A before–after control–impact assessment to understand the potential impacts of highway construction noise and activity on an endangered songbird

Ashley M. Long | Melanie R. Colón | Jessica L. Bosman | Dianne H. Robinson | Hannah L. Pruett | Tiffany M. McFarland | Heather A. Mathewson | Joseph M. Szewczak | J. Cal Newnam | Michael L. Morrison

Abstract

Anthropogenic noise associated with highway construction and operation can have individual- and population-level consequences for wildlife (e.g., reduced densities, decreased reproductive success, behavioral changes). We used a before–after control–impact study design to examine the potential impacts of highway construction and traffic noise on endangered golden-cheeked warblers (*Setophaga chrysoparia*; hereafter warbler) in urban Texas. We mapped and monitored warbler territories before (2009–2011), during (2012–2013), and after (2014) highway construction at three study sites: a treatment site exposed to highway construction and traffic noise, a control site exposed only to traffic noise, and a second control site exposed to neither highway construction or traffic noise. We measured noise levels at varying distances from the highway at sites exposed to construction and traffic noise. We examined how highway construction and traffic noise influenced warbler territory density, territory placement, productivity, and song characteristics. In addition, we conducted a playback experiment within study sites to evaluate acute behavioral responses to highway construction noises. Noise decreased with increasing distance from the highways. However, noise did not differ between the construction and traffic noise sites or across time. Warbler territory density increased over time at all study sites, and we found no differences in warbler territory placement, productivity, behavior, or song characteristics that we can attribute to highway construction or traffic noise. As such, we found no evidence to suggest that highway construction or traffic noise had a negative effect on warblers during our study. Because human population growth will require recurring improvements to transportation infrastructure, understanding wildlife responses to anthropogenic noise associated with the construction and operation of roads is essential for effective management and recovery of prioritized species.

Keywords

before–after control–impact, construction noise, golden-cheeked warbler, impact assessment, *Setophaga chrysoparia*, traffic noise
INTRODUCTION

Anthropogenic noise associated with the construction and operation of highways can have individual- and population-level consequences for wildlife (e.g., insects [Costello & Symes, 2014; Lampe, Reinhold, & Schmoll, 2014], amphibians [e.g., Bee & Swanson, 2007; Hoskin & Goosem, 2010], mammals [e.g., Schaub, Ostwald, & Siemers, 2008; Shier, Lea, & Owen, 2012]). Birds are the most well-studied taxa concerning this topic, and research suggests that birds inhabiting areas near highways may be at reduced densities and have lower reproductive success (e.g., Halfwerk, Holleman, Lessells, & Slabbeekoor, 2011b; Halfwerk et al., 2011a; Reijnen & Foppen, 1991). Noise pollution along highways can also inflict hearing damage, induce physiological stress, and mask intra- and interspecific communications in birds (Dooling & Popper, 2007; Kaseloo, 2004; Slabbeekoor & den Boer-Visser, 2006; Slabbeekoor & Peet, 2003; Warren, Katti, Ermann, & Brazel, 2006). In response to masking, birds may sing at higher minimum frequencies, a phenomenon termed vocal adjustment, which can require increased energy and, at the temporal extreme, could contribute to population divergence (e.g., Slabbeekoor & Smith, 2002). However, the impacts of highway construction and traffic noise on birds are species specific, and not all avifauna respond negatively (Clark & Karr, 1979; Ferris, 1979; Heldlin & Seiler, 2003; Reijnen & Foppen, 2006). Therefore, it is important to quantify avian responses to noise disturbance and use the data to help guide management and regulatory actions, especially for species of conservation concern.

Determining the potential impacts of highway noise on birds can be difficult outside of laboratory conditions unless the effects are great and the potential impact is well defined. Researchers must account for (1) correlated variables (Dooling & Popper, 2007), (2) different kinds of noise occurring at the same time (e.g., vehicular traffic vs. construction activity; Burton, Armitage, Musgrove, & Rehfsch, 2002; Lackey et al., 2011; Blickley & Patricelli, 2012), and (3) variation in avian responses with increasing distance from the noise source (Halfwerk et al., 2011b; Summers, Cunnington, & Fahrig, 2011). As with other environmental impact assessments, field-based noise studies may be limited by replication and randomization because it is rarely appropriate to replicate a potentially damaging impact, and there are few situations where assigning multiple impacts to random locations would be possible or desirable (e.g., constructing multiple roads in random locations at the same time across a variety of ecological conditions; Marshall et al., 2012). Given these limitations, researchers can employ before–after control–impact (BACI) study designs to evaluate whether a change in environmental conditions has occurred and to estimate the magnitude and duration of exposure (Morrison, Block, Strickland, Collier, & Peterson, 2008). Due to resource and time constraints, BACI designs are infrequently used to examine the potential effects of noise on birds (but see Goudie & Jones, 2004). However, the BACI framework allows researchers to address lack of replication and randomization by examining avian responses before, during, and after a noise disturbance across treatment and control sites, and to statistically evaluate potential impacts by testing for interactions between time and site variables (Green, 1979; Underwood & Chapman, 2003).

We used a BACI design to examine the potential impacts of highway construction noise on golden-cheeked warbler (Setophaga chrysoparia; hereafter warbler) habitat selection, reproduction, and behavior in an urban setting. The warbler is an endangered, migratory songbird that breeds exclusively in central Texas, USA (Komar et al., 2013; Ladd & Gass, 1999; Pulich, 1976). The U.S. Fish and Wildlife Service listed the species under the U.S. Endangered Species Act in 1990, citing habitat loss and fragmentation as the primary threats to warbler persistence (USFWS 1990). These factors will likely remain a concern for warblers as human populations grow and their associated infrastructure expands to meet demand (Groce, Mathewson, Morrison, & Wilkins, 2010). Previous research suggests that highway noise does not affect the presence, productivity, density, or behavior of warblers in rural locations (Benson, 1995; Lackey et al., 2011; Mathewson et al., 2013), but warbler responses to anthropogenic noise in louder, urban settings are unknown.

We mapped and monitored warbler territories before (2009–2011), during (2012–2013), and after (2014) highway construction at (1) a treatment site exposed to highway construction and traffic noise, (2) a control site exposed only to traffic noise, and (3) a control site exposed to neither highway construction or traffic noise. We recorded noise at varying distances from the highways at our construction and traffic noise sites. We expected that noise would be greatest at the construction site during the years of construction and that noise would decrease with increasing distance from the highway at both sites. If warblers responded negatively to highway construction noise, we predicted they would exhibit one or more of the following responses at the construction site during- or postconstruction relative to the preconstruction period: reduced densities, displacement from the highway, decreased pairing or fledging success, or higher minimum song frequencies. In addition, we predicted that warblers at the control site and those farther from highways would exhibit acute responses to experimentally introduced highway construction noise as individual birds located further from the sound source would be experiencing a novel disturbance. The results of our comprehensive assessment may help inform conservation efforts for warblers. In addition, our study demonstrates the use of a robust BACI study design to quantify wildlife responses to anthropogenic noise.

MATERIALS AND METHODS

2.1 Study area and design

We conducted our research from March to July 2009–2014 in Austin, Texas (~30°N, 98°W), located on the eastern edge of the warbler’s breeding range (Figure 1). Warbler habitat in this region is typically composed of Ashe juniper (Juniperus ashei), Texas oak (Quercus buckleyi), live oak (Q. virginiana), and various other hardwoods (Diamond, 1997). Existing habitat in the city of Austin is fragmented by urban and residential development (Collier et al., 2012; Mathewson et al., 2012). Local mean minimum and mean maximum temperatures in July are 27°C and 35°C (NOAA 2015). Mean annual precipitation is 87 cm (NOAA 2015).
We delineated one treatment site and two types of control sites at the Barton Creek Habitat Preserve, a 1,600-ha property managed by The Nature Conservancy. We selected study sites with similar ecological characteristics that were exposed to similar environmental conditions throughout the year (e.g., temperature, precipitation). The treatment site (hereafter construction site) was a 301-ha area of potential warbler habitat located ≤800 m from a 5.2 km segment of Highway 71 that was exposed to construction noise associated with highway expansion in 2012 and 2013 and traffic noise throughout the study. Annual average daily traffic (AADT) rates for this portion of the highway were 30,000–39,000 vehicles/day (TXDOT 2012). As such, AADT on Highway 71 was comparable to traffic loads on highways located in other large U.S. cities (e.g., Houston, Dallas; TXDOT 2016).

During the Highway 71 expansion project, the Texas Department of Transportation did not remove warbler habitat along the highway, but warblers were exposed to noises associated with construction activities, such as backup warning beepers, diesel engine noise, and loading dump trucks. The first of our control sites (hereafter traffic noise site) was a 416-ha area of potential warbler habitat located ≤800 m from a 2.8-km segment of Southwest Parkway adjacent to Highway 71 (Figure 1) that did not undergo construction during our study and, therefore, allowed us to separate the effects of traffic noise from construction noise on warbler responses. AADT rates for this portion of Southwest Parkway were 16,200 vehicles/day (C. Newnam, pers. comm.). Our second control site (hereafter control site) included 682-ha of potential warbler habitat located >800 m from Highway 71 or other major roads. We collected data at all sites during three treatment phases: preconstruction (2009–2011), construction (2012–2013), and postconstruction (2014).

2.2 Noise

We established paired transects perpendicular to Highway 71 in the construction site and perpendicular to Southwest Parkway in the traffic noise site. We spaced transect pairs across the construction and traffic noise sites to account for potential within-site variability in warbler density. As such, the number of transect pairs (two or three) depended on the total area of each study site. We placed Extech 407764 Datalogging Sound Meters (Extech Instruments, Nashua, New Hampshire, USA) programmed to record noise from 06:00 to 12:00 on each transect at stations 16, 32, 64, 128, 256, and 512 m from the highways. We randomly sampled one transect pair every 2 days from late March to late May, rotating between the construction and traffic noise sites. This protocol allowed us to sample 2–3 transect pairs per week throughout much of the warbler breeding season during the hours when songbirds are most active. We calculated the mean and maximum noise for each sound meter for use in analyses. We did not place sound meters at the control site because pilot data collected in 2008 indicated that highway noise could not be detected at distances >800 m from highways in the study area. During the pilot year, mean noise levels were 36 dBA at the control site, which is consistent with noise levels recorded in libraries and quiet rural areas.

2.3 Territory density, placement, and size

We established transects ≥300 m apart covering the spatial extent of each study site. Transects in the construction and traffic noise sites extended ≤1 km from the highways. Transects in the control site were ≤1.5 km and located ≥800 m from the nearest highway. Each day from late February to late March, we slowly walked (~1 km/h) along transects from 07:00 to 13:00 and recorded the locations of singing male warblers using handheld Global Positioning System (GPS) units (≤10 m accuracy). If we heard another warbler in close proximity to our initial detection, we walked to the newly identified bird and recorded a GPS point at its location. After we obtained GPS locations on all singing males in the area, we returned to the transect to search for additional warblers. We used this methodology to ensure full survey coverage of the study sites, but we did not use detections recorded during transect surveys for analyses purposes. Rather, we used the locations to aid relocation of male warblers during subsequent territory mapping and monitoring activities.

We mapped and monitored each territory for up to 1 hr at least once per week for the duration of the warbler breeding season (March–June). If we detected previously unidentified individuals during our territory mapping and monitoring surveys, we recorded GPS locations for the new individuals and added the territories to our weekly survey rotation. Our intent with this methodology was to identify all territorial males within each study site.

During territory mapping in 2009–2010, we recorded GPS locations of males each time they moved ≥20 m until we recorded 3–6 locations per sampling occasion. In 2011, we modified our territory mapping protocols and recorded GPS locations of males every 2 min
for 1 hr or until we could no longer detect focal individuals (Barg, Jones, & Robertson, 2005). We used data collected by both methods to create minimum convex polygons (MCPs; the outermost points in a location dataset) for all territories with ≥15 point locations and identified the associated centroids (i.e., the central point in each MCP) for each territorial male (i.e., male relocated for ≥4 weeks). We stopped mapping territories once we detected fledglings or once we were unable to detect the focal male during three consecutive visits. Because we repeatedly and thoroughly covered each study site during our surveys, we defined territory density as the number of MCPs per hectare of potential warbler habitat within each study site. We defined territory placement as the distance of the territory from the highway, which we measured as the shortest distance of each territory centroid from the highway in the construction and traffic noise sites. We only included warbler territories that were located ≤400 m from highways in our distance analyses to ensure that territories were plausibly exposed to construction or traffic noise (see Noise section above; Reijnen & Poppen, 2006; Summers et al., 2011; McClure, Ware, Carlisle, Kaltenecker, & Barber, 2013).

2.4 | Pairing and fledging success

We used a modified version of the Vickery Index (Vickery, Hunter, & Wells, 1992) to examine the reproductive status of each territory, specifically the male’s pairing and fledging success (as in Klassen, Morrison, Mathewson, Rosenthal, & Wilkins, 2012; Marshall, Morrison, & Wilkins, 2013; Stewart, Morrison, Hutchinson, Appel, & Wilkins, 2014). We observed warbler behavior and activity during each territory mapping visit and ranked the status of the territory as follows: (1) male present ≥4 weeks, (2) pair present ≥4 weeks, (3) material carried to the presumed nestling, (4) food carried to the presumed nestlings, and (5) fledglings sighted by the observer. When the behavioral rank recorded in a territory was ≥2, we considered the male successfully paired. When we recorded a behavioral rank of five, we considered the pair reproductively successful. We calculated pairing success as the number of successfully paired territorial males relative to the total number of territorial males. We calculated fledging success as the number of paired territorial males that successfully fledged one or more host young relative to the total number of paired territorial males.

Direct measures of nest success would provide more detailed analyses of reproductive output (Reidy, O’Donnell, & Thompson, 2015). However, reproductive indices, such as the Vickery method, allow observers to avoid potential biases associated with nonrandomly collected nest data (Martin & Geupel, 1993), sample a larger spatial extent (Villard & Pärt, 2004), and predict territory outcomes when females or nests are difficult to locate and monitor (Craft, 1998). Additionally, the Vickery method limits disruption of nesting pairs (Götmark, 1992; Maas, 1998), which is important for studies that involve rare or endangered species. Warblers maintain territorial boundaries during the breeding season (Ladd & Gass, 1999), but there can be overlap around territory edges. We designed our methods such that incursions of neighboring warblers into adjacent territories did not negatively affect our ability to assign productivity outcomes to territories. We took extreme care to properly link breeding outcomes with specific territories by conducting repeated visits to each territory over the course of the breeding season and only assigning fledglings ≤2 weeks of age to territories. Because we used the same methodology across sites, we are confident in assuming that any error in assigning reproductive outcomes to territories was similar across sites.

2.5 | Song characteristics

Each year of the study, we placed Song Meter SM2 digital field automatic recording units (ARUs; Wildlife Acoustics, Maynard, Massachusetts, USA) across all study sites to examine how highway construction and traffic noise influenced warbler song characteristics. We placed ARUs in randomly selected territories at various distances from the highways (0–300, 300–600, 600–900 m) at the construction and traffic noise sites. We placed ARUs randomly within the control site given a lack of linear features comparable to the highways at other sites. We allowed each ARU to record warbler songs for 3–4 weeks before moving it to another randomly selected territory.

We used SonoBird™ v1.5.8 (DNDesign, Arcata, CA, USA) to extract warbler songs from our recordings. The extraction process identified warbler songs using time–frequency patterns within the waveforms of the recordings but also identified songs of other species that fell within the same frequency range (e.g., black-throated green warblers [S. virens] and northern cardinals [Cardinalis cardinalis]). Therefore, we visually inspected the sonograms of extracted songs to ensure proper species identification. We also identified and excluded any sonograms with extensive background noise that could interfere with subsequent calculations of warbler song metrics (e.g., warbler song with northern cardinal singing in the background).

We used SonoBird™ v1.6.5 (DNDesign, Arcata, CA, USA) to manually analyze warbler songs. Warblers have two primary song types, the A-song and the B-song (Bolsinger, 2000), and each type is divided into three phrases. We identified each individual song by type and phrase. Within each phrase, we obtained lower and upper bandwidth cutoffs across phrase-specific time steps to represent the mean lower frequency and mean upper frequency. The difference between the two bounds represented the bandwidth of the phrase.

2.6 | Playback experiment

We conducted a playback experiment within a subset of territories to examine warbler responses to played recordings of construction noise at ~80 dBA (measured at ~5 m)—a level known to be annoying to humans but that does not cause hearing damage (Ristovska, Gjorgjev, Polozhani, Kočubovski, & Kendrovski, 2009). The primary noises of the treatment broadcast included backup warning beeps, diesel engine noise, and loading dump trucks, and we used the same noise clip in all surveys. To control for the potential effects of observer presence, we also replicated the methodology of the playback surveys without playing the construction noise recordings. We conducted
our playback surveys on days with and without construction activity, but we did not broadcast construction noise more than once every 10 days to avoid habituating individuals to the recordings.

We randomly selected warbler territories in all sites at varying distances from the highways to receive a construction or control playback. Once we located a male warbler in the selected territory, we recorded the individual's behavior for 2 min. We then broadcast construction noise with a handheld speaker or displayed a silent handheld speaker to the warbler for a maximum of 5 s. During playback surveys, we maintained a distance of ~20 m from the focal bird to limit observer influence on the warbler's response. Each construction or control playback ceased after 5 s or as soon as the subject's behavior changed. We considered a playback experiment to have elicited a behavioral response if the warbler stopped singing or flew from its perch and out of the surveyor's view (≥10 m). We recorded the presence or absence of a behavioral response to the construction or control playback.

2.7 Analyses

For an impact assessment using the BACI framework, data analyses should include an interaction term between treatment site and phase to determine whether there is a statistically significant difference at the treatment site following the disturbance (Morrison et al., 2008:229–264). For this study, a change in any of the metrics of interest at the construction site during or after the construction phase relative to other phases and sites—as represented by a statistically significant interaction—would suggest that construction activities had affected warblers. For example, to find evidence in support of the vocal adjustment hypothesis under the BACI framework, higher minimum frequency songs recorded at the construction site during- or postconstruction relative to the preconstruction phase could indicate that warblers adjusted their communication signals to avoid masking (reviewed in Patricelli & Blickley, 2006) and, therefore, could suggest that a construction noise-related impact had occurred.

We used two-way factorial analyses of variance (ANOVA) to test the interactive effects of site, treatment phase, and distance from the highway on our continuous response variables (i.e., noise, song metrics). We used logistic regression to examine the interactive effects of site and phase on our binary response variables (i.e., pairing and fledging success). If there was a significant interaction (α = 0.05), we visually examined plots with calculated means and 95% confidence intervals (hereafter 95% CI) to determine the direction, magnitude, and biological significance of the patterns. Sample sizes or other factors sometimes required that we deviate from the general approach described above. We used a nonparametric Friedman's rank-sum test to examine territory density in relation to site and phase (Zar, 1999). Friedman's test is preferred over ANOVA with repeated measures when there is only one observation for the response variable in each combination of levels of groups and blocks and where the normality assumption may be violated (Zar, 1999). In our case, we had one measure of territory density for each site and phase combination. Additionally, low sample sizes prohibited us from examining the interactive effects of site, phase, and distance from the roadway on territory placement within 400 m of highways. Instead, we used linear regression to examine how distance from the highway affected territory placement separately by site and phase. We did not examine warbler responses as a function of distance at our control site because the minor roads and trails within the site were seldom used and did not resemble linear edges comparable to Highway 71 or Southwest Parkway. We used logistic regression to determine whether survey type or site independently influenced warbler responses during our playback experiments. We then used logistic regression to determine whether the probability of a warbler response to experimental playback recordings increased with increasing distance from highways. We performed all statistical analyses using the open-source program R v. 3.2.2 (R Core Development Team, Vienna, Austria).

3 RESULTS

3.1 Noise

We found a statistically significant interaction between distance and site (F_1,183 = 9.81, p < .01), indicating that differences in noise levels across the distance from highway categories depended on whether the sound meters were located in the construction site or traffic noise site. As such, we examined noise across treatment phases separately by site. Mean noise levels were 54 dB(A) ± 8 SD in the construction site and 53 dB(A) ± 6 SD in the traffic noise site. Mean maximum noise levels were 67 dB(A) ± 8 SD in the construction site and 66 dB(A) ± 7 SD in the traffic noise site. Mean and maximum noise decreased by ≤8 dB(A) with each increasing distance category from the highway across all three treatment phases at both the construction and traffic noise sites (Figure 2). We did not find a statistically significant interaction between treatment phase and distance from the highway on mean noise in the construction site (F_10,561 = 0.57, p = .84) or in the traffic noise site (F_10,298 = 0.65, p = .77). Similarly, we did not find a statistically significant interaction between treatment phase and distance from the highway on maximum noise in the construction site (F_10,561 = 0.41, p = .94). However, we did find a statistically significant interaction at the traffic noise site (F_10,298 = 2.36, p < .01). Mean and maximum noise at distances closest to the highway in the traffic noise site were ≤10 dB(A) higher during the construction and postconstruction phases when compared to the preconstruction phase. However, the substantially overlapping 95% CIs indicated that the differences in noise were not statistically different across the treatment phases for most of the distance categories at either site (Figure 2).

3.2 Territory density and placement

We mapped and monitored 450 warbler territories across the years of this study (Table 1). We found a significant difference in territory density across treatment sites and phases (Friedman χ² = 6.00, p = .05). Mean territory density was 1.3 to 1.8 times greater in the control site than the construction and traffic noise sites (Table 2). Mean territory density was between 1.5 and 1.7 times greater during the postconstruction
We found no statistically significant interaction between site and phase on warbler pairing success ($\chi^2 = 7.14, p = .13$). We also found no statistically significant interaction between site and phase on warbler fledging success ($\chi^2 = 2.42, p = .66$).

### 3.4 Song characteristics

We analyzed >19,000 A-songs ($n = 72$ song meters) and >3,500 B-songs ($n = 48$ song meters). Sample sizes were low for B-songs recorded during the postconstruction phase, so we were unable to examine statistically significant interactions for any of the B-song metrics. As such, we excluded these data from this study. We found no statistically significant interactions between treatment site and phase for most A-song metrics (Tables 3 and 4), and differences that were statistically significant were unrelated to construction noise. Similarly, we found no statistically significant interactions between treatment phase and distance from the highway (0–300, 300–600, 600–900, and >900 m) for most A-song metrics (Tables 3 and 5). Again, statistically significant differences were unrelated to construction noise.

### 3.5 Playback experiment

We conducted 321 experimental playback surveys and 96 control surveys within 172 warbler territories. Playback surveys ranged from 48 to 1,900 m from the highway. In the construction site, six warblers (10%) responded to experimental playback and one warbler (~6%) responded to control surveys. In the traffic noise site, five warblers (~6%) responded to experimental playback and one warbler (~5%) responded to control surveys. In the control site, 20 warblers (~11%) responded to experimental playback and two warblers (~3%) responded to control surveys. We found no significant main effect of playback survey type ($\chi^2 = 3.30, p = .07$) or site ($\chi^2 = 0.90, p = .64$) on warbler responses, and the predicted probability of a warbler response to experimental playback recordings of construction noise did not increase.

![Figure 2](image-url)  
**FIGURE 2** Mean and maximum noise and associated 95% confidence intervals recorded in golden-cheeked warbler (Setophaga chrysoparia) habitat at varying distances from the road before (2009–2011), during (2012–2013), and after (2014) construction activity in Austin, Texas, USA.

| Treatment phase | Site                  | Monitored territories | Pairing success | Fledging success |
|-----------------|-----------------------|-----------------------|-----------------|-----------------|
|                 |                       | #                     | %              | #               | %              |
| Preconstruction | Construction          | 39                    | 33 85          | 26 79           |
|                 | Traffic noise         | 42                    | 33 79          | 22 67           |
|                 | Control               | 105                   | 75 71          | 54 72           |
| Construction    | Construction          | 29                    | 21 72          | 13 62           |
|                 | Traffic noise         | 40                    | 27 68          | 18 67           |
|                 | Control               | 101                   | 75 74          | 57 76           |
| Postconstruction| Construction          | 19                    | 13 68          | 10 77           |
|                 | Traffic noise         | 23                    | 21 91          | 13 62           |
|                 | Control               | 52                    | 38 73          | 29 76           |

*Preconstruction = 2009–2011, construction = 2012–2013, and postconstruction = 2014.

*Territories defined as paired if a female was present for ≥4 weeks.

*Territories defined as fledged if ≥1 host young fledged from any nest attempt within a territory.

### TABLE 1

Summary of cumulative pairing and fledging success in monitored territories by treatment site and phase used to examine the potential impacts of highway construction noise on golden-cheeked warblers (Setophaga chrysoparia) in Austin, Texas, USA (2009–2014). Construction occurred from 2012 to 2013.

---

3.3 | Pairing and fledging success

Pairing success and fledging success ranged from 68% to 91% and 62% to 79%, respectively, during the three phases of our study (Table 1).
warbler (Setophaga chrysoparia) territory densities with standard deviations in parentheses and mean distance with 95% confidence intervals in parentheses for territories <400 m from roads by treatment site and phase in Austin, Texas, USA

with increasing distance from Highway 71 or Southwest Parkway ($\chi^2 = 0.03, p = .86$).

4 | DISCUSSION

Warbler territory density increased over time at all study sites, and we found no differences in warbler territory placement, productivity, song characteristics, or behavior that we could attribute to the highway construction or traffic noise that occurred during our study. Noise levels recorded at our study sites were similar or higher when compared to those recorded within warbler habitat at rural locations (Benson, 1995; Mathewson et al., 2013), and previous research suggests that some bird species are sensitive to noise levels we recorded at our study sites (e.g., Forman, Reineking, & Hersperger, 2002; Kaseloo, 2004; Reijnen, Poppen, & Veenbaas, 1997). However, the noise levels we recorded in Austin, Texas, were similar before, during, and after construction at the construction site, and noise levels were similar at the construction and traffic noise sites (Figure 2). As such, we would only expect to find differences in our warbler responses between these sites if there was an unmeasured source of anthropogenic disturbance associated with construction or traffic (e.g., visual disturbance, vibrations, dust) that negatively impacted the birds or if there were ecological differences across study sites that we did not account for in our study design. Given similarities in warbler responses across all treatment phases and sites and with increasing distance from the highways, there is no evidence to support these alternative hypotheses.

It is possible that greater levels of highway construction or traffic noise could have a negative impact on warblers. However, the results of our playback study where we exposed birds to recordings of construction noise at ~80 dB(A) suggest that the noise would have to be close range and much higher than levels typically recorded at construction sites (e.g., 90 dB(A); Kerr, Brousseau, & Johnson, 2002). Alternatively, warblers may be more responsive to construction noise that is chronic. Previous research demonstrated that yellow-rumped warblers (S. coronata) are less likely to place their territories in close proximity to compressors used in oil and gas production, which typically operate at 75–90 dB(A) (maximum 105 dB(A)), 24 hr a day, 365 days a year (Bayne, Habib, & Boutin, 2008). Similarly, ovenbirds (Seiurus aurocapilla) exhibit reduced pairing success when exposed to sustained oil and gas compressor noise (Habib, Bayne, & Boutin, 2008). Golden-cheeked warblers at our construction and traffic noise sites experienced noise levels similar to those produced by oil and gas compressors, but only periodically, so we cannot address this topic without experimentally introducing warblers to louder, more sustained construction noise, an exercise unlikely to mimic a plausible disturbance in warbler habitat.

The frequency of anthropogenic noise that birds are exposed to may be more influential than amplitude (Dooling & Popper,
Typical traffic noise ranges from 1 to 2 kHz (Blickley & Patricelli, 2012; Dooling & Popper, 2007; Warren et al., 2006), which overlaps with the song frequencies of many, but not all, songbirds (Morton, 1975; Rheindt, 2003). Species, like the golden-cheeked warbler, that forage in the upper portions of the canopy often sing at higher frequencies (Ficken & Ficken, 1962; Lemon, Struger, Lechowicz, & Norman, 1981) and may be less susceptible to vocal masking. For example, the yellow-rumped warbler, a congeneric species that inhabits similar ecological conditions, has life-history characteristics comparable to the golden-cheeked warbler, and sings from ~3 to 7 kHz. avoids chronic industrial noise but not roads (Ware, McClure, Carlisle, &

### TABLE 4

Means and associated 95% confidence intervals in parentheses for lower frequency, upper frequency, and bandwidth of A-songs per treatment site and phase used to examine the potential impacts of highway construction on golden-cheeked warblers (*Setophaga chrysoparia*) in Austin, Texas, USA (2009–2014)

| Treatment phase | Phrase | Metric (kHz) | Construction | Traffic noise | Control |
|-----------------|--------|--------------|--------------|---------------|---------|
| Preconstruction 1 | Lower frequency | 3.75 (0.13) | 3.75 (0.14) | 3.76 (0.17) | 3.67 (0.16) |
|                  | Upper frequency | 6.13 (0.13) | 6.13 (0.09) | 5.98 (0.19) | 5.89 (0.17) |
|                  | Bandwidth | 2.25 (0.19) | 2.38 (0.19) | 2.22 (0.12) | 2.18 (0.12) |
| 2                | Lower frequency | 4.30 (0.09) | 4.28 (0.10) | 4.22 (0.11) | 4.17 (0.10) |
|                  | Upper frequency | 6.56 (0.09) | 6.58 (0.07) | 6.33 (0.16) | 6.25 (0.14) |
|                  | Bandwidth | 2.27 (0.10) | 2.30 (0.11) | 2.10 (0.10) | 2.05 (0.10) |
| 3                | Lower frequency | 6.23 (0.10) | 6.15 (0.06) | 6.18 (0.08) | 6.12 (0.07) |
|                  | Upper frequency | 7.64 (0.11) | 7.67 (0.16) | 7.61 (0.11) | 7.56 (0.10) |
|                  | Bandwidth | 1.41 (0.08) | 1.52 (0.17) | 1.44 (0.15) | 1.38 (0.14) |
| Construction     | Lower frequency | 3.94 (0.18) | 4.02 (0.15) | 3.87 (0.14) | 3.82 (0.12) |
|                  | Upper frequency | 6.16 (0.09) | 6.20 (0.13) | 6.19 (0.11) | 6.15 (0.10) |
|                  | Bandwidth | 2.22 (0.19) | 2.18 (0.21) | 2.32 (0.15) | 2.29 (0.13) |
| 2                | Lower frequency | 4.35 (0.06) | 4.33 (0.10) | 4.31 (0.09) | 4.29 (0.08) |
|                  | Upper frequency | 6.51 (0.07) | 6.61 (0.12) | 6.53 (0.11) | 6.47 (0.10) |
|                  | Bandwidth | 2.15 (0.08) | 2.28 (0.14) | 2.22 (0.10) | 2.20 (0.09) |
| 3                | Lower frequency | 6.18 (0.09) | 6.22 (0.09) | 6.17 (0.10) | 6.12 (0.08) |
|                  | Upper frequency | 7.65 (0.15) | 7.55 (0.15) | 7.62 (0.15) | 7.57 (0.14) |
|                  | Bandwidth | 1.47 (0.13) | 1.33 (0.14) | 1.44 (0.16) | 1.40 (0.14) |
| Postconstruction 1 | Lower frequency | 4.00 (0.16) | 4.06 (0.20) | 3.99 (0.13) | 3.95 (0.12) |
|                  | Upper frequency | 6.11 (0.15) | 6.31 (0.27) | 6.15 (0.18) | 6.10 (0.16) |
|                  | Bandwidth | 2.11 (0.16) | 2.25 (0.38) | 2.16 (0.17) | 2.14 (0.15) |
| 2                | Lower frequency | 4.32 (0.14) | 4.36 (0.11) | 4.30 (0.09) | 4.27 (0.08) |
|                  | Upper frequency | 6.35 (0.08) | 6.57 (0.19) | 6.50 (0.14) | 6.45 (0.12) |
|                  | Bandwidth | 2.03 (0.13) | 2.21 (0.11) | 2.20 (0.15) | 2.18 (0.14) |
| 3                | Lower frequency | 6.06 (0.09) | 6.13 (0.13) | 6.21 (0.11) | 6.17 (0.10) |
|                  | Upper frequency | 7.56 (0.13) | 7.57 (0.23) | 7.67 (0.29) | 7.61 (0.27) |
|                  | Bandwidth | 1.50 (0.12) | 1.44 (0.12) | 1.46 (0.22) | 1.42 (0.18) |

*Preconstruction = 2009‒2011, construction = 2012‒2013, and postconstruction = 2014.

### TABLE 5

Means and associated 95% confidence intervals for selected A-song metrics per treatment phase and distance from the road used to examine the potential impacts of highway construction on golden-cheeked warblers (*Setophaga chrysoparia*) in Austin, Texas, USA (2009–2014)

| Treatment phase | Phrase | Metric (kHz) | Distance (m) | Mean (95% CI) |
|-----------------|--------|--------------|--------------|---------------|
| Preconstruction 1 | Lower frequency | 0–300 | 3.74 (0.20) | 3.88 (0.16) |
| | 600–900 | 2.35 (0.11) | 2.29 (0.14) | |
| 2 | Bandwidth | 0–300 | 2.93 (0.12) | 2.87 (0.11) |
| | 600–900 | 2.93 (0.12) | 2.87 (0.11) | |
| Construction     | Lower frequency | 0–300 | 4.19 (0.14) | 4.19 (0.14) |
| | 600–900 | 3.79 (0.24) | 3.79 (0.24) | |
| Postconstruction 1 | Lower frequency | 0–300 | 4.19 (0.31) | 4.19 (0.31) |
| | 300–600 | 4.19 (0.31) | 4.19 (0.31) | |

*Preconstruction = 2009‒2011, construction = 2012‒2013, and postconstruction = 2014.
Barber, 2015). These species can likely hear low-frequency traffic noise, but because they communicate at higher frequencies, individuals may be unaffected by the sound. The golden-cheeked warbler’s song ranges from 3 to 9 kHz, but is typically between 4 and 8 kHz (Bolsinger, 2000), which may explain why we did not observe negative responses to noise associated with highway construction or traffic. We did find a small number of statistically significant differences in certain song characteristics, but these were not related to construction or traffic noise and are likely attributable to individual variation.

The USFWS previously indicated that noise levels occurring at ≥60 dB(A) during the loudest hour of the day may negatively influence songbirds (Barrett, 1995; Dooling & Popper, 2007). However, the USFWS also recognizes that species respond differently to noise depending on their life-history traits and the level and persistence of noise exposure. As such, noise levels are considered high when they exceed 10 dB(A) over background noise (Patricelli, Blickley, & Hooper, 2012). Although maximum noise occasionally exceeded 60 dB(A) nearest to the highways at our construction and traffic noise sites, mean noise levels were ~60 dB(A) closest to the roads and decreased with increasing distance from Highway 71 and Southwest Parkway (Figure 2). Moreover, the average maximum noise at our construction and traffic noise sites was only ~5 dB(A) greater than the average maximum noise recorded at a rural control site during a similar study where we also found no evidence to suggest that construction noise and activity had a negative effect on warblers (M. L. Morrison, unpublished data).

Anthropogenic noise associated with highway construction and operation can have individual- and population-level consequences for wildlife. However, the impacts of highway noise on birds are species specific (reviewed in Reijnen & Foppen, 2006). As such, the potential impacts to individual species should be experimentally tested rather than assumed. We found no quantitative evidence that highway construction and traffic noise at our sites had a negative effect on warblers, but many other factors can influence warbler abundance and productivity (e.g., patch size: Arnold, Coldren, & Fink, 1996; Baccus, Tolle, & Cornelius, 2007; Butcher, Morrison, Ransom, Slack, & Wilkins, 2010; Robinson, 2013; landscape composition: Collier et al., 2012; Mathewson et al., 2012; edge-to-area ratio: Peak, 2007: tree species composition: Marshall et al., 2013; Long, 2014; canopy cover: Dearborn & Sanchez, 2001; Magness, Wilkins, & Hejl, 2006; age: Jette, Hayden, & Cornelius, 1998; Pruett, 2014; presence of conspecifics: Farrell, Morrison, Campomizzi, & Wilkins, 2012), and there is evidence to suggest that warblers are more sensitive to these explanatory variables in urban settings (Robinson, 2013). Research that examines these potential constraints, especially in light of habitat loss and conversion, may promote more effective management and recovery of the species. Human population growth will require recurring improvements to transportation infrastructure. We encourage the use of a robust BACI design, or similar experimental field-based approaches, to quantitatively assess the potential impacts of highway construction on wildlife, the results of which can be used to support conservation of prioritized species.

ACKNOWLEDGMENTS

We acknowledge the Texas Department of Transportation for funding our research. We thank Brandon Crawford with The Nature Conservancy of Texas for facilitating data collection at the Barton Creek Habitat Preserve. We thank Kristin Davis and Chris Littuna for field season management, data collection oversight, annual report preparation, and project presentations. We also thank our many field technicians and graduate students for their assistance. Zac Loman assisted J. Szewczak with automatic recording unit design. Ross Anderson, Bret Collier, Debbie Danfor, Amanda Dube, Brent Stevener, and Kevin Skow from the Texas A&M Institute of Renewable Natural Resources provided technical and logistical support.

CONFLICT OF INTEREST

None declared.

REFERENCES

Arnold, K. A., Coldren, C. L., & Fink, M. L. (1996). The interactions between avian predators and golden-cheeked warblers in Travis County. College Station, Texas, USA: Texas A&M Transportation Institute. Available at: http://d2dti5nnplfror.cloudfront.net/tti.tamu.edu/documents/1983-2.pdf (accessed 20 July 2015).

Baccus, J. T., Tolle, M. E., & Cornelius, J. D. (2007). Response of golden-cheeked warblers (Dendroica chrysoparia) to wildfires at Fort Hood, Texas. Occasional Publication of the Texas Ornithological Society, 7, 1–37.

Barg, J. J., Jones, J., & Robertson, R. J. (2005). Describing breeding territories of migratory passerines: Suggestions for sampling, choice of estimator, and delineation of core areas. Journal of Animal Ecology, 74, 139–149.

Barrett, D. E. (1995). Traffic noise impact study for least bell’s vireo habitat along California State Route B3. Transportation Research Record, 1559, 3–7.

Bayne, E. M., Habib, L., & Boutin, S. (2008). Impact of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. Conservation Biology, 22, 1186–1193.

Bee, M. A., & Swanson, E. M. (2007). Auditory masking of anuran advertisement calls by road traffic noise. Animal Behaviour, 74, 1765–1776.

Benson, R. H. (1995). The effect of roadway traffic noise on territory selection by golden-cheeked warblers. Bulletin of the Texas Ornithological Society, 28, 42–51.

Blickley, J. L., & Patricelli, G. L. (2012). Potential acoustic masking of greater sage-grouse (Centrocercus urophasianus) display components by chronic industrial noise. Ornithological Monographs, 74, 23–35.

Bolsinger, J. S. (2000). Use of two song categories by golden-cheeked warblers. Condor, 102, 539–552.

Burton, N. H. K., Armitage, M. J. S., Musgrove, A. J., & Rehfsisch, M. M. (2002). Impacts of man-made landscape features on numbers of estuarine waterbirds at low tide. Environmental Management, 30, 857–864.

Butcher, J. A., Morrison, M. L., Ransom, R. D. Jr, Slack, R. D., & Wilkins, R. N. (2010). Evidence of a minimum patch size threshold of reproductive success in an endangered songbird. Journal of Wildlife Management, 74, 133–139.

Clark, W. D., & Karr, J. R. (1979). Effects of highways on red-winged blackbird and horned lark populations. The Wilson Bulletin, 91, 143–145.

Collier, B. A., Groce, J. E., Morrison, M. L., Newnam, J. C., Campomizzi, A. J., Farrell, S. L., ... Wilkins, R. N. (2012). Predicting patch occupancy in fragmented landscapes at the rangewide scale for an endangered species: An example of an American warbler. Diversity and Distributions, 18, 158–167.
Costello, R. A., & Symes, L. B. (2014). Effects of anthropogenic noise on male singing behaviour and female phonotaxis in Oecanthus tree cricket. Animal Behaviour, 95, 15–22.

Craft, R. A. (1998). 1997 Field studies of golden-cheeked warblers (Dendroica chrysoparia) on Fort Hood, Texas. The Nature Conservancy. Summary of 1997 Research Activities, pp. 28–52in. Fort Hood, TX, USA: Texas Conservation Data Center, The Nature Conservancy.

Dearborn, D. C., & Sanchez, L. L. (2001). Do golden-cheeked warblers select nest locations on the basis of patch vegetation? Auk, 118, 1052–1057.

Diamond, D. D. (1997). Ferris,	C.	R.	(1979).	Effects	of	Interstate	95	on	breeding	birds	in
northern

Fero, S. (2012). The effects of highway noise on birds. Rockville, Maryland, USA: Environmental BioAcoustics LLC.

Ferris, L. M., Morrison, M. L., Block, W. M., Strickland, M. D., Collier, B. A., & Peterson, D. R. (2011). Conspicuous cues and breeding habitat selection in an endangered woodland warbler. Journal of Animal Ecology, 81, 1056–1064.

Fenn, C. R. (1979). Effects of Interstate 95 on breeding birds in northern Maine. Journal of Wildlife Management, 43, 421–427.

Ficken, M. S., & Ficken, R. W. (1962). The comparative ethology of wood warblers: A review. The Living Bird, 1, 103–121.

Forman, R. T. T., Reineking, B., & Hesperger, A. M. (2002). Road traffic and nearby grassland bird patterns in a suburbanizing landscape. Environmental Management, 29, 782–800.

Gottmark, F. (1992). The effects of investigator disturbance on nesting birds. Current Ornithology, 9, 63–104.

Goudie, R. L., & Jones, L. O. (2004). Dose-response relationships of harlequin duck behaviour to noise from low-level military jet over-flights in central Labrador. Environmental Conservation, 31, 289–298.

Green, R. H. (1979). Sampling design and statistical methods for environmental biologists. New York, New York, USA: John Wiley and Sons.

Groce, J. E., Mathewson, H. A., Morrison, M. L., & Wilkins, R. N. (2010). Scientific evaluation for the 5-year status review of the golden-cheeked warbler. College Station, Texas, USA: Texas A&M Institute of Renewable Natural Resources. Available at: http://irr.tamu.edu/media/252621/gcwa_scientific_evaluation.pdf (accessed 20 July 2015).

Habib, B., Bayne, E. M., & Boutin, S. (2006). Chronic industrial noise affects pairing success and age structure of ovenbirds Seiurus aurocapilla. Journal of Applied Ecology, 44, 176–184.

Halfwerk, W., Bot, S., Bulikx, J., van der Velde, M., Komdeur, J., ten Cate, C., & Slabbekeorn, H. (2011a). Low-frequency songs lose their potency in noisy urban areas. Proceedings of the National Academy of Sciences, 108, 14549–14554.

Halfwerk, W., Holleman, L. M. J., Lessells, C. M., & Slabbekeorn, H. (2011b). Negative impact of traffic noise on avian reproductive success. Journal of Applied Ecology, 48, 210–219.

Hedlin, J. O., & Seiler, A. (2003). Effects of roads on the abundance of birds in Swedish forest and farmland. In T. Damrad and Bekker, G. J. (Ed.), Habitat Fragmentation due to Habitat Infrastructure: Findings of the COST ACTION 341. Brussels, Belgium: Infra Eco Network Europe.

Hoskin, C. J., & Goossem, M. W. (2010). Road impacts on abundance, call traits, and body size of rainforest frogs in northeast Australia. Ecology and Society, 15, 15.

Jette, L. A., Hayden, T. J., & Cornellius, J. D. (1998). Demographics of the golden-cheeked warbler (Dendroica chrysoparia) on Fort Hood, Texas. U.S. Army Construction Engineering Research Laboratories Technical Report 98/52. Available at: www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA342389 (accessed 20 July 2015).

Kassle, P. (2004). Synthesis of noise effects on wildlife populations. U.S. Department of Transportation, Federal Highway Administration Report No. FHWA-HEP-06-016, McLean, Virginia, USA. Available at: http://www.fhwa.dot.gov/environment/noise/noise_effect_on_wildlife/effects/effects.pdf (accessed 20 July 2015).

Kerr, M. J., Brousseau, L., & Johnson, S. (2002). Noise levels of selected construction tasks. AIHA Journal, 63, 334–339.

Klassen, J. A., Morrison, M. L., Mathewson, H. A., Rosenthal, G. G., & Wilkins, R. N. (2012). Canopy characteristics affect reproductive success of golden-cheeked warblers. Wildlife Society Bulletin, 36, 54–60.

Korner, O., Ladd, C., Lockwood, M., Lyons, J., Peak, R., Sterling, J., & Reidy, J. (2013). Dendroica chrysoparia. The IUCN Red List of Threatened Species v. 2015.1. Available at: http://www.iucnredlist.org (accessed 19 August 2015).

Lackey, M. A., Morrison, M. L., Loman, Z. G., Fishner, N., Farrell, S. L., Collier, B. A., & Wilkins, R. N. (2011). Effects of road construction noise on the endangered golden-cheeked warbler. Wildlife Society Bulletin, 35, 15–19.

Ladd, C., & Gass, L. (1999). Golden-cheeked warbler. The Birds of North America Online. Cornell Lab of Ornithology, Ithaca, New York, USA. Available at: http://bna.birds.cornell.edu/bna/species/420 (accessed 20 July 2015).

Lampe, U., Reinhold, K., & Schmoll, T. (2014). How grasshoppers respond to road noise: Developmental plasticity and population differentiation in acoustic signaling. Functional Ecology, 25, 660–668.

Lemon, R. E., Struger, J., Lechowicz, M. J., & Norman, R. F. (1981). Song features and singing heights of American warblers: Maximization or optimization of distance. Journal of the Acoustical Society of America, 69, 1169–1176.

Long, A. M. (2014). The influence of vegetation structure and composition on songbird abundance and productivity. PhD Dissertation, College Station, Texas, USA: Texas A&M University.

Maas, D. S. (1998). Factors influencing demographics of golden-cheeked warblers (Dendroica chrysoparia) at Fort Hood Military Reservation, Texas. MA Thesis, Norman, Oklahoma, USA: University of Oklahoma.

Magenis, C. E., Wilkins, R. N., & Hejli, S. J. (2006). Quantitative relationships among golden-cheeked warbler occurrence and landscape size, composition, and structure. Wildlife Society Bulletin, 34, 473–479.

Marshall, M. E., Long, A. M., Farrell, S. L., Mathewson, H. A., Morrison, M. L., Newnam, C., & Wilkins, R. N. (2012). Using impact assessment study designs for addressing impacts to species of conservation concern. Wildlife Society Bulletin, 36, 450–456.

Marshall, M. E., Morrison, M. L., & Wilkins, R. N. (2013). Tree species composition and food availability affect productivity of an endangered species: The golden-cheeked warbler. Condor, 115, 882–892.

Martin, T. E., & Geupel, G. R. (1993). Nest-monitoring plots: Methods for locating nests and monitoring success. Journal of Field Ornithology, 54, 507–519.

Mathewson, H. A., Groce, J. E., McFarland, T. M., Morrison, M. L., Newnam, J. C., Snelgrove, R. T., ... Wilkins, R. N. (2012). Estimating breeding season abundance of golden-cheeked warblers in Texas, USA. Journal of Wildlife Management, 76, 1117–1128.

Mathewson, H. A., Locatelli, A., McFarland, T., Lackey, M., Stewart, L. R., & Morrison, M. L. (2013). Analysis of the golden-cheeked warbler in relation to construction activity. College Station, Texas, USA: Texas A&M Institute of Renewable Natural Resources.

McClure, C. J. W., Ware, H. E., Carlisle, J., Kaltenecker, G., & Barber, J. R. (2013). An experimental investigation into the effects of traffic noise on distributions of birds: Avoiding the phantom road. Proceedings of the Royal Society of London B: Biological Sciences, 280, 20132290.

Morrison, M. L., Block, W. M., Strickland, M. D., Collier, B. A., & Peterson, M. J. (2008). Wildlife study design, 2nd ed. New York, New York, USA: Springer.

Morton, E. S. (1975). Ecological sources of selection on avian sounds. American Naturalist, 109, 17–34.

NOAA. (2015). Summary of monthly normals 1981-2010. Camp Mabry, Austin, Texas, USA: National Oceanic and Atmospheric Administration. Available at: http://www.ncdc.noaa.gov/cdo-web/search (accessed 20 July 2015).
Schaub, A., Ostwald, J., & Siemers, B. M. (2008). Foraging bats avoid noise. Auk, 123, 639–649.

Patricelli, G. L., Blickley, J. L., & Hooper, S. L. (2012). The impacts of noise on greater sage-grouse: A discussion of current management strategies in Wyoming with recommendations for further research and interim protections. Report to The Bureau of Land Management and Wyoming Game and Fish Department. Davis, California, USA.

Peak, R. G. (2007). Forest edges negatively affect golden-cheeked warbler nest survival. Condor, 109, 628–637.

Pruett, H. L. (2014). Age structure of golden-cheeked warblers in areas of low abundance. MS Thesis. College Station, Texas, USA: Texas A&M University.

Reijnen, R., Foppen, R., & Veenbaas, G. (1997). Disturbance by traffic of the breeding birds caused by traffic noise? Wildlife Society Bulletin, 39, 721–734.

Reijnen, R., & Foppen, R. (1991). Effect of road traffic on the breeding site tenacity of male willow warblers (Phylloscopus trochilus). Journal Für Ornithologie, 132, 291–295.

Reijnen, R., & Foppen, R. (2006). Impact of road traffic on breeding bird populations. In J. Davenport, & J. L. Davenport (Eds.), The ecology of transportation: Managing mobility for the environment (pp. 255–274). Netherlands: Springer.

Reijnen, R., Foppen, R., & Veenbaas, G. (1997). Disturbance by traffic of breeding birds: Evaluation of the effect and considerations in planning and managing road corridors. Biodiversity and Conservation, 6, 567–581.

Rheindt, F. E. (2003). The impact of roads on birds: Does song frequency play a role in determining susceptibility to noise pollution. Journal für Ornithologie, 144, 295–306.

Ristovska, G., Gjorgjev, D., Polozhani, A., Kočubovski, M., & Kendrovski, V. (2009). Environmental noise and annoyance in adult population of Skopje: A cross-sectional study. Archives of Industrial Hygiene and Toxicology, 60, 349–355.

Robinson, D. H. (2013). Effects of habitat characteristics on occupancy and productivity of a forest dependent songbird in an urban landscape. MS Thesis. College Station, Texas, USA: Texas A&M University.

Schauß, A., Ostwald, J., & Siemers, B. M. (2008). Foraging bats avoid noise. Journal of Experimental Biology, 211, 3174–3180.

Shier, D. M., Lea, A. J., & Owen, M. A. (2012). Beyond masking: Endangered Stephen's kangaroo rats respond to traffic noise with footdrumming. Biological Conservation, 150, 53–58.

Slabbekoorn, H., & den Boer-Visser, A. (2006). Cities change the songs of birds. Current Biology, 16, 2326–2331.

Slabbekoorn, H., & Peet, M. (2003). Birds sing at a higher pitch in urban noise. Nature, 424, 267.

Slabbekoorn, H., & Smith, T. B. (2002). Bird song, ecology and speciation. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 357, 493–503.

Stewart, L. R., Morrison, M. L., Hutchinson, M. R., Appel, D. N., & Wilkins, R. N. (2014). Effects of a forest pathogen on habitat selection and quality for the endangered golden-cheeked warbler. Wildlife Society Bulletin, 38, 279–287.

Summers, P. D., Cunnington, G. M., & Fahrig, L. (2011). Are negative effects of roads on breeding birds caused by traffic noise? Journal of Applied Ecology, 48, 1527–1534.

TXDOT. (2012). Texas Department of Transportation District Traffic Maps. Austin. Available at: http://ftp.dot.state.tx.us/pub/txdot-info/tpp/traffic_counts/2012/aus_base.pdf (accessed 03 October 2016).

TXDOT. (2016). Texas Department of Transportation Statewide Planning Map. Available at: http://www.txdot.gov/inside-txdot/division/transportation-planning/maps/statewide-planning.html (accessed 06 October 2016).

Underwood, A. J., & Chapman, M. G. (2003). Power, precaution, type II error and sampling design in assessments of environmental impacts. Journal of Experimental Marine Biology and Ecology, 296, 49–70.

USFWS. (1990). Endangered and threatened wildlife and plants; final rule to list the golden-cheeked warbler as endangered. United States Fish and Wildlife Service, Federal Register, 55, 53153–53160. Available at: http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?sp-code=B07W (accessed 16 October 2015).

Vickery, P. D., Hunter, M. L. Jr, & Wells, J. V. (1992). Use of a new reproductive index to evaluate relationship between habitat quality and breeding success. Auk, 109, 697–705.

Villard, M., & Pärt, T. (2004). Don’t put all your eggs in real nests: A sequel to Faaborg. Conservation Biology, 18, 371–372.

Ware, H. E., McClure, C. J. W., Carlisle, J. D., & Barber, J. R. (2015). A phantom road experiment reveals traffic noise is an invisible source of habitat degradation. Proceedings of the National Academy of Sciences, 112, 12105–12109.

Warren, P. S., Katti, M., Ermann, M., & Brael, A. (2006). Urban bioacoustics: It’s not just noise. Animal Behaviour, 71, 491–502.

Zar, J. H. (1999). Biostatistical analysis. 4th ed.. Englewood Cliffs, New Jersey, USA: Prentice-Hall.

How to cite this article: Long, A. M., Colón, M. R., Bosman J. L., Robinson, D. H., Pruett, H. L., McFarland, T. M., Mathewson, H. A., Szewczak, J. M., Newnam, J. C. and Morrison, M. L. (2017), A before–after control–impact assessment to understand the potential impacts of highway construction noise and activity on an endangered songbird. Ecology and Evolution, 7: 379–389. doi: 10.1002/ede.26208