

Impacts of Chronic Anthropogenic Noise from Energy-Sector Activity on Abundance of Songbirds in the Boreal Forest

ERIN M. BAYNE,* LUCAS HABIB, AND STAN BOUTIN

Integrated Landscape Management Group, Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada

Abstract: *The effects of human activities in forests are often examined in the context of habitat conversion. Changes in habitat structure and composition are also associated with increases in the activity of people with vehicles and equipment, which results in increases in anthropogenic noise. Anthropogenic noise may reduce habitat quality for many species, particularly those that rely on acoustic signals for communication. We compared the density and occupancy rate of forest passerines close to versus far from noise-generating compressor stations and noiseless well pads in the boreal forest of Alberta, Canada. Using distance-based sampling, we found that areas near noiseless energy facilities had a total passerine density 1.5 times higher than areas near noise-producing energy sites. The White-throated Sparrow (*Zonotrichia albicollis*), Yellow-rumped Warbler (*Dendroica coronata*), and Red-eyed Vireo (*Vireo olivaceus*) were less dense in noisy areas. We used repeat sampling to estimate occupancy rate for 23 additional species. Seven had lower conditional or unconditional occupancy rates near noise-generating facilities. One-third of the species examined showed patterns that supported the hypothesis that abundance is influenced by anthropogenic noise. An additional 4 species responded negatively to edge effects. To mitigate existing noise impacts on birds would require approximately \$175 million. The merits of such an effort relative to other reclamation actions are discussed. Nevertheless, given the \$100 billion energy-sector investment planned for the boreal forest in the next 10 years, including noise suppression technology at the outset of construction, makes noise mitigation a cost-effective best-management practice that might help conserve high-quality habitat for boreal birds.*

Keywords: Alberta, boreal forest, chronic noise, compressor stations, edge effects, energy industry, forest songbird, passerines

Impactos de Ruido Antropogénico Crónico de la Actividad del Sector Energético sobre la Abundancia de Aves Canoras en el Bosque Boreal

Resumen: *Los efectos de las actividades humanas en los bosques a menudo son examinados en el contexto de la conversión del hábitat. Sin embargo, en asociación con cambios en la estructura y composición del hábitat hay incrementos en la actividad de personas con vehículos y equipo, lo que resulta en incrementos en el ruido antropogénico. El ruido antropogénico puede reducir la calidad del hábitat para muchas especies, particularmente las que dependen de señales acústicas para su comunicación. Comparamos la densidad y la tasa de ocupación de paserinos de bosque cerca versus lejos de estaciones compresoras generadoras de ruido y pozos silenciosos en el bosque boreal de Alberta, Canadá. Utilizando muestreo basado en distancias, encontramos que las áreas cerca de instalaciones energéticas silenciosas tenían una densidad total de paserinos 1.5 veces mayor que las áreas cercanas a sitios generadores de ruido. La densidad de *Zonotrichia albicollis*, *Dendroica coronata* y *Vireo olivaceus* fue menor en áreas ruidosas. Utilizamos muestreos de repetición para estimar la tasa de ocupación de 23 especies adicionales. Siete tenían menores tasas de ocupación condicional o incondicional cerca de las instalaciones generadoras de ruido. Un tercio de las especies examinadas mostró patrones que soportaron la hipótesis que la abundancia esta influida por el ruido antropogénico. Cuatro*

*email bayne@ualberta.ca

Paper submitted August 3, 2007; revised manuscript accepted January 7, 2008.

especies adicionales respondieron negativamente a los efectos de borde. Para mitigar los impactos del ruido sobre las aves se requeriría aproximadamente US \$175 millones. Se discuten los méritos de tal esfuerzo en relación con otras acciones de reclamación. Sin embargo, dada la inversión de \$100 billones planeada por el sector energético en el bosque boreal en los próximos 10 años, la inclusión de tecnología supresora de ruido al comienzo de la construcción, hace que la mitigación de ruido sea una práctica de manejo rentable que podría ayudar a conservar hábitat de buena calidad para las aves boreales.

Palabras Clave: Alberta, ave canora de bosque, bosque boreal, efectos de borde, estaciones de compresores, industria de la energía, paserinos, ruido crónico

Introduction

Human activity is increasing throughout the world's forests. Many of these activities are associated with changes in the structure and composition of native vegetation. A large body of literature addresses the effects of these footprint-related changes on wildlife. Less understood are the impacts caused by the "foot," or in other words, the presence of people and their tools on forested areas. One of the consequences of industrial activity in forested environments is increased anthropogenic noise due to vehicles, machinery, and infrastructure. Industrial noise can take many forms. Forestry and energy-sector operations can generate intense noise for periods of days to weeks in a relatively small area. Aircraft and cars moving through an area relatively infrequently create periodic but very intense noise disturbances. Responses of animals such as caribou (*Rangifer tarandus*, Bradshaw et al. 1997), whales (Myrberg 1990), and Spotted Owls (*Strix occidentalis*, Delaney et al. 1999) have been examined in this context. In general, such species seem to abandon the area when the noise is occurring and return once the noise has dissipated.

The effects on wildlife of chronic anthropogenic noise from busy highways, urban areas, and permanent industrial structures are not as well understood. Presumably, if noise levels are chronic, animals will either avoid the noisy area or become habituated to noise and remain, although remaining may have consequences for reproductive success (Habib et al. 2007). It seems logical that because of the importance of acoustic information to forest songbirds and the myriad number of ways anthropogenic noise can affect avian communication, that birds might avoid chronically noisy locations. Nevertheless, birds are plastic in their song repertoire, and many can modify song characteristics to fit their environment (Slabbekoorn & Peet 2003). If this phenomenon is generally true, then birds may be able to adapt to chronic noise, which means there would be no net loss of habitat for birds as a result of anthropogenic noise.

In much of the boreal forest of Alberta, Canada, human activity is rapidly increasing in an effort to extract oil and gas. To locate, take to the surface, and ship energy products, an intricate system of roads, pipelines,

wells, and other energy facilities has been created. Compressor stations are part of the pipeline network and serve to maintain the flow of gas through pipelines. A compressor consists of 1–3 motors cooled by an equal number of large fan units housed in an insulated metal shed in a small clearing (2–4 ha). Noise levels produced by compressor stations are typically between 75 and 90 dB(A) at the source (Bolstad Engineering Associates 1978; ATCO Noise Management 2007), but can reach 105 dB(A) at large facilities (MacDonald et al. 1996). Compressor stations run 24 h a day, 365 days a year other than for periodic maintenance. Compressor noise can be heard at distances of well over 1 km in the boreal forest (E.M.B., personal observation). There are approximately 5000 compressor stations in boreal Alberta.

Our objective was to compare bird occupancy and density close to versus far from noise-generating compressor stations relative to control well pads that had similar levels of habitat disturbed but no noise. We predicted that birds would be most affected by noise if an interactive effect of noise and distance existed (i.e., bird abundance near control sites and compressor stations would differ the most). We expected sites farther from compressor stations and control sites to exhibit less of a difference in bird abundance because noise dissipates over space.

Methods

Field Methods

To study the effect of noise from compressor stations, some type of control is required. In experiments assessing the impacts of highway noise as a factor influencing birds, comparisons between highway edge and forest interior are often made. The difficulty with this design is highways are associated with other factors (i.e., edges) that make it difficult to isolate the effect of noise. Compressor stations have a significant amount of edge habitat, so comparing areas close to compressor stations to forest interior provides only a weak control. Nevertheless, across Alberta there are hundreds of thousands of well pads. Like compressor stations, well pads are clearings of forest habitat linked to the pipeline and road network.

Unlike compressor stations, natural-gas well pads produce no chronic noise; thus, we used them as our control sites.

We conducted our study in northeastern Alberta during June 2003 and 2004 in the Alberta-Pacific Forest Industries Inc. (ALPAC) Forest Management Agreement area (FMA) (see Bayne et al. [2005] for map). The landscape is a boreal mixed-wood forest (Strong & Leggat 1992), where lowland vegetation is dominated by black spruce (*Picea mariana*) bogs and fens, and upland areas are dominated by trembling aspen (*Populus tremuloides*) and white spruce (*P. glauca*).

Compressor stations and well pads were preselected in a geographic information system (GIS) with Alberta Vegetation Inventory (AVI) data, energy facility data, and road data provided by ALPAC. Bird surveys were conducted in mature, 60- to 90-year-old, aspen-dominated forest (<25% conifer). We identified all possible compressor sites identified in the GIS. Sites were then ground truthed to ensure that the energy facility was appropriate and the vegetation was of the correct type. Within the pool of ground-truthed sites with appropriate forest cover, we selected sites that were accessible by truck and close enough together to make travel between sites practical on a daily basis. Compressor sites were >3 km away from other sites to ensure noise from one site did not reach another. Well pads were occasionally <3 km away from each other. No noise was emitted from well pads, so noise contamination between sites was not a concern. Although logging occurs in the area, no sites were located within 1 km of a harvested area or within 2 km of ongoing logging at the time of study.

Ten-minute variable-radius point counts were conducted at each site to measure bird abundance. The location of each singing bird was recorded as occurring in 1 of 3 concentric circles during each point-count visit (0–50 m, 50–100 m, and 100–150 m from observer). At each site, the location where bird surveys were conducted (hereafter point-count stations) was in 1 of 2 bands around each compressor or well pad. Four point-count stations were within 100–300 m of the edge of the energy clearing (hereafter close), and 4 others were within 400–700 m (hereafter far). Each point-count station was visited 4 times. Point-count stations were a minimum of 300 m apart and at least 50 m from linear-feature edges, such as seismic lines or pipelines. The rationale for using the 2 “distance” groups was that linear features and natural vegetation patterns prevented identification of a uniform set of distances at each site. At point-count stations near compressor stations, the average noise level was 48 db(A) (SD 6), whereas the average distance from the compressor centroid was 242 m (SD 86).

Point counts were conducted from 4 through 30 June in 2003 and from 2 through 25 June in 2004 between 04:24 and 09:27. All counts were done on days with

no significant precipitation and little to no wind (<3 on the Beaufort scale). Overall, we conducted counts at 104 point-count stations (52 close and 52 far) at 13 compressor stations. At 8 well pads, we surveyed 64 stations (32 close and 32 far). Non-passerines were counted but excluded from all analyses. Time of day, date, and observer (3 individuals) were fully randomized among treatments such that each station received equal effort by each observer at different times of the day and year. These nuisance variables were not included in the analysis as a result of this randomization.

At each station we recorded canopy cover, proportion of trees that were coniferous, shrub cover, canopy height, and shrub height. Cover estimates were placed in 1 of 5 ranks by 1 observer (0, none present; 1, 1–25% cover; 2, 26–50% cover; 3, 51–75% cover; 4, 76–100% cover). We used principal components analysis after variable standardization to reduce these 5 variables to 2 variables, which we used as vegetation covariates in subsequent analysis.

Estimating Density and Occupancy

Inherent in studies of bird response to ambient noise is the possibility of detectability bias. Detectability has many components, but the main concern related to anthropogenic noise is whether the observer hears a bird given that it sings within a distance detectable by the observer (Farnsworth et al. 2002). Equal detectability among habitats is assumed in most studies, but if violated as it may be in noisy versus quiet environments, estimates of density or occupancy may be biased. Absolute occurrence or true density is not particularly important for statistical inference about the effects of noise if noise has no effect on the ability of an observer to hear birds. Occupancy rate or density will simply underestimate the true value. Nevertheless, if detection error is differentially affected by the level of background noise it is plausible that a greater number of absences or the number of birds that observers can hear at noisy locations may be a function of detection error generated by noise rather than birds having reduced abundance in noisy areas. Statistical modeling of occupancy via repeat sampling (MacKenzie et al. 2002) and density estimation via distance sampling (Buckland et al. 2001) are 2 methods that allow detection error to be estimated in response to noise level and with which appropriate corrections can be made to density or occupancy estimates.

To estimate density we measured the distance to each bird and then used Program Distance (Thomas et al. 2006) to calculate detection probabilities. We fit detection functions for half-normal and uniform models with cosine and simple polynomial expansions to the second order to determine which series and key function provided the best-fitting detection curve for each distance-noise stratum.

Data from all visits and all point-count stations within each stratum were used to derive the detection function. Density was estimated for each point-count station with

$$\hat{D} = \frac{n}{\pi w^2 \hat{P}_a v}, \quad (1)$$

where n is the number of birds counted per point-count station, w^2 is the known radius of sampling (150 m), \hat{P}_a is the expected proportion of birds detected with a radius w (estimated detection function), and v is the number of visits to each point-count station.

Some researchers think the ability of observers to estimate distance to singing birds on the basis of acoustic cues (even in the coarse categories we used) is not accurate enough to effectively estimate distance. In addition to a 2-week training period each year, during which we practiced estimating distance, we used a field point-count simulation with known numbers of “birds” to validate our ability to estimate distances. The simulation was done when few real birds were singing and wind was minimal. The simulation took place at 3 point-count stations at one compressor site. Background noise at the points varied from 48 to 53 dB(A). Three people moved quietly throughout the forest playing randomly selected song recordings of 6 species at appropriate volumes at distances up to 150 m. The 2 main observers stood blindfolded, standing back-to-back and counted simulated birds. A total of 200 singing events were simulated. A correct identification required the species to be identified at the correct bearing, within the correct 50-m-distance band, and at the correct time. In only one case did an error in identification occur in the simulation within 50 m of the observer, whereas 89% of simulated call playbacks at distances between 50 and 150 m were identified correctly by observers.

Using the detection-error function, we changed our counts per point-count station into estimated density of birds per point-count station. Density of birds was analyzed subsequently with a generalized linear model to determine whether the following variables were significant predictors: noise (dummy variable for compressor vs. well pad), distance (dummy variable close to vs. far from energy sector clearings), and the interaction between treatment and distance. The 2 principal-component factors that described vegetation composition were also included. If the interaction between noise and distance was not significant at $p \leq 0.05$, it was dropped from the model.

Our data were hierarchically structured, with point-count stations nested within sites, which made sites the unit of replication. To account for the potential lack of independence of point-count stations within sites, site was treated as a random effect in the model. This convention partitioned the appropriate degrees of freedom and estimated unique site-level effects, thus accounting for the

multilevel structure of the data (Rabe-Hesketh & Skrondal 2005). Although distribution of density was similar to a Gaussian distribution for the common species, density of some species was not distributed normally. To ensure the p values used in statistical inference were robust to distributional assumptions, we used a permutation test run 1000 times to estimate statistical significance. All generalized linear models were run in the program Stata 9.2 (Statacorp 2005).

For many species there were insufficient data to estimate density, so we also modeled the occupancy rate. Using the program Presence (Hines 2006), we estimated detection error for each species by recording the proportion of point-count stations in which species were detected over our 4 visits and adjusted occupancy estimates accordingly. The key assumption of the MacKenzie method is that if a species is detected once during repeated visits to a site, it had to have been present but was not detected on the other visits, which generates a detection-error function (closed population assumption). If a bird is never detected at a point-count station it does not necessarily imply absence, and the approach estimates the probability that a bird would occur at each point-count station on the basis of the detection-error function. We estimated a unique detection function for each stratum and controlled for this difference when estimating occupancy rate. Likelihood-ratio tests were used to determine whether there was any evidence that the interaction between noise and distance, and the main effects of distance and noise—while controlling for vegetation covariates—influenced conditional occupancy rate (occurrence corrected for detection error within each stratum). For some species, program Presence would not converge, and in these cases we used logistic regression with a random effect to test whether occurrence differed between treatments. Occurrence was defined as whether a species was detected during any of the 4 visits.

Results

We recorded the location of 5129 passerine birds of 56 species. Of these, 23 species were detected at 2 or more point-count stations within each noise-distance stratum and were considered for analysis. We generated unique detection functions via distance estimation for all passerines combined: Ovenbird, Red-eyed Vireo, Tennessee Warbler, White-throated Sparrow, and Yellow-rumped Warbler (scientific names in Table 2). The selected functions and expansions used to estimate density were selected on the basis of model goodness of fit. For the remaining species there were insufficient detections within each stratum (60–100 detections is recommended) to estimate a suitable detection-error function with distance sampling (Buckland et al. 2001).

Table 1. Density of birds (95% CI) at the edge of natural gas well pads (noiseless sites) and compressor stations (noise-generating sites) relative to areas in the forest interior.*

Species	Compressor near	Compressor far	Well pad near	Well pad far	Well pad vs. compressor (p)	Near vs. far (p)	Interaction (p)
All	18.8	22.0	32.3	29.3	.	.	0.019
Passerines	(17.3–20.2)	(20.4–23.6)	(30.2–34.4)	(27.3–31.2)			
Ovenbird	5.5	7.5	7.2	7.6	0.359	0.009	0.181
	(4.7–6.3)	(6.7–8.4)	(6.1–8.3)	(6.7–8.6)			
Red-eyed Vireo	3.0	3.7	5.4	3.8	.	.	0.004
	(2.3–3.7)	(3.2–4.2)	(4.6–6.2)	(3.0–3.7)			
Tennessee Warbler	4.4	4.0	3.3	3.4	0.076	0.695	0.558
	(3.9–4.9)	(3.4–4.6)	(2.5–4.1)	(2.7–4.1)			
White-throated Sparrow	0.7	0.5	1.8	1.5	<0.001	0.211	0.750
	(0.5–0.9)	(0.4–0.7)	(1.5–2.2)	(1.1–1.9)			
Yellow-rumped Warbler	1.5	1.1	2.1	1.4	0.021	0.114	0.592
	(1.1–2.0)	(0.8–1.5)	(1.3–3.0)	(1.0–1.8)			

*Density is the number of birds per 10 ha after statistical correction with different distance-correction functions. Detection functions were derived independently for each noise-distance category. Data are reported as means adjusted to average vegetation conditions. The 95% CIs were derived from a bias-corrected and accelerated bootstrap. The p values were generated via Monte Carlo permutations. Main effects were not tested for significance if the interaction between noise and distance was significant at $p \leq 0.05$.

The density of all passerines was significantly lower near compressor stations than all other strata (Table 1). The rank order of passerine bird density was: near well pads > far well pads > far compressor > near compressor. This was the pattern we expected to see. Correcting for detection error, density estimates were not significantly different between noisy versus quiet areas for Ovenbirds, although the density estimate near compressor stations was the lowest of the 4 strata. The Red-eyed Vireo had its lowest density near compressor station edges, which was significantly lower than near the edges of well pads. There was no significant difference in Tennessee Warbler density between treatments. White-throated Sparrows were 2 to 4 times more abundant at well-pad edges than at compressor-station edges (Table 1). The density of Yellow-rumped Warblers was significantly lower near compressor stations.

Occupancy rates determined from conditional estimators showed that American Redstarts, Least Flycatchers, Red-breasted Nuthatches, Red-eyed Vireos, and Yellow-rumped Warblers were less likely to occur near compressor stations (Table 2). Conditional estimators could not be calculated for the Red-breasted Nuthatch and Rose-breasted Grosbeak, but the unconditional estimator showed they were less likely to occur in noisy areas. There was no statistically significant evidence of any species being more likely to occur near compressor stations.

Discussion

A large body of literature comparing bird abundance near highways relative to forest interiors has led to the conclu-

sion that chronic noise is a critical factor influencing habitat quality for forest birds (e.g., Reijnen & Foppen 1995; Forman & Deblinger 2000; Peris & Pescador 2004). Despite the large number of studies, the inferences drawn about the effects of road noise on birds are weak because the majority of researchers compared road edges to forest interiors, which confounds factors such as edge effects, traffic mortality, and visual cues from cars with the effects of noise. Our result that overall passerine density was significantly influenced by the interaction between noise level and distance to compressor stations provides some of the strongest support that chronic anthropogenic noise does influence habitat quality for forest birds.

Relatively few of the species we surveyed exhibited the expected interactive pattern. Nevertheless, one-third of the species supported our hypothesis that noise reduced abundance, as areas both close to and far from compressor stations had lower abundance than near well pads. This suggests that noise levels from compressor stations may be sufficiently loud to affect birds up to 700 m into the forest. Alternatively, we may have had insufficient statistical power to detect the interactive effect of noise and distance. In European road studies, where noise has been purported to cause declines in birds, lower abundances of birds near roads have been observed in 15–74% of species analyzed, with overall density typically being lower at road edges. Our results are at the low end of this range. Importantly, in none of these studies did researchers correct for detection error caused by vehicle noise.

Why some forest birds avoid noisy areas and others do not is not well understood. Birds communicate primarily through vocalizations. Males of territorial species use song to advertise their breeding status to females (Lein

Table 2. Estimates of occupancy rate (95% CI) at the edge of natural gas well pads (noiseless sites) and compressor stations (noise-generating sites) relative to matched areas in the forest interior.^a

Species	Est. ^b	Compressor near	Compressor far	Well pad near	Well pad far	Well pad vs. compressor (p)	Near vs. far (p)	Interaction (p)
Alder Flycatcher (<i>Empidonax alnorum</i>)	U	0.18 (0.08–0.37)	0.04 (0.01–0.15)	0.09 (0.02–0.29)	0.09 (0.03–0.29)	0.533	0.032	0.137
American Redstart (<i>Setophaga ruticilla</i>)	C	0.07 (0.02–0.22)	0.20 (0.06–0.51)	0.53 (0.10–0.92)	0.32 (0.15–0.56)	.	.	0.034
American Robin (<i>Turdus migratorius</i>)	C	0.69 (0.01–0.99)	0.48 (0.09–0.89)	0.66 (0.18–0.94)	0.54 (0.03–0.98)	0.950	0.691	0.919
Black-and-white Warbler (<i>Mniotilta varia</i>)	C	0.29 (0.14–0.49)	0.46 (0.22–0.72)	0.26 (0.10–0.55)	0.71 (0.01–0.99)	0.952	0.146	0.639
Black-capped Chickadee (<i>Poecile atricapilla</i>)	U	0.18 (0.09–0.32)	0.28 (0.16–0.43)	0.09 (0.03–0.25)	0.37 (0.21–0.57)	0.873	0.011	0.131
Chipping Sparrow (<i>Spizella passerine</i>)	C	0.52 (0.31–0.72)	0.30 (0.13–0.57)	0.53 (0.33–0.73)	0.61 (0.33–0.83)	0.446	0.737	0.242
Connecticut Warbler (<i>Opornis agilis</i>)	C	0.23 (0.10–0.43)	0.32 (0.20–0.48)	0.33 (0.18–0.51)	0.28 (0.15–0.46)	0.413	0.937	0.413
Gray Jay (<i>Perisoreus canadensis</i>)	U	0.16 (0.08–0.28)	0.16 (0.08–0.29)	0.12 (0.04–0.28)	0.24 (0.12–0.42)	0.449	0.268	0.254
Hermit Thrush (<i>Catharus guttatus</i>)	C	0.30 (0.11–0.61)	0.52 (0.18–0.85)	0.59 (0.15–0.92)	0.47 (0.27–0.68)	0.703	0.694	0.375
Least Flycatcher (<i>E. minimus</i>)	C	0.20 (0.10–0.34)	0.35 (0.22–0.49)	0.52 (0.34–0.69)	0.42 (0.24–0.62)	.	.	0.049
Magnolia Warbler (<i>Dendroica magnolia</i>)	C	0.55 (0.02–0.98)	0.30 (0.13–0.57)	0.54 (0.03–0.98)	0.71 (0.01–0.99)	0.370	0.577	0.649
Mourning Warbler (<i>O. philadelphica</i>)	C	0.31 (0.17–0.48)	0.33 (0.20–0.49)	0.50 (0.28–0.72)	0.58 (0.23–0.86)	0.209	0.868	0.890
Ovenbird (<i>Seiurus aurocapilla</i>)	U	0.98 (0.84–0.99)	0.99 (0.88–0.99)	1	1	0.999	0.685	.
Red-breasted Nuthatch (<i>Sitta canadensis</i>)	U	0.08 (0.03–0.20)	0.13 (0.06–0.27)	0.10 (0.03–0.28)	0.40 (0.22–0.61)	0.016	0.010	0.193
Red-eyed Vireo (<i>Vireo olivaceus</i>)	C	0.85 (0.71–0.93)	0.95 (0.94–0.98)	1	0.95 (0.77–0.99)	0.041	0.275	.
Rose-breasted Grosbeak (<i>Pheucticus ludovicianus</i>)	U	0.03 (0.01–0.12)	0.12 (0.05–0.27)	0.55 (0.31–0.76)	0.51 (0.28–0.73)	0.001	0.061	0.103
Ruby-crowned Kinglet (<i>Regulus calendula</i>)	U	0.13 (0.06–0.30)	0.12 (0.05–0.28)	0.13 (0.04–0.33)	0.13 (0.04–0.33)	0.908	0.942	0.842
Swainson's Thrush (<i>C. ustulatus</i>)	C	0.82 (0.17–0.99)	0.43 (0.29–0.57)	0.64 (0.32–0.87)	0.78 (0.39–0.95)	0.106	0.083	0.143
Tennessee Warbler (<i>Vermivora peregrina</i>)	C	0.84 (0.72–0.92)	0.83 (0.70–0.91)	0.82 (0.64–0.92)	0.75 (0.58–0.87)	0.866	0.790	0.992
White-throated Sparrow (<i>Zonotrichia albicollis</i>)	C	0.57 (0.43–0.70)	0.61 (0.45–0.75)	0.76 (0.58–0.88)	0.84 (0.65–0.94)	0.103	0.564	0.734
Winter Wren (<i>Troglodytes troglodytes</i>)	C	0.11 (0.03–0.30)	0.13 (0.06–0.28)	0.09 (0.02–0.36)	0.12 (0.03–0.33)	0.646	0.291	0.981
Yellow Warbler (<i>D. petechia</i>)	U	0.06 (0.01–0.23)	0.02 (0.01–0.11)	0.02 (0.01–0.19)	0.06 (0.01–0.30)	0.755	0.507	0.086
Yellow-rumped Warbler (<i>D. coronata</i>)	C	0.49 (0.36–0.63)	0.72 (0.50–0.87)	0.66 (0.42–0.84)	0.88 (0.43–0.99)	0.003	0.011	0.633

^aData are reported as proportion of point-count stations occupied adjusted to average vegetation conditions. The 95% confidence intervals were derived empirically. The p values are from likelihood-ratio tests. Main effects were not tested for significance if the interaction between noise and distance was significant at $p \leq 0.05$.

^bConditional occupancy rate (C) was derived from an adjusted occupancy rate corrected for detection error estimated separately for each stratum. When conditional models would not converge, we used standard unconditional logistic regression (U) in which a species was considered present if it was detected during any of the 4 visits.

1981) and to provide an indicator of their quality as potential mates (Gil & Gahr 2002; Nowicki & Searcy 2005). In noisy areas male birds may not transmit their song as clearly or over as great a distance as they otherwise could. Thus, reduced song transmission might influence the number of females that hear an individual male's song

or result in females' receiving false information about a male's quality (Ballentine et al. 2004). At some of the sites examined in this study, Habib et al. (2007) found that male Ovenbirds are 17% less likely to attract a female mate if their territory was adjacent to a compressor station than if their territory was adjacent to a well pad.

Ovenbird males near compressor stations also tended to be younger (48% of birds captured were first-time breeders) than individuals near well pads (30%). This suggests that mating success may play a role in altering whether males and females chose to settle in an area with noise.

Using a naïve estimator derived from raw counts and a method of detection-error correction from Farnsworth's (2002) removal modeling approach, Habib (2006) concluded that Ovenbird abundance was somewhat lower near compressor stations than near well pads. Nevertheless, when we corrected for differences in density of Ovenbirds with distance sampling, this effect was no longer significant, which highlights the importance of the underlying detection-error function as a factor in assessing the effects of noise on birds. Whether there is a direct link between changes in pairing success and bird density remains unclear as a result. Differences in pairing success between noisy and quiet areas and among different habitats need to be looked at for forest passerines besides the Ovenbird to determine the generality of the link between pairing success, human disturbance, and bird abundance.

Song is important in identification of neighboring males, demarcation and passive defence of territory boundaries, and assessment of the physiological state of conspecifics (Lein 1981; Lemon et al. 1981; Brenowitz 1982). Noise may create difficulties in territorial defense by reducing the ability of male birds to acoustically estimate the location of known conspecifics, resulting in more physical encounters between individuals. An increase in physical encounters may increase stress in forest songbirds (Mazerolle & Hobson 2002). Campo et al. (2005) found that prerecorded mechanical noises, such as fans and vehicles, increased stress levels in laying hens and that the level of that stress was directly related to noise amplitude. In the wild, females may be less likely to hear quiet acoustic cues given by chicks in response to hunger or predation risk, which could translate into reduced fecundity. Many other acoustic communication cues used by birds may be affected as anthropogenic noise increases beyond the range of natural noise under which bird communication evolved. Further investigation of the specific communication cues and aspects of avian life history that are affected by anthropogenic noise are warranted.

Demands for energy reserves from Alberta's boreal forest continue to put stress on this ecosystem and the species in it. Our results suggest that one management action to reduce energy impacts on birds would be to suppress noise at compressor stations. If 2 ha of forest around each of the approximately 5000 compressor stations in Alberta's boreal forest are cleared, then approximately 10,000 ha of trees have been lost to compressor construction. If one assumes no forest passerines use compressor stations, then habitat for approximately 27,000 birds has

been lost because of land clearing (on the basis of average density of forest passerines in forest interiors). If the effects of noise that we found are the same for birds in forests other than those dominated by aspen trees, then the effective habitat loss in boreal Alberta caused by noise within 300 m of a compressor station would result in an additional 85,000 birds lost. The cost of retroactive reduction of noise levels at existing compressor stations would vary, but a typical retrofit to reduce noise by 4 db(A) at the source would be \$35,000 to \$50,000 (P. Wierzba, personal communication). If a noise reduction of 4 db(A) were to return forest habitat to its original value, then the cost to recover habitat lost to noise would be approximately \$175–250 million. In construction of new compressors, the latest technology in noise suppression should be used because the costs of incorporating these technologies during the construction phase are believed to be less than the cost of retrofitting.

Compressor stations are only one type of disturbance in a myriad of other human disturbances occurring in boreal Alberta, so it is important to put this loss of bird habitat in context. There is a large backlog of other types of energy sites that have reduced habitat quality for birds in the boreal forest. For example, in 2005 it was estimated that there were approximately 175,000 well pads in Alberta, of which approximately one-half are abandoned (Pembina Institute 2007). Current reclamation guidelines require these wells be returned "to an equivalent land capability." Although this implies well pads must be capable of growing trees, most have been reseeded to grass and will not return to a forested state without different reclamation techniques (Schneider 2002). Current estimates suggest the average well pad can be reclaimed in a way that allows forest succession to occur for approximately \$2000–4000 (B. Coupal, personal communication). If planting trees on well pads restores their value for boreal birds, then the same \$175–250 million used to reduce noise could restore "forested" habitat at 44,000–63,000 well pads. Replanting well pads to trees rather than retrofitting compressor stations to reduce noise could result in increased habitat for 118,000–169,000 birds when the well pads become mature forest.

In the next 10 years a \$100-billion influx of energy-sector development is planned for northern Alberta. The large reduction in habitat that will occur and the reduced quality of forested areas affected by industrial noise will result in a decrease in the number of passerine birds. Add to energy-sector disturbances the change in forest structure and age caused by industrial forestry, and the threat of extirpation of some boreal forest passerines becomes quite real. To minimize this risk it is important that energy-sector companies use new mitigation approaches that address issues related to habitat conversion and the more subtle effects, such as chronic noise, created by their activities.

Acknowledgments

We thank C. Gray, D. Pueschel, E. Cameron, A. Blake, M. Lankau, M. C. Arienti, H. Clarke, M. Conboy, T. Hope, and S. Nielsen for assistance in the field and ALPAC and IHS Energy for AVI and facility GIS data layers. This research was conducted as part of the Natural Sciences and Engineering Research Council of Canada (NSERC) Industrial Research Chair in Integrated Landscape Management. Additional funding was provided by the Canadian Circumpolar Institute, Alberta Sport, Recreation, Parks, and Wildlife Foundation, and the Alberta Conservation Association Challenge Grants in Biodiversity. Personal funding to L. H. was provided by NSERC, Alberta Ingenuity Fund, and the Alberta Society of Professional Biologists.

Literature Cited

- ATCO Noise Management. 2007. Environmental noise control. ATCO Noise Management, Calgary. Available from http://www.atconoise.com/mediaroom/NOISE_HANDBOOK.pdf (accessed December 2007).
- Ballentine, B., J. Hyman, and S. Nowicki. 2004. Vocal performance influences female response to male bird song: an experimental test. *Behavioral Ecology* **15**:163–168.
- Bayne, E. M., S. L. Van Wilgenburg, S. Boutin, and K. A. Hobson. 2005. Modeling and field-testing of Ovenbird (*Seiurus aurocapillus*) responses to boreal forest dissection by energy sector development at multiple spatial scales. *Landscape Ecology* **20**:203–216.
- Bolstad Engineering Associates Limited. 1978. Engineering report on noise emissions from gas compressor stations and processing plants. Bolstad Engineering, Edmonton, Alberta.
- Bradshaw, C. J., S. Boutin, and D. Hebert. 1997. Effects of petroleum development on woodland caribou in northeastern Alberta. *Journal of Wildlife Management* **61**:1127–1133.
- Brenowitz, E. A. 1982. Long-range communication of species identity by song in the red-winged blackbird. *Behavioral Ecology and Sociobiology* **10**:29–38.
- Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press, Oxford, United Kingdom.
- Campo, J. L., M. G. Gil, and S. G. Davila. 2005. Effects of specific noise and music stimuli on stress and fear levels of laying hens of several breeds. *Applied Animal Behaviour Science* **91**:75–84.
- Delaney, D. K., T. G. Grubb, P. Beier, L. L. Pater, and M. H. Resier. 1999. Effects of helicopter noise on Mexican spotted owls. *Journal of Wildlife Management* **63**:60–76.
- Farnsworth, G. L., K. H. Pollock, J. D. Nichols, T. R. Simons, J. E. Hines, and J. R. Sauer. 2002. A removal model for estimating detection probabilities from point-count surveys. *Auk* **119**:414–425.
- Forman, R. T. T., and R. D. Deblinger. 2000. The ecological road-effect zone of a Massachusetts (USA) suburban highway. *Conservation Biology* **14**:36–46.
- Gil, D., and M. Gahr. 2002. The honesty of bird song: multiple constraints for multiple traits. *Trends in Ecology & Evolution* **17**:133–141.
- Habib, L. D. 2006. Effects of chronic industrial noise disturbance on boreal forest songbirds. MS thesis. University of Alberta, Edmonton, Canada.
- Habib, L. D., 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.
- Hines, J. E. 2006. PRESENCE2—software to estimate patch occupancy and related parameters. U.S. Geological Survey, Patuxent Wildlife Research Center, Maryland. Available from http://www.mbr-pwrc.usgs.gov/software/bin/setup_presence.exe (accessed December 2007).
- Lein, M. R. 1981. Display behavior of Ovenbirds (*Seiurus aurocapillus*). 2. Song variation and singing behavior. *Wilson Bulletin* **93**: 21–41.
- 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.
- MacDonald, R., N. Ewanek, and P. Tilley. 1996. Trapping and suppressing compressor axial fan intake noise. Proceedings of the spring environmental noise conference: innovations in noise control for the energy industry. Alberta Energy and Utilities Board, Calgary, Canada.
- MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* **83**:2248–2255.
- Mazerolle, D. F., and K. A. Hobson. 2002. Physiological ramifications of habitat selection in territorial male ovenbirds: consequences of landscape fragmentation. *Oecologia* **130**:1432–1439.
- Myrberg, A. A. 1990. Effects of man-made noise on the behaviour of marine mammals. *Environment International* **16**:575–586.
- Nowicki, S., and W. A. Searcy. 2005. Song and mate choice in birds: how the development of behavior helps us understand function. *Auk* **122**:1–14.
- Pembina Institute. 2007. When the government is the landlord. Pembina Institute, Edmonton, Alberta. Available from http://pubs.pembina.org/reports/Regional%20Details_Alberta.pdf (accessed December 2007).
- Peris, S. J., and M. Pescador. 2004. Effects of traffic noise on passerine populations in Mediterranean wooded pastures. *Applied Acoustics* **65**:357–366.
- Rabe-Hesketh, S., and A. Skrondal. 2005. Multilevel and longitudinal modeling using Stata. Stata Press, College Station, Texas.
- Reijnen, R., and R. Foppen. 1995. The effects of car traffic on breeding bird populations in woodland. 4. Influence of population size on the reduction of density close to a highway. *Journal of Applied Ecology* **32**:481–491.
- Schneider, R. 2002. Alternative futures: Alberta's boreal forest at the crossroads. The Alberta Centre for Boreal Research and the Federation of Alberta Naturalists, Edmonton, Canada.
- Slabbekoorn, H., and M. Peet. 2003. Birds sing at higher pitch in urban noise. *Nature* **424**:267.
- StataCorp. 2005. Stata statistical software. Release 9. StataCorp, College Station, Texas.
- Strong, W. L., and K. R. Leggat. 1992. Ecoregions of Alberta. Alberta Forestry, Lands, and Wildlife Branch, Edmonton, Canada.
- Thomas, L., et al. 2006. Distance 5.0. Release 2. Research Unit for Wildlife Population Assessment, University of St. Andrews, United Kingdom. Available from <http://www.ruwpa.st-and.ac.uk/distance/> (accessed December 2007).