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16. Abstract

This report summarizes the 2008–2011 field seasons for the Highway 71 impact assessment of highway construction noise and activity on golden-cheeked warblers (*Setophaga chrysoparia*). Researchers examined if construction activity and noise altered the reproductive success and behavior of birds, with an emphasis on the golden-cheeked warbler.

Researchers found that ambient noise levels were significantly higher in 2011 than 2010 across study sites, and decreased significantly as distance from ROW increased. Ambient noise levels were louder 512 m from the ROW in the construction site when compared to levels at 256 m and 512 m in the pre-construction site. Pairing success was significantly lower in the control site in 2010 than any other site and year combinations. Fledging success was significantly lower in 2009 than in other years, across all study sites.

There was no indication that birds directly reacted to construction noise or that they altered their singing or nesting behavior. Researchers found no effect from study site, distance from the ROW, or year on warbler reactions to construction noise playbacks.

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STUDY OF THE POTENTIAL IMPACTS OF HIGHWAY CONSTRUCTION ON SELECTED BIRDS WITH EMPHASIS ON THE GOLDEN-CHEEKED WARBLER: FINAL REPORT 2008-2011

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

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EXECUTIVE SUMMARY

This report is the final summary of the 2008–2011 field seasons for the Highway 71 impact assessment of highway construction noise and activity on golden-cheeked warblers (*Setophaga chrysoparia*), conducted under Contract No. 0-6263 between the Texas Department of Transportation (TXDOT) and the Texas A&M Institute of Renewable Natural Resources (IRNR). Our goal was to determine if construction activity and noise altered the reproductive success and behavior of birds, with an emphasis on the golden-cheeked warbler. Funding under this contract ended with little construction data gathered, and no post-construction data. We compared differences in productivity measures and behavioral responses relative to distance from ROW and using a before-after impact assessment study design wherein we designated study areas as impacted by construction or roads, or control (i.e., non-impact) sites. If highway construction noise impacted warbler productivity and behavior, we would expect to see different productivity and behavioral responses within the construction site, relative to the road-noise only and control sites.

Study sites were located within the Barton Creek Habitat Preserve (BCHP), managed by The Nature Conservancy. These study sites included a section of Highway 71 and Southwest Parkway, west of Austin, Texas. Pre-construction data collection started in 2008, and in 2011, we began collecting the first year of construction data at our study site.

We identified 3 types of sites for this study: treatment-impact (construction and pre-construction), road-noise only (no construction), and control (no road or construction influence). Starting in late 2010 after the breeding season, TXDOT initiated construction along a half-mile portion of Highway 71 in the northern part of this study site. Therefore, we referred to the northern part of the treatment site experiencing construction disturbance in 2011 as the construction site, whereas the southern portion of the treatment site that did not undergo construction during this study remained the pre-construction site. The treatment (construction and pre-construction sites) and the road-noise only sites extended approximately 1 km from the right-of-way (ROW). The control sites were located >1 km from any ROW.

We conducted surveys along transects at the beginning of each breeding season to locate golden-cheeked warbler territories. After locating territorial birds, we conducted productivity surveys at least once every 7 days and obtained measures of reproductive success for warbler territories. We mapped warbler territories using minimum convex polygons to determine territory density and territory distance from the ROW. Starting in 2009, we monitored warbler nests at a subsample of surveyed territories, and used nest cameras to examine adult behavior and predation events at nests. We obtained ambient noise level measurements to examine our hypothesis that noise levels associated with construction were different from road-noise only and control sites. We collected warbler song recordings to determine vocalization adjustments due to construction noise. Starting in 2009, we conducted playback experiments to evaluate behavioral changes due to construction noise.

Ambient noise levels were significantly higher in 2011 than 2010 across study sites, and decreased significantly as distance from ROW increased. Ambient noise levels were louder 512 m from the ROW in the construction site when compared to levels at 256 m and 512 m in the pre-construction site.

Pairing success was significantly lower in the control site in 2010 than any other site and year combinations. Fledging success was significantly lower in 2009 than in other years, across all study sites.

We monitored territory placement in relation to the ROW and within each study site. Territories were placed closer to the ROW in 2010 than other years, across study sites. In 2009, we banded 8 adult males. We did not resight any of these 8 birds in 2010 or 2011 within our study area. In 2010, we banded 2 adult males. In 2011, we resighted both birds within 100 m of the 2010 banding location. In 2008 and 2011, we did not band any birds.

We monitored a subsample of nests using video cameras, within each study site. There were no effects on adult visiting rates from year or study site. We played recordings of road construction noise to golden-cheeked warblers to examine their immediate behavioral response to introduced construction noise. We found no effects on behavioral responses by year, study site, or distance from the ROW.

For song type A, we found significant differences between years within phrase 2 and 3. We found a larger mean bandwidth in phrase 2 for 2010 than 2009, and a larger bandwidth in 2009 than 2011 across study sites; this was likely due to lower minimum frequencies in 2009 and 2011, and higher maximum frequencies in 2009. We found a larger mean bandwidth in phrase 3 for 2009 than 2010 and 2011 across study sites; this was likely due to lower minimum frequencies in 2009. We found a higher maximum frequency for phrase 3 in the control site for 2011 than the control site and pre-construction sites for 2009.

For song type B we found significant differences between years for all 3 phrases. We found a smaller mean bandwidth for phrase 1, 2 and 3 in 2011 than 2009 across study sites; this was likely due to lower minimum frequencies in 2009 than 2011 across all phrases. We also found a smaller mean bandwidth for phase 1 and 2 in 2011 than 2010 across study sites; this was likely due to lower minimum frequencies in 2010 than 2011 for both phrases. We also found an interaction between study site and distance from the ROW for all years in phrase 2. We found a higher minimum frequency at 0-300 m from the ROW within the construction site than the pre-construction site.

INTRODUCTION

Activities associated with highways and roads can negatively affect species' demography and behaviors because of direct alterations to a species' habitat, increased levels of human disturbances, and increased levels of noise (Burton et al. 2002, Forman et al. 2002). Habitat fragmentation from construction of new roadways can influence predator communities, movement patterns, or activity (Reijnen et al. 1995, Federal Highway Administration 2004). Increases in background sound levels can interfere or mask communication signals used in breeding and survival, which consequently could influence mating activity, population distributions, and detection of predators or prey (Patricelli and Blickley 2006).

To minimize masking from anthropogenic noises, birds may alter their behavior to sing at higher frequencies (Wood and Yezerinac 2006). Past studies have found a positive relationship between the minimum frequency of male song and the amplitude of anthropogenic noise in several songbirds. Males shift energy into the higher frequencies (4–9 kHz) of their songs in noisy areas. Urban noise is loudest between 1–2 kHz, so both of these responses should serve to decrease masking by shifting the spectral energy of the vocalization away from the spectral energy of the noise. These results suggest that birds can respond to changes in the acoustic environment by altering their songs, referred to as "vocal adjustment." All known examples of avian vocal adjustment in response to urban noise have involved song, but adjustments might occur to other types of vocalizations such as begging calls, alarm calls, and food calls (see review by Patricelli and Blickley 2006).

A literature review by the Federal Highway Administration (2004) showed that many species showed a decrease in breeding activity and abundance when in proximity to highways. The distances at which these effects were shown, however, varied from <100 m to ~3 km from the ROW (right of way), most species that showed an effect did so between 100 and 1500 m.

Most studies, however, did not analyze highway noise as a function of distance from the ROW. The general conclusion was that some bird species were sensitive at least during breeding to noise levels and that the distances over which this effect is seen can be considerable, varying from a few meters to more than 3 km.

A recent study (Lackey et al. 2010) found increased, but not statistically significant, reproductive success in the golden-cheeked warbler away from road construction. They found construction and road noise did not appear to impact territory placement, reproductive success, or local densities in golden-cheeked warblers.

This report is a summary of the 2008 to 2011 field seasons for the Highway 71 impact assessment of highway construction noise and activity on golden-cheeked warblers, conducted under Contract No. 0-6263 between the Texas Department of Transportation (TXDOT) and the Texas A&M Institute of Renewable Natural Resources (IRNR). The goal of this study was to determine if construction activity and noise influenced abundance, breeding success, and behavior of birds with an emphasis on the golden-cheeked warbler. We compared differences in productivity measures and behavioral responses relative to distance from ROW and among three study areas: treatment (construction), road-noise only, and control sites. If highway construction noise impacted warbler productivity and behavior, we would expect to see different productivity and behavioral responses within the construction site, relative to the road-noise only and control sites.

To test for elevated noise levels in the construction site, we recorded ambient noise levels across a distance gradient from the ROW across the study areas. Specific objectives were:

1. Compare direct impacts of highway construction noise on measures of reproductive success. We conducted transect surveys, mapped and monitored territories, and monitored nests to determine (1) pairing success, (2) territory fledging success, and (3) nest success and predation events.

2. Quantify behavioral responses of golden-cheeked warblers to construction activity and noise. We examined behavioral responses of adult golden-cheeked warblers to construction noise and activity by (1) assessing territory establishment using measures of territory density, location of territories relative to the ROW, and returns of banded birds in subsequent breeding seasons; (2) recording adult activity patterns at the nest using digital video recorders; (3) determining the initial behavioral response to recordings of construction noises using an experimental design (hereafter playback experiment); and (4) recording vocalizations of territorial males to determine if golden-cheeked warblers alter their vocalizations to account for construction noise and activity.

3. As indicated from the study results, evaluate the spatial and temporal extent of highway construction impacts on the study species. This objective cannot be addressed until adequate post-construction data are gathered, and thus will not be addressed herein.

4. Make recommendations for alleviating any negative impacts of highway construction noise on warblers. This objective cannot be addressed until adequate post-construction data are gathered, and thus will not be addressed herein.

In this report, we describe our study design and methods, including a description of data recorded, and our analyses and results for 2008 to 2011. Construction was initiated by TXDOT at only a portion of the anticipated construction site in 2011, thus the majority of this report is a comparison among the study sites prior to construction. The stated intention of TXDOT is to continue data collection in 2012, followed by one year post-treatment in 2013.

STUDY AREA AND DESIGN

The study area undergoing construction is a section of Highway 71 west of Austin in Travis County, Texas (Appendix, Figure A1). TXDOT is widening and straightening the roadway to improve vehicle flow and safety. Prior to the initiation of the construction, we collected pre-construction data during the breeding seasons of 2008 through 2010. Construction began after the 2010 field season, and will continue for up to 2 years. Construction is planned to be completed in 2012 and we will commence post-construction monitoring for one year following completion of construction.

The study design is that of an impact assessment study, conforming to the before-after-control-impact (BACI) protocol (Figure 1). Using a BACI design allows us to account for temporal variation that might influence the magnitude of differences among bird responses within the study areas before or after an impact (Morrison et al. 2008). For this report, it is important to note that we do not have "after" treatment data because construction did not start until the last year of this study, and it was only along a small portion of the proposed construction area. We identified 3 types of sites for this study, 1 treatment (construction) site and 2 reference sites (road-noise only and control). Selection of 2 reference sites allows for spatial replication across the study area. These reference sites were similar enough to the treatment site to allow us to assume that temporal variation would have similar impacts on all 3 study sites (Morrison et al. 2008). All study sites were within Barton Creek Habitat Preserve, managed by The Nature Conservancy, thus land management practices were consistent across all three study types.

1. <u>Treatment (construction) site</u>: Site along Highway 71 undergoing construction activities; this site experienced both construction activity and road noise (vehicle traffic). This study site included potential habitat along Highway 71, up to 1 km perpendicular to the ROW. Prior

to TXDOT beginning construction, we referred to this site as the pre-construction site; however, in late 2010 (after the breeding season) TXDOT initiated construction along a half-mile portion of the highway in the northern part of this study site. We referred to the area experiencing construction disturbance in 2011 as the construction site, whereas the portion of this study site to the south not undergoing construction this year remained the pre-construction site (Appendix, Figure A1).

2. Road-noise only reference sites: We assigned land along a road (Southwest Parkway) adjacent to Highway 71 that was not undergoing construction as the road-noise only control site. This study site extended up to 1 km perpendicular to the ROW. This site allowed us to separate the effects of road noise from construction activity on bird behavior.

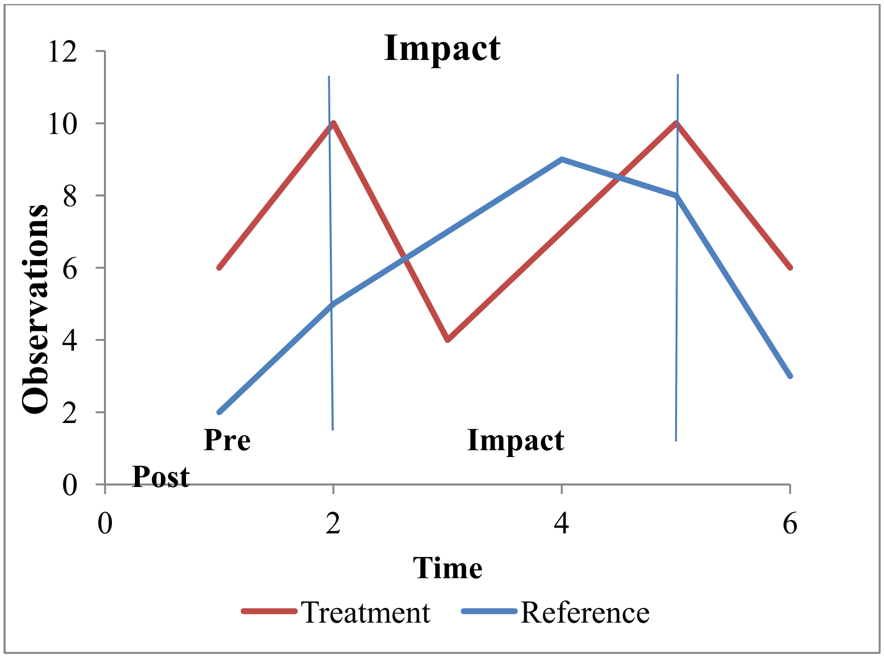
3. Control sites: These sites experienced no road or construction noise and activity. We used sites on Barton Creek Habitat Preserve that were >1 km from any roads or Highway 71, thus eliminating road noise and construction activity as factors potentially influencing birds. These sites allowed us to separate the effects of road noise and disturbance on bird behavior.

For the playback experiments, we did not introduce construction noise into our control site. Instead, we limited playback surveys to the treatment (construction and pre-construction) and road-noise only sites, and we considered areas of both the treatment and road-noise only site > 400 m from the road to be a “no construction-noise” control area.

Predictions

If construction noise and activity impacted golden-cheeked warblers, there would be a noticeable statistical interaction before and after the start of construction noise, between the treatment site and the control sites (Morrison et al 2008). If there was an impact on golden-cheeked warblers from construction noise and activity, measures recorded from the treatment and control sites would vary across time (Figure 1a). If there was no impact, response measures recorded in the treatment and control sites would fluctuate on a more or less consistent pattern (Figure 1b). Therefore, if construction noise and activity negatively affected golden-cheeked warblers, we expected warbler reproductive and behavioral responses to be negative or lower in the construction site than responses in the control sites relative to when the construction started. We also predicted responses to change with increasing distance from the ROW.

A



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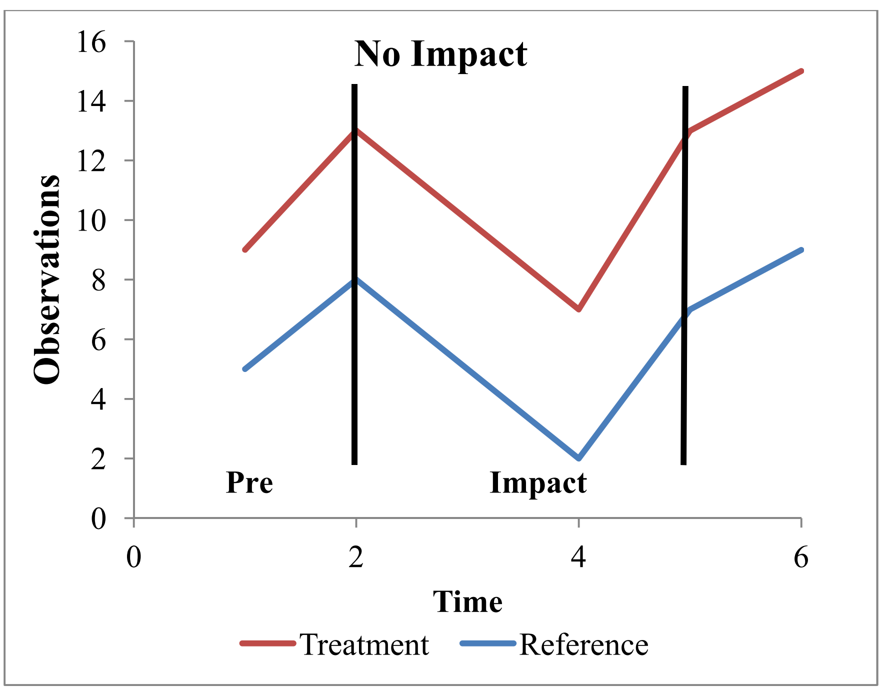

Figure 1. Example of Predicted Response to an Impact Using a BACI Study Design. (a) Indication that an Impact Has Occurred. (b) No Indication that an Impact Has Occurred.

METHODS

Ambient Noise

We predicted that construction noise would negatively influence productivity and behavioral responses by warblers, thus we needed to test our assumption that background noise levels were elevated in the construction sites. Increases in background noise levels can interfere or mask communication signals used in breeding and survival, which consequently can influence mating activity, population distributions, and detection of predators or prey. To determine background noise levels associated with distance from ROW, we set up Extech 407764 Datalogging Sound (dB) meters at varying distances (16 m, 32 m, 64 m, 128 m, 256 m, 512 m) along transects perpendicular to the road in the treatment (construction and pre-construction) and road-noise only sites to measure background noise in 2010 and 2011. Sound meters recorded from 06:00 and 12:00, approximately twice a week, throughout the field season. We calculated the average dB level for each dB meter, and used this value to compare measurements between sites, years, and in relation to distance to the ROW.

TRANSECT SURVEYS

We conducted transect surveys between mid-March and early April in 2008 to 2011 to locate singing male warblers across the study sites. We used these surveys to ensure we detected all territorial warblers across the study sites, and to focus more intensive monitoring efforts (see below, e.g., territory mapping, productivity surveys, banding and nest searching efforts). We established transects a minimum of 300 m apart. In 2008, line transects extended 500–600 m into the habitat adjacent to the ROW. In 2009 – 2011 we extended our survey coverage in the treatment and road-noise only sites to 1 km into the habitat (Appendix, Figure A2). We began surveys no earlier than local sunrise and continued no later than 6 hours after sunrise (~07:00 to 13:00). We recorded and compiled Global Positioning System (GPS) locations of detected golden-cheeked warblers in an ArcMap™ 9.3.1.

Territory Mapping and Productivity Surveys

We conducted territory mapping and productivity surveys from March through June in all study years. We monitored each territory at least once every 7 days. We observed focal individuals or pairs for ≤ 60 minutes using an observational method for identifying reproductive status (Vickery et al. 1992) and to collect data for territory mapping.

Territory mapping allowed us to determine the area of use by each territorial male or warbler pair. We mapped warbler territories using hand-held GPS units to mark singing locations of focal males. In 2008–2010, we recorded 3-6 points per visit until we obtained a minimum of 13 points per territory. In 2011, we mapped warbler territories by recording 1 point every 2 minutes for ≤ 1 hour per visit.

We determined productivity using an index developed by Vickery et al. (1992) that allows quantification of the potential nesting status of the territory without requiring nest searching and monitoring. Because nest searching and monitoring is time-intensive, we conducted Vickery surveys across all monitored territories. We used the ranking system developed by Vickery et al. (1992) and successfully used by others (e.g., Christoferson and Morrison 2001) to determine reproduction activity of the warbler. The basic ranks used were:

- Rank 1—Territorial male present 4+ weeks
- Rank 2—Territorial male and female present 4+ weeks
- Rank 3—Pair found nest building, laying or incubating eggs or giving distraction display
- Rank 4—Adults carrying food to presumed nestlings
- Rank 5—Evidence of fledging success. For double-brooded species, evidence of fledging success in one brood only

Using the Vickery et al. (1992) method, we determined which territorial males remained unpaired throughout the breeding season (i.e., pairing success), and whether a paired territory successfully fledged greater than one host young (i.e., fledging success).

Adult Banding and Resights

To examine movement of breeding birds between years, we banded a subsample of adults within the study sites and conducted band resights in subsequent years. We conducted all banding under supervision of a Master Bird Bander or sub-permittee (USGS Federal bird banding permit for Dr. Michael L. Morrison). We broadcast conspecific or heterospecific songs at normal frequencies to attract warblers to the nets, for no more than 30 minutes within 1 territory in a single day. We placed nets within sight of the banders, so that banders monitored nets constantly and to allow for removal of warblers as quickly as possible. We did not mist net if we detected any potential predators in the area or in inclement weather (i.e., cold, rain, or windy conditions). We fitted warblers with USGS metal band and plastic color bands; unique color combinations were obtained from The Nature Conservancy, Fort Hood, TX. We resighted adult warblers throughout the field season, documenting whether the warbler was banded or unbanded. If the individual was banded, we resighted the bird at least 3 times to confirm the color combination of the bands.

Nest Searching and Monitoring and Nest Cameras

Starting in 2009, we located nests using a combination of behavioral cues from the adults and using a search image in appropriate potential nest locations within known territories. We followed standard nest searching guidelines and precautions for monitoring passerine nests (Martin and Geupel 1993). Once we located a nest, we marked the location with a flag (>15 m away) and recorded the GPS location of the nest. We did not approach nests during the nest building stage, and did not check nests if we detected potential nest predators in the area or if weather was cold or rainy. We checked nests every 3-4 days and we recorded the following information during nest checks; date, time, presence of adults, whether nest contents were seen, number of eggs of a given species (host and brown-headed cowbird [*Molothrus ater*]), and number and age of nestlings. When possible, we estimated date of first egg, clutch completion date, hatching date, day of banding, and fledging date.

Starting in 2009, we placed cameras (Detection Dynamics, Rainbow B/W IR Bullet camera) at nests to record adult behavior and nest predator, parasitism, or fledgling events. Observations included direct disturbances to nests, adult visiting rates by nest stage, and predation events. We set up cameras to record after the female had begun incubation to reduce the potential for nest abandonment. We placed cameras approximately 1-2 m from the nest with little to no disturbance to surrounding vegetation. After camera set up, we observed the nest for no more than 30 minutes to verify that adults returned to the nest and resumed normal activity. We checked cameras every 3-4 days as needed to replace batteries and memory cards.

Playback Experiment

Starting in 2010, we conducted an experiment to examine the acute behavioral responses of territorial warblers to loud, erratic construction and road noises by playing recordings of construction noise to individual male golden-cheeked warblers. Research showed that birds hear no better than humans (Dooling 1982). Based on this knowledge, we played the construction noise recordings at approximately 80 dB, a level known to be annoying to humans but that will not cause hearing damage (Chasin 2007). The primary noises included: 1) backup warning beeps, 2) diesel engine noise, and 3) loading dump trucks. We conducted playback surveys between March and June. Playback surveys occurred no more than once every 10 days to avoid habituating birds to the recordings. We recorded behavior for 2 minutes before playback then broadcast construction noise with a hand-held speaker for a maximum of 5 seconds. Each playback bout ceased as soon as the subject's behavior changed. We recorded presence or absence of behavioral responses to playback and the associated behavioral change. We then documented warbler behavior for 10 minutes post-playback, or until the surveyor was no longer able to locate the warbler. We considered a playback experiment to have elicited a behavioral response if the warbler ceased singing, flew from its previous perch and out of the surveyor's view ($\geq$10 m) or changed behavior before or exactly at the end of hearing 5 seconds of construction noise.

We also conducted control playbacks, to control for the potential effects of observer presence. Experimental protocol for the control group duplicated that of the experimental group, except we did not play the construction noise recordings. To avoid introducing construction noise to our control site, playback surveys were restricted to the treatment (construction and pre-construction) and road-noise only sites. Instead, for the purposes of this experiment we considered areas $\geq$ 400 m from the road to be a "no-noise" control area. Our analysis compared the responses to playback in this pooled no-noise area, with the responses in the treatment and road-noise only sites less than 400 m from the road.

WARBLER SONG RECORDINGS

In 2008 and 2009, we placed 10 Song Meter SM2 Digital Field Automatic Recording Units (ARUs) to gather audio data on warbler songs' and potential changes in singing due to construction activity. We began recordings at 06:45-07:00 for 4-hour time blocks. We placed ARUs in the center of GCWA territories allowing the recorder to run for 3-4 days per territory. We moved ARUs to different territories so that none were in the same territory in successive weeks. We stationed 4 units in the treatment site, 4 units in the road-noise only site, and 2 units at the control site in each week.

In 2010 and 2011, we placed nine ARUs across the study area across 3 time periods to gather audio data on the warblers' songs, resulting in 27 ARU locations in different territories throughout the season. We programmed the ARUs to record from 07:00-11:00 daily. We placed each ARU near a known singing location in a golden-cheeked warbler territory and allowed the recorder to run for 3-4 weeks before moving it to another territory. We placed 3 units within the treatment site, 3 units within the road-noise only site, and 3 units within the control site.

Golden-cheeked warblers have two primary song types, the A song and the B song. We identified each individual song as type A or type B and divided the songs into three phrases (e.g., Figures 2 and 3). To extract individual songs from our recordings, we used SonoBirdTM v1.5.5 in 2008 and SonoBirdTM v1.6.5 in 2009–2011. Because of differences in the software program versions, we changed what parameters we extracted from the song recordings after 2008. In 2008 we measured maximum frequency and time to maximum frequency (for each phrase and song type), because songbirds tend to alter their maximum frequency to account for added noise pollution. From 2009–2011 for each phrase and song type we measured minimum frequency, maximum frequency, and bandwidth. Minimum and maximum frequency cutoffs were set 15 dB below peak amplitude to filter out effects of random background noise (Texas A&M University 2009).

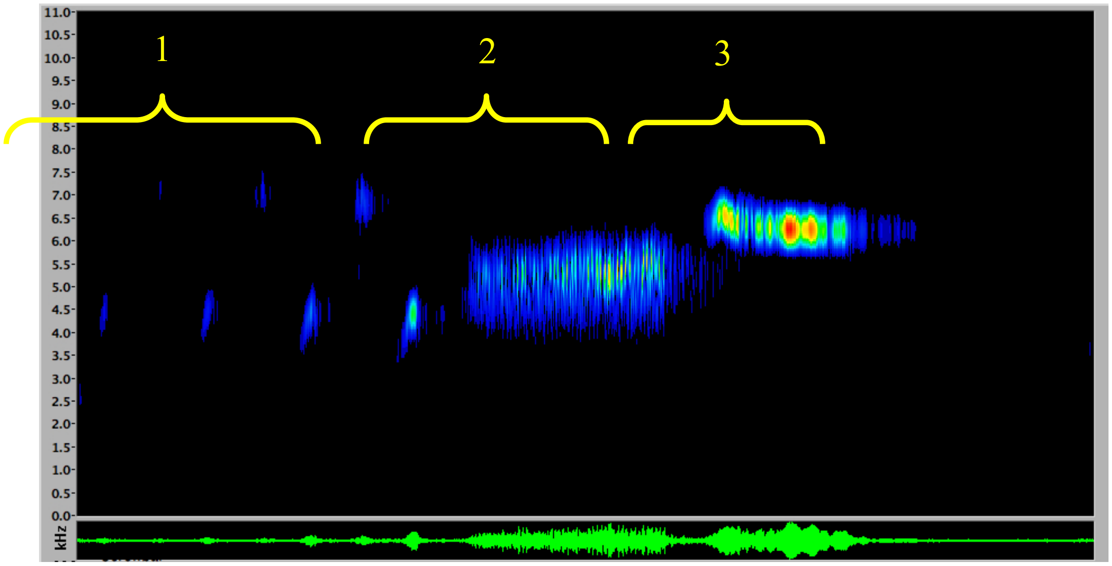

Figure 2. Typical Golden-Cheeked Warbler A Song. Brackets Indicate the Three Phrases Used for Analysis.

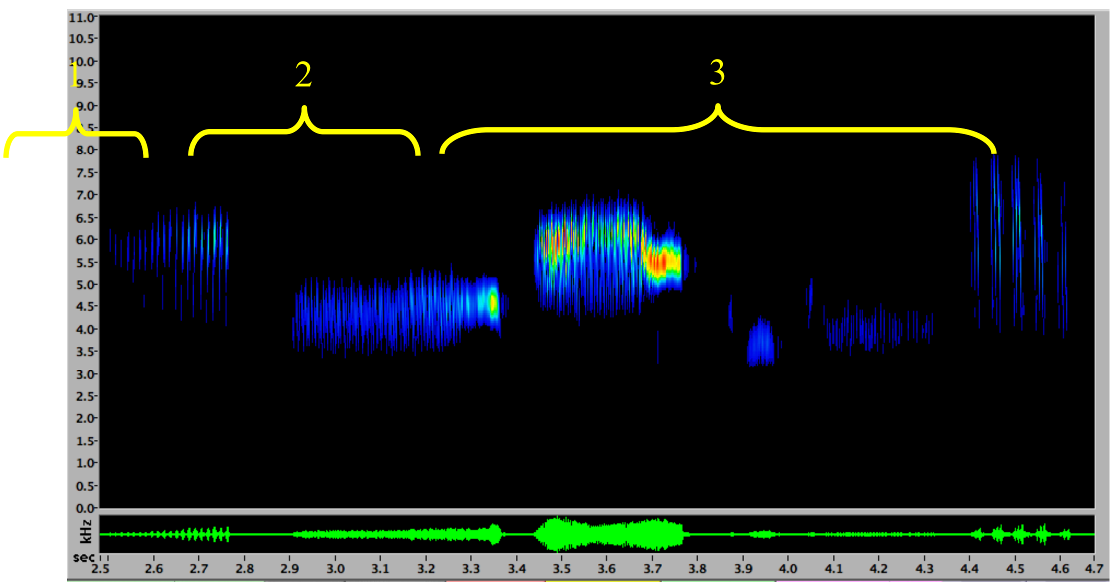

Figure 3. Typical Golden-Cheeked Warbler B Song. Brackets Indicate the Three Phrases Used for Analysis.

STATISTICAL ANALYSIS

For a before-after impact assessment, analyses of the data should include an interaction term between site and year to determine if there is a significant difference at the impacted site in the years following the disturbance (Morrison et al. 2008). However, this report includes only one year of construction for which the sample sizes within that treatment were too small to include in any statistical analyses. We included in our analyses consideration of an interactive effect between site and year but it is uninformative for impact assessment and instead indicates variance among our study years or sites. For this reason, we also examined the main effects of year and site. For all ANOVA or ANCOVA analyses where we found significant differences, we used Tukey's Honestly Significant Difference (HSD) to make pairwise comparisons.

Ambient Noise

In order to compensate for baseline ambient noise level, which offsets the variation in noise level, we subtracted the minimum noise level for each given year (i.e., the value of noise at the quietest location) from the computed noise levels at each location. We used a factorial analysis of variance (ANOVA) to test the main effects of study site (pre-construction, construction, and road-noise only sites) and year (2009–2011) on ambient noise levels. We could not include an interactive effect of year and study site because there was no construction in the previous years. We placed dB meters at varying distances from the ROW, and we used an analysis of covariance (ANCOVA), with distance from the ROW as a covariate, to compare mean ambient noise levels between study sites.

Productivity

We considered males unpaired if we never observed them with a female, paired if we observed them with a female (i.e., pairing success), and successfully fledged if we detected ≥1 fledgling warbler with a pair (i.e., fledging success). We calculated pairing success by dividing the number of paired males by the total number of territories. We calculated fledging success by dividing the number of territories where we observed fledglings by the total number of paired males on each site.

We used logistic regression to test the interactive effects of year and study site on golden-cheeked warbler pairing success for 2009–2011, fledging success for 2008–2011, and to determine if distance from the ROW in the treatment or road-noise only site predicted pairing or fledging success of warbler territories. We were not able to analyze construction site for 2011, because of small samples sizes, and thus provided descriptive statistics for productivity. We report the likelihood ratio test results for individual contributions of study site, year, or an interaction between site and year to the overall model. For individual site and year combinations, we examined the partial regression coefficients. We examined differences in apparent nest success for monitored nests from 2009–2011 using descriptive statistics because sample sizes within sites and years were small.

Behavioral Responses

We measured territory density within a study site, by dividing the number of territories in a study site by the total area surveyed to determine territories/ha. We provided descriptive statistics for territory across years and study sites.

We placed center points within minimum convex polygons with ArcMap™ 9.3.1 and calculated the mean distance from territory centers to the ROW in treatment and road-noise only sites. We used a factorial ANOVA to compare the mean distance from ROW of territory centers among study sites and years for 2008–2011. We also used a one-way ANOVA to compare the mean distance from ROW of territory centers to fledging success. Because of the small number of banded birds, we provided descriptive statistics for breeding bird movement between years.

For our video analysis, we randomly selected 2 4-hour daytime segments of nest video for every 4 days of recorded footage, to determine average nest activity across each nest stage. While watching these segments, we recorded behavior such as adult arrival and exit, feeding nestlings or adult, length of time spent sitting on nest, shading nest, or standing near nest. We also recorded fledging events, nest predation, and partial predation events. We determined nest visits per hour using nest cameras for 2009-2011, and used a two-way ANOVA to test the effects of year and study site on visits per hour.

We used logistic regression to test for interactive effects of year, study site, and distance from the ROW on golden-cheeked warbler behavioral responses to road construction noise. We used logistic regression to test for effects of playback (experiment or control) on behavioral response to construction noise, to test for observer effect.

We used a factorial ANOVA to test the effects of study site and year on song characteristics for 2009–2011. We analyzed minimum frequency bandwidth of each song phrase, maximum frequency bandwidth, and the mean bandwidth for the phrase (Wood and Yezerinac 2006). Because we placed ARUs at varying distances from the ROW, we used an additional ANCOVA, with distance from the ROW as a covariate, to compare average audio level changes between study sites.

RESULTS

Ambient Noise

For the purposes of this analysis, ambient noise level refers to the loudness of background noise above the lowest calculated average value for each year at a recording location. Ambient noise levels did not vary by study site ($F_{2,300} = 0.98$, $P = 0.38$). Ambient noise levels were significantly louder in 2011 than other years ($F_{2,300} = 19.39$, $P < 0.001$). A Tukey post-hoc comparison indicated that 2011 was significantly louder than 2009 ($P < 0.001$) and 2010 ($P = 0.009$). Ambient noise levels decreased significantly as distance from ROW increased ($F_{5,301} = 100.34$, $P < 0.001$, for all years and sites combined. Ambient noise levels did vary between the construction, pre-construction, and road-noise only sites in relation to distance from the ROW ($F_{10,296} = 5.67$, $P < 0.001$, Fig. 4). A Tukey post-hoc comparison indicated that ambient noise levels 512 m from the ROW in the construction site were louder than levels 512 m from the ROW in the pre-construction site ($P = 0.006$), and 256 m from the ROW in the pre-construction site ($P = 0.001$, Fig. 4).

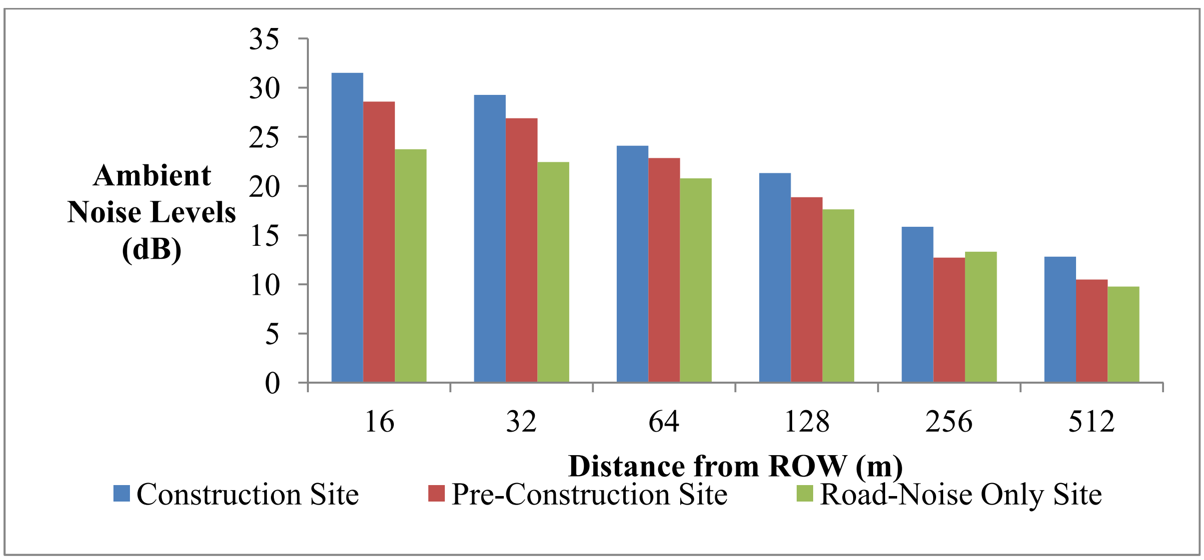

Figure 4. Distribution of Average Ambient Noise Levels by Distance from the ROW for Each Study Site across Years.

PRODUCTIVITY

Pairing Success

Across all years, pairing success was highest in the pre-construction site (82%, n = 45), followed by the road-noise only site (79%, n = 43) and control site (70%, n = 101, Appendix, Figure A3). In 2011, one (33%) of 3 territories observed within the construction site paired. We did not include in our logistic regression analyses pairing success in the construction portion of the treatment site, due to the small number of birds in a small portion of our study area. Based on likelihood ratio tests there was a significant interactive effect on pairing success of study site and year ($\chi^2_4 = 10.11$, $P = 0.039$) and there was no effect of year ($\chi^2_2 = 0.97$, $P = 0.61$) or study site ($\chi^2_2 = 5.15$, $P = 0.76$). Pairing success for the control site was significantly lower in 2011 than in 2010 ($\chi^2_8 = 4.3$, $P = 0.04$; Figure 5). Pairing success did not differ significantly with distance from ROW ($\chi^2_1 = 0.14$, $P = 0.71$) for all years and sites (treatment and road-noise only) combined.

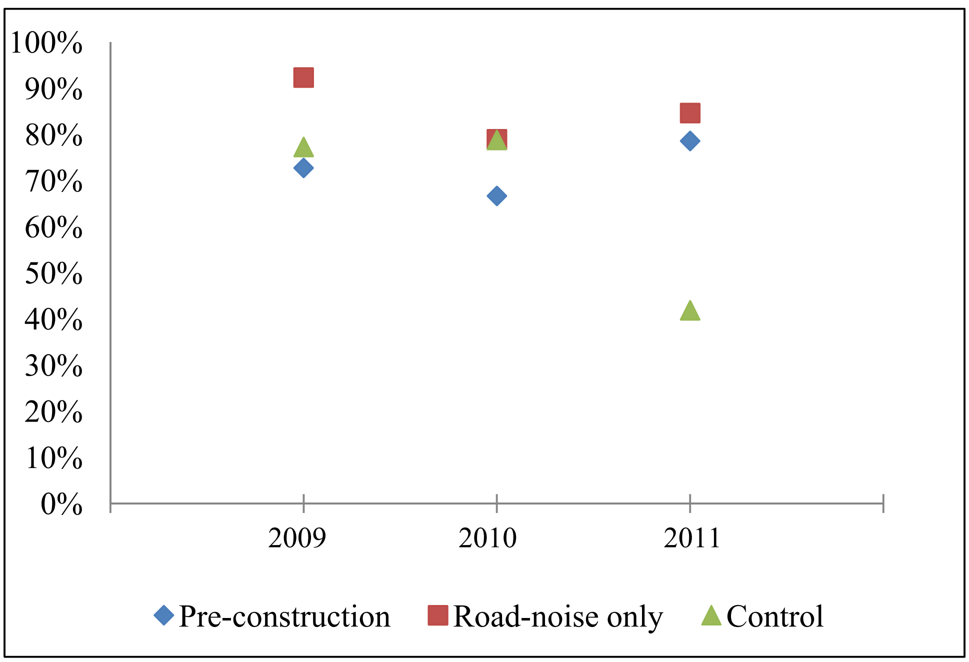

Figure 5. Percentage of Territorial Golden-Cheeked Warbler Males Successfully Paired by Study Site, 2009–2011.

Fledging Success

Across all years, fledging success was highest in the road-noise only site (92%, n = 47), followed by the control site (91%, n = 92), and the pre-construction site (88%, n = 54, Appendix, Figure A3). In 2011, the single territory within the construction site that paired also fledged. We did not include in our logistic regression analyses fledging success for the construction portion of the treatment site, due to the small number of birds in a small portion of our study area. Likelihood ratio tests indicated that there was an effect of year ($\chi^2_3 = 25.24$, $P < 0.001$) on fledging success but no interactive effect of study site and year ($\chi^2_6 = 2.57$, $P = 0.86$) or study site ($\chi^2_2 = 0.58$, $P = 0.75$, Figure 6). Fledging success was significantly lower in 2009 ($\chi^2_{11} = 21.3$, $P < 0.001$) and significantly higher in 2008 ($\chi^2_{11} = 8.0$, $P = 0.005$). Fledging success did not differ significantly by distance from ROW ($\chi^2_1 = 0.21$, $P = 0.65$) for all years, and treatment and road-noise only sites combined.

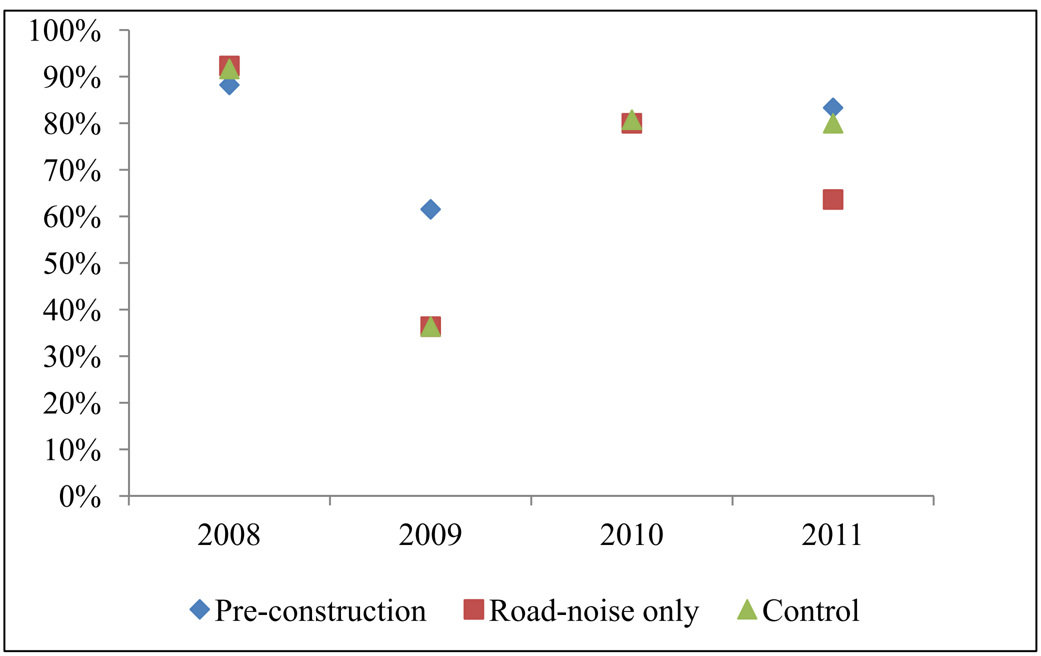

Figure 6. Percentage of Successful Golden-Cheeked Warbler Pairs by Study Site, 2009–2011.

Nest Success

We monitored 27 warbler nests in 2009–2011, of which 70% (*n* = 26) fledged ≥1 warbler young, 33% failed by predation, and 11% were abandoned (we were unable to determine the fate of one nest in 2009). Using nest cameras, we captured 4 predation events, of which 3 were from Texas rat snakes (*Elaphe obsoleta lindheimerii*) and one from an unknown raptor (Table 1). Within study sites across all years, 57% (*n* = 7) nests fledged in the pre-construction site, 80% (*n* = 5) fledged in the road-noise only site, and 66% (*n* = 15) fledged in the control sites (Table 1). In 2011, 3 nests were abandoned by the adults either during the building stage or during egg-laying (i.e., we never observed the adults incubating on the nest; these nests did not have camera units).We witnessed parasitism by brown-headed cowbirds for one nest that fledged in 2011 from the road-noise only site. Sample sizes were too small to determine if there were any effects of site or year on apparent nest success. A single nest was located in the construction site in 2011 and it fledged 3 warbler young.

Distance of Territories from the ROW

Territory centers were closer to the ROW in 2008 than any other years. Birds generally placed territories closer to the road in the road-noise only site, averaging approximately 393 m from ROW, than those placed in the treatment site, averaging approximately 494 m (Figure 7). We did not analyze distance from the ROW in the construction portion of the treatment site, due to the small number of birds in a small portion of our study area. There was no difference in distance from the ROW among study sites ($F_{5,10}$ = 0.61, P = 0.45) or by fledging success ($F_{5,10}$ = 0.05, P = 0.83). Territories were significantly farther from the ROW in 2009 and 2011 than in 2010 across study sites ($F_{5,10}$ = 5.60, P = 0.02).

Table 1. Nest Success of Golden-Cheeked Warblers by Study Site, 2009–2011.

Year		Study Site		Nest Outcome		Camera
2009		Pre-construction	1	Fledge host		Yes
			2	Fledge host		No
			3	Fledge host		No
			4	Predation; raptor		No
			5	Unknown fate		No
		Road-noise Only	6	Fledge host		Yes
			7	Fail, unknown cause		Yes
		Control	8	Fail, unknown cause		Yes
2010		Pre-construction	1	Predation, snake		Yes
			2	Fail, unknown cause		No
		Control	3	Fledge host		No
			4	Fledge host		No
			5	Predation, snake		Yes
			6	Fail, unknown cause		No
2011		Construction	1	Fledge host		No
		Pre-construction	2	Fledge host		Yes
			3	Abandoned prior to incubation		No
		Road-noise Only	4	Fledge host		Yes
			5	Parasitized; Fledged 1 host, 1 cowbird		No
			6	Fledge host		No
			7	Abandoned prior to incubation		No
			8	Abandoned prior to incubation		No
		Control	9	Fledge host		No
			10	Fledge host		No
			11	Fledge host		No
			12	Fledge host		No
			13	Fledge host		No
			14	Fledge host		No
			15	Fledge host		No
			16	Fledge host, successful double brood [a]		No
			17	Fail, unknown cause		No
			18	Fail, unknown cause		No

[a] Double brood signifies a territory where a pair has successfully fledged ≥ 1 host fledgling out of two separate nests during the field season.

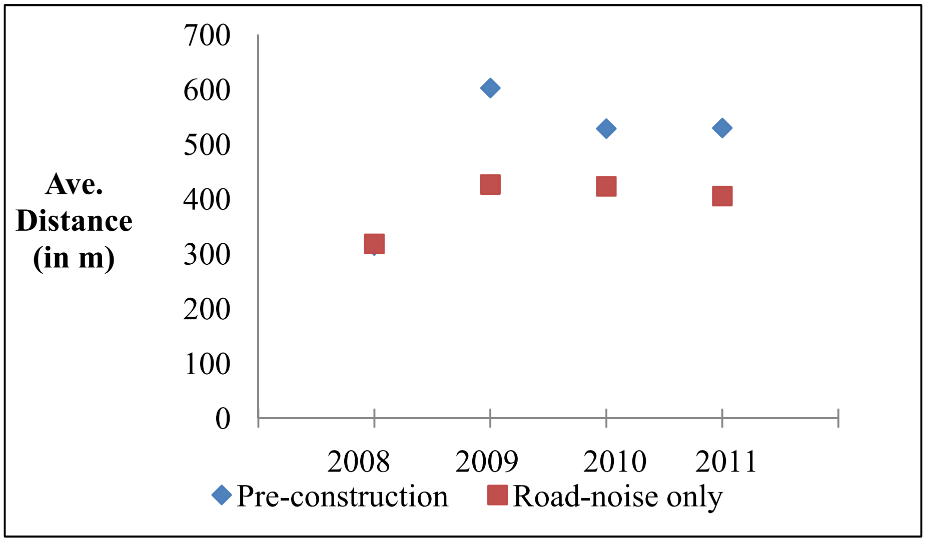

Figure 7. Average Distance of Warbler Territories to the ROW, by Study Site, 2008–2011.

Density

Our density estimates are a minimum because we were not able to monitor all territorial birds in the study areas each year. In 2008, a smaller portion of the control study area was surveyed and the estimate is biased high because we did not monitor in areas with sparse habitat. The pre-construction site had the most consistent density across years, ranging from 0.031 to 0.038 birds/ha (Table 2). The control study site had a slightly higher density than the pre-construction or road-noise only sites across the years (Figure 8).

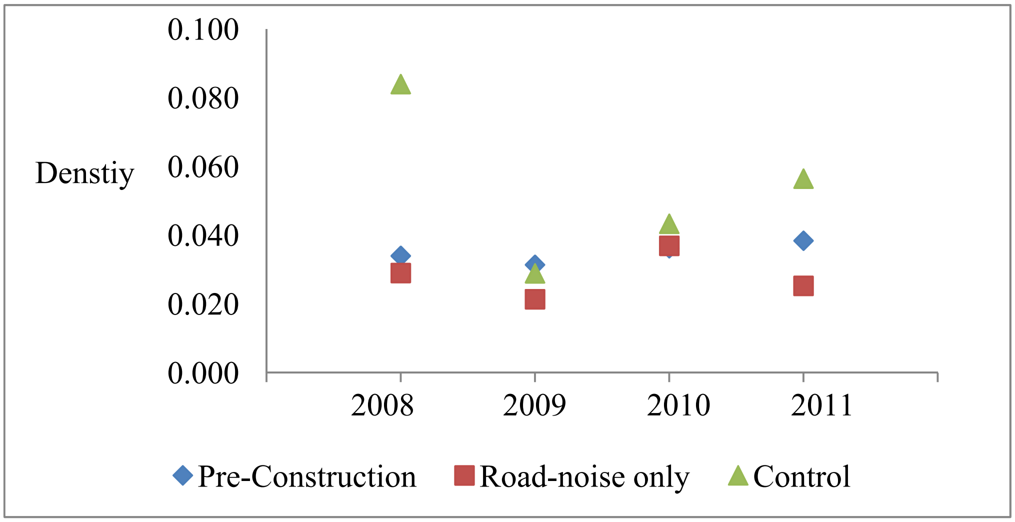

Figure 8. Density (Territories per ha) of Golden-Cheeked Warblers by Study Site, 2008–2011.

Table 2. Density (Territory/ha) of Golden-Cheeked Warblers by Study Site Type from 2008–2011.

	Area surveyed (ha)	Total number of territories	Density (territories/ha)
2008			
Pre-construction	414.09	14	0.034
Road-noise only	514.55	15	0.029
Control	307.34[a]	26	0.085[a]
Total	1235.98	55	0.044
2009			
Pre-construction	414.09	13	0.031
Road-noise only	514.55	11	0.021
Control	761.43	22	0.029
Total	1690.07	46	0.027
2010			
Pre-construction	414.09	15	0.036
Road-noise only	514.55	19	0.037
Control	761.43	33	0.043
Total	1690.07	67	0.040
2011			
Construction	49.5	3	0.061
Pre-construction	364.59	14	0.038
Road-noise only	514.55	13	0.025
Control	761.43	43	0.057
Total	1690.07	73	0.043

[a] Density estimates for the control study site in 2008 are biased high because total survey area was minimal that year.

Adult Banding and Resights

We banded 7 adult (after-hatch year) male warblers and 1 adult female warbler in 2009, and 2 adult male warblers (AHY) in 2010. We did not detect any of the adults banded in 2009 during 2010 and 2011 territory monitoring. We detected both adults banded in 2010 during the 2011 field season. Both birds established a territory within 25 m of their 2010 territory location (Appendix, Figure A4).

Nest Behavior

We placed nest cameras on 8 nests in 2009-2011 (Table 2 and 4). Of the 8 nest cameras, 4 recorded predation events, 3 from Texas rat snakes and one due to an unknown raptor (Appendix A, Table 6). Mean number of visits to the nest by adults ranged from 0.25/hour to 10.2/hour (Table 3). We found no effect from study site ($F_{8,4}$ = 0.22, P = 0.81) or year ($F_{8,4}$ = 0.36, P = 0.72) on adult visits per hour; however, sample sizes within study site types and years was small.

Table 3. Mean Visits to Nests by Adult Warblers per Hour to Nests, Separated by Nest Stage and Stage Period, from Nest Video Data Recorded in 2009–2011.

Nest	Study Site	Nest Stage	Stage Days	Visits per hour
2009				
1	Road-noise Only	Nestling	1-4	7.88
		Nestling	1-4	1.06
2	Pre-construction	Nestling	5-8	0.75
3	Pre-construction	Nestling	1-4	0.25
		Incubation	1-4	1.75
4	Control	Incubation	5-8	1.25
2010				
		Nestling	5-8	6.50
1	Pre-construction	Nestling	9-12	8.80
		Incubation	9-12	0.60
		Incubation	13-16	1.00
2	Control	Nestling	1-4	3.30
2011				
1	Pre-construction	Nestling	13-16	10.20
2	Road-noise Only	Nestling	13-16	4.10

Playback Study

Between 2010 and 2011, we conducted 174 playback surveys on golden-cheeked warblers in our treatment and road-noise only study sites, 38 no-noise control surveys (conducted

> 400 m from the ROW), and 136 experimental construction noise playback surveys. Of these surveys, 2 of the control surveys elicited a response and 10 construction noise playback surveys resulted in a response (Table 4). There was no interaction between study site and distance from the ROW ($F_{3,170} = 0.31$, $P = 0.58$), and there was no effect on warbler behavioral responses from study site ($F_{2,171} = 2.7$, $P = 0.11$) or distance from the ROW ($F_{2,171} = 0.98$, $P = 0.32$). There was no interaction between year and study site ($F_{3,170} = 0.78$, $P = 0.38$), and there was no effect from year ($F_{1,172} = 1.31$, $P = 0.25$) on warbler behavioral responses. There was no effect from type of playback survey ($F_{1,172} = 0.20$, $P = 0.66$).

Table 4. Results of Playback Experiments by Study Site and Survey Type, 2010–2011.

Site	Survey Type	Total	Response Number
2010			
Pre-construction			
	Experimental	4	0
	Control	0	0
Road-noise only			
	Experimental	11	1
	Control	3	0
Control			
	Experimental	41	3
	Control	14	2
2011			
Construction			
	Experimental	5	0
	Control	1	0
Pre-construction			
	Experimental	12	0
	Control	2	0
Road-noise only			
	Experimental	14	0
	Control	2	0
Control			
	Experimental	49	5
	Control	15	0

Experimental survey implies recorded noises broadcast; control survey implies no noises broadcast, to test for potential observer effect.
Treatment (pre-construction and construction) and road-noise only playbacks < 400 m from the ROW. Control (no-noise) playbacks > 400 m from the ROW; still within treatment and road-noise only study sites (< 1 km from ROW).

Warbler Song Recordings

For song type A we found significant differences between years within Phrase 2 and 3 (Table 5). A Tukey post-hoc comparison indicated that mean bandwidth for phrase 2 was greater in 2009 than in 2011 ($P < 0.001$), due to lower minimum frequencies ($P = 0.028$) and higher maximum frequencies, ($P < 0.001$). Additionally, bandwidth for phrase 2 in 2010 had a larger bandwidth than 2009 ($P = 0.016$), due to a lower minimum frequency in 2010 than 2009 ($P = 0.028$). A Tukey comparison indicated a similar difference among years for phrase 3, with a larger bandwidth in 2009 than 2010 ($P = 0.005$) and 2011 ($P < 0.001$), due to a lower minimum frequency in 2009 than 2010 ($P = 0.001$) and 2011 ($P < 0.001$). We found a significant interaction between year and study site for maximum frequency in phrase 3; the maximum frequency in the control site for 2011 was higher than the control site for 2009 ($P = 0.004$) and the treatment site for 2009 ($P = 0.026$). We found no statistically significant differences in characteristics of song type A among study sites or site by distance at $\alpha < 0.05$ (Table 5).

For song type B we found significant differences across phrases between years (Table 5). A Tukey comparison indicated phrase 1 and phrase 2 for 2011 had smaller mean bandwidths than 2009 ($P = 0.002$, $P = 0.007$, respectively) and 2010 ($P = 0.033$, $P = 0.004$, respectively). This was likely due to a lower minimum frequency for 2009 (P $P = 0.003$, $P < 0.001$, respectively), and a slightly lower minimum frequency for 2010 ($P = 0.07$), $P = 0.04$, respectively) although not significant at $\alpha < 0.05$ for phrase 1. An additional Tukey comparison also indicated a smaller mean bandwidth in phrase 3 for 2011 than 2009 ($P = 0.019$), due to lower minimum frequency in 2009 than 2011 ($P = 0.027$).

We also found a study site by distance from the ROW interaction for the lower frequency of phrase 2 within song type B. A Tukey comparison indicated an increased lower frequency within the treatment site between 0-300 m in phrase 2; however, no values within the Tukey comparison were found to be significant for study site when distance from the ROW was taken into account, at $\alpha < 0.05$.

Table 5. Results for Factorial ANOVA and ANCOVA, Comparing Average Bandwidth, Lower Frequency, and Upper Frequency for Each Song Phrase of Warblers by Distance to the ROW, Year, and Study Sites. Comparisons separated by A and B type songs.

* denotes significance at α = 0.05.

A song	**Site**		**Site by Year**		**Year**		**Site by Distance**	
Phrase 1	$F_{4,54}$	**P-value**	$F_{8,50}$	**P-value**	$F_{4,54}$	**P-value**	$F_{2,34}$	**P-value**
Mean bandwidth	0.969	0.386	0.613	0.655	0.554	0.578	0.877	0.426
Lower frequency	0.804	0.453	0.733	0.574	1.315	0.277	0.107	0.899
Upper Frequency	0.934	0.399	0.624	0.648	0.825	0.444	0.749	0.481
Phrase 2								
Mean bandwidth	0.555	0.578	0.665	0.619	18.847	<0.001*	0.237	0.790
Lower frequency	1.252	0.294	0.104	0.981	16.935	<0.001*	0.077	0.926
Upper Frequency	0.320	0.728	1.969	0.114	4.128	0.022*	0.360	0.701
Phrase 3								
Mean bandwidth	1.128	0.331	0.598	0.666	17.406	<0.001*	0.368	0.695
Lower frequency	2.056	0.138	0.070	0.991	18.871	<0.0001*	0.121	0.887
Upper Frequency	0.587	0.560	3.534	0.013*	2.985	0.059	1.228	0.307
B song								
Phrase 1	$F_{4,54}$	**P-value**	$F_{8,50}$	**P-value**	$F_{4,54}$	**P-value**	$F_{2,34}$	**P-value**
Mean bandwidth	1.621	0.207	2.250	0.077	6.604	0.003*	0.547	0.584
Lower frequency	1.006	0.372	0.574	0.683	6.143	0.004*	3.181	0.054
Upper Frequency	2.150	0.126	2.333	0.068	1.367	0.264	1.817	0.178
Phrase 2								
Mean bandwidth	1.229	0.301	1.918	0.122	6.511	0.003*	0.547	0.584
Lower frequency	0.127	0.881	0.527	0.716	9.086	<0.001*	3.445	0.043*
Upper Frequency	1.088	0.344	1.577	0.195	2.758	0.072	0.264	0.769
Phrase 3								
Mean bandwidth	0.165	0.848	0.958	0.439	4.597	0.014*	0.153	0.858
Lower frequency	0.238	0.789	0.089	0.987	3.599	0.034*	2.518	0.096
Upper Frequency	0.338	0.714	1.055	0.389	2.285	0.112	1.092	0.347

DISCUSSION

Construction activity along Highway 71 occurred in a small portion of the study area during the 2011 field season, and the area included few birds (Appendix, Figure A5). Because of this small sample size and without post-impact data, we can make limited assessments of the impact of highway construction on the productivity and behavior of golden-cheeked warblers. Instead this report demonstrates that inter-annual and site variability are important considerations in an impact assessment such as this study.

Our assumption that ambient noise would vary with distance from the ROW was not supported by our study, suggesting that the effects of roadways permeates into the oak-juniper woodland for a greater distance than expected. In 2011, we observed increased ambient noise levels across the study area, possibly due to an increase in vehicle loading. We also observed louder noise levels within the construction site than the pre-construction site, specifically when compared to distances farther from the ROW. However, because there was no increase in noise levels close to the ROW, this was likely due to something other than road construction.

Productivity changed with years and study sites but not in response to road noise. We observed no changes in pairing success or fledging success by study site or distance from the ROW. Pairing success was lower in 2010 in the control site and fledging success was lower in 2009 than other years. If construction noise impacted golden-cheeked warbler productivity, we would expect to see a change in productivity between the construction and control site, between 2010 and 2011; this did not occur.

There was no indication that birds directly reacted to construction noise or that they altered their singing or nesting behavior. We found no effect from study site, distance from the ROW, or year on warbler reactions to construction noise playbacks. Analysis of warbler song recordings displayed larger bandwidths for song type A, phrase 2 in 2010, and song type A, phrase 3 in 2009. Analysis also displayed smaller bandwidths in 2011 phrase 1, 2, and 3, and specifically a smaller bandwidth within 2011 treatment sites than 2009 or 2010 treatment sites. These changes in bandwidth do not suggest any reaction to road noise. Additionally, we discovered an increased lower frequency closer to the ROW for phrase 2 of song type A. This suggests a reaction to noise, however because this shift was not within the construction site only, this was likely a result of road noise, not road construction noise. We found no effects on nest behavior or territory placement.

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APPENDIX: MAPS AND DATA FROM THE STUDY

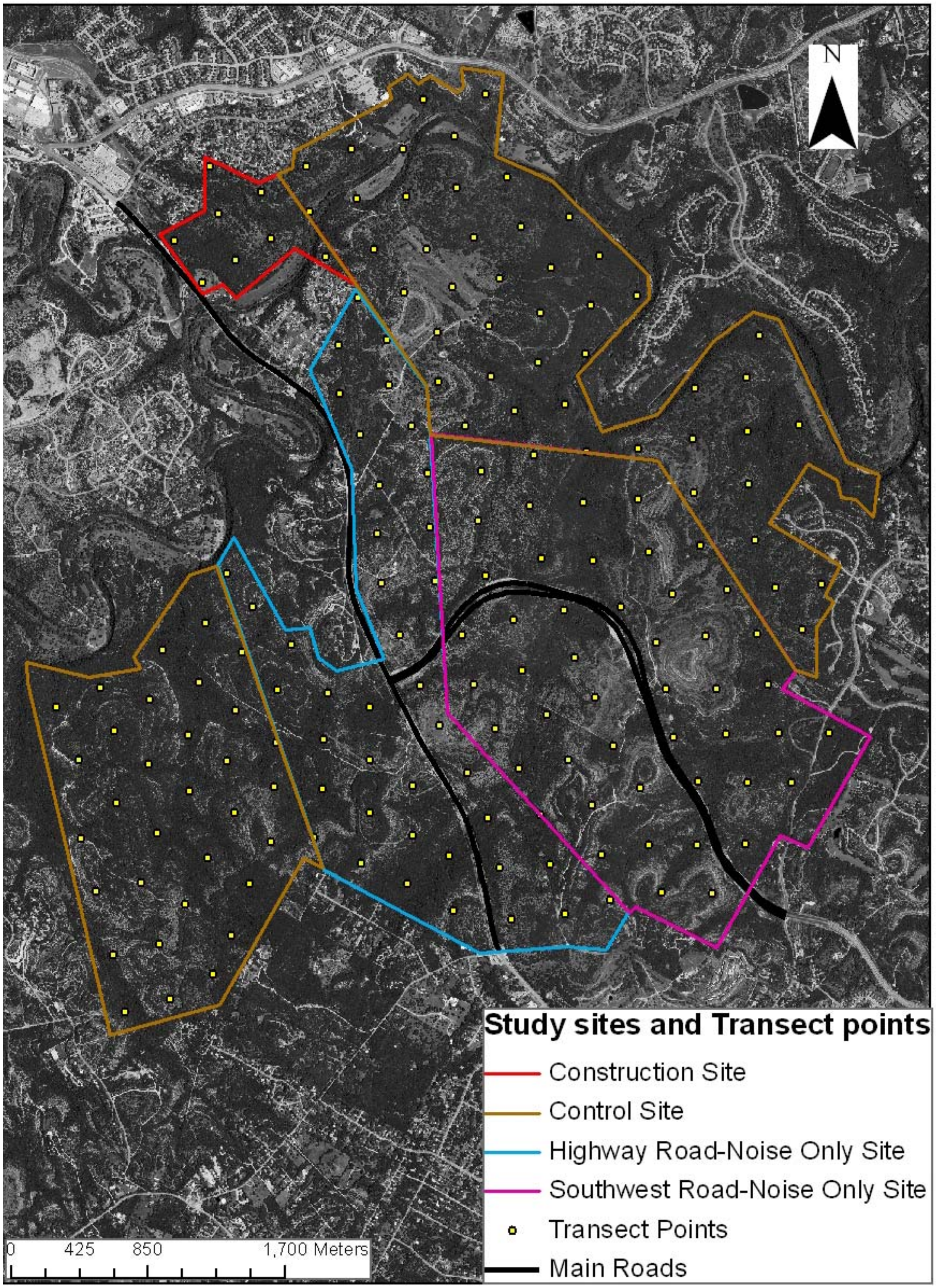

Figure A1. Map Showing Study Sites and Transect Points across Barton Creek Habitat Preserve for 2011.

This was the first year of road construction activity at our study site.

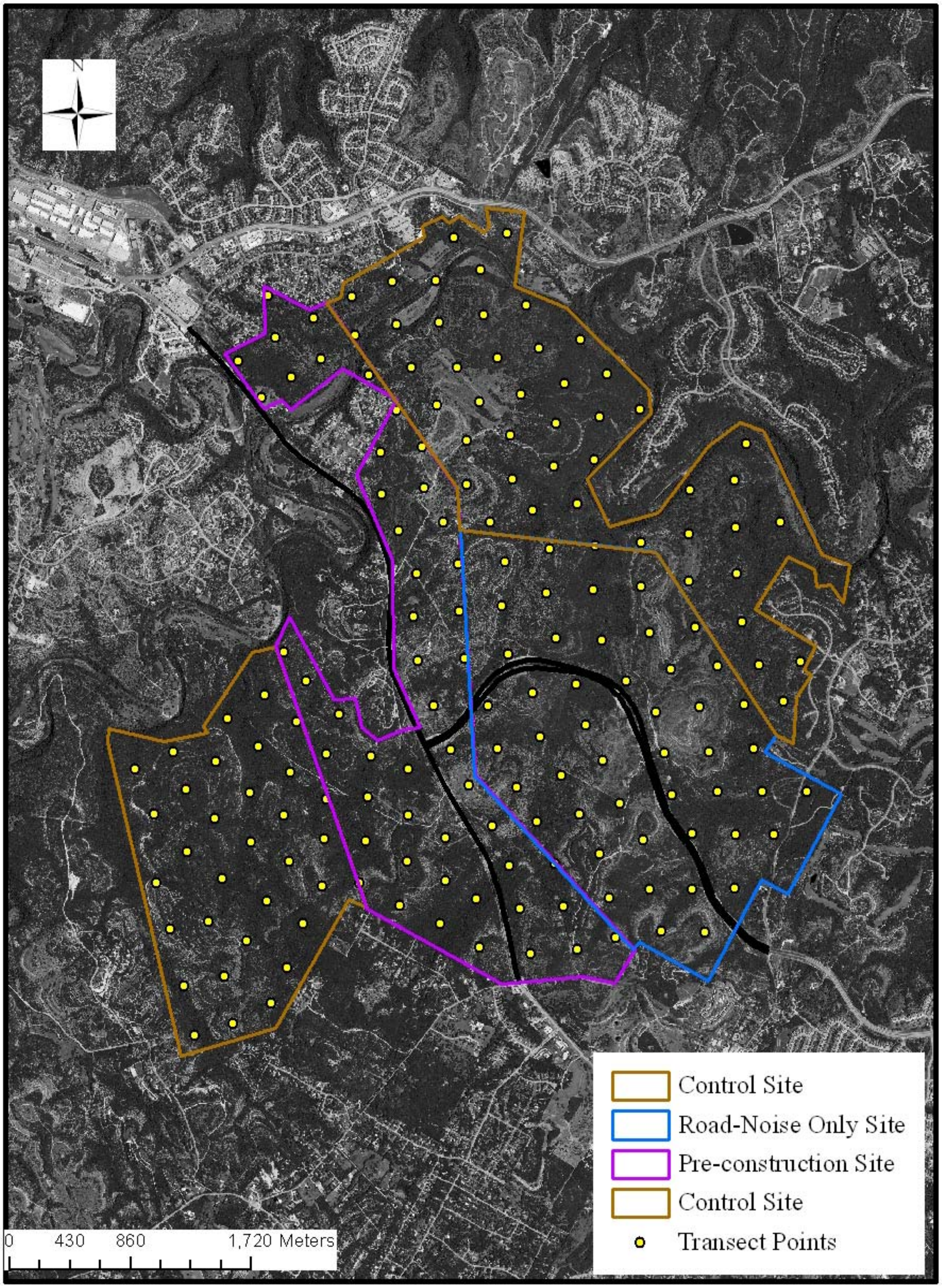

Figure A2. Map Showing Study Sites and Transect Points across Barton Creek Habitat Preserve for 2009 and 2010.

These study sites were utilized during the pre-construction monitoring phase.

Year	Study Site Type		Detections		Monitored Territories		Paired Territories			Territories Fledged			Nests	fledged
			n		n		%	total		%	total		total	total
2008														
	Pre-construction		17		17		n/a			88.2	15			
	Road-noise Only		13		13		n/a			92.3	12			
	Control		26		23		n/a			91.3	21			
2009														
	Pre-construction		19		16		87.5	14		57.4	8		5	3
	Road-noise Only		16		11		72.7	8		50	4		2	1
	Control		43		25		76	19		52.6	10		1	0
2010														
	Pre-construction		16		15		73.3	11		71.7	8		2	0
	Road-noise Only		19		19		78.9	15		80	12		0	n/a
	Control		35		33		75.8	25		80	20		4	2
2011														
	Construction		3		3		33.3	1		100	1		1	1
	Pre-construction		16		14		85.7	12		83.3	10		2	1
	Road-noise Only		18		13		84.6	11		72.7	8		5	3
	Control		45		43		58.1	25		80	20		10	8

Figure A3. Count and Percentage of Paired and Successful Golden-Cheeked Warbler Territories, Nest Success in Study Sites for 2008–2011.

Pairing success was not measured in 2008.

Detections includes birds that did not settle a territory (i.e., floaters), birds that we detected early in the season that were migrating through the area, or non-monitored territories.

Paired territories is equivalent to the number of females that we detected within monitored territories during the season.

Failed nests includes those that were predated, abandoned, or failed for unknown reasons

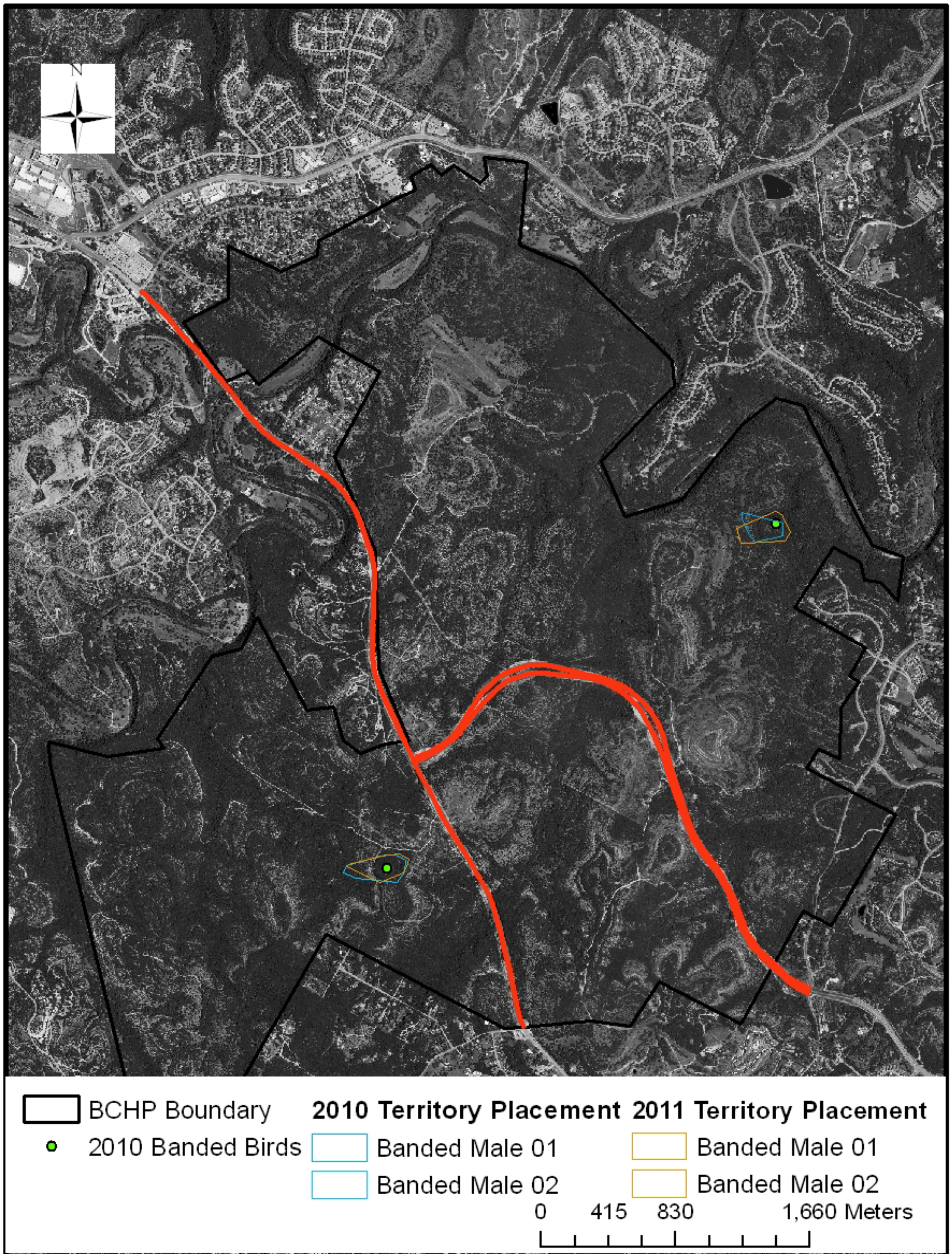

Figure A4. Map Showing a) 2010 Banding Locations, b) 2010 Territory Placement of Banded Birds, and c) 2011 Territory Placement of Banded Birds.

Territory centroids for both birds in 2011 were within 25 m of territory centroids for 2010.

Figure A5. Map Showing Warbler Territory Placement within the Construction Site, in Relation to Highway 71.

These territories were mapped during road construction activity in 2011. Distances from each territory centroid to Highway 71 were 156 m, 261 m, and 536 m.