intensity(ha)*	Developed, high intensity(ha)*
Trees and chaparral (ha)	Barren land (ha)*	Barren land (ha)*
Salt water (ha)*	Deciduous forest (ha)	Deciduous forest (ha)*
Elevation (m)*	Evergreen forest (ha)	Evergreen forest (ha)
Year built*	Mixed forest (ha)	Mixed forest (ha)
	Shrub, scrub (ha)*	Shrub, scrub (ha)*
	Grassland, herbaceous (ha)*	Grassland, herbaceous (ha)*
	Pasture, hay (ha)	Pasture, hay (ha)*
	Cultivated crops (ha)*	Cultivated crops (ha)*
	Woody wetlands (ha)	Woody wetlands (ha)
	Emergent herbaceous wetlands (ha)	Emergent herbaceous wetlands (ha)
	Elevation (m)*	Elevation (m)*
	Year built*	Year built*
	Categorical	
Road/railroad or water underneath*	Road/railroad or water underneath*	Road/railroad or water underneath*
Overpass, underpass*	Overpass, underpass*	Overpass, underpass*
Deck/Abutment angles*	Deck/Abutment angles*	Deck/Abutment angles*
Column/Deck angles*	Column/Deck angles*	Column/Deck angles*
Undersurface*	Undersurface*	Undersurface*
Region*	Region*	Region*
Obstruction	Obstruction	Obstruction
Area of opening	Area of opening	Area of opening
Material	Material	Material

Variables either obtained from field surveys, dot grid analyses of Google Earth photographs, or the 2001 National Land Cover Database. An asterik (*) indicates a significant difference existed between occupied and unoccupied sites for that variable. That variable was then used for developing the logistic regression model.

Table 6. Prediction accuracy for occupied and unoccupied sites in 10% of sites not used in creation of each validation model.

	Correctly predicted (%)	
Validation model	Unoccupied sites	Occupied sites
1	80	50
2	88	20
3	100	88
4	88	25
5	91	80
6	100	70
7	100	50
8	81	60
9	86	71
10	79	57

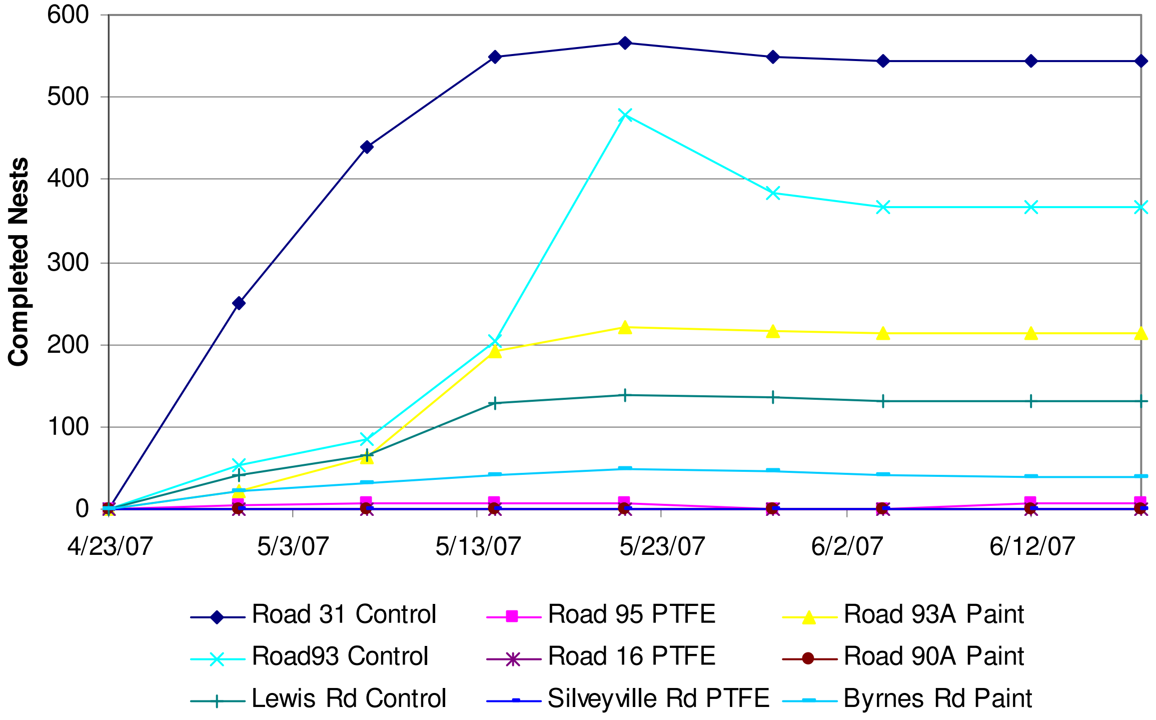

Figure 6. Number of completed nests for all sites over 9 weeks in 2007.

Figure 7. Mud sliding down surface of PTFE surface modification on column.

Figure 8. Completed nests on columns and overhead surfaces treated with silicone paint.

Figure 9. Completed nests at a control site.

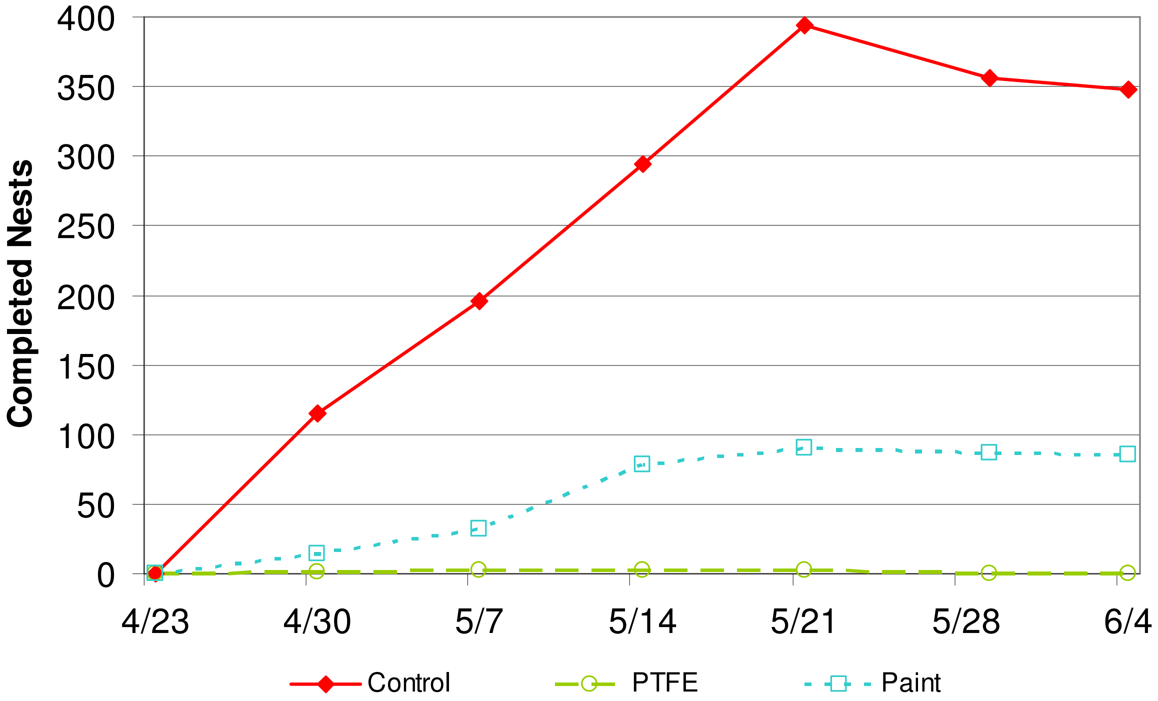

Figure 10. Average number of completed nests over 7 weeks in 2007.

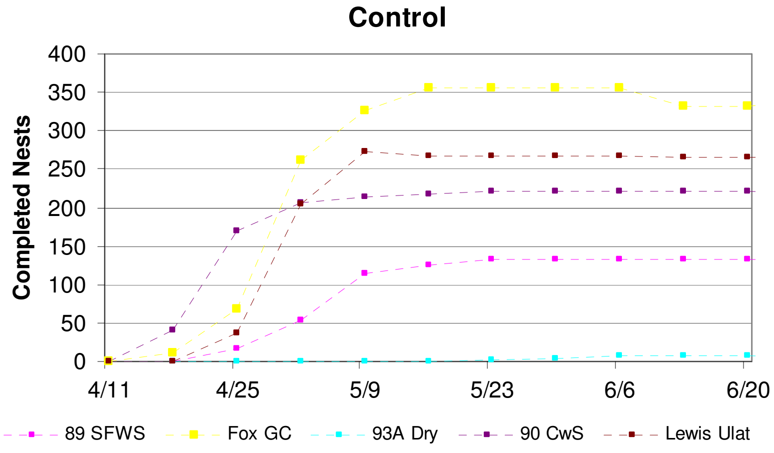

Figure 11. Number of completed nests for control sites over 11 weeks in 2008.

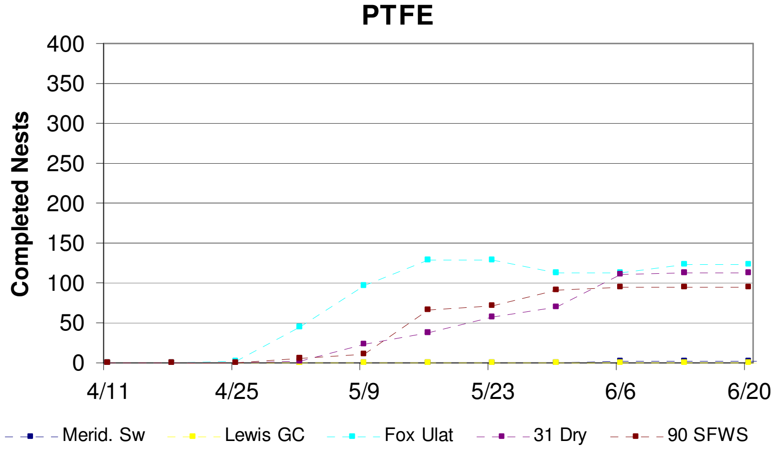

Figure 12. Number of completed nests for PTFE-treated sites over 11 weeks in 2008.

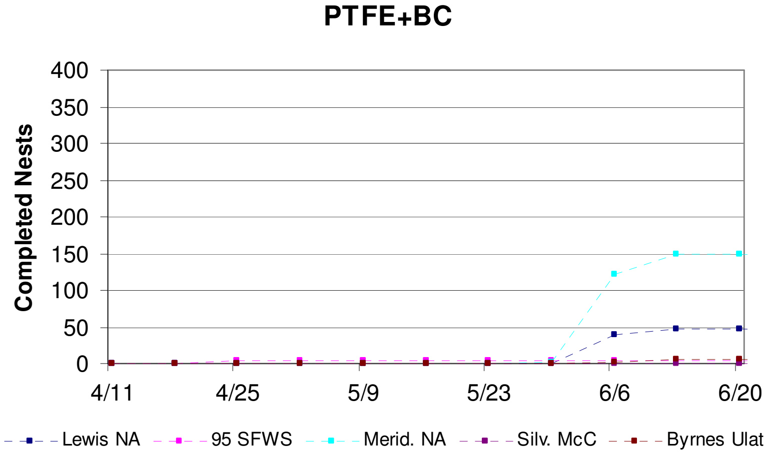

Figure 13. Number of completed nests for PTFE-and-BC-treated sites over 11 weeks in 2008.

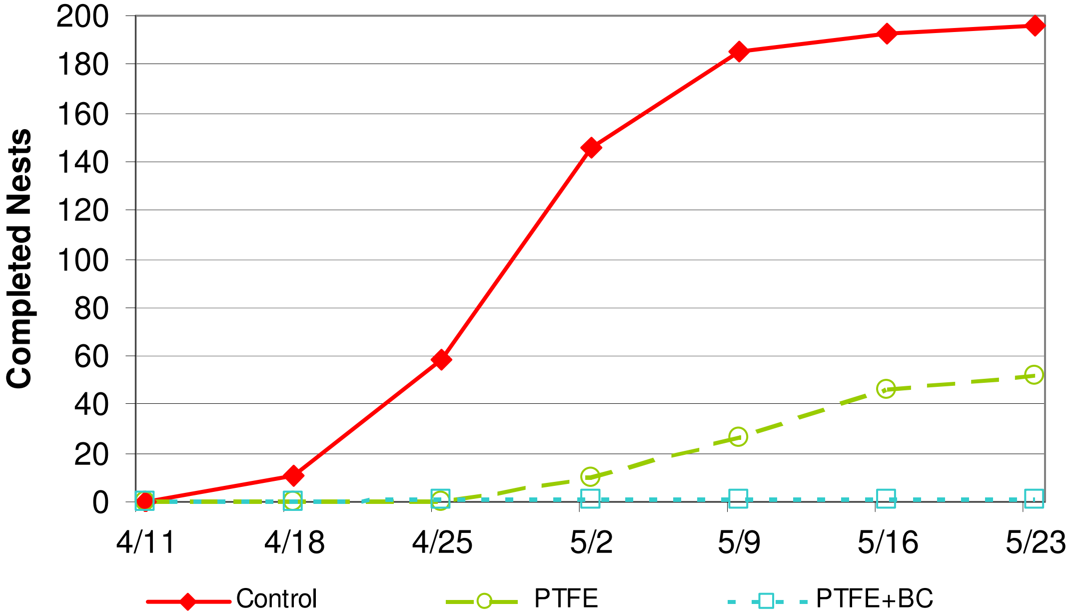

Figure 14. Average number of completed nest over 7 weeks in 2008.

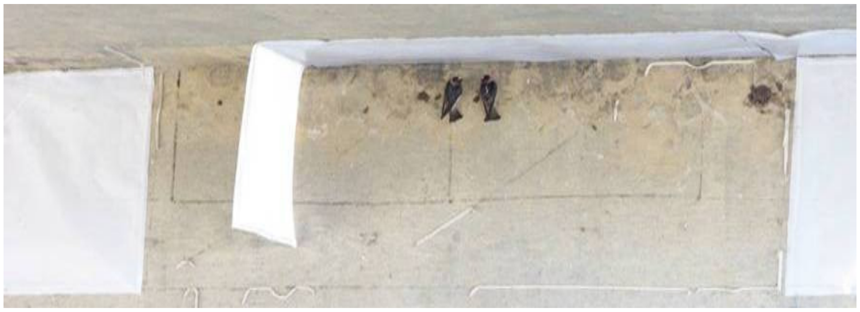

Figure 15. PTFE sheets detaching from the highway structure surfaces and cliff swallows building nests.

Figure 16. Completed nests below the bottom edge of PTFE treatments on a pier wall.

Figure 17. Completed nests on an overhead concrete seam at a PTFE-treated site.

List of Appendices

Appendix A. An Annotated Bibliography of Control Techniques and Other Information Applicable to Cliff Swallow Management on Highway Structures in California.

Appendix B. Cliff swallow questionnaire for U.S. DOTs and USFWS regions.

Appendix C. Results of 2006 field study (published report, 2009).

Appendix D. Description of control method selection, experimental plan, data analysis, and results in 2006 (M.S. thesis by J. S. Conklin).

Appendix E. Names, characteristics, and latitude/longitude of sites used for habitat selection model.

Appendix F. Descriptions of habitat classes for Dot grid and NLCD 2001 data.