**Investigating the Role of Mortality in Explaining the Negative Road Effect on Birds**

by

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# Abstract

Lower abundance of forest birds near high traffic roads has been attributed to traffic noise, but the potential role of traffic mortality has not been adequately tested. To test the hypothesis that traffic mortality is an important contributor, I predicted that where there is a higher risk of traffic collision, there would be a stronger decrease in the number of forest birds close to roads over the course of the breeding season. I compared relative abundance of forest birds, at four distances from high traffic roads, at ten sites where the birds were more likely to cross the road (forest on the other side) vs. at ten sites where they were less likely to cross the road (open field on the other side). The prediction was supported, suggesting that roads bisecting natural areas may create population sinks. This highlights the importance of mitigating traffic mortality in important bird habitats.

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## Introduction

We are only beginning to understand the ecological consequences of the 100 million km road network spanning the world's terrestrial ecosystems (CIA 2008). The effects of roads are diverse and complex (Forman et al. 2003), resulting in a range of impacts on wildlife populations, many of them negative (Fahrig & Rytwinski 2009). Building new roads involves the destruction of former habitat. Road construction also introduces changes to adjacent habitat which animals may avoid, including visual disturbances, chemical pollution and noise from traffic. Those remaining in the modified habitat may choose to cross the road and risk being killed by oncoming vehicles. Though the relative importance of the underlying mechanisms behind reduced wildlife abundance in habitats near roads (e.g. behavioural avoidance vs. mortality) remains to be explored in many cases, numerous studies have reported this phenomenon (Forman et al. 2003; Fahrig & Rytwinski 2009).

Among the studies documenting impacts of roads on wildlife, it has been shown that birds are less abundant near high traffic roads. A study examining the effect of roads in the Netherlands found lower densities of breeding birds in agricultural grasslands close to roads where traffic was higher (Van Der Zande et al. 1980). This result was further supported by later studies examining other European agricultural grasslands (Reijnen et al. 1996),  forests (Reijnen et al. 1995; Brotons & Herrando 2001; Kuitunen et al. 2003; Rheindt 2003; Polak et al. 2013), hedgerows (Fuller et al. 2001) and wooded pasturelands (Peris & Pescador 2004). Outside of Europe, a similar pattern was found in

Australian forest (Pocock & Lawrence 2005) as well as in North American open habitats (Forman et al. 2002) and woodlots (Summers et al. 2011). Hereafter I refer to this phenomenon of reduced bird abundance with proximity to high traffic roads as the "negative road effect" on birds.

In past studies, the negative road effect on birds has usually been attributed to traffic noise. Birds rely on sound to attract mates, defend territories (Nowicki & Searcy 2004) and avoid predation (Klump & Shalter 1984). Because such important activities depend on being able to effectively communicate by sound, and traffic noise increases with proximity to roads, it has been identified as the most important component of the negative road effect (Reijnen & Foppen 2006). This is supported by studies showing that other sources of anthropogenic noise affect bird reproduction, behaviour and abundance. Ovenbirds (*Seiurus aurocapilla*) near noise-emitting natural gas compressor stations have shown reduced pairing success (Habib et al. 2006). A study on chaffinches (*Fringilla coelebs*) found that they increased their visual surveillance activity when exposed to background noise generated at frequencies intended to reduce their ability to use auditory cues (Quinn et al. 2006) . Finally, the abundance of certain bird species appears to be reduced  near noisy compressor stations (Bayne et al. 2008; Francis et al. 2009). Though studies have demonstrated that anthropogenic noises have an effect on birds, the characteristics of noise studied to date can be different from those of traffic noise, both in terms of loudness and frequency (Summers et al. 2011).

Despite the evidence that birds are affected by other sources of anthropogenic noise, there is little direct evidence that traffic noise is the main road-related mechanism influencing bird abundance. In past studies examining the effects of roads, other potential road-related impacts correlated with traffic noise have rarely, if ever, been controlled for. These include possible visual disturbances, chemical pollution, and risk of collisions. Some of these variables appear to be of limited concern. The only study that examined vehicle visibility did not support the visual disturbance hypothesis (Reijnen et al. 1995). While no study examining the negative road effect on birds has attempted to control for the effects of chemical pollution, it has been estimated that chemical pollutants reach background levels within 50m of roads (Reijnen et al. 1995) while the negative road effect on birds has been measured up to 2800m from the road in woodland (Reijnen et al. 1995) and 3530m from the road in grasslands (Reijnen et al. 1996). Thus, it is unlikely that pollution is the main cause of the negative road effect on birds. In contrast, while it is known that birds are killed by collisions with vehicles, no study examining the negative road effect has either measured or controlled for the contribution that traffic mortality makes toward the observed negative road effect.

Several studies have assumed that traffic mortality is not an important component of the negative road effect on bird populations (Reijnen et al. 1995; Forman et al. 2002; Rheindt 2003; Peris & Pescador 2004), belying the many studies showing that birds are frequently killed on roads during the breeding season, particularly where traffic volume is high. Studies reporting road-killed birds have been conducted in Europe (Erritzoe et al. 2003), Australia (Taylor & Goldingay 2004), South America (Teixeira et al. 2013), and

North America (Clevenger et al. 2003; Eberhardt 2009). Bird carcasses have been found

with greater frequency during  seasons when most birds breed and fledge, and where

traffic volume is high, with several, but not all, studies reporting a positive relationship

between traffic volume and the presence of road-killed birds (Erritzoe et al. 2003;

Orłowski 2008; Eberhardt 2009;  but see Clevenger et al. 2003). A recent analysis

estimated that 13.8 million birds are killed annually on paved roads during the breeding

season in Canada (Bishop & Brogan 2013). This conservative estimate was largely based

on the few surveys performed in Canadian ecozones, without correcting for detection.

The estimate suggests that almost 0.26% of all land birds in southern Canada are killed

each year on roads (Bishop & Brogan 2013). Though this may seem a low proportion, it

represents one of  the cumulative anthropogenic pressures on our declining bird

populations (Calvert et al. 2013). Estimates for the United States, a country with higher

road density, have been calculated at a much coarser level, but Erickson et al. estimated

that at least 80 million birds are killed  on U.S. roads each year (2005).

Some studies have suggested that the traffic mortality on birds can affect bird

population responses. For both pied flycatchers (*Ficdula hypoleuca*) and great tits (*Parus

Major*), nestlings were found to be less likely to fledge from nestboxes close to roads

than nestlings in nestboxes farther away from roads (Kuitunen et al. 2003; Holm &

Laursen 2011), possibly because the nestlings starved when parents were hit by cars.  In

North America, road-killed gray jays (*Perisoreus canadensis*) were found along a major

two-lane highway running through Algonquin Park (Strickland 2013). An analysis of gray

jay survivorship near and far from the same highway found jays inhabiting territories

adjacent to the highway had lower survival rates than those on territories away from the road.  Further south, Florida scrub-jays (*Aphelocoma coerulescens*) living next to a two-lane highway were found to have mortality rates nearly twice as high as those living away from the road (Mumme et al. 2000). In territories next to roads, more scrub-jays were killed than yearlings produced.

Recently, a study carried out  by Summers et al. (2011) in eastern Ontario indicated that traffic noise did not explain declines in bird abundance with proximity to high traffic four-lane highways; the authors suggested the possibility that mortality may play an important role. They recorded traffic noise during bird point count surveys performed along transects perpendicular to ten high traffic sections of road. Though both traffic noise and bird abundance were negatively correlated with distance from the road, they found that bird abundance was not related to variation in traffic noise after correcting for distance from the roads. This suggests that some other mechanism was playing a role in reducing the number of birds near roads. As risk of collision would have also been negatively correlated with distance from the roads, I hypothesize that traffic mortality could be an important mechanism explaining the negative road effect.

To test this hypothesis, I sought to test a prediction that derives specifically from the mortality hypothesis, and that would not be predicted by the noise hypothesis. To avoid confounding the two hypotheses, I therefore compared the negative road effect between forest sites with similar noise levels but with differing probabilities that birds would be killed crossing the road. Unlike past studies, where noise and probability of

collision were correlated with distance from the road, I identified two site types, where

birds had either a greater or a reduced chance of suffering traffic mortality. I inferred

this difference based on the assumption that forest birds are more likely to cross small

forest gaps created by the road than they are to cross large forest gaps created by the

road and an adjacent clearing. The lower probability of forest birds crossing larger gaps

has been documented using methods including territorial call playbacks (Rail et al.

2011), mobbing call playbacks (Bélisle & Desrochers 2002; St.Clair 2003), simple

observation (Grubb & Doherty 2011) and radio tracking (Norris & Stutchbury 2001;

Fraser & Stutchbury 2004; Evans et al. 2008). In addition, roadkill studies have suggested

that collisions are more frequent where roads traverse forests (Erritzoe et al. 2003).

Birds have been shown to cross four-lane highways with forest on either side (St.Clair

2003). Along the same four-lane highway, Clevenger et al. (2003) found more dead birds

where the road was separated by a median than where the highway had no median at

all, a result they attributed to forested medians reducing the size of forest gap perceived

by birds.

Though it would be useful to conduct roadkill surveys testing the assumption that birds

are more likely to be hit by vehicles where there are small gaps in the forest than where

there are large gaps in the forest, it was not possible to incorporate this component into

the study. I could not perform such surveys because I  could not obtain legal permission

to stop a vehicle  or to enter the high-traffic roadways on foot or other non-motorized

means (e.g. bicycle; see Eberhardt 2009), due to the danger associated with high traffic

volumes and speeds. I considered  the gap-crossing studies and roadkill studies cited

above to be sufficient support for my assumption that birds are more likely to attempt to cross roads  at sites where the road represents a small-gap in the forest (hereafter "small-gap sites") than at sites with no forest immediately across the road (hereafter "large-gap sites"). I then focussed my tests on an associated population-level prediction arising from the mortality hypothesis.

I predicted that the negative road effect would become stronger over the breeding season at small-gap sites than at large-gap sites. The effects of traffic mortality should accumulate throughout the breeding season, assuming a dead bird's territory remains empty for at least part of that season. If birds are more likely to cross the road at small-gap sites than at large-gap sites, higher bird mortality at the small-gap sites should lead to a greater decrease in abundance at those sites than at large-gap sites. This reduction in abundance at small-gap sites should become increasingly apparent at locations closest to the road as the breeding season progresses, due to the accumulation of empty territories.  In addition, a measurement of the negative road effect itself – the slope of the relationship between bird abundance and distance from the road - should become stronger (increasingly positive, as birds become less abundant close to the road) throughout the breeding season. The mortality hypothesis predicts that this intensification of the negative road effect should be stronger at small-gap sites than at large-gap sites, due to higher mortality at the former than at the latter. If mortality is an important contributor to the negative road effect on birds, both a greater decrease in abundance closest to the road as well as a stronger negative road effect should be

found at small-gap sites relative to large-gap sites later in the breeding season, even if

traffic volume (and traffic noise) is the same at the two site types.

## Methods

Throughout the 2012 breeding season from the end of May to early July, I surveyed for

birds along transects perpendicular to the road in forest sites next to high traffic roads.

These forest sites were selected such that the adjacent highway either (i) represented a

small-gap in the forest (small-gap sites), or (ii) had no forest immediately on the other

side of it (large-gap sites).  Simultaneous to the bird surveys, I collected audio recordings

to test for potential issues with bird detectability and potential differences in traffic

noise levels between site types. To document habitat structure, I also conducted

vegetation surveys at the point count sites.

*Site Selection*

I selected 20 forest sites adjacent to high traffic four-lane highways in Southern and

Eastern Ontario (**Figure 1**). All sites were greater than two km apart. Forest patches

contained a mix of coniferous and deciduous trees. All roads exceeded 10000 annual

average daily traffic (AADT)(Ministry of Transportation 2010).  I selected (1) small-gap

sites, where there was forest immediately across the road from the sample site, i.e. the

road created a small-gap in the forest (75-110m), and (2) large-gap sites, where there

was no forest immediately across the road, but instead a large agricultural clearing such

that the distance from the road-side perimeter of the sample site to the nearest forest

patch (> 1ha in size) on the other side of the road ranged from 175 to 1000m (**Figure 2** and **Figure 3**). Sites were also selected to minimize differences in AADT although it was not possible to find sites with identical traffic volume that met my selection criteria; on average, traffic volume was 2710 (AADT) lower at small-gap sites than at large-gap sites, though this difference was not statistically significant (t=0.69,df=18,p=0.50,**Figure 4**).

*Point Count Surveys*

I performed bird surveys on weekday mornings from May 30 to July 5 2012. Because of the time it took to access each site, I could not survey multiple sites in a single day. Consequently, I could only survey each site once in the breeding season. To avoid confounding date of survey with site type, I alternated surveys of small-gap and large-gap sites through the season. To avoid confounding date of survey with geographic location, I surveyed half of all sites from the north, south-west and south-east early in the breeding season and then surveyed the remainder of the sites from those three areas later in the season. As part of my bird survey protocol, I followed the recommendations for point counts outlined in Bibby et al. (2000). One person performed all point counts for this study, thus avoiding observer bias. I performed the point counts along a transect perpendicular to the road at points 50, 150, 250 and 350m from the road-side edge of the forest (**Figure 2**). To avoid confounding time of point count with distance from the road, the order of point counts ran from either 50m to 350m or from 350m to 50m. Half of the small-gap sites were randomly selected to start at 350m. Accordingly, the rest of the small-gap surveys started at 50m. Each large-gap

site survey was always performed in the same direction as the small-gap survey

preceding it. I started the first point count 30 minutes before sunrise. Each point count

was for ten minutes. This resulted in the final point count at all sites ending before

6:45am. To maximize detectability, I did not conduct point counts during rainy or windy

conditions (greater than four on the Beaufort scale). To avoid an effect of traffic noise

on bird detectability, I only included birds heard within 50m of the observer during the

point count. In a study measuring how well birds were detected by observers under

different conditions, low-frequency background noise had essentially no effect on bird

detectability within a radius of 50m in a mixed wood forest (Pacifici et al. 2008).

*Audio Recordings*

I took audio recordings to verify bird identifications made during the point count

surveys. I also used the recordings to test (and correct if necessary) for effects of traffic

noise on bird detectability, to verify that traffic noise did not differ between small-gap

and large-gap sites, and to verify that it did not increase over the field season. To

estimate traffic noise from the recordings, I measured noise within a frequency range

chosen to avoid incorporating sounds unrelated to traffic within traffic noise

measurement. To be able to compare noise measured using different microphones, a

correction was made to adjust for differences in sensitivity of the microphones.

The day before each point count survey, I set up four automated digital recorders (SM2

and SM2+ Song Meters, Wildlife Acoustics), each programmed to record sound at one of

the four locations where the point count would be performed the next day. All four

Song Meters then recorded audio simultaneously on the morning of the survey from 4:30am to 9:00am to capture peak rush-hour traffic noise during the period of day when diurnal forest birds sing most frequently. The Song Meters made recordings using a 2Hz high pass filter, a combined gain stage of 48dB and a sampling rate of 48 kHz. Each Song Meter was equipped with two omni-directional SMX-II microphones (with a sensitivity of -36dB ±4dB), aimed parallel to the road in opposing directions at each point count location (**Figure 2**). The Song Meters were attached to small trees, 1.5m above the ground. On one occasion the recordings were affected by high wind, on a second occasion by rain and on a third occasion by a traffic accident, following the morning's point count. For these three cases, replacement recordings were made for the full recording period of 4:30am to 9:00am on weekdays in July and August.

I later verified all bird identifications from the point counts by listening to the segments of the recordings taken during the point count surveys.

To determine whether there was an effect of traffic noise on bird detectability, I documented birds singing during traffic-free periods recorded at five small-gap and five large-gap sites (as a sub-sample of the twenty study sites) and then calculated traffic noise recorded during the in-person point count at those same locations. I reasoned that if traffic noise had affected the observer's ability to detect birds, the difference between the birds documented from the traffic-free recordings and the birds documented during the in-person point counts would increase with greater traffic noise

during the in-person point count. To test this question, I collected two pieces of

information from the sound recordings made on the day of each in-person point count:

i.    To generate my traffic free estimate of bird abundance, I used sections of each

recording that had no traffic from the first two hours of the morning. This was

done for recordings at all four point count locations of the ten sites, yielding 40

points for the analysis. From the portion of the recordings taken between 30

minutes before dawn to 90 minutes after dawn, i.e. the period with the lowest

traffic and the most frequent birdsong, I identified segments of the sound

recordings without traffic noise. From these traffic-free segments, I stitched

together randomly selected segments longer than six seconds into a four minute

audio file for each point count location. I then identified all birds recorded

singing during these traffic-free audio files.

ii.   To measure the traffic noise that occurred during the in-person point count, I

used only the ten minute period of time during which each in-person point count

occurred. From these ten minutes of recorded sound, I then calculated an index

of traffic noise (as described below).

I used this information in conjunction with that collected during the in-person point

counts to test whether traffic noise had an effect on bird detectability, as later described

under Statistical Analyses.

To verify that traffic noise at the sites was not confounded with either site type (small-

gap vs. large-gap sites) or date of survey I calculated an index of traffic noise using the

sound recordings taken from 4:30-9:00am at each site. First, I excluded from all recordings periods of noise generated by the observers as they approached and left each point count location. The shortest observer-free recording was 3.7 hours long. I then calculated my traffic noise index for every site using the last 3.7 hours of observer-free audio recordings taken before 9:00am. This ensured that the loudest period of traffic noise in the morning was included. To calculate the index of traffic noise, I measured the average power, in unweighted dB, of each second of sound across 0.3kHz-2kHz using Raven pro 1.4 (Cornell lab of Ornithology). Traffic noise tends to be loudest below 2kHz (Warren et al 2006). Because most noise from birdsong occurs above 2kHz (Slabbekoorn & Ripmeester 2008) and I wanted to control for wind and recorder vibrations below 0.3kHz that could not be reliably eliminated from the recordings, I did not include noise above or below these frequencies (respectively).

Following the field season, I calculated differences in microphone sensitivity to adjust for them when comparing my index of traffic noise between point count sites. I measured differences in sensitivity using an Extech 407766 sound calibrator, which generates a 1 kHz sine wave at 94dB to an accuracy of ±0.8dB. In conducting these comparisons, I discovered that three microphones were unreliable, i.e. they failed to produce a consistent measure in average power (dB) of the noise produced by the sound calibrator. Therefore, for measuring traffic noise, I did not use the recordings made by these three microphones. This reduced sample sizes in analyses that included traffic noise.

*Vegetation Surveys*

I conducted a vegetation survey at each point count location between mid-July and mid-August. Within the 50m radius of each point count, I randomly located and surveyed a 100m$^2$ circular plot, divided into quadrants defined by the cardinal directions. To survey trees, I used the point centre quarter method (Cottam and Grant 1956): Within each quadrant, I determined the distance to the nearest tree, the species of that tree and its diameter at breast height. Within all four quadrants, I recorded the total number of shrubs as well as an estimate of average shrub height and average ground vegetation height. I also took measurements of percent canopy and percent ground cover at the centre and edge of the circular plot in each cardinal direction.   I took these measurements by looking up (for canopy vegetation) and down (for ground vegetation) through an ocular tube (tissue roll with cross hairs). If vegetation crossed the field of view where the crosshairs intersected, I recorded a positive observation (Grushecky and Fajvan 1999). I then summed these observations and divided by five to generate coarse measures of percent cover of canopy and ground vegetation.

*Statistical Analyses*

To determine whether bird detectability declined with increasing traffic noise, I conducted a mixed effects linear model. The response variable was the difference in bird abundance between the measurements from the traffic-free recordings and the measurements from the in-person point counts. Traffic noise during the in-person point count (measured using average power, dB) was a fixed effect, and site was a random

effect. For this analysis I had 39 points; traffic noise for one of the 40 locations could not

be used, because one of the three unreliable microphones had been used to measure it,

as explained above.

To test the similarity of habitat between the two site types, I ran generalized linear

mixed models with each of my vegetation measurements as a response variable, as

follows: canopy cover (binomial distribution), ground cover (binomial distribution),

ground cover height (normal distribution), number of shrubs (negative binomial

distribution), shrub height (normal distribution), average distance to the nearest trees

(normal distribution), and average diameter of trees (normal distribution). For all of the

models, site type was a fixed effect and distance from the road was a random effect. I

performed these analyses using SAS 9.2.

To test whether traffic noise was confounded with site type (small-gap sites vs. large-

gap sites), I performed a mixed effects linear model with the site's traffic noise as the

response variable, site type as the fixed effect, and distance from the road as the

random effect. For this analysis, I had 75 points; five traffic recordings could not be used

in this analysis due to the problems with unreliable microphones explained above.

To test whether traffic noise was confounded with date, I performed a mixed effects

linear model with the site's traffic noise as the response variable, date of survey as the

fixed effect and distance from the road as a random effect. In this analysis, I had had 66

points; I excluded recordings taken by the unreliable microphones explained above, and

I only included traffic noise estimates measured during the morning of the actual bird survey, which means I excluded the three recordings previously mentioned.

To test whether the strength of the road effect was related to traffic noise, I measured the road effect at each site. I did this by calculating the slope of bird abundance relative to the distance from the road where the point count took place (eg. 50, 150, 250 or 350m). When this slope is more positive it indicates a stronger negative road effect, i.e. fewer birds near the road than far from the road. I then ran a regression with these slope values as the response and traffic noise measured at the point closest to the road (50m from the road) as the predictor. This analysis had 20 points (the 20 sites).

To test my prediction that the negative road effect would become stronger over time at small-gap sites than at large-gap sites, I conducted two analyses:

i.  I examined bird abundance measured at the point closest to the road (50m from the road) at the two site types, expecting that the difference in abundance between small-gap and large-gap sites would be strongest close to the road.  I calculated a generalized linear model using a Poisson distribution. The response variable was bird abundance 50m from the road at each site, and the predictors were site type (small-gap sites vs. large-gap sites), date of survey, and their interaction. I ran this analysis using SAS 9.2.

ii. I examined the road effect (the slope of bird abundance vs. distance from the road) at each site, expecting the negative road effect to intensify

(reflected in increasingly positive slope value measurements) throughout the breeding season more strongly at the small-gap sites than at the large-gap sites. I then ran a regression with road effect (the slope) as the response, and site type, date of survey and their interaction as predictors. I also calculated separate regressions of road effect on date of survey for small-gap and large-gap sites.

I did not perform analysis of individual species due to low sample sizes (Appendix D). Unless otherwise noted, I performed all analyses using R (3.0.1)

## Results

Altogether I detected 45 bird species and found, on average, eleven species per site. There was rarely more than one individual of each species within the 50m point count radius. As a result, bird abundance was highly correlated with species richness (r=0.87, p<0.001). I observed five birds on average during each point count, with the number ranging from one to twelve.

The bird abundance estimates from the traffic free recordings were correlated with the bird abundance estimates from the in-person point counts (Pearson r=0.41, p<0.01, see **Figure 5**). If traffic noise had decreased the observer's ability to detect birds, I would have expected to find that the difference between bird abundances estimated from the traffic free recordings and the in-person point counts would be positively related to

traffic noise. This was not the case ($F_{1,28}$=0.30, p=0.59, see **Figure 6**). Therefore, there is no evidence for an effect of traffic noise on bird detectability in the data.

The vegetation characteristics that I measured were not significantly different between site types, with the exception of the average distance to trees, which was 0.93m greater at the large gap sites ($F_{1,75}$=4.7  p=0.03, see **Table 1**). Traffic noise also did not significantly differ between site types (see **Table 1**), though it did have a significant relationship with date of survey, decreasing by -0.13dB per day (F1,61=6.67, p =0.01, see **Figure 7**). This made our tests of the traffic mortality hypothesis conservative, as we predicted an increasing road effect with date of survey at the small-gap sites.

The negative road effect did not strengthen (the slope of abundance vs. distance from the road did not become more positive) with increasing traffic noise. In fact, the slope values *decreased* by -0.0012 for each additional dB of traffic noise, though this decrease was not statistically significant ($F_{1,18}$=3.3, p=0.084,$R^2$ =0.16, see **Figure 8**).

The first test of the traffic mortality hypothesis, using the abundance data collected 50m from the roads, tentatively supported my prediction. Bird abundance close to the road was lower at the small-gap sites surveyed later in the season, and this was not the case for the large-gap sites (see **Figure 9**), though the difference was not statistically significant (interaction between site type and date of survey: $F_{1,16}$=6.3, p=0.087).

The second test of the traffic mortality hypothesis, based on the slope of abundance vs. distance from the road, i.e. the negative road effect itself, supported my prediction. The interaction between site type and date of survey was statistically significant ($F_{1,16}$=6.3,

p=0.023); the negative road effect on bird abundance became stronger (as shown by more positive slope values) over the breeding season at small-gap sites ($F_{1,8}=35.2$, p=0.00035) but not at large-gaps sites ($F_{1,8}=0.52$, p=0.52, see **Figure 10**).

## Discussion

This study provides evidence that traffic mortality is an important component of the negative effect of roads on bird abundance. I predicted that, if mortality was important, the negative road effect would become stronger at small-gap sites than at large-gap sites through the breeding season, on the assumption that birds are more likely to be hit by vehicles at small-gap sites than at large-gap sites. This prediction was supported, particularly clearly in the second analysis in which the slope of the relationship between abundance and distance from the road (the negative road effect) became stronger as the season progressed at the small-gap sites but not at the large-gap sites.

I suggest that these results are consistent with traffic mortality and would not be predicted by other potential mechanisms, especially traffic noise, that might cause negative effects of roads. I selected sites such that traffic volume was similar between the small-gap and large-gap sites. This allowed me to vary traffic mortality (i.e. higher mortality in small-gap sites than large-gap sites) while controlling for other road effects that co-vary with traffic volume, including traffic noise, visual disturbances and chemical pollution. Consequently, the differences I observed between small-gap and large-gap sites cannot be explained by any of these variables. To be confident that traffic noise did not somehow bias my data, I verified that my ability to detect birds was not influenced

by traffic noise. I also verified that traffic noise was similar between site types, that it did not increase over the course of the breeding season (it actually decreased), and that differences in traffic noise between sites did not explain difference in the strength of the road effect between sites.

My results did not arise from habitat differences between site types. I carefully chose sites comparable in habitat structure, within the constraints of site availability. Given my study design, however, the large-gap sites were situated in landscapes with a higher ratio of agricultural land to forest than the landscapes surrounding the small-gap sites. If nest predators are more abundant along edges in landscapes with more forest, then nest predation, rather than road mortality, might explain the observed pattern of diminishing bird abundance near the edge at the two site types. However, the opposite is true. A review of studies on nest predators suggests that nest predators are actually more abundant in agricultural landscapes than in forest landscapes (Chalfoun et al. 2002).  Therefore it is highly unlikely that my results are confounded by effects of nest predation. The same can be said of any negative effects of agricultural practices (eg. pesticide use) on forest birds.

An interesting and unexpected pattern in the data is that the road effect was positive (negative slope values) at the small-gap sites surveyed early in the season (**Figure 10**). This may be explained by birds being attracted to roadside territories, due to higher primary productivity (denser vegetation) and associated insect abundance, similar to that observed in forest gaps. For example, two studies of regenerating clearcuts (Strelke

& Dickson 1980; Hansson 1983) found forest bird densities to be higher at the forest/clearcut edge than in the forest interior. However, I acknowledge that this explanation is highly speculative, since studies comparing  interior and edge habitats created by powerline corridors (Kroodsma 1982; Small & Hunter 1989) and small roads (Rich et al. 1994) did not find higher bird densities at the forest edges. I  hypothesize that this pattern is not found at the large-gap sites because the benefits of edge habitat may be outweighed by a higher perceived risk of predation, due to a  greater abundance of predators, such as the American Crow (*Corvus brachyrhynchos)* (Bayne et al 1997), near open agricultural areas.

My results are particularly significant considering that, given the availability of resources and sites, I was only able to sample 20 sites, and with only one survey date at each site. Even in my first analysis, using only the data from the point counts nearest the roads (50 m from the roads), the relationship was in the predicted direction. The second analysis, using all the data, showed clearly that the negative road effect strengthened over the breeding season at small-gap sites but not at large-gap sites. Future studies should survey multiple sites, each several times throughout the breeding season. Here I chose, rather, to study different sites at different times, to ensure a reasonable sample size of sites (20). Nonetheless, I was able to make sure that other variables were not confounded with date of survey, by alternating site type, geographic region and direction of survey. Thus, my results do support the notion that traffic mortality is an important component of the negative road effect, and that mortality should be considered in future studies on the effects of roads on birds.

Past studies of the negative road effect attributed the effect to traffic noise, dismissing the role of traffic mortality. For example, Reijnen and Foppen (2006) suggested that traffic mortality may not affect recruitment rates for bird populations because many of the road-killed birds found were juveniles (Erritzoe et al. 2003), an age class with a naturally high mortality rate. However, this argument depends on the assumption that mortality is compensatory, or in other words that other forms of mortality are reduced when traffic mortality is increased, an assumption that has yet to be tested. Though my study did not directly measure traffic mortality in either juvenile or adult birds, it does indirectly add to the growing body of evidence that adult birds are being killed on roads because it suggests a decreasing number of singing adult birds close to the road throughout the breeding season at sites where risk of collision was high. This finding is corroborated by studies that reported the age of road-killed birds, showing that there were substantial numbers of adults killed and, in some cases, more adults killed than juveniles (Erritzoe et al. 2003). Studies examining decreased rates of fledging for birds in nests near roads (Kuitunen et al. 2003; Holm & Laursen 2011) further emphasize the implications of adults being killed. Loss of an adult bird not only has a direct effect on the population, it also means a reduction in nestling survival for that year, as well as the loss of any future opportunity for that adult to breed. Thus, the contribution of traffic mortality merits further consideration when drawing inferences from past and future studies that examine the negative effects of roads on bird populations.

Although there are some examples of bird populations adapting to road mortality, for most bird species, habitats next to roads are likely acting as population sinks. Over a 30-

year study period, Brown & Bomberger Brown (2013) showed that cliff swallows (*Petrochelidon pyrrhonota)* nesting colonially on culverts and bridges were hit on the road less frequently while the population increased over time (Brown & Bomberger Brown 2013). Over the same period the average wing length of the swallows had shortened, likely increasing their manoeuvrability in the face of oncoming cars. A study in western France found that birds sitting on roads and roadsides initiate flight sooner on roads with higher speed limits, which the authors interpreted as a learned behaviour (Legagneux & Ducatez 2013). Though these findings might suggest that some species adapt rapidly to roads, not all bird species do. Many birds are clearly not avoiding road mortality, as documented by recent roadkill studies (Eberhardt 2009; Guinard et al. 2012). Birds in Banff National Park were found to be more likely to cross highway gaps than they were to cross rivers creating gaps of similar width (St.Clair 2003), suggesting that those species have not identified the risks associated with crossing roads. Gray jays in Algonquin Park were found to establish territories in roadside and non-roadside habitat with equal preference, despite the lower survivorship on territories adjacent to roads (Strickland 2013). Similarly, overall mortality of Florida scrub jays was found to exceed the number of yearlings produced in roadside territories (Mumme et al. 2000), despite the superior foraging opportunities on those territories and the apparent ability of older birds to avoid vehicle collisions (Mumme et al. 2000; Morgan et al. 2010). In the case of this species, experience with roads and an ability to avoid collisions did not appear to be passed on from parents to their young (Mumme et al. 2000). These examples suggest that not all birds that tolerate or are even attracted to habitats near

roads may be able to adequately identify or avoid the risks of vehicle collision. For these birds, roadside habitats may be acting as population sinks or, in some cases, ecological traps.

The results of this study do not necessarily indicate that noise plays no role in the negative effect of roads on bird abundance. For example, there could be an interaction effect between noise and mortality, such that birds that tolerate traffic noise may be more vulnerable to traffic mortality. One of the studies examining the effects of chronic industrial noise on birds suggested that some species do not identify noisy habitat as undesirable (Francis et al. 2009). Certain bird species may be more prone to set up territories next to busy roads because their songs are not masked by the traffic noise (Rheindt 2003). This may result in traffic mortality becoming an additional cost of living in a noisy neighbourhood (Francis & Barber 2013). The great tit, for example, has been shown to sing at a higher pitch where there is loud, low-frequency traffic noise, thereby avoiding masking of their songs  (Slabbekoorn et al. 2003). Great tit nests have been found to be more abundant in forest closer to roads, despite lower nestling survival at those locations (Holm & Laursen 2011; Polak et al. 2013). The reduction in nestling survival is likely caused by parents being hit by vehicles. Though the great tit is not a declining species, other traffic noise-tolerant birds may be killed on roads. For some of these bird species, traffic mortality could negate any benefits derived from an ability to tolerate traffic noise in habitat next to roads.

Most importantly, this study's results indicate that mitigation of road effects on birds should include mitigation for traffic mortality. The data indicate that mortality rates are higher on high traffic roads that bisect natural habitat. These are exactly the sites where new roads tend to be built, because it is cheaper to construct a new road on undeveloped land. However, such practices may have particularly detrimental effects on birds attempting to cross the small gaps created by these roads. If a road bisects the natural habitat of an important bird community, mitigation measures that limit traffic mortality would be particularly appropriate. In contrast, measures aimed only at mitigating the traffic noise effect, such as quieter vehicles or road surfaces, might improve perceived habitat quality for birds without discouraging them from flying at traffic level. If such measures encouraged additional species to nest near roads, the measures themselves could unintentionally increase traffic mortality. Consequently, a failure to address traffic mortality as an important component of negative road effects could mean that vulnerable bird communities might not be protected by the mitigation measures put in place. However, mitigation for traffic noise and traffic mortality are not necessarily mutually exclusive. For example, sound barriers designed to encourage birds to cross roads above the height of traffic could potentially serve both purposes.

It would be erroneous to infer from this study that removing forest on one side of the road would benefit forest birds due to a reduction in road mortality of birds residing on the forested side of the road. Habitat loss is generally acknowledged to be the most important cause of current species declines (Kerr & Deguise 2004). Therefore, it is highly unlikely that reductions in road mortality would outweigh population reductions due to

lost habitat on the other side of the road. Put simply, low quality habitat is better than no habitat. The only condition under which removing forest on one side of the road might produce a positive effect on a population would be if forest bisected by a road were an "attractive sink" (Battin 2004). However, this has not been demonstrated. Even if habitat bisected by a road were demonstrated to be an ecological trap for a species of conservation concern, the net effect on the population of removing habitat might still be negative.

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**Table 1.** Average measurements of vegetation structure and traffic noise recorded at the two site types (small-gap and large gap), alongside the results from testing whether either vegetation structure or traffic noise differed between site types.

| Measurements | Average Value by Site Type | | Test Results* | | |
| --- | --- | --- | --- | --- | --- |
| | Small-Gap | Large-Gap | df | F | p |
| Canopy Cover % | 87 | 81 | 1,75 | 1.34 | 0.25 |
| Ground Cover % | 58 | 63 | 1,75 | 0.78 | 0.38 |
| Ground Cover Height (cm) | 30.2 | 33.4 | 1,75 | 1.82 | 0.18 |
| Number of Shrubs | 67 | 96 | 1,75 | 3.49 | 0.07 |
| Shrub Height (m) | 1.07 | 1.47 | 1,75 | 0.59 | 0.45 |
| Average Distance to Trees (m) | 2.21 | 3.14 | 1,75 | 4.7 | 0.03 |
| Average Diameter of Trees (cm) | 20.8 | 15.7 | 1,75 | 0.42 | 0.52 |
| Traffic Noise (dB) | 88.5 | 89.1 | 1,70 | 0.47 | 0.50 |

*Each test was performed by running a generalized linear mixed model with each measurement as a response, site type as a fixed effect and distance as a random effect.*
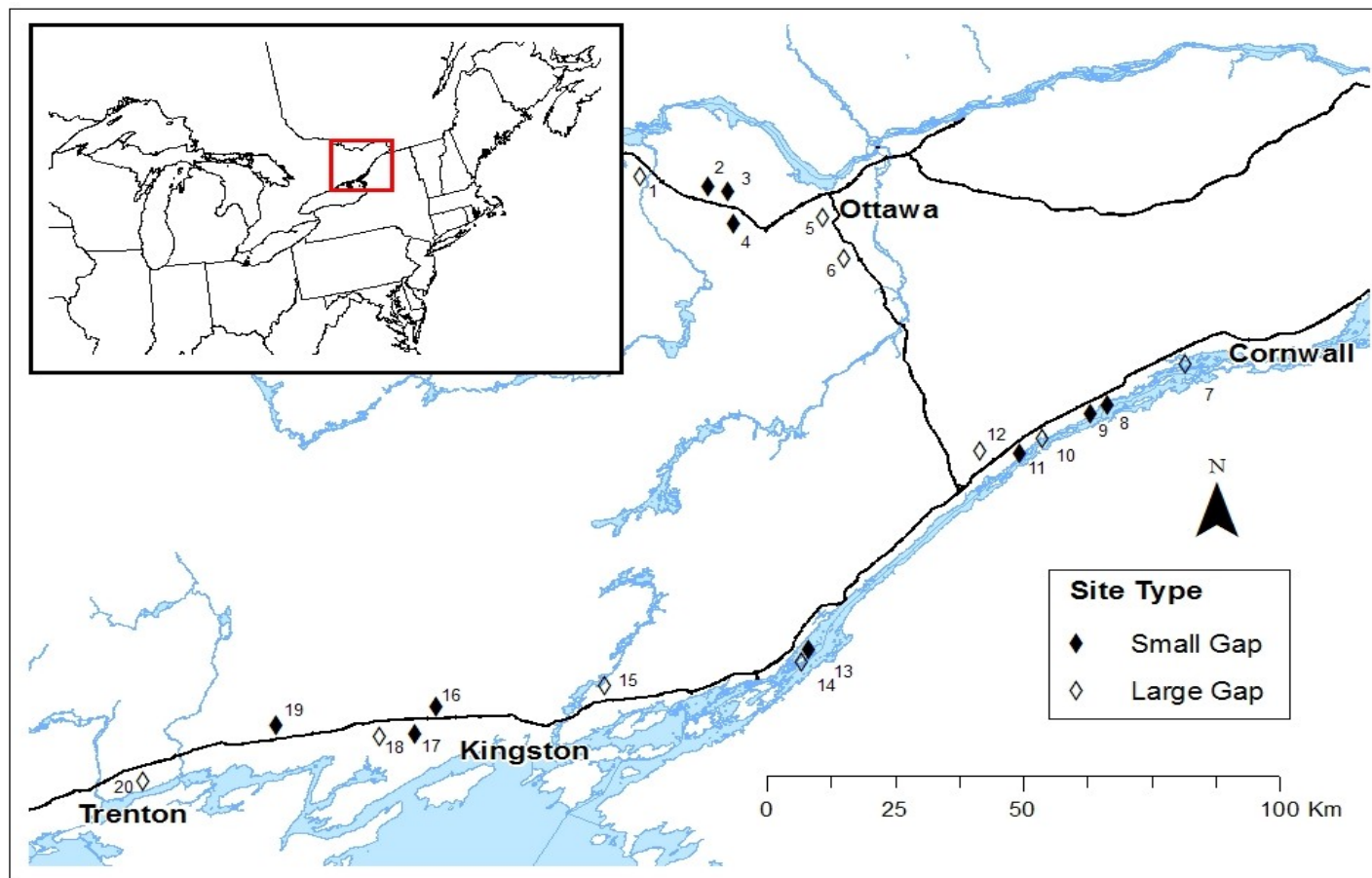
**Figure 1.** Map of study sites in southern and eastern Ontario, Canada, with inset highlighting location of study area within eastern North America.
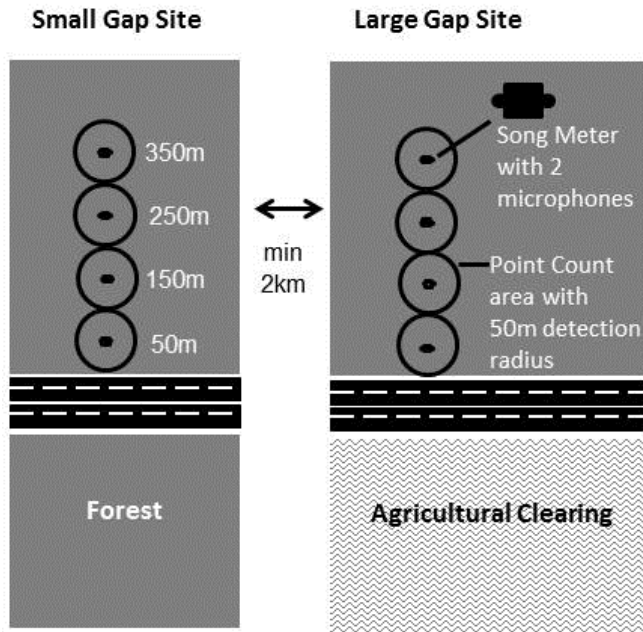
**Figure 2**. Illustration of study design for each of the two types of sites surveyed. Point counts were carried out where Song Meters were located.
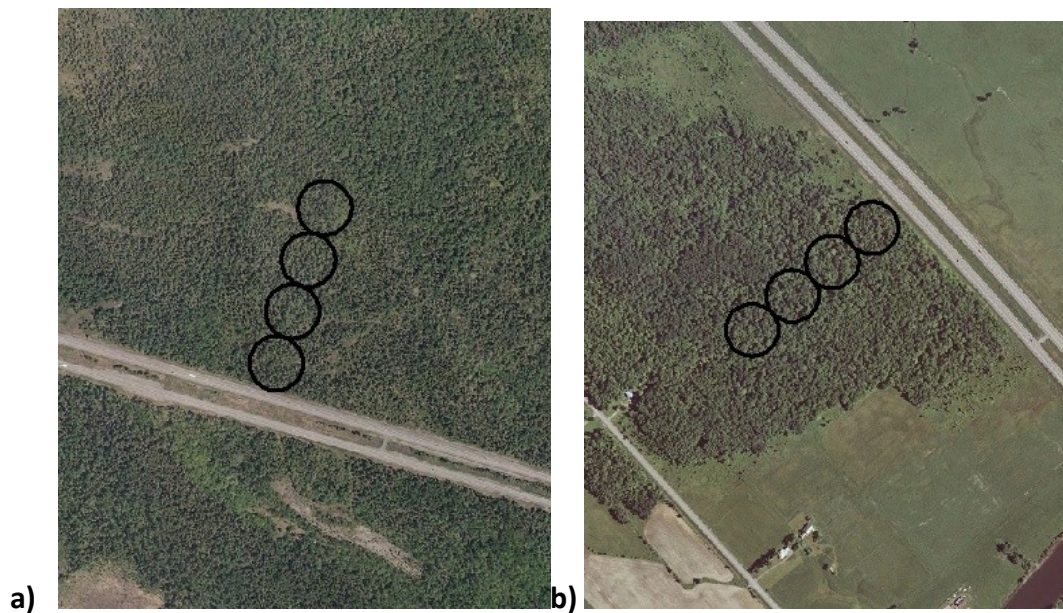


**Figure 3.** Aerial image of a) a small-gap site and b) a large-gap site. Circles represent the detection areas within which point counts were conducted.
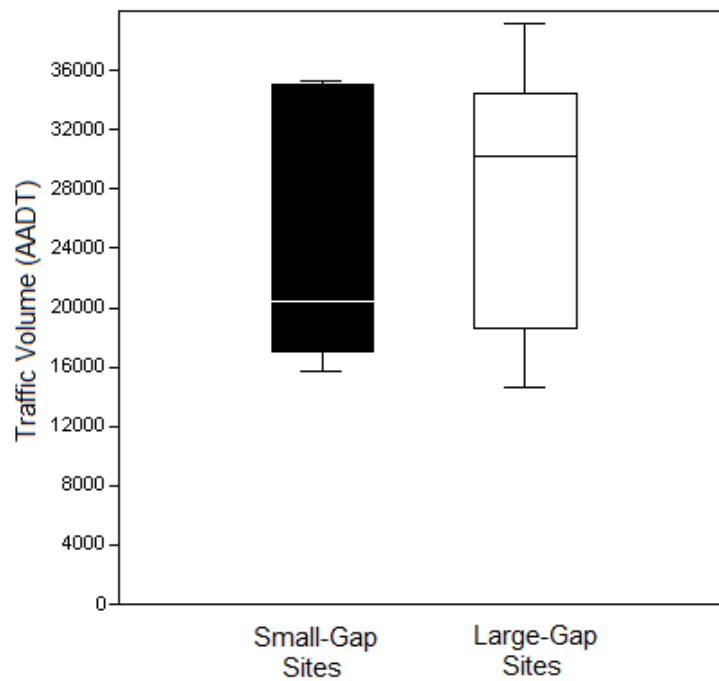
**Figure 4.** Boxplots of traffic volume at small-gap sites (n=10) and large-gap sites (n=10) (Ministry of Transportation 2010). Medians, first and third quartiles are presented for each site type. Whiskers indicate minimum and maximum values.
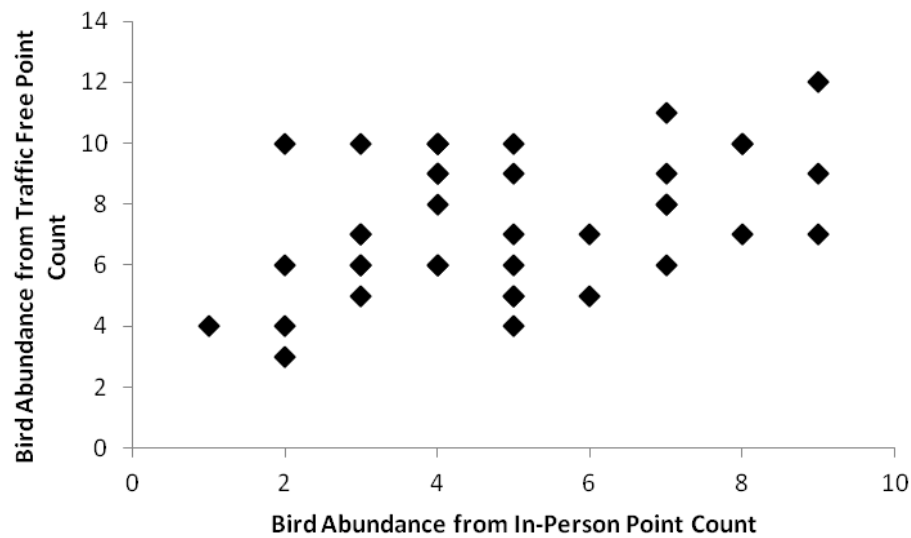


**Figure 5.** Bird abundances measured from traffic free recordings vs. in-person point counts (Pearson r=0.41, p<0.01)
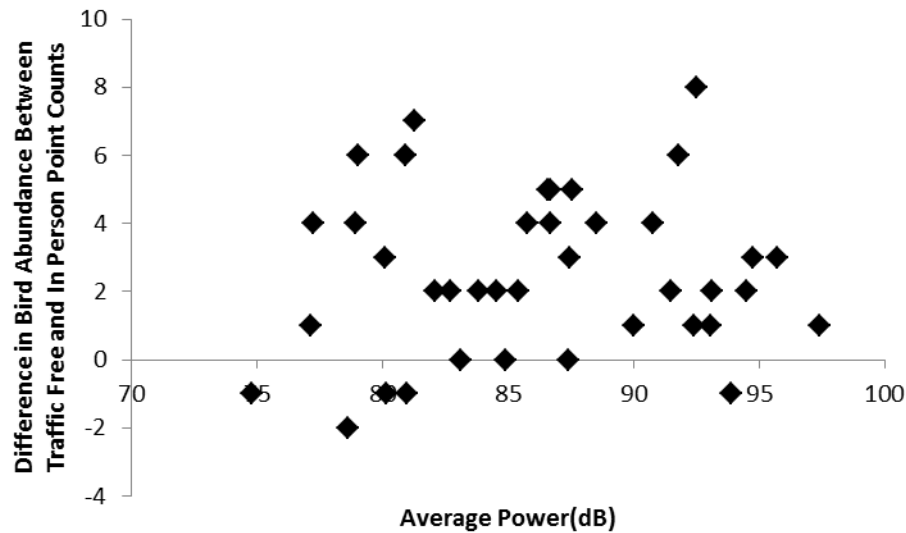
**Figure 6.** Differences in bird abundance measured from traffic free recordings (unlimited radius) and in-person point counts (50m radius) relative to traffic noise during in-person point counts at 39 point count sites.
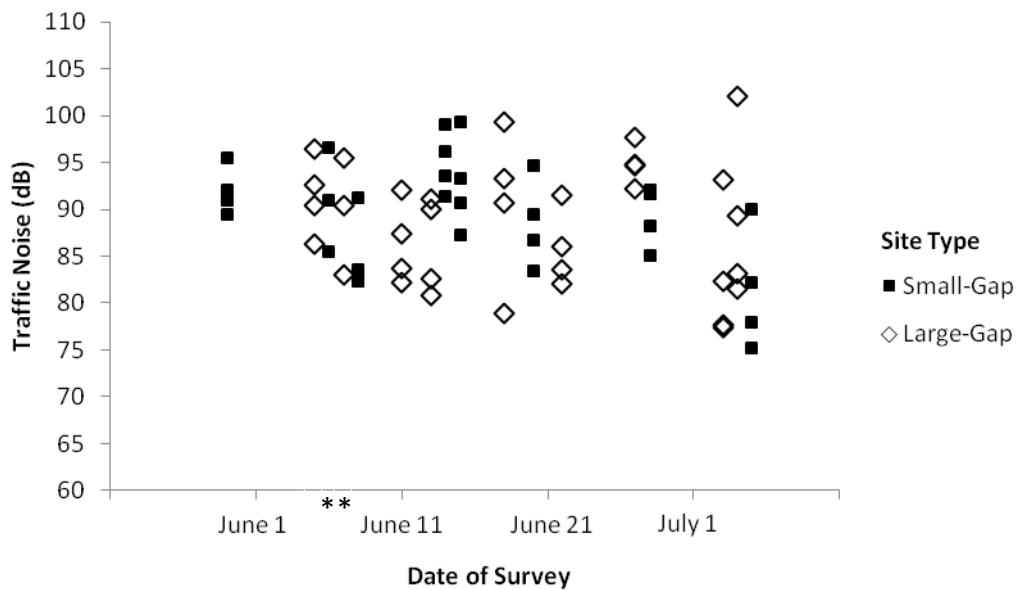


**Figure 7.** Traffic noise (measured in average power (dB)) recorded throughout the morning of each bird survey at all four distances from the road. Measurements are missing from point count locations 250m from the road at the two sites surveyed on June 6 and 7, marked with a *, as well as from the three sites where the morning's recordings were not completed on the date of survey.
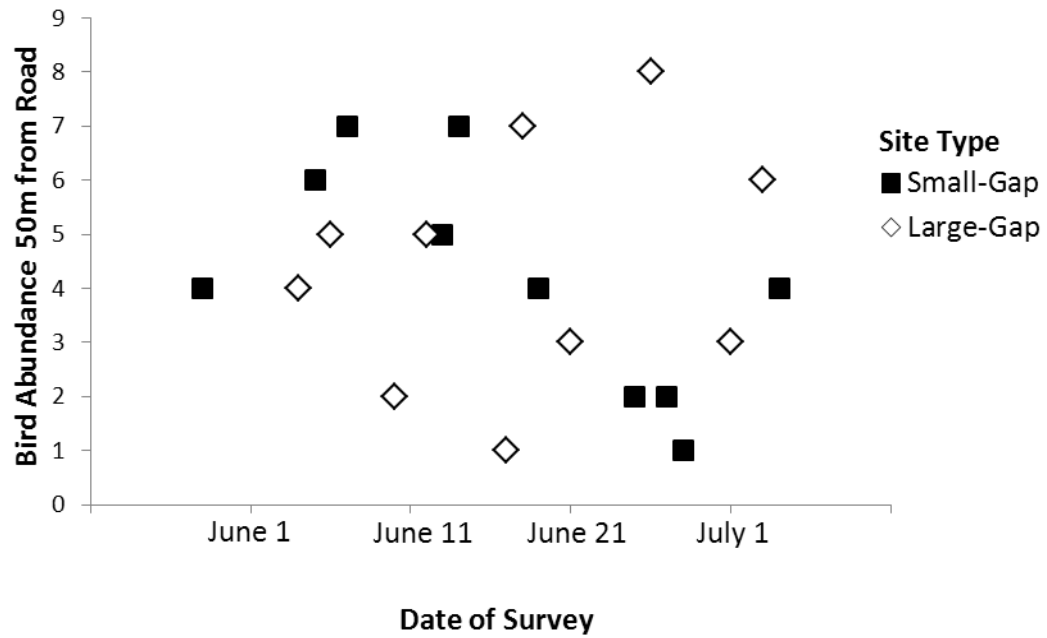
**Figure 8.** Strength of the negative road effect (shown by more positive slope values) relative to traffic noise (measured in average power (dB)) 50 metres from the road at each site.
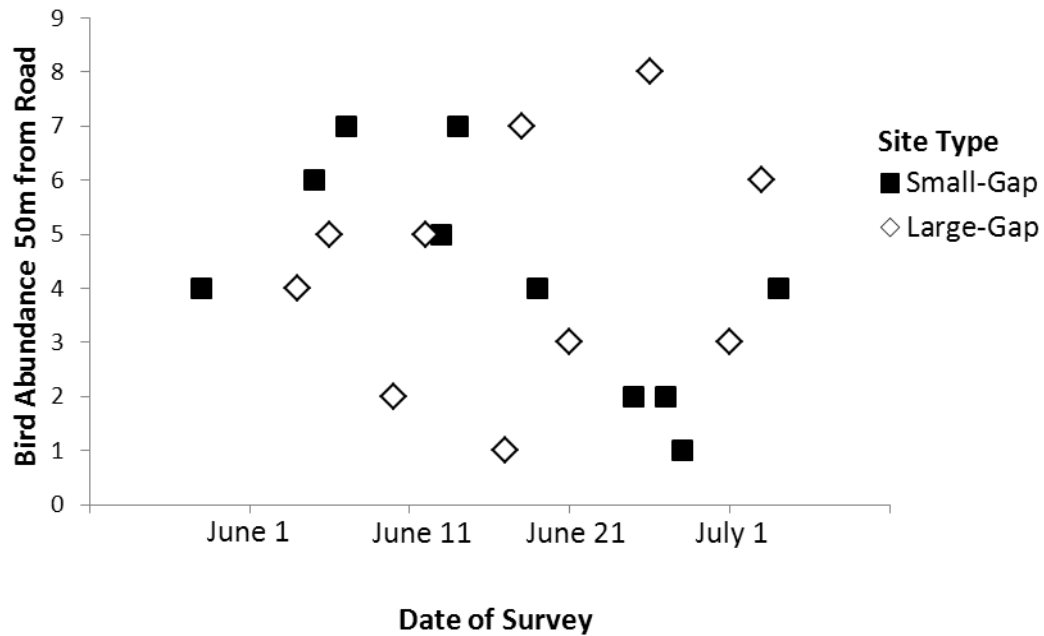
**Figure 9.** Bird abundance 50m from the road was lower at the small-gap sites surveyed later in the season, and this was not the case for the large-gap sites. The effect was not statistically significant (interaction between date of survey and site type $F_{1,16}=6.3$, p=0.087).
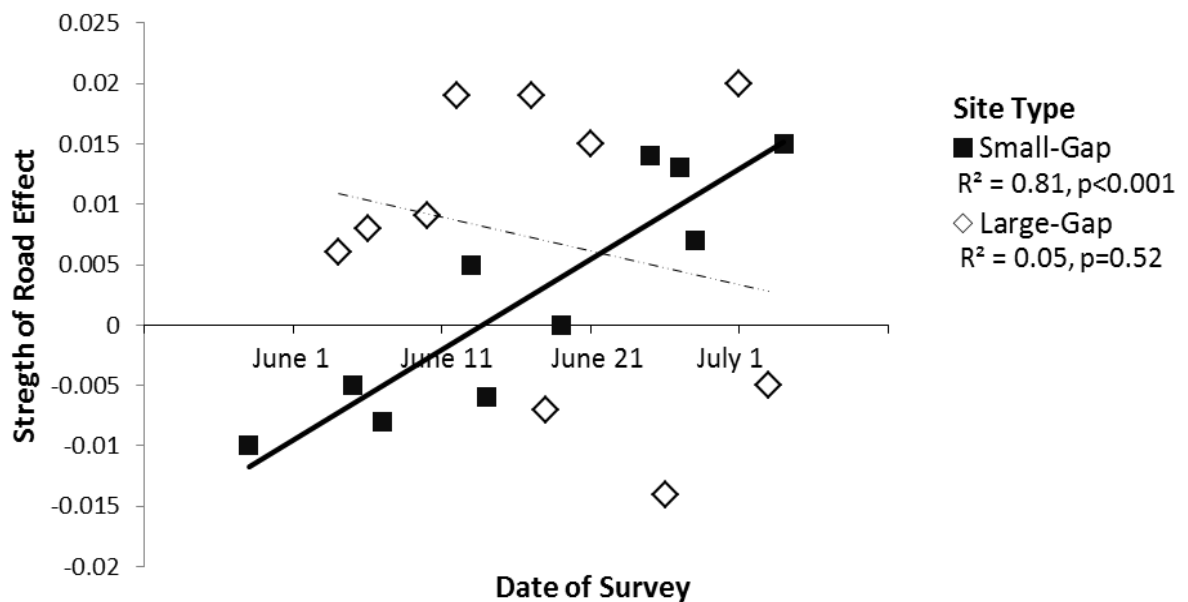


**Figure 10.** Strength of the negative road effect (shown by increasingly positive values) increased over time at small-gap sites, but not at large-gap sites.

**Appendix A.** Location of in-person point counts and audio recordings in decimal degrees (GCS North American Datum 1983).

| Site | Distance from Road (m) | Longitude | Latitude |
| --- | --- | --- | --- |
| 1 | 350 | -76.270379 | 45.385048 |
| 1 | 250 | -76.26943 | 45.385645 |
| 1 | 150 | -76.268481 | 45.386242 |
| 1 | 50 | -76.267531 | 45.38684 |
| | | | |
| 2 | 350 | -76.131951 | 45.330745 |
| 2 | 250 | -76.132316 | 45.329877 |
| 2 | 150 | -76.13268 | 45.329012 |
| 2 | 50 | -76.133043 | 45.328146 |
| | | | |
| 3 | 350 | -76.082976 | 45.321505 |
| 3 | 250 | -76.083344 | 45.320644 |
| 3 | 150 | -76.083714 | 45.319782 |
| 3 | 50 | -76.084085 | 45.318918 |
| | | | |
| 4 | 350 | -76.033144 | 45.298679 |
| 4 | 250 | -76.032216 | 45.299303 |
| 4 | 150 | -76.031289 | 45.299927 |
| 4 | 50 | -76.030368 | 45.300547 |
| | | | |
| 5 | 350 | -75.798656 | 45.301827 |
| 5 | 250 | -75.797537 | 45.302262 |
| 5 | 150 | -75.796418 | 45.302696 |
| 5 | 50 | -75.7953 | 45.30313 |
| | | | |
| 6 | 350 | -75.751597 | 45.22154 |
| 6 | 250 | -75.750436 | 45.221913 |
| 6 | 150 | -75.74928 | 45.222284 |
| 6 | 50 | -75.74812 | 45.222657 |

| Site | Distance from Road (m) | Longitude | Latitude |
|------|------------------------|-----------|----------|
| 7 | 350 | -74.941011 | 45.029641 |
| 7 | 250 | -74.941589 | 45.030444 |
| 7 | 150 | -74.942168 | 45.031249 |
| 7 | 50 | -74.942748 | 45.032055 |
| | | | |
| 8 | 350 | -75.135271 | 44.939186 |
| 8 | 250 | -75.135907 | 44.939959 |
| 8 | 150 | -75.136595 | 44.940709 |
| 8 | 50 | -75.137181 | 44.941507 |
| | | | |
| 9 | 350 | -75.173141 | 44.923086 |
| 9 | 250 | -75.173846 | 44.923838 |
| 9 | 150 | -75.17455 | 44.924591 |
| 9 | 50 | -75.175245 | 44.925333 |
| | | | |
| 10 | 350 | -75.297068 | 44.870276 |
| 10 | 250 | -75.297803 | 44.871011 |
| 10 | 150 | -75.298538 | 44.871744 |
| 10 | 50 | -75.299268 | 44.872473 |
| | | | |
| 11 | 350 | -75.349632 | 44.840796 |
| 11 | 250 | -75.350379 | 44.841525 |
| 11 | 150 | -75.351127 | 44.842256 |
| 11 | 50 | -75.351871 | 44.842982 |
| | | | |
| 12 | 350 | -75.413245 | 44.810688 |
| 12 | 250 | -75.412563 | 44.809931 |
| 12 | 150 | -75.411878 | 44.809172 |
| 12 | 50 | -75.411193 | 44.808414 |
| | | | |
| 13 | 350 | -75.87969 | 44.454602 |
| 13 | 250 | -75.88076 | 44.455074 |
| 13 | 150 | -75.881831 | 44.455548 |
| 13 | 50 | -75.882902 | 44.456021 |

| Site | Distance from Road (m) | Longitude | Latitude |
|------|------------------------|-----------|----------|
| 14 | 350 | -75.888519 | 44.436071 |
| 14 | 250 | -75.889756 | 44.436217 |
| 14 | 150 | -75.890997 | 44.436363 |
| 14 | 50 | -75.892242 | 44.436509 |
| | | | |
| 15 | 350 | -76.345366 | 44.32576 |
| 15 | 250 | -76.345345 | 44.324855 |
| 15 | 150 | -76.345358 | 44.32395 |
| 15 | 50 | -76.345304 | 44.323045 |
| | | | |
| 16 | 350 | -76.751111 | 44.284297 |
| 16 | 250 | -76.751046 | 44.283393 |
| 16 | 150 | -76.750982 | 44.282494 |
| 16 | 50 | -76.750917 | 44.281595 |
| | | | |
| 17 | 350 | -76.821724 | 44.274276 |
| 17 | 250 | -76.821798 | 44.275174 |
| 17 | 150 | -76.821872 | 44.276071 |
| 17 | 50 | -76.821946 | 44.27697 |
| | | | |
| 18 | 350 | -76.907469 | 44.268818 |
| 18 | 250 | -76.907514 | 44.269718 |
| 18 | 150 | -76.907559 | 44.270618 |
| 18 | 50 | -76.907604 | 44.271517 |
| | | | |
| 19 | 350 | -77.151621 | 44.235921 |
| 19 | 250 | -77.151252 | 44.23506 |
| 19 | 150 | -77.150884 | 44.2342 |
| 19 | 50 | -77.150517 | 44.233344 |
| | | | |
| 20 | 350 | -77.487727 | 44.166169 |
| 20 | 250 | -77.488035 | 44.167045 |
| 20 | 150 | -77.488343 | 44.167922 |
| 20 | 50 | -77.48865 | 44.168796 |

**Appendix B.** The number of individuals of each species observed during in-person point counts within 50m at all study sites at all four distances from the road from May 30 to July 5 2012, as well as date, start time, first point count, cloud cover and wind on the morning of each study site's survey.

| | |
|---|---|
| **Site:** | 1 |
| **Date:** | June 11 |
| **Start Time:** | 4:58am |
| **First Point Count:** | 350m |
| **Cloud Cover (%):** | 0 |
| **Wind (Beaufort Scale):** | 0 |

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRO | 1 | 0 | 0 | 0 |
| BCCH | 1 | 0 | 0 | 0 |
| BRCR | 0 | 1 | 0 | 0 |
| BAWW | 0 | 0 | 1 | 1 |
| EAWP | 1 | 1 | 0 | 0 |
| GCFL | 1 | 0 | 0 | 0 |
| OVEN | 0 | 0 | 1 | 1 |
| REVI | 0 | 1 | 0 | 0 |
| VEER | 0 | 0 | 1 | 0 |
| YBSA | 1 | 1 | 1 | 0 |
| **Total Abundance** | **5** | **4** | **4** | **2** |
| **Total Species Richness** | **5** | **4** | **4** | **2** |

**Site:** 2

**Date:** July 5

**Start Time:** 5:03am

**First Point Count:** 350m

**Cloud Cover (%):** 0

**Wind (Beaufort Scale):** 0 with occasional gust of 3-4

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRO | 0 | 1 | 1 | 1 |
| BCCH | 1 | 2 | 1 | 1 |
| BAWW | 0 | 2 | 0 | 0 |
| CEDW | 1 | 0 | 0 | 0 |
| CONI | 1 | 0 | 0 | 0 |
| MODO | 2 | 0 | 0 | 0 |
| NOFL | 0 | 1 | 0 | 0 |
| RBNU | 0 | 0 | 1 | 1 |
| REVI | 0 | 0 | 1 | 1 |
| WTSP | 3 | 1 | 0 | 0 |
| **Total Abundance** | **8** | **7** | **4** | **4** |
| **Total Species Richness** | **5** | **5** | **4** | **4** |

**Site:** 3

**Date:** June 8

**Start Time:** 5:04am

**First Point Count:** 350m

**Cloud Cover (%):** 30

**Wind (Beaufort Scale):** 0

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRO | 1 | 0 | 0 | 1 |
| BCCH | 0 | 2 | 0 | 0 |
| BLJA | 0 | 0 | 1 | 0 |
| BRCR | 0 | 0 | 1 | 0 |
| BTNW | 0 | 1 | 0 | 0 |
| BAWW | 0 | 0 | 1 | 1 |
| GCFL | 1 | 2 | 0 | 0 |
| NOWA | 1 | 2 | 2 | 1 |
| OVEN | 0 | 0 | 1 | 0 |
| PUFI | 0 | 0 | 0 | 1 |
| RBNU | 1 | 1 | 0 | 0 |
| REVI | 0 | 0 | 1 | 1 |
| VEER | 0 | 1 | 0 | 0 |
| WIWR | 0 | 0 | 1 | 2 |
| **Total Abundance** | **4** | **9** | **8** | **7** |
| **Total Species Richness** | **4** | **6** | **7** | **6** |

**Site:** 4

**Date:** June 26

**Start Time:** 4:57am

**First Point Count:** 50m

**Cloud Cover (%):** 100

**Wind (Beaufort Scale):** 0, with occasional gusts of 4-5

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRO | 1 | 0 | 1 | 0 |
| BHVI | 0 | 1 | 0 | 0 |
| BAWW | 1 | 0 | 0 | 0 |
| CEDW | 0 | 1 | 0 | 0 |
| EATO | 0 | 0 | 0 | 1 |
| GCFL | 1 | 0 | 0 | 0 |
| NOWA | 1 | 1 | 1 | 0 |
| OVEN | 0 | 0 | 0 | 1 |
| REVI | 1 | 1 | 1 | 0 |
| VEER | 1 | 1 | 0 | 0 |
| **Total Abundance** | **6** | **5** | **3** | **2** |
| **Total Species Richness** | **6** | **5** | **3** | **2** |

**Site:** 5

**Date:** July 4

**Start Time:** 4:59

**First Point Count:** 350m

**Cloud Cover (%):** 0

**Wind (Beaufort Scale):** 0

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| ALFL | 0 | 0 | 0 | 1 |
| AMRE | 1 | 0 | 0 | 0 |
| AMRO | 1 | 0 | 1 | 0 |
| BAOR | 0 | 0 | 1 | 0 |
| BCCH | 0 | 0 | 0 | 1 |
| BTBW | 0 | 1 | 0 | 0 |
| CEDW | 0 | 1 | 0 | 0 |
| COYE | 0 | 0 | 0 | 1 |
| CSWA | 0 | 0 | 0 | 0 |
| EAWP | 1 | 0 | 1 | 1 |
| OVEN | 0 | 2 | 0 | 0 |
| REVI | 1 | 1 | 1 | 0 |
| SOSP | 0 | 0 | 0 | 1 |
| SWSP | 0 | 0 | 0 | 1 |
| **Total Abundance** | **4** | **5** | **4** | **6** |
| **Total Species Richness** | **4** | **4** | **4** | **6** |

| Site: | 6 |
| Date: | June 22 |
| Start Time: | 4:57 |
| First Point Count: | 50m |
| Cloud Cover (%): | 30% |
| Wind (Beaufort Scale): | 4:57 |

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRE | 1 | 0 | 0 | 0 |
| AMRO | 0 | 0 | 1 | 0 |
| BCCH | 0 | 0 | 1 | 0 |
| BAWW | 1 | 0 | 0 | 0 |
| COYE | 1 | 1 | 0 | 1 |
| CSWA | 0 | 3 | 2 | 1 |
| NOWA | 1 | 0 | 0 | 0 |
| OVEN | 0 | 1 | 0 | 0 |
| RBGR | 1 | 1 | 1 | 0 |
| REVI | 0 | 0 | 2 | 0 |
| VEER | 3 | 1 | 2 | 1 |
| WOTH | 0 | 2 | 0 | 0 |
| **Total Abundance** | **8** | **9** | **9** | **3** |
| **Total Species Richness** | **6** | **6** | **6** | **3** |

| | | | | |
|---|---|---|---|---|
| **Site:** | 7 | | | |
| **Date:** | June 19 | | | |
| **Start Time:** | 4:57 | | | |
| **First Point Count:** | 50m | | | |
| **Cloud Cover (%):** | 100 | | | |
| **Wind (Beaufort Scale):** | 0 | | | |

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| BCCH | 0 | 0 | 0 | 2 |
| COYE | 1 | 0 | 0 | 0 |
| EAWP | 1 | 1 | 1 | 0 |
| NOWA | 0 | 1 | 0 | 0 |
| OVEN | 0 | 0 | 1 | 1 |
| RBGR | 0 | 0 | 0 | 2 |
| REVI | 0 | 1 | 0 | 0 |
| RWBL | 1 | 0 | 0 | 0 |
| SWSP | 1 | 0 | 0 | 0 |
| VEER | 0 | 0 | 1 | 2 |
| WOTH | 0 | 1 | 0 | 0 |
| YBSA | 0 | 1 | 0 | 0 |
| **Total Abundance** | **4** | **5** | **3** | **7** |
| **Total Species Richness** | **4** | **5** | **3** | **4** |

**Site:** 8

**Date:** June 20

**Start Time:** 4:59

**First Point Count:** 50m

**Cloud Cover (%):** 100

**Wind (Beaufort Scale):** 1

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRO | 0 | 0 | 0 | 1 |
| CEDW | 1 | 0 | 0 | 1 |
| COYE | 1 | 0 | 0 | 0 |
| EAWP | 0 | 0 | 1 | 0 |
| GCFL | 0 | 3 | 0 | 0 |
| HAWO | 0 | 0 | 1 | 0 |
| OVEN | 0 | 1 | 1 | 1 |
| REVI | 0 | 1 | 1 | 1 |
| VEER | 2 | 0 | 0 | 0 |
| WTSP | 0 | 0 | 1 | 0 |
| **Total Abundance** | **4** | **5** | **5** | **4** |
| **Total Species Richness** | **3** | **3** | **5** | **4** |

**Site:**                        9

**Date:**                       May 30

**Start Time:**            4:50am

**First Point Count:**     50m

**Cloud Cover (%):**      0

**Wind (Beaufort Scale):**   0

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRE | 0 | 0 | 0 | 1 |
| COYE | 0 | 1 | 1 | 1 |
| NOWA | 1 | 0 | 2 | 0 |
| OVEN | 0 | 1 | 0 | 0 |
| SWSP | 0 | 0 | 0 | 1 |
| VEER | 0 | 1 | 1 | 1 |
| **Total Abundance** | **1** | **3** | **4** | **4** |
| **Total Species Richness** | **1** | **3** | **3** | **4** |

**Site:** 10

**Date:** June 7

**Start Time:** 5:09am

**First Point Count:** 50m

**Cloud Cover (%):** 90

**Wind (Beaufort Scale):** 0

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMCR | 0 | 0 | 0 | 1 |
| AMRO | 1 | 1 | 0 | 0 |
| BRCR | 1 | 0 | 0 | 0 |
| COYE | 2 | 0 | 0 | 0 |
| CSWA | 0 | 0 | 1 | 0 |
| EAWP | 0 | 0 | 1 | 0 |
| GCFL | 2 | 0 | 0 | 1 |
| NOWA | 1 | 0 | 1 | 0 |
| OVEN | 0 | 1 | 1 | 1 |
| REVI | 0 | 1 | 0 | 0 |
| SWSP | 1 | 0 | 0 | 0 |
| VEER | 0 | 0 | 0 | 2 |
| **Total Abundance** | **8** | **3** | **4** | **5** |
| **Total Species Richness** | **6** | **3** | **4** | **4** |

| | | | | |
|---|---|---|---|---|
| **Site:** | 11 | | | |
| **Date:** | June 6 | | | |
| **Start Time:** | 5:00am | | | |
| **First Point Count:** | 50m | | | |
| **Cloud Cover (%):** | 10 | | | |
| **Wind (Beaufort Scale):** | 0 | | | |

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRE | 0 | 0 | 1 | 0 |
| AMRO | 0 | 1 | 0 | 2 |
| BCCH | 0 | 1 | 0 | 1 |
| BLJA | 1 | 0 | 1 | 0 |
| BRCR | 0 | 1 | 0 | 0 |
| COYE | 0 | 0 | 0 | 2 |
| CSWA | 0 | 0 | 1 | 0 |
| EAWP | 0 | 1 | 1 | 0 |
| NOWA | 0 | 0 | 1 | 0 |
| OVEN | 1 | 0 | 0 | 0 |
| RBGR | 0 | 1 | 0 | 0 |
| REVI | 1 | 1 | 0 | 0 |
| VEER | 0 | 0 | 1 | 0 |
| WOTH | 1 | 0 | 0 | 0 |
| YBSA | 0 | 1 | 0 | 0 |
| YEWA | 0 | 0 | 0 | 1 |
| **Total Abundance** | **4** | **7** | **6** | **6** |
| **Total Species Richness** | **4** | **7** | **6** | **4** |

| | | | | |
|---|---|---|---|---|
| **Site:** | 12 | | | |
| **Date:** | June 5 | | | |
| **Start Time:** | 5:56am | | | |
| **First Point Count:** | 50m | | | |
| **Cloud Cover (%):** | 0 | | | |
| **Wind (Beaufort Scale):** | 0 | | | |

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| ALFL | 0 | 0 | 1 | 0 |
| AMRO | 0 | 2 | 0 | 0 |
| BAOR | 1 | 1 | 0 | 0 |
| BCCH | 1 | 1 | 3 | 0 |
| BAWW | 0 | 0 | 1 | 0 |
| COYE | 0 | 1 | 2 | 1 |
| CSWA | 1 | 0 | 0 | 0 |
| NAWA | 0 | 0 | 0 | 1 |
| NOCA | 0 | 1 | 0 | 0 |
| NOFL | 0 | 0 | 0 | 0 |
| NOPA | 0 | 0 | 0 | 0 |
| NOWA | 0 | 0 | 0 | 0 |
| OVEN | 2 | 1 | 0 | 0 |
| RBGR | 0 | 0 | 1 | 1 |
| REVI | 1 | 0 | 1 | 0 |
| WOTH | 1 | 0 | 1 | 1 |
| **Total Abundance** | **7** | **7** | **10** | **4** |
| **Total Species Richness** | **6** | **6** | **7** | **4** |

**Site:** 13

**Date:** June 29

**Start Time:** 4:58am

**First Point Count:** 350m

**Cloud Cover (%):** 100

**Wind (Beaufort Scale):** 0

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRO | 1 | 0 | 0 | 1 |
| BCCH | 1 | 0 | 0 | 0 |
| BRCR | 0 | 0 | 1 | 0 |
| BTNW | 0 | 1 | 0 | 0 |
| OVEN | 0 | 2 | 1 | 0 |
| REVI | 1 | 1 | 1 | 0 |
| **Total Abundance** | **3** | **4** | **3** | **1** |
| **Total Species Richness** | **3** | **3** | **3** | **1** |

**Site:** 14

**Date:** July 3

**Start Time:** 4:58am

**First Point Count:** 350m

**Cloud Cover (%):** 0

**Wind (Beaufort Scale):** 0

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRE | 0 | 0 | 0 | 1 |
| AMRO | 1 | 0 | 0 | 0 |
| BCCH | 0 | 2 | 0 | 0 |
| BLJA | 2 | 1 | 0 | 0 |
| BAWW | 1 | 0 | 0 | 0 |
| COYE | 2 | 0 | 0 | 0 |
| HETH | 1 | 0 | 0 | 0 |
| OVEN | 0 | 0 | 0 | 1 |
| PIWA | 0 | 0 | 1 | 0 |
| REVI | 0 | 0 | 1 | 1 |
| VEER | 1 | 1 | 2 | 0 |
| WOTH | 0 | 1 | 0 | 0 |
| YRWA | 1 | 1 | 0 | 0 |
| **Total Abundance** | **9** | **6** | **4** | **3** |
| **Total Species Richness** | **7** | **5** | **3** | **3** |

**Site:** 15

**Date:** June 13

**Start Time:** 4:58

**First Point Count:** 350m

**Cloud Cover (%):** 0

**Wind (Beaufort Scale):** 1

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRE | 0 | 0 | 0 | 1 |
| AMRO | 1 | 1 | 1 | 1 |
| BCCH | 0 | 0 | 0 | 1 |
| CEDW | 0 | 0 | 1 | 0 |
| COYE | 0 | 0 | 0 | 1 |
| CSWA | 3 | 1 | 2 | 1 |
| EATO | 0 | 1 | 0 | 0 |
| GRCA | 0 | 1 | 0 | 0 |
| RBGR | 2 | 0 | 0 | 0 |
| VEER | 1 | 0 | 0 | 0 |
| WOTH | 4 | 2 | 1 | 0 |
| YRWA | 0 | 0 | 1 | 0 |
| YEWA | 0 | 1 | 0 | 0 |
| **Total Abundance** | **11** | **7** | **6** | **5** |
| **Total Species Richness** | **5** | **6** | **5** | **5** |

| Site: | 16 |
|---|---|
| Date: | June 15 |
| Start Time: | 4:58 |
| First Point Count: | 350m |
| Cloud Cover (%): | 0 |
| Wind (Beaufort Scale): | 0 |

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMCR | 1 | 0 | 0 | 0 |
| AMRO | 1 | 0 | 0 | 0 |
| BCCH | 1 | 0 | 1 | 1 |
| BRTH | 1 | 0 | 0 | 0 |
| BAWW | 1 | 1 | 0 | 0 |
| GCFL | 0 | 0 | 1 | 0 |
| HAWO | 0 | 0 | 1 | 1 |
| OVEN | 1 | 1 | 1 | 4 |
| RBGR | 0 | 0 | 1 | 0 |
| REVI | 0 | 0 | 1 | 0 |
| SOSP | 0 | 0 | 0 | 1 |
| WOTH | 0 | 1 | 0 | 0 |
| **Total Abundance** | **6** | **3** | **6** | **7** |
| **Total Species Richness** | **6** | **3** | **6** | **4** |

**Site:**                       17

**Date:**                     June 14

**Start Time:**          4:57

**First Point Count:**    350m

**Cloud Cover (%):**      0

**Wind (Beaufort Scale):**   0

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRO | 1 | 0 | 0 | 2 |
| BCCH | 2 | 1 | 0 | 1 |
| BLJA | 0 | 1 | 0 | 0 |
| NOWA | 0 | 0 | 0 | 1 |
| OVEN | 2 | 1 | 1 | 0 |
| REVI | 0 | 1 | 2 | 1 |
| SCTA | 0 | 1 | 0 | 0 |
| WOTH | 1 | 0 | 0 | 0 |
| **Total Abundance** | **6** | **5** | **3** | **5** |
| **Total Species Richness** | **4** | **5** | **2** | **4** |

**Site:** 18

**Date:** June 27

**Start Time:** 4:58

**First Point Count:** 50m

**Cloud Cover (%):** 0

**Wind (Beaufort Scale):** 0

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| AMRO | 1 | 0 | 3 | 2 |
| BCCH | 3 | 0 | 1 | 2 |
| BLJA | 0 | 0 | 3 | 0 |
| CEDW | 0 | 1 | 0 | 0 |
| COYE | 0 | 0 | 1 | 0 |
| MODO | 0 | 0 | 1 | 0 |
| OVEN | 0 | 1 | 1 | 1 |
| REVI | 0 | 0 | 0 | 1 |
| SOSP | 0 | 1 | 1 | 1 |
| WOTH | 2 | 1 | 1 | 1 |
| **Total Abundance** | **6** | **4** | **12** | **8** |
| **Total Species Richness** | **3** | **4** | **8** | **6** |

**Site:** 19

**Date:** June

**Start Time:** 4:54

**First Point Count:** 50m

**Cloud Cover (%):** 0

**Wind (Beaufort Scale):** 0

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| BCCH | 0 | 1 | 0 | 0 |
| BLJA | 2 | 2 | 2 | 1 |
| EATO | 1 | 1 | 0 | 0 |
| NAWA | 1 | 0 | 0 | 0 |
| NOCA | 0 | 0 | 1 | 1 |
| OVEN | 1 | 1 | 0 | 0 |
| REVI | 0 | 1 | 0 | 0 |
| WTSP | 0 | 1 | 0 | 0 |
| **Total Abundance** | **5** | **7** | **3** | **2** |
| **Total Species Richness** | **4** | **6** | **2** | **2** |

**Site:**                     20

**Date:**                   June 18

**Start Time:**         5:20am

**First Point Count:**   350m

**Cloud Cover (%):**    100

**Wind (Beaufort Scale):**  1-2

| Species | 350m | 250m | 150m | 50m |
|---|---|---|---|---|
| BLJA | 1 | 0 | 0 | 0 |
| COYE | 2 | 1 | 1 | 0 |
| EAWP | 1 | 0 | 0 | 0 |
| NOFL | 0 | 1 | 0 | 0 |
| OVEN | 1 | 0 | 1 | 1 |
| REVI | 1 | 1 | 0 | 0 |
| WOTH | 1 | 0 | 0 | 0 |
| **Total Abundance** | **7** | **3** | **2** | **1** |
| **Total Species Richness** | **6** | **3** | **2** | **1** |

**Appendix C.** Vegetation survey data collected in July and August 2012. Average measurements are calculated from the four quadrants.

| Site | Point Count Distance to Road (m) | Canopy Cover % | Ground Cover % | Shrub Height (m) | Ground Cover Height (m) | Number of Shrubs | Average Dist. to Tree (m) | Average Diameter (m) | Tree Species from each of the Four Quadrants |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 350 | 100 | 40 | 1.35 | 0.16 | 62 | 11.0 | 0.05 | *Fraxinus nigra* <br> *Abies balsamea* <br> *Abies balsamea* <br> *Abies balsamea* |
| 1 | 250 | 100 | 60 | 1.08 | 0.20 | 47 | 2.3 | 0.10 | *Fraxinus pennsylvanica* <br> *Quercus alba* <br> *Fraxinus pennsylvanica* <br> *Fraxinus nigra* |
| 1 | 150 | 100 | 50 | 0.72 | 0.20 | 39 | 11.0 | 0.10 | *Acer saccharinum* <br> *Acer rubrum* <br> *Acer rubrum* <br> *Abies balsamea* |
| 1 | 50 | 80 | 40 | 1.17 | 0.20 | 36 | 1.9 | 0.07 | *Acer rubrum* <br> *Acer rubrum* <br> *Acer rubrum* <br> *Abies balsameam* |
| 2 | 350 | 100 | 80 | 0.60 | 0.16 | 77 | 2.5 | 0.12 | *Juniperus Virginia* <br> *Juniperus Virginia* <br> *Abies balsamea* <br> *Juniperus virginia* |
| 2 | 250 | 80 | 20 | 0.59 | 0.10 | 32 | 1.6 | 0.11 | *Thuja occidentalis* <br> *Thuja occidentalis* <br> *Thuja occidentalis* <br> *Juniperus virginia* |
| 2 | 150 | 40 | 60 | 0.69 | 0.13 | 44 | 4.7 | 0.09 | *Rhamnus cathartica* <br> *Thuja occidentalis* <br> *Juniperus Virginia* <br> *Thuja occidentalis* |
| 2 | 50 | 100 | 60 | 0.92 | 0.20 | 73 | 1.0 | 0.07 | *Populus tremuloides* <br> *Abies balsamea* <br> *Cornus sp.* <br> *Abies balsamea* |

| Site | Point Count Distance to Road (m) | Canopy Cover % | Ground Cover % | Shrub Height (m) | Ground Cover Height (m) | Number of Shrubs | Average Dist. to Tree (m) | Average Diameter (m) | Tree Species from each of the Four Quadrants |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 350 | 100 | 60 | 0.72 | 0.20 | 23 | 1.8 | 0.23 | *Thuja occidentalis* <br> *Thuja occidentalis* <br> *Thuja occidentalis* <br> *Acer rubrum* |
| 3 | 250 | 100 | 40 | 1.05 | 0.28 | 27 | 1.9 | 0.15 | *Fraxinus pennsylvanica* <br> *Fraxinus pennsylvanica* <br> *Fraxinus pennsylvanica* <br> *Fraxinus pennsylvanica* |
| 3 | 150 | 100 | 40 | 1.27 | 0.20 | 0 | 1.2 | 0.05 | *Fraxinus pennsylvanica* <br> *Quercus alba* <br> *Fraxinus pennsylvanica* <br> *Fraxinus nigra* |
| 3 | 50 | 100 | 80 | 1.53 | 0.25 | 126 | 2.4 | 0.16 | *Fraxinus pennsylvanica* <br> *Fraxinus pennsylvanica* <br> *Thuja occidentalis* <br> *Thuja occidentalis* |
| 4 | 350 | 80 | 60 | 1.65 | 0.20 | 70 | 1.1 | 0.08 | *Fraxinus nigra* <br> *Fraxinus nigra* <br> *Fraxinus nigra* <br> *Fraxinus nigra* |
| 4 | 250 | 100 | 40 | 1.45 | 0.21 | 119 | 3.4 | 0.12 | *Fraxinus nigra* <br> *Fraxinus nigra* <br> *Fraxinus nigra* <br> *Fraxinus nigra* |
| 4 | 150 | 100 | 80 | 1.05 | 0.19 | 67 | 2.5 | 0.17 | *Fraxinus nigra* <br> *Populus grandidentata* <br> *Acer saccharum* <br> *Rhamnus cathartica* |
| 4 | 50 | 100 | 60 | 1.23 | 0.20 | 72 | 2.5 | 0.16 | *Fraxinus pennsylvanica* <br> *Fraxinus pennsylvanica* <br> *Fraxinus pennsylvanica* <br> *Fraxinus pennsylvanica* |

| Site | Point Count Distance to Road (m) | Canopy Cover % | Ground Cover % | Shrub Height (m) | Ground Cover Height (m) | Number of Shrubs | Average Dist. to Tree (m) | Average Diameter (m) | Tree Species from each of the Four Quadrants |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 350 | 80 | 40 | 0.72 | 0.30 | 331 | 3.7 | 0.12 | *Rhamnus cathartica*<br>*Rhamnus cathartica*<br>*Pinus resinosa*<br>*Ulmus sp.* |
| 5 | 250 | 80 | 20 | 0.40 | 0.23 | 300 | 3.2 | 0.29 | *Acer saccharum*<br>*Acer saccharum*<br>*Acer saccharum*<br>*Acer saccharum* |
| 5 | 150 | 100 | 20 | NA | 0.15 | 0 | 2.8 | 0.08 | *Fraxinus Americana*<br>*Ulmus sp.*<br>*Acer saccharum*<br>*Acer saccharum* |
| 5 | 50 | 100 | 0 | 0.72 | 0.20 | 384 | 1.7 | 0.06 | *Acer saccharum*<br>*Tilia Americana*<br>*Acer saccharum*<br>*Tilia americana* |
| 6 | 350 | 100 | 20 | 1.65 | 0.55 | 161 | 1.8 | 0.09 | *Rhamnus frangula*<br>*Rhamnus frangula*<br>*Populus tremuloides*<br>*Rhamnus frangula* |
| 6 | 250 | 80 | 100 | 1.61 | 0.75 | 35 | 2.4 | 0.11 | *Populus grandidentata*<br>*Rhamnus frangula*<br>*Populus grandidentata*<br>*Rhamnus frangula* |
| 6 | 150 | 60 | 100 | 0.96 | 0.41 | 95 | 3.7 | 0.08 | *Ulmus sp.*<br>*Shiny buckthorn*<br>*Shiny buckthorn*<br>*Shiny buckthorn* |
| 6 | 50 | 100 | 20 | 0.70 | 0.16 | 0 | 2.1 | 0.06 | *Rhamnus frangula*<br>*Rhamnus frangula*<br>*Rhamnus frangula*<br>*Rhamnus frangula* |

| Site | Point Count Distance to Road (m) | Canopy Cover % | Ground Cover % | Shrub Height (m) | Ground Cover Height (m) | Number of Shrubs | Average Dist. to Tree (m) | Average Diameter (m) | Tree Species from each of the Four Quadrants |
|---|---|---|---|---|---|---|---|---|---|
| 7 | 350 | 100 | 80 | 12.00 | 0.31 | 14 | 2.6 | 0.14 | Acer rubrum<br>Acer rubrum<br>Acer saccharinum<br>Acer rubrum |
| 7 | 250 | 100 | 100 | 1.13 | 0.38 | 51 | 2.9 | 0.17 | Acer rubrum<br>Acer rubrum<br>Acer rubrum<br>Acer rubrum |
| 7 | 150 | 100 | 80 | 0.88 | 0.30 | 51 | 4.4 | 0.09 | Acer rubrum<br>Acer rubrum<br>Acer saccharinum<br>Ulmus sp. |
| 7 | 50 | 80 | 60 | 0.88 | 0.40 | 29 | 2.5 | 0.16 | Fraxinus nigra<br>Ulmus sp.<br>Ulmus sp.<br>Ulmus sp. |
| 8 | 350 | 40 | 40 | 1.22 | 0.23 | 60 | 1.3 | 4.03 | Ulmus sp.<br>Populus sp.<br>Populus sp.<br>Fraxinus nigra |
| 8 | 250 | 100 | 20 | 0.57 | 0.28 | 61 | 4.3 | 0.22 | Ulmus sp.<br>Acer saccharum<br>Acer saccharum<br>Ulmus sp. |
| 8 | 150 | 100 | 100 | 0.89 | 0.38 | 70 | 2.0 | 0.11 | Fraxinus americana<br>Tilia americana<br>Fraxinus pennsylvanica<br>Tilia americana |
| 8 | 50 | 100 | 20 | 0.69 | 0.39 | 111 | 2.8 | 0.29 | Fraxinus pennsylvanica<br>Acer rubrum<br>Fraxinus americana<br>Fraxinus americana |

| Site | Point Count Distance to Road (m) | Canopy Cover % | Ground Cover % | Shrub Height (m) | Ground Cover Height (m) | Number of Shrubs | Average Dist. to Tree (m) | Average Diameter (m) | Tree Species from each of the Four Quadrants |
|---|---|---|---|---|---|---|---|---|---|
| 9 | 350 | 80 | 80 | 1.36 | 0.6 | 68 | 2.6 | 0.13 | *Ulmus sp.* *Fraxinus sp.* *Fraxinus sp.* *Acer saccharinum* |
| 9 | 250 | 100 | 60 | 2.03 | 0.7 | 14 | 1.3 | 0.06 | *Salix sp.* *Acer saccharinum* *Ulmus sp.* *Acer saccharinum* |
| 9 | 150 | 100 | 100 | 1.01 | 1.0 | 17 | 2.8 | 0.11 | *Acer saccharinum* *Acer Rubrum* *Fraxinus pennsylvanica* *Fraxinus nigra* |
| 9 | 50 | 100 | 80 | 1.11 | 0.4 | 41 | 2.5 | 0.10 | *Fraxinus pennsylvanica* *Fraxinus pennsylvanica* *Fraxinus pennsylvanica* *Tilia americana* |
| 10 | 350 | 100 | 100 | 1.32 | 0.4 | 25 | 2.0 | 0.19 | *Fraxinus pennsylvanica* *Fraxinus nigra* *Fraxinus nigra* *Fraxinus pennsylvanica* |
| 10 | 250 | 100 | 60 | 0.93 | 0.2 | 160 | 1.5 | 0.12 | *Carpinus caroliniana* *Fraxinus pennsylvanica* *Fraxinus pennsylvanica* *Fraxinus pennsylvanica* |
| 10 | 150 | 100 | 20 | 1.42 | 0.3 | 80 | 2.0 | 0.15 | *Acer rubrum* *Ulmus sp.* *Ulmus sp.* *Ulmus sp.* |
| 10 | 50 | 80 | 40 | 1.79 | 0.2 | 63 | 1.8 | 0.09 | *Ulmus sp.* *Ulmus sp.* *Fraxinus sp.* *Ulmus sp.* |

| Site | Point Count Distance to Road (m) | Canopy Cover % | Ground Cover % | Shrub Height (m) | Ground Cover Height (m) | Number of Shrubs | Average Dist. to Tree (m) | Average Diameter (m) | Tree Species from each of the Four Quadrants |
|---|---|---|---|---|---|---|---|---|---|
| 11 | 350 | 80 | 40 | 0.96 | 0.3 | 109 | 2.2 | 0.09 | *Fraxinus nigra*<br>*Ostrya virginiana*<br>*Fraxinus nigra*<br>*Fraxinus nigra* |
| 11 | 250 | 100 | 40 | 0.73 | 0.2 | 110 | 1.3 | 0.12 | *Acer rubrum*<br>*Acer rubrum*<br>*Fraxinus nigra*<br>*Acer rubrum* |
| 11 | 150 | 100 | 100 | 0.90 | 0.2 | 126 | 1.6 | 0.07 | *Thuja occidentalis*<br>*Rhamnus cathartica*<br>*Rhamnus cathartica*<br>*Prunus virginiana* |
| 11 | 50 | 60 | 100 | 1.99 | 0.8 | 48 | 2.7 | 0.22 | *Ostrya virginiana*<br>*Fraxinus pennsylvanica*<br>*Fraxinus pennsylvanica*<br>*Fraxinus pennsylvanica* |
| 12 | 350 | 100 | 20 | 1.51 | 0.2 | 50 | 2.0 | 0.14 | *Acer saccharum*<br>*Fraxinus nigra*<br>*Fraxinus americana*<br>*Fraxinus americana* |
| 12 | 250 | 40 | 80 | 1.32 | 0.6 | 24 | 11.9 | 0.14 | *Thuja occidentalis*<br>*Larix laricina*<br>*Thuja occidentalis*<br>*Thuja occidentalis* |
| 12 | 150 | 60 | 80 | 1.56 | 0.6 | 75 | 2.4 | 0.04 | *Thuja occidentalis*<br>*Thuja occidentalis*<br>*Thuja occidentalis*<br>*Thuja occidentalis* |
| 12 | 50 | 100 | 100 | 0.78 | 0.3 | 231 | 1.7 | 0.11 | *Fraxinus pennsylvanica*<br>*Ostrya virginiana*<br>*Fraxinus pennsylvanica*<br>*Fraxinus pennsylvanica* |

| Site | Point Count Distance to Road (m) | Canopy Cover % | Ground Cover % | Shrub Height (m) | Ground Cover Height (m) | Number of Shrubs | Average Dist. to Tree (m) | Average Diameter (m) | Tree Species from each of the Four Quadrants |
|---|---|---|---|---|---|---|---|---|---|
| 13 | 350 | 20 | 80 | 1.81 | 0.9 | 116 | 5.0 | 0.17 | Fraxinus americana<br>Fraxinus americana<br>Fraxinus americana<br>Fraxinus americana |
| 13 | 250 | 100 | 0 | 1.16 | 0.3 | 19 | 1.3 | 0.09 | Acer saccharum<br>Fraxinus americana<br>Acer saccharum<br>Acer saccharum |
| 13 | 150 | 100 | 20 | 1.23 | 0.3 | 14 | 1.6 | 0.12 | Ostrya virginiana<br>Acer saccharum<br>Quercus alba<br>Quercus alba |
| 13 | 50 | 100 | 20 | 0.58 | 0.3 | 9 | 1.5 | 0.11 | Ulmus sp.<br>Tsuga Canadensis<br>Acer rubrum<br>Ulmus sp. |
| 14 | 350 | 80 | 40 | 1.05 | 0.5 | 50 | 2.6 | 0.22 | Pinus strobus<br>Pinus strobus<br>Pinus strobus<br>Ulmus sp. |
| 14 | 250 | 60 | 100 | 1.79 | 0.6 | 53 | 5.8 | 0.07 | Pinus strobus<br>Ulmus sp.<br>Pinus strobus<br>Ulmus sp. |
| 14 | 150 | 80 | 20 | 1.48 | 0.2 | 29 | 3.0 | 0.07 | Acer saccharum<br>Fraxinus americana<br>Ulmus sp.<br>Rhus typhina |
| 14 | 50 | 60 | 60 | 0.95 | 0.5 | 46 | 2.6 | 0.18 | Ostrya virginiana<br>Fraxinus americana<br>Ulmus sp.<br>Ulmus sp. |

| Site | Point Count Distance to Road (m) | Canopy Cover % | Ground Cover % | Shrub Height (m) | Ground Cover Height (m) | Number of Shrubs | Average Dist. to Tree (m) | Average Diameter (m) | Tree Species from each of the Four Quadrants |
|---|---|---|---|---|---|---|---|---|---|
| 15 | 350 | 0 | 100 | 1.72 | 0.6 | 185 | 4.8 | 0.03 | Viburnum sp.<br>Rhamnus cathartica<br>Viburnum sp.<br>Viburnum lentago |
| 15 | 250 | 100 | 80 | 1.38 | 0.3 | 172 | 1.1 | 0.06 | Prunus serotina<br>Prunus serotina<br>Cornus sp.<br>Cornus sp. |
| 15 | 150 | 60 | 60 | 1.80 | 0.2 | 127 | 1.5 | 0.07 | Fraxinus americana<br>Rhus typhina<br>Crataegus sp.<br>Fraxinus americana |
| 15 | 50 | 20 | 100 | 2.08 | 0.5 | 218 | 3.0 | 2.05 | Fraxinus americana<br>Cornus sp.<br>Malus domestica<br>Cornus sp. |
| 16 | 350 | 100 | 60 | 0.76 | 0.1 | 62 | 1.9 | 0.06 | Fraxinus americana<br>Ostrya virginiana<br>Ostrya virginiana<br>Fraxinus americana |
| 16 | 250 | 100 | 80 | 0.84 | 0.2 | 57 | 2.8 | 0.11 | Carya ovate<br>Ostrya virginiana,<br>Fraxinus sp.<br>Ostrya virginiana |
| 16 | 150 | 100 | 40 | 1.55 | 0.2 | 83 | 1.5 | 0.04 | Rhamnus cathartica<br>Rhamnus cathartica<br>Rhamnus cathartica<br>Rhamnus cathartica |
| 16 | 50 | 80 | 80 | 1.58 | 0.3 | 154 | 1.2 | 0.06 | Fraxinus americana<br>Ulmus sp.<br>Rhamnus cathartica<br>Fraxinus americana |

| Site | Point Count Distance to Road (m) | Canopy Cover % | Ground Cover % | Shrub Height (m) | Ground Cover Height (m) | Number of Shrubs | Average Dist. to Tree (m) | Average Diameter (m) | Tree Species from each of the Four Quadrants |
|---|---|---|---|---|---|---|---|---|---|
| 17 | 350 | 60 | 40 | 0.61 | 0.2 | 60 | 1.8 | 0.10 | Thuja occidentalis<br>Quercus rubra<br>Ostrya virginiana<br>Fraxinus americana |
| 17 | 250 | 100 | 60 | 0.85 | 0.2 | 59 | 2.2 | 0.61 | Ostrya virginiana<br>Acer saccharum<br>Carya ovate<br>Acer saccharum |
| 17 | 150 | 100 | 80 | 0.89 | 0.3 | 48 | 3.5 | 0.08 | Quercus rubra<br>Acer saccharum<br>Acer saccharum<br>Acer saccharum |
| 17 | 50 | 80 | 60 | 1.31 | 0.3 | 24 | 1.4 | 0.21 | Thuja occidentalis<br>Thuja occidentalis<br>Thuja occidentalis<br>Thuja occidentalis |
| 18 | 350 | 80 | 80 | 1.13 | 0.2 | 54 | 2.0 | 0.06 | Fraxinus americana<br>Juniperus Virginia<br>Acer saccharum<br>Fraxinus americana |
| 18 | 250 | 80 | 100 | 1.36 | 0.3 | 20 | 2.1 | 0.09 | Fraxinus pennsylvanica<br>Ulmus sp.<br>Fraxinus pennsylvanica<br>Fraxinus pennsylvanica |
| 18 | 150 | 80 | 100 | 1.34 | 0.5 | 55 | 2.4 | 0.11 | Fraxinus pennsylvanica<br>Fraxinus pennsylvanica<br>Fraxinus pennsylvanica<br>Fraxinus pennsylvanica |
| 18 | 50 | 60 | 60 | 0.78 | 0.2 | 112 | 1.5 | 0.09 | Juniperus Virginia<br>Juniperus Virginia<br>Juniperus Virginia<br>Juniperus virginia |

| Site | Point Count Distance to Road (m) | Canopy Cover % | Ground Cover % | Shrub Height (m) | Ground Cover Height (m) | Number of Shrubs | Average Dist. to Tree (m) | Average Diameter (m) | Tree Species from each of the Four Quadrants |
|---|---|---|---|---|---|---|---|---|---|
| 19 | 350 | 0 | 40 | 0.82 | 0.2 | 136 | 2.5 | 0.08 | Quercus alba<br>Tilia americana<br>Prunus virginiana<br>Rhamnus cathartica |
| 19 | 250 | 100 | 60 | 0.91 | 0.2 | 53 | 1.7 | 0.12 | Populus grandidentata<br>Abies balsamea<br>Abies balsamea<br>Populus grandidentata |
| 19 | 150 | 100 | 60 | 0.90 | 0.25 | 103 | 2.1 | 0.05 | Rhamnus cathartica<br>Rhamnus cathartica<br>Rhamnus cathartica<br>Juniperus virginia |
| 19 | 50 | 80 | 60 | 0.79 | 0.2 | 115 | 1.7 | 0.08 | Juniperus Virginia<br>Juniperus Virginia<br>Juniperus Virginia<br>Juniperus Virginia |
| 20 | 350 | 80 | 100 | 1.89 | 0.3 | 20 | 2.4 | 0.22 | Fraxinus americana<br>Fraxinus americana<br>Fraxinus americana<br>Fraxinus americana |
| 20 | 250 | 100 | 80 | 0.90 | 0.3 | 21 | 1.7 | 0.07 | Rhamnus cathartica<br>Rhamnus cathartica<br>Rhamnus cathartica<br>Rhamnus cathartica |
| 20 | 150 | 80 | 40 | 0.65 | 0.2 | 282 | 2.0 | 0.10 | Rhamnus cathartica<br>Rhamnus cathartica<br>Fraxinus sp.<br>Fraxinus sp. |
| 20 | 50 | 80 | 80 | 1.16 | 0.3 | 68 | 2.2 | 0.08 | Rhamnus cathartica<br>Fraxinus sp.<br>Rhamnus cathartica<br>Fraxinus sp. |

**Appendix D.** Number of study sites where each species was observed in at least one of the four point counts, divided into site types. Note: Each site type (small-gap and large-gap), had 10 sites.

| | No. of each site type with observations | | | No. of each site type with observations | |
|---|---|---|---|---|---|
| Species | Small-Gap | Large-Gap | Species | Small-Gap | Large-Gap |
| ALFL | 0 | 2 | MODO | 1 | 1 |
| AMCR | 1 | 1 | NAWA | 1 | 1 |
| AMRE | 2 | 4 | NOCA | 1 | 1 |
| AMRO | 8 | 8 | NOFL | 1 | 1 |
| BAOR | 0 | 2 | NOWA | 5 | 3 |
| BCCH | 7 | 8 | OVEN | 9 | 9 |
| BHVI | 1 | 0 | PIWA | 0 | 1 |
| BLJA | 4 | 3 | PUFI | 1 | 0 |
| BRCR | 3 | 2 | RBGR | 2 | 4 |
| BRTH | 1 | 0 | RBNU | 2 | 0 |
| BTBW | 0 | 1 | REVI | 9 | 9 |
| BTGW | 2 | 0 | RWBL | 0 | 1 |
| BWWA | 4 | 4 | SCTA | 1 | 0 |
| CEDW | 3 | 3 | SOSP | 1 | 2 |
| CONI | 1 | 0 | SWSP | 1 | 3 |
| COYE | 3 | 9 | VEER | 5 | 6 |
| CSWA | 1 | 4 | WIWR | 1 | 0 |
| EAWP | 2 | 5 | WOTH | 3 | 7 |
| EATO | 2 | 1 | WTSP | 3 | 0 |
| GCFL | 4 | 2 | YBSA | 1 | 2 |
| GRCA | 0 | 1 | YRWA | 0 | 2 |
| HAWO | 2 | 0 | YWAR | 1 | 1 |
| HETH | 0 | 1 | | | |

**Appendix E.** List of American Ornithologist Union (AOU) codes (Pyle & Desante 2012) and associated scientific names of bird species detected during all point counts.

| AOU Code | Scientific Name | AOU Code | Scientific Name |
|---|---|---|---|
| ALFL | *Empidonax alnorum* | MODO | *Zenaida macroura* |
| AMCR | *Corvus brachyrhynchos* | NAWA | *Oreothlypis ruficapilla* |
| AMRE | *Setophaga ruticilla* | NOCA | *Cardinalis cardinalis* |
| AMRO | *Turdus migratorius* | NOFL | *Colaptes auratus* |
| BAOR | *Icterus galbula* | NOWA | *Parkesia noveboracensis* |
| BCCH | *Poecile atricapillus* | OVEN | *Seiurus aurocapilla* |
| BHVI | *Vireo solitarius* | PIWA | *Setophaga pinus* |
| BLJA | *Cyanocitta cristata* | PUFI | *Haemorhous purpureus* |
| BRCR | *Certhia americana* | RBGR | *Pheucticus ludovicianus* |
| BRTH | *Toxostoma rufum* | RBNU | *Sitta canadensis* |
| BTBW | *Setophaga caerulescens* | REVI | *Vireo olivaceus* |
| BTGW | *Setophaga virens* | RWBL | *Agelaius phoeniceus* |
| BWWA | *Mniotilta varia* | SCTA | *Piranga olivacea* |
| CEDW | *Bombycilla cedrorum* | SOSP | *Melospiza melodia* |
| CONI | *Chordeiles minor* | SWSP | *Melospiza georgiana* |
| COYE | *Geothlypis trichas* | VEER | *Catharus fuscescens* |
| CSWA | *Setophaga pensylvanica* | WIWR | *Troglodytes hiemalis* |
| EAWP | *Contopus virens* | WOTH | *Hylocichla mustelina* |
| EATO | *Pipilo erythrophthalmus* | WTSP | *Zonotrichia albicollis* |
| GCFL | *Myiarchus crinitus* | YBSA | *Sphyrapicus varius* |
| GRCA | *Dumetella carolinensis* | YRWA | *Setophaga coronata* |
| HAWO | *Picoides villosus* | YWAR | *Setophaga petechia* |
| HETH | *Catharus guttatus* | | |

**Appendix F.** Summary table of site-specific information for both site types (small-gap vs. large-gap) arranged by date of survey. Information includes traffic volume (AADT), distance to the closest patch of forest >1ha across the road, direction of survey relative to road, bird abundance, species richness and morning traffic noise documented at all four distances from the road.

| Date of Survey | Site | AADT | Distance to Forest >1ha | Direction of Survey | Bird Abundance | | | | Species Richness | | | | Traffic Noise Average Power (dB) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance from Road (m) | | | | | 350 | 250 | 150 | 50 | 350 | 250 | 150 | 50 | 350 | 250 | 150 | 50 |
| **Small-Gap Sites** | | | | | | | | | | | | | | | | |
| June 5 | 12 | 18600 | 174 | Away | 7 | 7 | 10 | 4 | 6 | 6 | 7 | 4 | 86.3 | 90.4 | 92.56 | 96.38 |
| June 7 | 10 | 17100 | 290 | Away | 8 | 3 | 4 | 5 | 6 | 3 | 4 | 4 | 83.0 | - | 90.38 | 95.55 |
| June 11 | 1 | 14600 | 560 | Toward | 5 | 4 | 4 | 2 | 5 | 4 | 4 | 2 | 82.2 | 83.7 | 87.40 | 92.1 |
| June 13 | 15 | 34400 | 530 | Toward | 11 | 7 | 6 | 5 | 5 | 6 | 5 | 5 | 80.76 | 82.6 | 89.95 | 91.06 |
| June 18 | 20 | 39200 | 1000 | Toward | 7 | 3 | 2 | 1 | 6 | 3 | 2 | 1 | 78.9 | 90.7 | 93.23 | 99.27 |
| June 19* | 7 | 19600 | 700 | Away | 4 | 5 | 3 | 7 | 4 | 5 | 3 | 4 | 81.7 | 86.6 | - | 97.95 |
| June 22 | 6 | 23800 | 630 | Away | 8 | 9 | 9 | 3 | 6 | 6 | 6 | 3 | 82.0 | 83.6 | 86.00 | 91.54 |
| June 27 | 18 | 35100 | 550 | Away | 6 | 4 | 12 | 8 | 3 | 4 | 8 | 6 | 92.2 | 94.8 | 94.71 | 97.66 |
| July 3 | 14 | 30200 | 220 | Toward | 9 | 6 | 4 | 3 | 7 | 5 | 3 | 3 | 82.3 | 77.4 | 77.63 | 93.22 |
| July 4 | 5 | 35100 | 895 | Toward | 4 | 5 | 4 | 6 | 4 | 4 | 4 | 6 | 81.5 | 83.2 | 89.37 | 102.0 |
| **Large-Gap Sites** | | | | | | | | | | | | | | | | |
| May 30 | 9 | 17200 | 95 | Away | 1 | 3 | 4 | 4 | 1 | 3 | 3 | 4 | 89.42 | 90.91 | 92.04 | 95.48 |
| June 6 | 11 | 17000 | 100 | Away | 4 | 7 | 6 | 6 | 4 | 7 | 6 | 4 | 85.5 | - | 90.96 | 96.61 |
| June 8 | 3 | 15700 | 90 | Toward | 4 | 9 | 8 | 7 | 4 | 6 | 7 | 6 | 82.3 | 82.8 | 83.61 | 91.17 |
| June 14 | 17 | 35100 | 80 | Toward | 6 | 5 | 3 | 5 | 4 | 5 | 2 | 4 | 91.4 | 93.6 | 96.12 | 99.07 |
| June 15 | 16 | 35300 | 95 | Toward | 6 | 3 | 6 | 7 | 6 | 3 | 6 | 4 | 87.3 | 90.7 | 93.23 | 99.27 |
| June 20 | 8 | 17200 | 90 | Away | 4 | 5 | 5 | 4 | 3 | 3 | 5 | 4 | 83.4 | 86.73 | 89.48 | 94.66 |
| June 26* | 4 | 20400 | 85 | Away | 6 | 5 | 3 | 2 | 6 | 5 | 3 | 2 | 84.0 | 86.7 | - | 97.70 |
| June 28 | 19 | 35000 | 75 | Away | 5 | 7 | 3 | 2 | 4 | 6 | 2 | 2 | 85.1 | 88.2 | 92.01 | 91.66 |
| June 29* | 13 | 30200 | 110 | Toward | 3 | 4 | 3 | 1 | 3 | 3 | 3 | 1 | 78.4 | 84.6 | - | 98.67 |
| July 5 | 2 | 15700 | 80 | Toward | 8 | 7 | 4 | 4 | 5 | 5 | 4 | 4 | 75.3 | 78.0 | 82.14 | 90.00 |

*Because of issues with using the full morning's recordings to estimate traffic noise, site estimates of traffic noise are derived from full-morning recordings made on July 31(site 7), August 2(site 13) and August 16 (site 4).*