Wildlife Society Bulletin 41(2):240–248; 2017; DOI: 10.1002/wsb.777

Original Article

Effects of Road Construction Noise on Golden-Cheeked Warblers: An Update

ASHLEY M. LONG,[1] *Institute of Renewable Natural Resources, Texas A&M University, College Station, TX 77843, USA*
MELANIE R. COLÓN, *Institute of Renewable Natural Resources, Texas A&M University, College Station, TX 77843, USA*
JESSICA L. BOSMAN, *Institute of Renewable Natural Resources, Texas A&M University, College Station, TX 77843, USA*
TIFFANY M. McFARLAND, *Institute of Renewable Natural Resources, Texas A&M University, College Station, TX 77843, USA*
ANTHONY J. LOCATELLI,[2] *Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX 77843, USA*
LAURA R. STEWART, *Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX 77843, USA*
HEATHER A. MATHEWSON,[4] *Institute of Renewable Natural Resources, Texas A&M University, College Station, TX 77843, USA*
JOHN C. NEWNAM, *Texas Department of Transportation, P. O. Box 15426, Austin, TX 78701, USA*
MICHAEL L. MORRISON, *Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX 77843, USA*

ABSTRACT Previously, we reported results from an impact assessment that examined the effects of road construction noise on habitat selection and productivity of an endangered songbird, the golden-cheeked warbler (*Setophaga chrysoparia*; warbler hereafter), in rural Texas, USA. We found no evidence that road construction or traffic noise negatively influenced warbler territory density, territory placement, pairing success, or fledging success during 3 years of road construction activities (2007–2009). In addition, warblers exhibited few acute responses to construction noise played at close range (2008–2009). Herein, we expanded on previous results to include an additional year of construction data (2010) and 3 years of post-construction data (2011–2013) because birds may exhibit delayed responses to disturbance. We also examined the potential influence of road construction noise and activity on warbler song characteristics because birds may sing at higher minimum frequencies if loud noise masks their communication signals. Similar to previous results, we found no evidence that road construction or traffic noise negatively influenced warblers in our rural study area. However, noise levels varied little across experimental and control study sites, with increasing distance from the road, or between the construction and post-construction phases of our study. Warblers may respond negatively to louder noise or other disturbances that accompany construction activities (e.g., vibrations), but our comparisons across study sites, the results of our playback experiment, and data collected during concurrent studies in urban Texas and on military land suggest this is unlikely.

KEY WORDS golden-cheeked warbler, impact assessment, road construction noise, *Setophaga chrysoparia*, Texas, traffic noise.

Though avian responses to roadway noise are species-specific (van der Zand et al. 1980, Reijnen et al. 1995, Rheindt 2003, Peris and Pescador 2004, Francis et al. 2011*b*), traffic noise can have individual- and population-level consequences for birds, including reduced densities (Ilner 1992, Reijnen et al. 1995, Rheindt 2003, Peris and Pescador 2004), displacement (Reijnen and Foppen 1991), lower reproductive success (Halfwerk et al. 2011), increased physiological stress (Hayward et al. 2011), and masking of communication signals (Rheindt 2003, Brumm 2004). Noise associated with road construction activity, though temporary, often exceeds background levels of daily traffic and could induce or amplify negative responses to roadway noise for some species.

We previously examined the potential effects of road construction noise on the federally endangered golden-cheeked warbler (*Setophaga chrysoparia*; hereafter warbler) along a rural stretch of Highway 83 in Texas, USA, that was expanded from 2 to 4 lanes (Lackey et al. 2011). We also examined acute responses of warblers to recorded construction noise played at close range (Lackey et al. 2012). We found no evidence that road construction or traffic noise

Received: 19 July 2016; Accepted: 26 March 2017
Published: 19 June 2017

[1]*E-mail: ashley.long@ag.tamu.edu*
[2]*Current affiliation: Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID 83844, USA.*
[3]*Current affiliation: Archaeological Consulting Services, Ltd., Tempe, AZ 85282, USA.*
[4]*Current affiliation: Department of Wildlife, Sustainability, and Ecosystem Sciences, Tarleton State University, Stephenville, TX 76402, USA.*

negatively influenced warbler territory density, territory placement, pairing success, or fledging success during 3 years of road construction activities (2007–2009; Lackey et al. 2011). In addition, warblers exhibited few responses during our playback experiments (2008–2009; Lackey et al. 2012). Herein, we expanded Lackey et al. (2011, 2012) to include an additional year of construction data (2010) and 3 years of post-construction data (2011–2013) because avian responses to disturbance can be delayed (Findlay and Bourdages 2000, Roedenbeck et al. 2007, Hagen et al. 2011). We also examined the potential influence of road construction noise and activity on warbler song characteristics because birds may sing at higher minimum frequencies if loud noises mask their communication signals, a behavior known as vocal adjustment (Slabbekoorn and Peet 2003, Wood and Yezerinac 2006, Hu and Cardoso 2010, Dowling et al. 2012, Ríos-Chelén et al. 2012).

In the current study, we quantified noise levels at varying distances from Highway 83 at sites exposed to road construction and traffic noise and at a control site that was not exposed to either type of roadway noise. We predicted that noise levels would be highest at the construction site during the construction phase and noise levels would decrease with increasing distance from the road. If warblers responded negatively to road construction noise and activity, we predicted that they would exhibit reduced densities, displacement from the highway, or decreased pairing and fledgling success at the construction site relative to the traffic noise or control sites. We also predicted that warblers would exhibit these same responses during the post-construction period when compared to the construction period if any negative effects of construction noise on warblers were delayed. We expected that warblers in close proximity to the highest levels of noise would be less likely to respond to experimentally introduced construction noise played at close range. Additionally, if warblers exhibited vocal adjustment in response to construction noise, we expected that they would sing songs with higher minimum frequencies and, consequently, narrower bandwidths, at the construction site during construction activities relative to other sites. Alternatively, if warblers demonstrated vocal adjustment at the construction site during the post-construction phase, it may indicate a delayed response following exposure to construction noise.

STUDY AREA

We collected data from March to July 2007–2013 at 3 study sites (i.e., construction, traffic noise, and control) in Real and Uvalde counties, Texas (Fig. 1). All of our study sites were similar with regards to topography, the frequency and timing of environmental disturbances (e.g., drought), and vegetation characteristics. Our study sites were located in distinct patches of oak-juniper (*Quercus* spp.-*Juniperus* spp.) woodlands that were >20 ha with >50% canopy cover and, as such, met the minimum thresholds for occupancy and reproductive success in rural areas as described by Butcher et al. (2010) and Klassen et al. (2012). Tree species at our study sites included Ashe juniper (*Juniperus asheii*), Texas oak

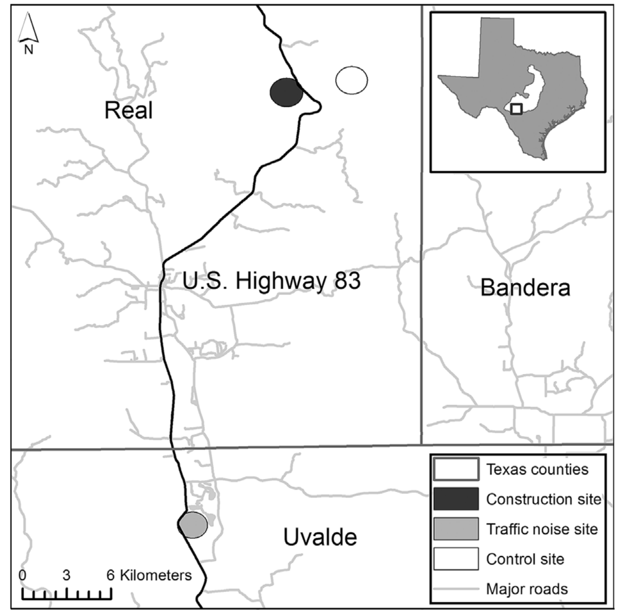

Figure 1. Study site locations along United States Highway 83 used during research examining the potential impacts of road construction noise on golden-cheeked warblers in Real and Uvalde counties, Texas, USA, from 2007 to 2013. Inset shows study site locations in relation to golden-cheeked warbler breeding range.

(*Quercus buckleyi*), live oak (*Q. virginiana*), and various other hardwoods (Diamond 1997, Long 2014). Mean minimum and maximum temperatures in July were 20° C and 33° C and mean annual precipitation was 77 cm (National Oceanic and Atmospheric Administration 2015).

The construction and control sites were located on Big Springs Ranch for Children (Big Springs RC), a privately owned ranch in Real County, Texas. Big Springs RC was adjacent to a 9-km stretch of Highway 83 that was widened from 2 lanes to 4 lanes from 2007 to 2010. During the road expansion project, the Texas Department of Transportation did not remove warbler habitat along Highway 83, but warblers were exposed to noises associated with construction activities (e.g., backup warning beepers, diesel engine noise, loading dump trucks). The construction site included areas within 800 m of Highway 83 that were exposed to traffic noise in addition to construction noise for the duration of our study. The annual average daily traffic (AADT) rate at the construction site was 1,100–1,400 vehicles per day (Texas Department of Transportation 2016*a*). The control site was $\geq$1 km from Highway 83 and did not experience construction or traffic noise for any portion of our study. The traffic noise site, which allowed us to separate the potential effects of construction and traffic noise on warblers, was located in Garner State Park, approximately 35 km south of Big Springs RC along Highway 83 in Uvalde County, Texas. The traffic noise site included areas within 800 m of the road that did not experience construction noise during our study but did experience traffic noise. The AADT along the stretch ($\sim$2 km) of road was 1,400–2,700 vehicles per day during our study (Texas Department of Transportation 2016*b*).

METHODS

Impact assessments ideally compare relative measures of wildlife responses before, during, and after a disturbance at treatment and control sites (Green 1979). However, construction on Highway 83 began prior to the year we initiated our study. As such, we employed an after-only impact assessment using data collected at treatment and control sites during (2007–2010) and after (2011–2013) road construction along Highway 83. This study design is appropriate when there are no available pre-treatment data and replication of the treatment is not possible or appropriate (Wiens and Parker 1995, Morrison et al. 2008, Marshall et al. 2012). For our study, a statistically significant interaction between site (i.e., construction, traffic noise, control) and phase (i.e., during, after) for an individual warbler metric (e.g., warbler territory density) would suggest that an impact had occurred, and the associated 95% confidence intervals provide details regarding the direction, magnitude, and biological significance of the results. We conducted all research activities in accordance with U.S. Fish and Wildlife Service Endangered Species permit TE195248-3 issued to M. L. Morrison and an approved protocol from the Texas A&M University Animal Care and Use Committee (no. 2015-0057).

In 2007, we randomly established 4–6 transects (400–600 m) perpendicular to Highway 83 at the construction and traffic noise sites and in directions that corresponded with the spatial distribution of warbler habitat at the control site. From 2007 to 2010, we placed 1–2 automatic recording units (ARUs) on each transect and positioned the ARUs within randomly selected warbler territories at varying distances from the road. We programmed each ARU to record continuous noise between 0600 and 1200 daily to correspond with peak warbler activity. We did not record noise in 2011 because of equipment failure and logistical constraints. In 2012 and 2013, we replaced the ARUs with datalogging sound meters (Extech 407764, Nashua, NH, USA), which we positioned at 50 m, 200 m, 350 m, and 500 m from the road along our previously established transects at the construction and traffic noise sites and similar distances apart along our previously established transects at the control site. Given the small number and short battery life of the new sound meters, we maximized our sampling effort by recording noise levels every 5 min for approximately 30 hr before rotating each sound meter to another location along the transects. We only included recordings of noise $\geq$31.5 dB(A) in our statistical analyses because lower values represent noise levels below a normal human conversation, and the sound meters produced inaccurate readings when noise levels were equivalent to or below the sound of a whisper. We compared mean and maximum noise levels during and after construction across all sites and with increasing distance from Highway 83. Given differences in sampling methodology between 2007–2010 and 2012–2013, we analyzed distance as a continuous variable.

We surveyed each randomly established transect between sunrise and 5 hr after sunrise 3 times during the early portion of the breeding season (i.e., second and third weeks in Mar) to determine the initial locations of male warblers at our study sites. During these early season transect surveys, we recorded Universal Transverse Mercator coordinates of all warblers detected using global positioning system units ($\leq$10-m accuracy). We then returned to the recorded coordinates from mid-March until the end of the breeding season (i.e., mid to late Jun depending on year) to map warbler territories. We surveyed territories every 7–10 days for 30–60 min. From 2007 to 2010, we recorded locations of male warblers each time they moved $\geq$20 m until we had recorded 3–6 locations per visit. From 2011 to 2013, we recorded the locations of each male every 2 min for 60 min or until the male was no longer visible. We considered males territorial if we consistently observed them in the same locations for $\geq$4 weeks.

Using ArcMap^{TM} 9.3.1 (Environmental Systems Research Institute, Redlands, CA, USA), we created minimum convex polygons (MCPs) for territories with $\geq$15 male point locations and identified each territory's associated centroid. We calculated territory density per study site as the number of territories (i.e., MCPs) at least partially located within 100 m of each transect divided by the area of the buffered zones. We excluded territories located completely outside of the 100-m buffers in our territory density estimates and included only transects in our analysis that we monitored during all years of our study. We used centroids to calculate mean distance from the road for territories in the construction and traffic noise sites. When we examined the effect of distance on territory placement, we limited our analyses to territories with centroids $\leq$400 m from the road to ensure that territories were plausibly exposed to road noise (Reijnen and Foppen 2006, Summers et al. 2011, McClure et al. 2013).

While mapping warbler territories, we documented behaviors of male and female warblers and used a modified ranking system developed by Vickery et al. (1992) and implemented by others to record the reproductive status of each male (e.g., Butcher et al. 2010, Lackey et al. 2011, Klassen et al. 2012, Marshall et al. 2013, Stewart et al. 2014). Observations of nests offer more detailed information on reproductive output than Vickery rankings (Reidy et al. 2015), but reproductive indices limit disruption to nesting pairs (Götmark 1992), which is important for studies involving endangered species. Moreover, they enable observers to avoid potential biases associated with non-randomly collected nest data (Martin and Geupel 1993), predict territory outcomes when females or nests are difficult to locate and monitor (Craft 1998), and sample a larger spatial extent (Villard and Pärt 2004).

We ranked territories as follows: 1) male present $\geq$4 weeks, 2) pair present $\geq$4 weeks, 3) material carried to the presumed nest, 4) food carried to the presumed nestlings, and 5) $\geq$1 fledgling observed. We considered males paired when the behavioral rank recorded in the territory was $\geq$2 and a territory successful when the recorded rank was 5. We defined pairing success as the number of successfully paired males relative to the total number of territorial males and defined fledging success as the number of reproductively successful territories relative to the total number of paired males. Warbler fledglings are mobile and begin foraging on their own approximately 2 weeks after fledging (Gass 1996), so we considered territories successful only if any fledglings observed were $\leq$2 weeks of age. Because we compared productivity measures across sites, we are confident that any error in assigning reproductive outcomes to a territory was similar across sites.

We conducted a playback experiment from 2008 to 2013 within a subset of warbler territories to examine acute responses of individual birds to recordings of construction noise at levels typical of construction equipment (e.g., 70–80 dB(A); Hanson et al. 2006). We randomly selected warbler territories at $\leq$400 m and >400 m from Highway 83 to receive a construction (noise) or control (silent) playback survey. We chose these distances so that some birds included in this portion of our study were plausibly exposed to construction or traffic noise whereas others were plausibly exposed to a novel disturbance (Summers et al. 2011). We conducted our playback surveys on days with and without construction activity, but we did not broadcast construction noise in the same territory more than once every 10 days to avoid desensitizing individuals to the recordings.

During each playback survey, we located a focal male warbler within its territory and recorded the individual's behavior for 2 min. We then broadcast construction noise at approximately 80 dB(A) (i.e., backup warning beepers, diesel engine noise, and loading dump trucks) with a hand-held speaker or displayed a silent hand-held speaker (control) to the warbler. During our playback surveys, we maintained a distance of approximately 20 m from birds to limit observer influence on warbler responses. Given sound attenuation with increasing distance from the source (Rathe 1969, Embleton 1996), warblers were exposed to noise levels of approximately 70 dB(A). We stopped playback broadcasts or controls after a maximum of 5 s or as soon as a subject's behavior changed. We selected this maximum period to simulate erratic construction noise. We considered a playback survey to have elicited a behavioral response if the warbler stopped singing or flushed from its previous perch and flew out of the surveyor's view ($\geq$10 m). We recorded the presence or absence of a behavioral response to the playback or control, identified the associated behavioral change, and compared responses during and after construction.

From 2009 to 2013, we recorded warbler vocalizations across all study sites to examine the potential influence of road construction noise and activity on warbler song characteristics. Warblers have 2 primary song types, the A-song and the B-song (Bolsinger 2000), with each song type divided into 3 distinct phrases. If warblers exhibited vocal adjustment in response to noise, we expected them to sing higher minimum (i.e., lower cutoff) song frequencies for individual phrases of each song in areas with louder noise. We employed the same methods as described for noise to record warbler songs, whereby we placed 1–2 ARUs on each transect and positioned the ARUs within randomly selected warbler territories at varying distances from the road. We then programmed each ARU to record continuously from 0600 to 1200 daily to correspond with peak warbler activity.

We extracted individual warbler songs from our recordings using SonoBird^{TM} v1.5.8 (DNDesign, Arcata, CA, USA). The program used time-frequency patterns within waveforms to identify warbler songs during the extraction process but also periodically identified the songs of other species with similar song frequencies (e.g., black-throated green warblers [*S. virens*], northern cardinals [*Cardinalis cardinalis*]). We visually inspected sonograms of all extracted songs and analyzed only songs specific to the golden-cheeked warbler. We also excluded extracted songs with extensive natural background noise (e.g., cicada calls), which would introduce inappropriate variability into the estimates of the warbler song metrics. We manually analyzed extracted warbler songs using SonoBird^{TM} v1.6.5. We identified each song by type (i.e., A- or B-song) and divided it into its component parts (i.e., 3 phrases). We then obtained the lower and upper bandwidth cut-offs for each phrase as measures of mean lower and mean upper frequencies and calculated the bandwidth as the difference between these 2 measures. Our initial goal was to examine each phrase of each song type in relation to all treatment, phase, and distance combinations. However, given low sample sizes of B-songs and some A-song phrases during the post-construction period, we restricted our analyses to the 3 phrases of the A-song and made statistical comparisons across our 3 study sites during 2 years of the construction phase (i.e., 2009 and 2010).

Analysis

We used 2-way factorial analysis of variance (ANOVA; Daniel 2009) to test for interactive effects of site (i.e., construction, traffic noise, control) and phase (i.e., during and after construction) on noise and territory placement (i.e., distance from territory centroid to road). If there was a statistically significant interactive effect of site and phase ($\alpha = 0.05$), we plotted these data with means and 95% confidence intervals and visually assessed these plots to determine the direction and magnitude of the differences. We used a nonparametric Friedman's test to examine territory density in relation to treatment site and phase (Daniel 2009). Friedman's rank sum test is preferred over single factor 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 (Daniel 2009). In our case, we had one measure of territory density for each site and phase combination. We used logistic regression to test the interactive effects of site and phase on pairing and fledging success. We also used logistic regression (Daniel 2009) to examine how distance from the road influenced pairing and fledging success for territories established $\leq$400 m from Highway 83. Given sample size constraints, we did not examine pairing and fledging success in relation to distance from the road in combination with other factors.

We used Fisher's exact tests (Daniel 2009) to examine the main effects of survey type, site, or phase on warbler

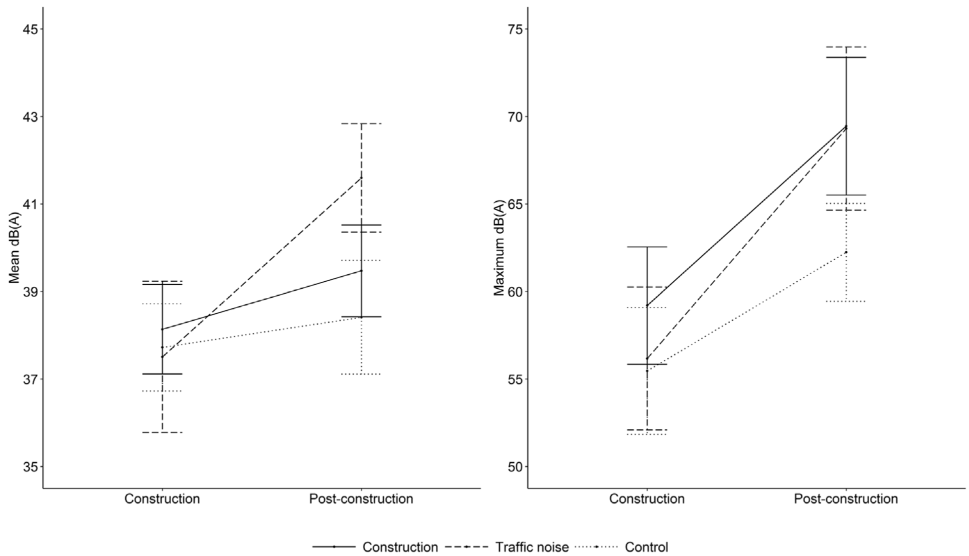

Figure 2. Mean and maximum noise with A-weighting and associated 95% confidence intervals recorded in golden-cheeked warbler habitat during and after road construction activity in Real and Uvalde counties, Texas, USA, during 2007–2013.

responses to our playback experiment and then to determine whether the probability of a warbler response to experimental playback recordings increased with increasing distance from the road. We calculated the odds ratio (OR; Daniel 2009) as a measure of effect size when testing for survey type. Lastly, we used one-way ANOVAs (Daniel 2009) to identify potential differences in song metrics among sites and examined 95% confidence intervals from Tukey's honest significant difference (HSD) tests to determine the direction and magnitude of the differences (Daniel 2009). We used Minitab Express^{TM} (Minitab, Inc., State College, PA, USA) to perform the Friedman's test and the open-source statistical program R v.3.2.2 (R Core Team, Vienna, Austria) for all other analyses.

RESULTS

We recorded noise at 54 sampling locations during construction and 88 sampling locations post-construction. Mean noise was <49 dB(A) at all sites during both phases of our study (Fig. 2). We found an interaction between site and phase for mean noise ($F_{2,136} = 3.98$, $P = 0.02$) whereby mean noise was similar at all sites during the construction phase (Fig. 2). However, mean noise at the traffic noise site was approximately 4 dB(A) greater during the post-construction phase when compared to the construction phase (Fig. 2). Additionally, mean noise was 2–3 dB(A) greater at the traffic noise site during the post-construction phase when compared to the construction or control sites during the post-construction phase (Fig. 2). Though statistically significant, these differences are barely perceptible and unlikely to be biologically significant. Maximum noise was >55 dB(A) at all sites during and after the construction phase (Fig. 2). We found no interaction between site and phase on maximum noise ($F_{2,136} = 1.07$, $P = 0.35$; Fig. 2).

Mean noise decreased with increasing distance from the road ($F_{1,102} = 8.64$, $P \leq 0.01$) but did not vary in relation to site ($F_{1,100} = 1.64$, $P = 0.20$) or phase ($F_{1,100} = 0.12$, $P = 0.73$). Again, although statistically significant, the difference in mean noise between the closest (<100 m) and farthest (400–500 m) recording stations from the road was <3 dB(A), and unlikely to represent a biologically significant difference. Maximum noise levels did not

Table 1. Summary of pairing and fledging success by treatment phase and study site for research examining the potential impacts of road construction noise and activity on golden-cheeked warblers in Real and Uvalde counties, Texas, USA, during 2007–2013.

		Monitored territories	Pairing success[b]		Fledging success[c]	
Treatment phase[a]	Site	No.	No.	%	No.	%
Construction	Construction noise	87	79	91	59	75
	Traffic noise	70	58	83	53	91
	Control	55	46	84	33	72
Post-construction	Construction noise	57	56	98	40	70
	Traffic noise	55	48	87	39	81
	Control	46	44	96	34	77

[a] Construction = 2007–2010, post-construction = 2011–2013.
[b] Territories defined as paired if female was present for ≥4 weeks.
[c] Territories defined as fledged if ≥1 fledgling was observed within a territory.

Table 2. Mean distance of golden-cheeked warbler territory centroids from roads and mean density of golden-cheeked warbler territories with associated standard deviations in parentheses by treatment site and phase in Real and Uvalde counties, Texas, USA, during 2007–2013.

Measure	Treatment phase[a]	Construction	Traffic noise	Control
Distance[b]	Construction	218 (97)	216 (105)	
	Post-construction	226 (85)	242 (95)	
Density[c]	Construction	0.35 (0.01)	0.40 (0.07)	0.36 (0.06)
	Post-construction	0.44 (0.04)	0.39 (0.00)	0.41 (0.02)

[a] Construction = 2007–2010, post-construction = 2011–2013.
[b] Distance from road (m) for all territories located <400 m from the right of way.
[c] Number of territories/ha.

decrease with increasing distance from the road ($F_{1,102} = 1.30$, $P = 0.26$) and we found no interaction between distance and site ($F_{1,100} = 0.40$, $P = 0.53$) or distance and phase ($F_{1,100} = 0.40$, $P = 0.53$) on maximum noise.

We mapped and monitored 370 warbler territories across all years of our study (Table 1). Overall mean territory density was 0.40 warblers/ha (Table 2) and we found no difference in territory density across the treatment sites and phases ($X^2_2 = 0.33$, $P = 0.56$). Overall, the mean distance of warbler territory centroids from Highway 83 at the construction and traffic noise sites was 226 m (Table 2). We did not find an interaction between site and phase for the mean distance of territory centroids from the road ($F_{1,193} = 0.41$, $P = 0.53$).

Overall pairing success was 89% (94% construction site, 85% traffic noise site, 90% control site; Table 1). We did not find an interaction between site and phase for pairing success ($X^2_2 = 2.36$, $P = 0.31$). Contrary to our predictions, pairing success decreased with increasing distance from the Highway 83 ($X^2_1 = 4.55$, $P = 0.03$). However, the difference in the predicted probability of pairing success between the territories closest and farthest from Highway 83 was <5%. Overall fledging success was 78% (73% construction site, 87% traffic noise site, 74% control site; Table 1). We did not find an interaction between site and phase on fledging success ($X^2_2 = 2.44$, $P = 0.29$) nor did we find an effect of distance to road on fledging success ($X^2_1 = 3.25$, $P = 0.07$).

We conducted 324 experimental playback surveys and 139 control surveys within 193 warbler territories located 27–767 m from the road. Warblers exhibited few (8%) acute responses during our playback surveys. However, they were more likely to respond to construction noise (11%) than silent speakers (2%; Fisher's exact test, $P < 0.01$, OR = 5.83). Warbler responses to experimental playback were not a function of site (Fisher's exact test $P = 0.90$), phase (Fisher's exact test $P = 0.30$), or distance to the road (Fisher's exact test $P = 0.72$).

We found differences in A-song metrics across all sites during the construction phase (Table 3) and Tukey's HSD tests indicated that all song metrics for each phrase were different across the sites (i.e., all pair-wise comparisons were statistically significant). Contrary to our predictions, we recorded the highest frequencies for the lower cutoff at the control site (Table 4). We also recorded narrower bandwidths at the traffic noise and control sites than in the construction site (Table 4).

DISCUSSION

The maximum noise levels we observed during our study (>55 dB(A); Fig. 2) can adversely affect some songbirds (Reijnen et al. 1996, McClure et al. 2013), but we found no evidence to suggest that warblers exhibited immediate or delayed responses to road construction or traffic noise at the levels we recorded at our study sites in rural Texas. In addition, warblers exhibited few acute responses to construction noise played at close range during our experimental playback surveys. Our results reflect the limited differences in noise that we found across our study sites, with increasing distance from the road, and between the construction and post-construction phases of our study. Louder highway construction or traffic noise could have a negative effect on warblers. However, results of our playback experiment and concurrent research conducted in urban areas and on military land where daily maximum noise levels exceed 70–100 dB(A) suggest this is unlikely (Long et al. 2017; M. L. Morrison, Texas A&M University, unpublished data).

Warblers could be more sensitive to the duration of noise, rather than its loudness. Studies suggest that birds may exhibit avoidance behaviors or experience reduced reproductive success near oil and gas compressors, which operate 24 hr a day, 365 days a year (Habib et al. 2007; Bayne et al. 2008; Francis et al. 2009, 2011*a*). We cannot address the potential impacts of chronic noise on warblers because the construction and traffic noise we recorded at our study sites was

Table 3. Results of one-way analyses of variance tests comparing frequency metrics for 3 phrases of the golden-cheeked warbler's A-song by treatment site (i.e., construction, traffic noise, control) in Real and Uvalde counties, Texas, USA, during construction along Highway 83 in 2009–2010.

Phrase	Lower frequency	Upper frequency	Bandwidth
1	$F_{2,1,360} = 230.70$, $P \leq 0.01$	$F_{2,1,360} = 239.40$, $P \leq 0.01$	$F_{2,1,360} = 124.70$, $P \leq 0.01$
2	$F_{2,1,895} = 177.60$, $P \leq 0.01$	$F_{2,1,895} = 148.20$, $P \leq 0.01$	$F_{2,1,895} = 45.55$, $P \leq 0.01$
3	$F_{2,1,792} = 168.90$, $P \leq 0.01$	$F_{2,1,792} = 277.80$, $P \leq 0.01$	$F_{2,1,792} = 637.70$, $P \leq 0.01$

Table 4. Means and associated standard deviations in parentheses for frequency metrics of 3 phrases of golden-cheeked warbler A-songs per treatment site (i.e., construction, traffic noise, control) in Real and Uvalde counties, Texas, USA, during construction along Highway 83 in 2009–2010.

Phrase	Metric (kHz)	Construction	Traffic noise	Control
1	Lower frequency	4.19 (0.45)	3.91 (0.14)	4.55 (0.18)
	Upper frequency	6.43 (0.68)	7.03 (0.44)	6.21 (0.43)
	Bandwidth	2.24 (0.98)	3.12 (0.47)	1.66 (0.33)
2	Lower frequency	3.93 (0.21)	4.04 (0.16)	4.11 (0.22)
	Upper frequency	5.99 (0.28)	5.90 (0.12)	6.06 (0.30)
	Bandwidth	2.06 (0.22)	1.86 (0.12)	1.95 (0.16)
3	Lower frequency	5.73 (0.25)	5.55 (0.08)	5.84 (0.14)
	Upper frequency	6.89 (0.21)	6.59 (0.10)	7.03 (0.21)
	Bandwidth	1.16 (0.17)	1.04 (0.07)	1.19 (0.10)

periodic. However, given the steep slopes, dense vegetation, and rocky soils that occur within warbler habitat, warbler exposure to land use types that produce chronic noise (e.g., energy development) may be of limited practical concern.

Ideally, impact assessments compare relative measures of wildlife responses before, during, and after a disturbance at treatment and control sites (Green 1979). Because construction on Highway 83 began the year before we initiated our study, we were unable to collect pre-treatment data and, thus, employed an after-only impact assessment (Wiens and Parker 1995, Morrison et al. 2008, Marshall et al. 2012). Warblers may have been negatively affected by construction noise and activity prior to the initiation of our study with lag effects continuing into the construction and post-construction phases. However, our noise analyses indicated that construction activity did not add significantly to the already low noise levels in this rural area, and warbler territory density, pairing success, and fledging success at our construction site during the construction phase were similar across our treatment and control sites and similar to or greater than estimates reported elsewhere across the species breeding range, suggesting this was not the case (e.g., Rowell et al. 1995, Groce et al. 2010). Similarly, though construction activity can negatively affect birds irrespective of noise (e.g., visual disturbance, vibrations, chemical pollutants; reviewed by Kociolek et al. 2011), our results provide no evidence to this effect.

Birds exposed to loud anthropogenic noise—including road construction and traffic noise—may adjust their vocalizations to avoid masking of their communication signals (Slabbekoorn and Peet 2003, Wood and Yezerinac 2006, Hu and Cardoso 2010, Dowling et al. 2012, Ríos-Chelén et al. 2012). Though we observed some differences in A-song metrics across sites during the construction phase, we found no differences in mean or maximum noise during this period. This suggests that any differences in song characteristics were attributable to individual variation rather than a response to differences in noise levels. Concurrent studies on warblers where mean and maximum noise levels were greater support these findings (Long et al. 2017; M. L. Morrison, unpublished data). However, birds may be more likely to adjust their songs in response to the frequency of noise rather than its loudness (Dooling and Popper 2007). Warblers, like other species that forage in the upper portions of the canopy (Ficken and Ficken 1962, Lemon et al. 1981), typically sing at frequencies of 4–8 kHz (Bolsinger 2000), whereas most construction and traffic noise is <3 kHz (Warren et al. 2006, Wood and Yerzinac 2006). Though warblers can likely hear low frequency noise, the higher frequencies of warbler songs may make them less susceptible to masking from construction and traffic noise (e.g., Warren et al. 2006, Hu and Cardoso 2010).

Human population growth and aging infrastructure will require recurring improvements to roadways for the foreseeable future, and road construction and operation are likely to be a consistent source of anthropogenic noise and potential disturbance along human-wildland interfaces. Our research corroborates other studies, which suggest that low frequency noise does not degrade warbler habitat (Benson 1995, Long et al. 2017). However, warblers are affected by patch size (Arnold et al. 1996, Baccus et al. 2007, Butcher et al. 2010, Robinson 2013), edge effects (Peak 2007), tree species composition (Marshall et al. 2013, Long 2014), and canopy cover (Dearborn and Sanchez 2001, Magness et al. 2006). As such, research that examines warbler responses in relation to these potential constraints may prove more useful for warbler conservation.

MANAGEMENT IMPLICATIONS

Though many papers published in the peer-reviewed literature report negative effects of anthropogenic noise on avian habitat quality, most acknowledge that bird responses to noise are species specific. In the present study, which we conducted for 7 breeding seasons using an experimental framework that included multiple avian response variables associated with habitat selection and behavior, we found no evidence to suggest that noise associated with construction or traffic had a negative effect on warblers at our study sites in rural Texas. Our results reiterate the importance of quantifying perceived disturbance to wildlife and using the information to help guide more effective management for species of conservation concern.

ACKNOWLEDGMENTS

We thank the Texas Department of Transportation for funding this research (contract no. 7-7XXIA001). We thank M. Priour for access to Big Springs RC. R. Meyers with Texas Parks and Wildlife was also helpful in allowing us to work at Garner State Park. J. Szewczak and Z. Loman designed the automatic recording units and developed the

SonoBird software used for processing audio data. We thank S. Farrell for helping to initiate our study. We also thank past field technicians and graduate students for their assistance with data collection, audio and video processing, and report preparation. B. Stevener, K. Skow, R. Anderson, and B. Collier at the Texas A&M Institute of Renewable Natural Resources provided technical and logistical support. We thank Associate Editor M. Donaghy-Cannon and two anonymous reviewers for their comments on earlier drafts of this manuscript.

LITERATURE CITED

Arnold, K. A., C. L. Coldren, and M. L. Fink. 1996. The interactions between avian predators and golden-cheeked warblers in Travis County. Texas A&M Transportation Institute, College Station, USA. <http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/1983-2.pdf>. Accessed 20 Jul 2015.

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

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

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

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

Brumm, H. 2004. The impact of environmental noise on song amplitude in a territorial bird. Journal of Animal Ecology 73:434–440.

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

Craft, R. A. 1998. 1997 field studies of golden-cheeked warblers (*Dendroica chrysoparia*) on Fort Hood, Texas. Pages 28–52 *in* The Nature Conservancy. Summary of 1997 research activities. The Nature Conservancy, Fort Hood, Texas, USA.

Daniel, W. W. 2009. Biostatistics: a foundation for analysis in the health sciences. Ninth edition. John Wiley and Sons, Hoboken, New Jersey, USA.

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

Diamond, D. D. 1997. An old-growth definition for western juniper woodlands: Texas ashe juniper dominated or co-dominated communities. U.S. Forest Service General Technical Report SRS-15, Southern Research Station, Asheville, North Carolina, USA. <http://www.srs.fs.usda.gov/*pubs*/gtr/gtr_srs015.pdf>. Accessed 20 Jul 2015.

Dooling, R. J., and A. N. Popper. 2007. The effects of highway noise on birds. Environmental BioAcoustics, Rockville, Maryland, USA.

Dowling, J. L., D. A. Luther, and P. P. Marra. 2012. Comparative effects of urban development and anthropogenic noise on bird songs. Behavioral Ecology 23:201–209.

Embleton, T. F. 1996. Tutorial on sound propagation outdoors. Journal of the Acoustical Society of America 100:31–38.

Ficken, M. S., and R. W. Ficken. 1962. The comparative ethology of wood warblers: a review. Living Bird 1:103–121.

Findlay, C. S., and J. Bourdages. 2000. Response time of wetland biodiversity to road construction on adjacent lands. Conservation Biology 14:86–94.

Francis, C. D., C. P. Ortega, and A. Cruz. 2009. Noise pollution changes avian communities and species interactions. Current Biology 19:1415–1419.

Francis, C. D., C. P. Ortega, and A. Cruz. 2011*a*. Noise pollution filters bird communities based on vocal frequency. PLoS One 6:e27052.

Francis, C. D., C. P. Ortega, and A. Cruz. 2011*b*. Vocal frequency change reflects different responses to anthropogenic noise in two suboscine flycatchers. Proceedings of the Royal Society B 278:2025–2031.

Gass, L. R. 1996. Nesting behavior of golden-cheeked warblers in Travis County, Texas. Thesis, Southwest Texas State University, San Marcos, USA.

Götmark, F. 1992. The effects of investigator disturbance on nesting birds. Current Ornithology 9:63–104.

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

Groce, J. E., H. A. Mathewson, M. L. Morrison, and R. N. Wilkins. 2010. Scientific evaluation for the 5-year status review of the golden-cheeked warbler. Final report submitted to the Texas Parks and Wildlife Department, Austin, Texas, and to the U.S. Fish and Wildlife Service, Region 2, Albuquerque, New Mexico, USA. <http://irnr.tamu.edu/media/252621/gcwa_scientific_evaluation.pdf>. Accessed 10 Nov 2016.

Habib, L., E. M. Bayne, and S. Boutin. 2007. Chronic industrial noise affects pairing success and age structure of ovenbirds *Seiurus aurocapilla*. Journal of Applied Ecology 44:176–184.

Hagen, C. A., J. C. Pitman, T. M. Loughin, B. K. Sandercock, R. Robel, and R. D. Applegate. 2011. Impacts of anthropogenic features on habitat use by lesser prairie-chickens. Studies in Avian Biology 39:63–75.

Halfwerk, W., L. J. Holleman, C. K. Lessells, and H. Slabbekoorn. 2011. Negative impact of traffic noise on avian reproductive success. Journal of Applied Ecology 48:210–219.

Hanson, C. E., D. A. Towers, and L. D. Meister. 2006. Transit noise and vibration impact assessment. Federal Transit Administration Office of Planning and Environment Report FTA-VA-90-1003-06. <https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/FTA_Noise_and_Vibration_Manual.pdf>. Accessed 20 Jul 2015.

Hayward, L. S., A. E. Bowles, J. C. Ha, and S. K. Wasser. 2011. Impacts of acute and long-term vehicle exposure on physiology and reproductive success of the northern spotted owl. Ecosphere 2:1–20.

Hu, Y., and G. C. Cardoso. 2010. Which birds adjust the frequency of vocalizations in urban noise? Animal Behaviour 79:863–867.

Ilner, H. 1992. Effects of roads with heavy traffic on grey patridge (*Perdix perdix*) density. Gibier Faune Sauvage 9:467–480.

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

Kociolek, A. V., A. P. Clevenger, C. C. St Clair, and D. S. Proppe. 2011. Effects of road networks on bird populations. Conservation Biology 25:241–249.

Lackey, M. A., M. L. Morrison, Z. G. Loman, B. A. Collier, and R. N. Wilkins. 2012. Experimental determination of the response of golden-cheeked warbler to road construction noise. Ornithological Monographs 74:91–100.

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

Lemon, R. E., J. Struger, M. J. Lechowicz, and R. F. Norman. 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. Dissertation, Texas A&M University, College Station, USA.

Long, A. M., M. R. Colón, J. L. Bosman, D. H. Robinson, H. L. Pruett, T. M. McFarland, H. A. Mathewson, J. M. Szewczak, J. C. Newnam, and M. L. Morrison. 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.

Magness, D. R., R. N. Wilkins, and S. J. Hejl. 2006. Quantitative relationships among golden-cheeked warbler occurrence and landscape size, composition, and structure. Wildlife Society Bulletin 34:473–479.

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

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

Martin, T. E., and G. R. Geupel. 1993. Nest-monitoring plots: methods for locating nests and monitoring success. Journal of Field Ornithology 64:507–519.

McClure, C. J., H. E. Ware, J. Carlisle, G. Kaltenecker, and J. R. Barber. 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., W. M. Block, M. D. Strickland, B. A. Collier, and M. J. Peterson. 2008. Wildlife study design. Second edition. Springer, New York, New York, USA.
National Oceanic and Atmospheric Administration. 2015. Summary of monthly normals 1981–2010. National Oceanic and Atmospheric Administration, Camp Mabry, Austin, Texas, USA. <http://www.ncdc.noaa.gov/cdo-web/search>. Accessed 20 Jul 2015.
Peak, R. G. 2007. Forest edges negatively affect golden-cheeked warbler nest survival. Condor 109:628–637.
Peris, S. J., and M. Pescador. 2004. Effects of traffic noise on passerine populations in the Mediterranean wood pastures. Applied Acoustics 65:357–366.
Rathe, E. J. 1969. Note on two common problems of sound propagation. Journal of Sound and Vibration 10:472–479.
Reidy, J. L., L. O'Donnell, and F. R. Thompson III. 2015. Evaluation of a reproductive index for estimating songbird productivity: case study of the golden-cheeked warbler. Wildlife Society Bulletin 39:721–731.
Reijnen, R., and R. Foppen. 1991. Effect of road traffic on the breeding site-tenacity of male willow warblers (*Phylloscopus trocilus*). Journal für Ornithologie 132:291–295.
Reijnen, R., and R. Foppen. 2006. Impact of road traffic noise on breeding bird populations. Pages 255–274 *in* J. Davenport and J. L. Davenport, editors. Ecology of transportation: managing mobility for the environment. Springer, Dordrecht, The Netherlands.
Reijnen, R., R. Foppen, and H. Meeuwsen. 1996. The effects of traffic on the density of breeding birds in Dutch agricultural grasslands. Biological Conservation 75:255–260.
Reijnen, R., R. Foppen, C. Ter Braak, and J. Thissen. 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction in the density in relation to the proximity of main roads. Journal of Applied Ecology 32:187–202.
Rheindt, F. E. 2003. The impacts of roads on birds: does song frequency play a role in determining susceptibility to noise pollution? Journal für Ornithologie 144:295–306.
Ríos-Chelén, A. A., C. Salaberria, I. Barbosa, C. M. Garcia, and D. Gil. 2012. The learning advantage: bird species that learn their song show a tighter adjustment of song to noisy environments than those that do not learn. Journal of Evolutionary Biology 25:2171–2180.
Robinson, D. H. 2013. Effects of habitat characteristics on occupancy and productivity of a forest dependent songbird in an urban landscape. Thesis, Texas A&M University, College Station, USA.
Roedenbeck, I. A., L. Fahrig, C. S. Findlay, J. E. Houlahan, J. A. G. Jaeger, N. Klar, S. Kramer-Schadt, and E. A. van der Grift. 2007. The Rauischholzhausen agenda for road ecology. Ecology and Society 12:11.
Rowell, G. A., D. P. Keddy-Hector, D. D. Diamond, J. Lloyd, B. McKinney, R. C. Maggio, and T. L. Cook. 1995. Remote sensing and GIS of golden-cheeked warbler breeding habitat and vegetation types on the Edwards Plateau. Texas Parks and Wildlife Department Grant No. l, E-1-7, Project No. 39. Austin, Texas, USA.
Slabbekoorn, H., and M. Peet. 2003. Ecology: birds sing at a higher pitch in urban noise. Nature 424:267.
Stewart, L. R., M. L. Morrison, M. R. Hutchinson, D. N. Appel, and R. N. Wilkins. 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., G. M. Cunnington, and L. Fahrig. 2011. Are negative effects of roads on breeding birds caused by traffic noise? Journal of Applied Ecology 48:1527–1534.
Texas Department of Transportation. 2016*a*. San Angelo District traffic maps. <http://ftp.dot.state.tx.us/pub/txdot-info/tpp/traffic_counts/>. Accessed 10 Mar 2016.
Texas Department of Transportation. 2016*b*. San Antonio District traffic maps. <http://ftp.dot.state.tx.us/pub/txdot-info/tpp/traffic_counts/>. Accessed 10 Mar 2016.
van der Zand, A. N., W. J. ter Keurs, and W. J. Van der Weijden. 1980. The impact of roads on the densities of four bird species in an open field habitat—evidence of a long distance effect. Biological Conservation 18:299–321.
Vickery, P. D., M. L. Hunter, Jr., and J. V. Wells. 1992. Use of a new reproductive index to evaluate relationship between habitat quality and breeding success. Auk 109:697–705.
Villard, M., and T. Pärt. 2004. Don't put all your eggs in real nests: a sequel to Faaborg. Conservation Biology 18:371–372.
Warren, P. S., M. Katti, M. Ermann, and A. Brazel. 2006. Urban bioacoustics: it's not just noise. Animal Behaviour 71:491–502.
Wiens, J. A., and K. R. Parker. 1995. Analyzing the effects of accidental environmental impacts: approaches and assumptions. Ecological Applications 5:1069–1083.
Wood, W. E., and S. M. Yezerinac. 2006. Song sparrow (*Melospiza melodia*) song varies with urban noise. Auk 123:650–659.

Associate Editor: *Donaghy-Cannon.*