Synthesis of Noise Effects on Wildlife Populations

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Synthesis of Noise Effects on Wildlife Populations

Foreword

This report contains a summary of ongoing work on the effects of noise on wildlife populations to date. Because the numbers and/or diversity of species have been used as indicators of the effects of noise, a number of studies that have indicated one or both of these factors for species alongside roads are included, although noise is not specifically mentioned in some of these reports. There is a paucity of information on the response of invertebrates to noise, particularly the levels likely to be encountered along roads. Significant populations of some species are found along rights-of-way, although others such as aquatic forms may be adversely affected; whether by the road itself or by noise is unclear. Existing information (although incomplete) would suggest that fish are unlikely to be adversely affected by noise levels from road. Reptiles and amphibians show some barrier effect due to roads, but there is no clear evidence of a noise effect alone. Recent work has suggested that behavior in burrowing toads may be affected by noise and this will require further study. Birds have received the most study and, in some cases, are strongly adversely affected both in numbers and in breeding by the proximity to roads. In other cases the effect is the opposite and there are reports of many species using roadside habitat in some areas. Large mammals may be repelled by noise, although in most cases the effect appears to be slight to moderate. Small mammals do not appear to be adversely affected by road noise occurring in significant numbers in rights-of-way. There appears to be a physical barrier effect of roads. This report also includes recommendations for future work based on the state of knowledge on the subject.

This report will be of most interest to those responsible for environmental impact assessments, road ecologists and those concerned with incorporating environmental concerns into highway planning.

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Notice

Quality Assurance Statement

SYNTHESIS OF NOISE EFFECTS ON WILDLIFE POPULATIONS

PREFACE

This report contains a summary of ongoing work on the effects of noise on wildlife populations to date. It will hopefully provide some indication of the current state of knowledge in the area – particularly with respect to studies of birds that have spurred increased discussion of the subject. No effort was made to evaluate the methodologies applied to any individual study although a large number have appeared in peer-reviewed journals and thus have already been scrutinized. Because the numbers and/or diversity of species have been used as indicators of the effects of noise, a number of studies that have indicated one or both of these factors for species alongside roads are included although noise is not specifically mentioned in some of these. Studies that directly measure the number of individuals or breeding along roadsides provide the most direct indication of the response of populations to road noise. This is supported by those studies in which noise has been used as the best predictor of the negative response of species to roads in recent studies (see Reijnen and colleagues [41, 96-100]; Forman et al.[45]).

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS AND SYMBOLS

SPL = sound production level
dB = decibel = unit of sound production level (logarithmic scale)
dB(A) = decibel on A-weighted scale (levels weighted according to sound frequency)

L_{eq} = equivalent continuous sound level
SEL = sound equivalent level integrated per 1 second

Hz = hertz = cycles per second (measure of sound frequency)
kHz = kilohertz (thousand hertz)

ROW = rights-of-way

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SYNTHESIS OF NOISE EFFECTS ON WILDLIFE POPULATIONS

INTRODUCTION

A recent estimate puts the area currently converted to highways, streets and rights of way (ROW) at some 20 million acres (8 million hectares).[34] As the total road area continues to increase contact with wildlife populations will likewise increase. Further, the cumulative effect of roads may reach some 20% of the total land area of the United States.[42] A number of factors have been suggested as contributing to this far-ranging impact including habitat fragmentation, landscape effects (such as water flow), air pollution, and increased mortality (See references 43,46, 69, and 115). However, recent studies have suggested that noise may have a significant and wide-ranging effect at least on some species (See references 41, 44, 97, 99, and116). Because of the pervasive nature and difficulty in mitigating noise, it may be the most significant factor impacting wildlife.[46] In this report some of the current research on the subject of noise and wildlife is reviewed, areas of incomplete knowledge are identified, and suggestions for future study are made.

MATERIALS AND METHODS

Beginning in the fall of 2003 an exhaustive search has been made of electronic and paper databases including (Infotrac, Cambridge Science, Agricola, Biological Sciences and the Biological and Agricultural Index) under the headings of wildlife, highways, noise, animal, noise pollution, roads, urban noise and the various groups of animals (fish, reptile, amphibian, bird, mammal). A search of all references was made and the bibliographies of all materials were reviewed for additional sources.

RESULTS AND DISCUSSION

Physics of Sound

Sound pressure level (SPL) is responded to in a logarithmic manner and sound levels are measured on a logarithmic decibel scale (dB), which corresponds fairly well to the human hearing response. The zero end of the scale corresponds to a pressure of about 0.00002 N/m^2 and a value of 120 dB corresponds to about 20 N/m^2 – a level at which pain will be experienced.

$$dB = 10 \text{ Log } \frac{I}{I_o}$$

where I = intensity of actual sound, I_o = intensity of sound at threshold level [89]

Human hearing extends from frequencies (perceived as pitch) from about 20 Hz (cycles per second) to about 20,000 Hz (20 kHz).[89] SPL levels are often weighted. One commonly used is the A-weighting network that assigns weights to sounds based on audibility to human hearing (low weights to low frequency sounds < 1000 Hz and higher weights to more audible high-frequency sounds). This is denoted as dB(A) in some studies. Other ways of representing levels of sound include L_{eq} = equivalent continuous sound level and SEL = sound exposure level integrated over 1 second.[16] In general sound attenuates as the square of the distance from the source and is greater at higher frequencies.

The sensitivities of various groups of wildlife can be summarized as:

Mammals < 10 Hz to 150 kHz ; sensitivity to -20 dB

Birds (more uniform than mammals) 100 Hz to 8-10 kHz; sensitivity at 0-10 dB

Reptiles (poorer than birds) 50 Hz to 2 kHz; sensitivity at 40-50 dB

Amphibians 100 Hz to 2 kHz; sensitivity from 10-60 dB

Overview

Animals rely on meaningful sounds for communication, navigation, avoiding danger and finding food against a background of noise. Here noise is defined as "any human sound that alters the behavior of animals or interferes with their functioning".[16] The level of disturbance may be qualified as damage (harming health, reproduction, survivorship, habitat use, distribution, abundance or genetic distribution) or disturbance (causing a detectable change in behavior).

An earlier review of this subject [84] contains some considerable information on the effects of acute noise on hearing loss in vertebrates (especially mammals), but concludes that, at the time, little or no knowledge of noise from roads and their effect on animals was known. A review of the effect of noise (principally from aircraft) concluded that there was no evidence of noise having a significant impact on cattle (milk production), swine, poultry (egg hatching) or mink (kits produced).[14] However, the effect on wildlife may be more significant than on domestic species. Greater behavioral and physiological responses to noise have been reviewed and studied with special emphasis on the greater noise of aircraft and sonic booms.[28,31,81] In a review of the effect of aircraft noise the authors identify a number of at least potentially, deleterious effects that accompany these sound levels in both domestic and wild species ranging from alert reactions to physiological indicators of stress (e.g. changes in hormonal levels, organ function, etc.).[81] It should be noted that noise levels in these studies are generally intermittent and occur at levels greater than that typically encountered for road traffic (i.e. aircraft sounds generally $\geq$ 100 dB). There is no significant review of materials already summarized in earlier works on the effect of aircraft noise or sonic booms except for more recent studies or when no other information on a particular group was available. Much information is available through earlier reviews on this subject.[81, 84]

The foremost difficulty in summarizing the effect of road noise on wildlife is the fact that very few studies have directly addressed the impact of noise from roads (i.e. the background sound that accompanies varying volumes of traffic). Studies of the noise from sonic booms or other sounds from aircraft utilize sounds that are louder and more

acute. Still other studies have looked the overall effect of roads noting numbers near roadsides, while failing to note the level of noise on the dispersal of animals at greater distances from the roadside (See references 75, 90, 125, and 126). Thus, the presence of significant numbers indicated by these studies can be used to indicate that there is no absolute barrier to use of roadside areas, however, these studies do not indicate how these areas compare to others further distant from the source of the noise.

Invertebrates

Little is known about the effects of noise related to roads and its effect on invertebrates. A few studies have indicated that several species are sensitive especially to low frequency vibration. Honeybees will stop moving for up to twenty minutes for sounds between 300 and 1 kHz at intensities between 107-120 dB.[51] Frings and Frings[49] reported that flies of the order *Diptera* showed a startle response at 80-800 Hz (at 80 dB) and at 120-250 Hz (from 3-18 dB above ambient levels). However, the longer term responses to these sounds are not given.

Earthworms have been shown to move toward the surface near roadways at low frequencies (~ 5 Hz) exposing them as a food source for birds.[113] Generally, roadsides have been found to provide habitat for significant numbers of invertebrates including 67 species of insects in the United Kingdom.[48] The authors reported no major distraction was evident in insect behavior related to nearby traffic. However, the significant numbers may have been due to limited forage available elsewhere. Similarly, road verges have been shown to provide significant habitat for butterfly and burnet populations with the roadway having no significant effect on movement and insignificant mortality.[88] Even on main roads (about 1,700-11,500 cars/day) there was an average of 9 species in a 100m transect and a maximum of 23 species of butterfly (40% of British species) found in one transect. A further review of roadside use in England (including county roads and larger highways found 25 of 60 butterfly species and 8 of 17 bumble bee species to breed alongside roads.[126] The utility of these areas compared to others which would help to indicate any effect of noise is not discussed specifically, but the

thesis of the article is that these rights-of–way (ROW) can provide valuable habitat should be noted.

In a study of invertebrate communities (mainly insects (arthropods) although other orders were also looked at) along a gravel road, greater numbers of individuals were found at 5 m from the road edge than at 10 or 15 m.(77) In this study the diversity of species did not differ (at the order level) up to distances of 15 m from the edge of the road. However, whether there would be an effect over greater distances or at higher traffic volumes is not known. A study of the effect of roads on aquatic macroinvertebrates (e.g. aquatic insects) showed a decline in diversity as the number of adjacent roadways increased using an index of the effective roaded area (ERA a method developed by the USDA Forest Service).(83) An ERA level above 5% was found to be significant.(83) The specific cause of this change related to roads was not given.

Mader (79) found a barrier effect of roads on carabid beetles to which he attributed a broad band of emissions as contributing including noise, exhaust and salinity. However, no attempt was made to quantify or partition these effects. Similarly, it has been reported that the orange tip butterfly (*Anthocharis cardamines* L.) was effectively barred from crossing a large roadway (~ 40,000 vehicles/day), however whether noise was a contributing factor is not indicated.

The direct effect of traffic noise on invertebrates has yet to be established by looking at community structure near roads and at varying distances and with different volumes of traffic or by simulating noise levels in controlled conditions. Knowledge of invertebrate communities may be particularly important given the importance of these organisms (e.g. as a food source for other species such as fish, amphibians, and birds).

Fish

Fish are capable of reception of sound in the water (see review by Hawkins [61]). The sensitivity of fish varies, but is generally in the range of 50-2,000 Hz and is best between 200-800 Hz.[60] The SPL underwater is usually indicated in reference to a unit (e.g. re 1 Pa = Pascal = 1 N/m^2) and many fish have threshold of 50-70 dB re 1 μPa.[60, 94] Several species have been reported to be adversely affected by sounds levels > 180 dB re 1 μPa presented for two hours or less. Hawkins[61] reports that sound perception of fish are generally below 2- 3 kHz and that they are more sensitive to low frequency sounds. In the ocean conversion of sound is usually made in reference (re 0.0002 $dynes/cm^2$ and 1 Hz; where 1 Pa = 1 N/m^2 = 10 μbars = 10 $dynes/cm^2$). [127] Background oceanic traffic was found in the range of 10-1 kHz.

A few studies have found a response by fish to noise. Naïve goldfish have altered their pattern of locomotion avoiding sounds at 30 cm distance (~2 kHz) and an intensity of 2 $dynes/cm^2$ (0.2 Pa).[80] Changes in pressure (2-18 Pa at a frequency of 70-200 Hz) have caused startle response in herring (*Clupea herengus* L.).[13] Banner and Hyatt[8] reported greater growth rate and fry survival of two minnow species (*Cyprinodon variegates* and *Fundulus similes*) held in quieter tanks. However, the level of noise required to have this effect on growth was greater than that normally encountered with traffic. Juvenile Atlantic salmon have shown an avoidance of low frequency sound (10 Hz), but failed to show a response at a higher frequency of 150 Hz.[70]

Simulated sonic booms have caused startle reactions in guppies.[103] Trout and salmon eggs and fry exposed to sonic booms showed no increase in mortality and there was no apparent difference in the development of fry.[103] The importance of road noise in affecting the behavior of fish populations, particularly the relationship between road traffic levels and any response is not known.

Reptiles and Amphibians

A few studies of the response of reptiles and amphibians to noise have been conducted, and, as with fish, no study investigating the impact of roads on these species has been made.

Minton [87] reported on several species in a suburban area (2 salamanders, 6 anurans, 6 turtles and 7 snakes), but did not indicate any effect of noise. However, a barrier effect of roads (city streets) to both breeding and hibernating habitats was significant. It is known that the auditory sensitivity of lizards changes with temperature and is generally greatest in those ranges they prefer for activity.[24]

A broader survey of amphibians found salamanders (woodland and stream species) to be most commonly found along roadsides (interstates) and ROW in both the southeast and northwest.[2] There is no indication of noise as a factor, however a barrier to movement by roads is indicated. Findlay and Houlihan[40] reported that reptiles and amphibians showed a reduced species richness up to 2000 m from the both two and four-lane highways with an improved diversity in areas of forest cover. The authors attribute this response to a lack of dispersal across roads and not to sound levels. A study of frogs and toads by Fahrig et al.[35], also found a decrease in numbers near roads with traffic densities of 8,500 – 13,000 vehicles/day. In this case traffic mortality is suggested as the cause. In contrast, cane toads were found to use roads with lower traffic densities as (including vehicle tracks) for dispersal.[106] In this case numbers were lower even 15 m from the edge of the road. However, whether this effect would occur at higher traffic densities is not indicated. Similarly, Rudolph et al. [104] report a reduction of up to 50% in large snake species up to a distance of 850 m from a road with the reduction attributed to increased road mortality. Indeed the effect was similar whether interstate, forest or county roads were studied indicating that the precipitating effect is not likely noise.

The study that has most specifically shown an adverse effect on amphibians related to road noise is that of Brattstrom and Bondello [18] who found spadefoot toads (*Scaphiopus couchi*) undergoing estivation to respond to motorcycle sounds (up to 95 dB(A) at 0.4-4.4

kHz) by leaving burrows, which could have a detrimental effect if it occurred at the wrong time of year. Further, “dune buggy” noise had an adverse effect on hearing in the fringe-toed lizard (*Uma scoparia*) at durations of 500 seconds or longer (95 db(A)). Whether traffic noise has a significant effect on a particular population or community of reptiles or amphibians remains to be determined. The fact that species can be disturbed by road noise makes this an area in need of further study.

Birds

In their environment birds must be able to discriminate their own and the song’s and those of other species apart from any background noise.(32) Calls are important in the isolation of species, pair bond formation, pre-copulatory display, territorial defense, danger, advertisement of food sources and flock cohesion.(68) The threshold for hearing in birds is higher than for humans at all frequencies and the overlap in the discernable frequencies between species indicates that birds do not filter out other species by simply being unable to detect them (i.e. birds can hear songs of other species). Studies of budgerigars indicate that at the best frequency (2.86 kHz) sound production needs to exceed background by 18-20 dB for detection.(32) Sound production from several bird species have been measured to peaks of about 90-95 dB and are generally greater for larger birds.(17) The rate of attenuation of the sound will be affected by the surroundings, but estimates range from 5 dB/m for a bird 10 m above ground in an open field to 20 dB/m for a bird on the ground in a coniferous forest.(82) In this study height and frequency were found to affect sound transmission more than habitat type. Sounds produced at between 15cm and 1m above ground attenuated more rapidly than at greater heights. In a study of the blackbird (*Turdus merula*) high pitched sounds were found to degrade more rapidly.(30) Further, sounds were heard better on a high perch probably due to the better position rather than better projection.

The distance separating signaler and receiver at which a vocalization may be detected increases according to source intensity, amount of masking and the rate of attenuation.(32) As an example (for budgerigars) with an attenuation of 5 dB/m and a background noise

level of 45 dB SPL with about 25 dB of masking the transmission distance would be about 100 m for a level of 70 dB and would increase to about 300 m at 90 dB. A subsequent study of several species including a number of passerines (European starling, song sparrow, swamp sparrow and zebra finch) found maximum sensitivity to sounds between 2 and 5 kHz.[91] Noise in the spectral region of the signal is the most effective in masking and signals must be 18-20 dB greater at the best frequencies to be detected.[32] A study of the auditory threshold in several species including European starling, song sparrow, swamp sparrow and zebra finch found the critical ratio (the signal to noise ratio at masked threshold) is about 3 dB/octave.[91]

Early studies of the effect of noise on birds indicated no significant impairment by noise. Thus, Stadelman[111] reported that broiler chickens could be grown without loss of weight at sound levels of 110 dB (20 Hz to 10 kHz). Hens showed no effect of laying in response to conveyor noise (66-76 dB) (Scott and Moran, 1993). Frings and Jumber [50] reported that starlings could be repelled with specific distress calls at about 85 dB from a distance of 10 m. Likewise, starlings were found to be sensitive to repellent tones at 1000-7500 Hz that caused a disturbance to feeding and the level of response increased linearly in a range of 50-100 dB.[74]

Grassland and woodland birds

One of the earliest studies to find a “highway effect” on bird populations was that of Räty[95] who measured numbers of birds in forested areas at distances up to 1 km from the road. Species studied included the capercallie (*Tetrao urogullus*), black grouse (*Lyrurus tetrix*) and hazel hen (*Lagopus lagopus*). There was a 2/3 reduction in numbers up to a distance of 250 m and some reduction up to 500 m. The traffic density was 700-3000 cars/day. Unfortunately, noise levels were not measured and the cause of the effect seen was not given. Further, measurements began 25 m from the edge of the road thus precluding any effect of the ROW.

More recently, study of the effect of road noise on bird populations appears to have resumed with reevaluation of data from an early study from the Netherlands on grassland habitats (Veen, [119] c.f. van der Zande et al., [116]) that concluded some species would avoid rural roads to a distance of 500-600 m and busy highways to 1600-1800 m. The data were subsequently reviewed and it was concluded that road noise appeared to be significant in the distribution (i.e. reduced nest density) of the lapwing (*Vanellus vanellus*), black-tailed godwit (*Limosa limosa*) and, perhaps the redshank (*Haematopus ostralegus*), however the effect was not found for the oystercatcher (*Tringa tetanus*).[116] The levels of noise were not measured in this study. A further series of studies from the Netherlands has supported this argument finding that numbers of breeding birds in wooded areas declined significantly near roads and in proportion to the density of traffic on the road. Reijnen et al.[96] reported a reduction in the numbers of breeding birds adjacent to a busy highway (30,000-40,000 vehicles/day) and at a distance of 300 m. The level of noise was not measured. Reijnen and Foppen[97] studied the willow warbler (*Phylloscopus trachilus*) and found that the density of territorial males was lower distances of up to 200m than at greater distances (up to 400 m). Also, older males were more abundant further from the road. It is suggested that noise may have an important effect (predicted to have a mean of 50 dB(A) at 500 m) along the highway (traffic density 50,000 cars/day). The dispersal of the breeding males away from the road was broken down subsequently to be progressively increasing in zones of 0-200 m, 200-400 m and a >400m control zone. Reijnen and Foppen[98] found 17 of 23 species studied for three years showed some negative effect of road (40-52,000 cars/day). The effect was diminished in years in which the overall population size was large and they suggest measuring effects of several years to ensure an accurate measure of the effect. Similar reductions in grasslands were reported in a subsequent study of 12 passerine species where the density of 7 were found to be reduced and predicted by the number of cars and distance from the road.[100] The effect appears to be most significant above a noise level of about 50 dB(A) with a level of 70 dB(A) on the verge of the road. At a traffic density of 5,000 cars/day most species showed a reduction of 12-56% within 100 m of the road. At distances of > 100m only the black-tailed godwit (*Limosa limosa*) and oystercatcher (*Haematopus ostralegus*) showed reduction in density. At a traffic density of 50,000

cars/day density was reduced between 12 and 52% for all species studied at distances of up to 500 m. Sensitive species include both waterfowl (shoveler ducks) and passerine species (black-tailed godwit, oystercatcher, lapwing, skylark) that were reduced in density between 14 and 44% up to a distance of 1500 m making it difficult to determine any particular group that might be more sensitive.

A more extensive study of 43 species of woodland birds in both deciduous and coniferous forests found that 26 (60%) showed some reduction in density adjacent to the road.[99] Noise was the only factor found to be a significant predictor and the number of cars and distance from the road were significant factors in the number of breeding birds. The "effect distances" were 40-1500 m (10,000 cars/day) and 70-2800m (60,000 cars/day). There was a reduction in density at 250 m from the road of between 20 and 98%. The frequency range of road noise was 100 Hz to 10 kHz with the loudest in the range of 100-200 Hz and 0.5-4 kHz with a threshold at between 20 and 56 dB(A). The authors note that if noise were constant there was no difference between plots with high and low car visibility. Further it is noted that there is no pattern of interference with song calls and, thus, the immediate cause of the effect is not apparent. It is suggested that a supplementary aspect may be stress.

A study along an interstate highway (34,000 – 50,000 vehicles/day) in the United States supported the findings previously reported[41, 96-100], however, the results rely heavily on assumptions from the work in the Netherlands being applicable and there is limited original data that would more conclusively support the earlier findings.[44] A >100 m avoidance zone is reported for moose, deer, amphibians, forest and grassland birds. Moose corridors and grassland bird avoidance extended >100 m. However, grassland bird data are scarce and scattered in the open areas near the highway and woodland bird data is extrapolated from the earlier studies by Reijnen and colleagues [41, 96-100]. More recently, Forman et al.[45] reported that several species of grassland bird (especially the bobolink and eastern meadowlark) decreased in numbers and breeding in patches as the amount of traffic on roadways increased. At light traffic volumes of between 3,000 and 8,000 vehicles there was no effect on distribution, whereas moderate traffic levels of

between 8,000 and 15,000 vehicles/day had no effect on the presence of birds, however, breeding was reduced to 400 m. Both presence and breeding of birds was reduced at traffic levels between 15,000 – 30,000 vehicles/day to a distance of 700 m and at >30,000 vehicles/day both presence and breeding were reduced up to a distance of 1200 m. The species affected are mainly the bobolink and eastern meadowlark. The levels of noise in this study are not given although studies that manipulate noise levels are suggested.

In a nocturnal species (the stone curlew, *Burhinus oedicnemus*) in England, roads were found to reduce numbers at distances of up to 3 km .(56) The authors suggest that visual stimuli (headlights) could have a greater effect than noise alone even though traffic noise or vehicle movements are suggested as primary causes.(56) It should be noted that, in this study there was no evidence of a lessening of the effect if nearby suitable habitat (away from the road) was scarce or abundant.

The general conclusion is that some (although not all) bird species are sensitive at least during breeding to noise levels and that the distances over which this effect is seen can be considerable varying from a few meters to more than 3 km (see Appendix A - Table 1 for a summary)

In contrast to these findings, other studies have found that roadside verges to provide habitat for, at least, some birds. In a study following highway construction, Michael et al.(86) found increased food and cover offered by ROW resulted in increases in the number of birds and the number of species in the ecotone when compared to the ROW and surrounding forest at distances of up to 1 mile. It was suggested that the ROW provided additional food sources such as insects and rodents and that species requiring forest habitat would be expected to be reduced. Species that are suggested to increase (at least potentially) in numbers through the use of the ecotone as the vegetation improved would be starlings, indigo buntings, red-winged blackbird and goldfinches. ROW plantings (mainly along interstate roadways) were found to provide habitat for a number of species (red-winged blackbird, American goldfinch, song sparrow) compared to unplanted control areas.(101) In a study of the skylark (*Alauda arvensis*) conducted in

Denmark birds were found to forage more along roadsides than in adjacent fields and these areas were preferred over adjacent fields.(75) The volume of traffic is not given, although the verges varied in width from 1.3 to 4.5 m and occurred outside of major urban areas. Similar results were also found for the house sparrow (*Passer domesticus*) and the tree sparrow (*Passer montanus*). Warner(125) measured a number of grassland bird species on rural interstate and secondary roads. He reported that the density of nests to be greater on heavily trafficked interstates than on secondary roads and that both the number of nests and species increased with the width of the roadside. The majority of nests (92%) were red-winged blackbird. Further, the amount of traffic on secondary roads did not influence the density of nests. While the noise levels are not mentioned, the fact that numbers were greater on busier roads indicates that there was no obvious negative effect of associated noise. Finally, it is pointed out that in areas of row-crop farming road rights of way may be critical in providing habitat for grassland bird nesting.

Clark and Karr(26) reported that numbers of one species (red-winged blackbird, *Agelaius phoeniceus*) increased near highways especially in the later census (May/June) while another (horned lark, *Eremophila alpestris*) numbers decreased at distances of up to 500 m from the edge of the road. In these works there is no indication if the numbers of individuals or species diversity is greater when compared to still more distant areas however the indications are that, at least in some situations roadways can provide habitat for nesting along the ROW. The avoidance of the road by the horned lark is attributed to its preference for larger areas of open ground. In a more comprehensive review of the effects of highways that extended (in transects) up to 400 m from the edge of the road (both interstate and county roads) nine birds species were found to become less common near roadways, while another nine species became more common near roads and the majority of bird species showed no effect.(2) This study encompassed a number of habitat types (southeast, Midwest, Orgeon and northern California). For example, the numbers of wintering cardinals and white-throated sparrows (in the southeast) became more numerous adjacent (<80 m) from the interstate whereas blue jays became more numerous at greater distances (>80 m) from the interstate(2) (see also Appendix A - Table 1). One suggestion (although not tested) is that both the white-throated sparrow and cardinal were

using seed and fruit available between the right-of-way (ROW) and adjacent habitat. Another study of impact of highways (although not addressing noise specifically) measured forest breeding birds in transects extending 400 m from the edge of an interstate highway (I-95) and found that four species were less abundant near the road while another six became more abundant near the roadway.[38] Species that became less abundant near the road include the bay-breasted warbler (*Dendroica castanca*), blue jay (*Cyanoeitta cristata*), blackburnian warblers (*Dendroica fusca*) and winter wrens (*Troglodytes troglodytes*). The six species that became more abundant near the road included the chestnut sided warbler (*Dendroica pensylvanica*), white-throated sparrow (*Zonotrichia albicollis*), wood thrush (*Hylecichla mustelina*), common yellowthroat (*Geothylpis trichas*), robin (*Turdus migratorius*) and Tenesee warbler (*Vermivora peregrine*). While these studies do not address noise directly or to the transect distances indicated in other studies [41, 96-100] they suggest that the negative impact on birds is not universal, but also dependent upon the species in question and perhaps other landscape factors such as the use of adjacent plots. Further, roadsides have been identified as providing valuable food sources (small mammals) for a raptor; the red-tailed hawk.[38] Jackson[65] reported that populations of the endangered red-cockaded woodpecker (*Dendrocopos borealis*) are found along interstates with others reported along other roads. The ROW is suggested as a corridor for dispersal. Again, noise levels are not indicated, but colonies are known to be found frequently near roads.

The major problem is summed up in a recent discussion, “Traffic noise is interpreted as the overwhelming cause of the underlying correlations of avian patterns with roads and traffic…” .[45] That is, as yet, there is no definitive evidence to explain why noise has a profound effect on some species but not others and at distances that would seem to preclude noise-masking vocalization (up to 3 km). Further, there is no indication of any other effects or interactions that might contribute to these results.

Other possible effects include visual disturbance, air pollution, microclimatic effects, road kill or increased attraction of predators to the roadside all of which appear unlikely to have such distant effects.[45] It is known that birds vary in habitat size requirements and it may be that the patch size available in conjunction with noise has influenced

distribution patterns.[120] For example, in a study of 10 grassland species of bird areas need to be approximately 200 hectares.[120] There is a variety in the requirements ranging from 200 ha for the upland sandpiper (> 50% incidence) to 10 ha (> 50% incidence) for the savannah sparrow. Interestingly the suggestion of the use of airports as potential habitat (due to large areas of undisturbed surroundings) is made. A further difficulty in establishing a pattern between noise and birds is that on the occasions when bird vocalizations have been measured there is no obvious impairment to communication related to highway noise (i.e. masking) which would be one potential cause of the negative correlation between traffic noise and numbers. Thus, golden-cheeked warblers (*Dendroica chrysoparia*) were found to sing without regard to the level of roadway noise in a state park (near a state highway with noise levels (L_{eq} = sound equivalent per hour) from 29.7 to 58.6 dB).[11] The frequency of the song was about 5.18 kHz which is higher than that of the associated road noise. A study of California Gnatcatchers found no significant effect of background traffic noise on the rate of calling and the authors point out that the masking for a typical call would extend only about 15 m from the edge of the interstate.[7] Calls were about 50 dB and ranged from 3-6 kHz with a peak at 4 to 5 kHz. At the noisiest location measured (near Interstate 15) the sound level was 69.1 dB. Further, the authors indicate that another breeding site was located near an airport (Lindberg field) and often experienced background levels of noise about 70 dB indicating that habitat quality was as important as noise in having an effect.[7]

Raptors

A number of raptors have been looked at in response to human activities which have addressed noise to some extent. Stalmaster and Newman[112] studied wintering bald eagles (*Haliaeetus leucocephalus*) and found that human activities such as boating and fishing could disturb the birds (especially adults), however any normally occurring sounds were not particularly disturbing although gunshots elicited escape behavior. The levels of sound were not measured in this study. Similarly, another study of bald eagles found human pedestrian activity was more disturbing than overflights by aircraft.[57] Unfortunately, the sound levels of the overflights are not given. A study of several raptor

species (red-tailed hawk, Swainson's hawk, golden eagle, Ferruginous hawk) found birds to increase home range size during military activity that included vehicle activity, camps and helicopter overflights.[5] Similarly, red-tailed hawks shifted their activity away from military activity and returned when training had ceased, however, no measurement or discussion of noise as a factor is given.[4] Noise is not indicated as having a separate effect although was certainly a possible factor in affecting bird behavior. Mexican spotted owls (*Strix occidentalis lucida*) were found to flush at noises such as those from overflights at levels of 92 dB(A) or greater.[31] Chain saws were found to be more disturbing, although the average sound level was only 46 dB(A). Grubb et al.[58] reported that there was no discernable effect of logging trucks on breeding goshawk (*Accipter gentiles*) female or juevenile at a distance of 500 m. Noise levels were sporadic with peaks at ~ 50 dB(A) at a frequency of about 80 Hz.

Waterfowl

In a study of several factors that could effect waterfowl jogging and grass-mowing were found to have the greatest impact with gulls and terns, intermediate on ducks and greatest for herons, egrets and shorebirds.[21] It is also noted that supersonic overflights with sound levels of about 108 dB(A) were disturbing. It may be inferred that the presence of humans (as much as noise) at lower sound levels was responsible for the disturbance. This is supported by the findings of Anderson[6] in a study of California brown pelicans (*Pelecanus occidentalis Californicas*) that humans walking along trails negatively affected breeding at distances of up to 600 m. It should be noted that white pelicans (*Pelecanus erythrorynchos*) showed a decline in breeding in areas of low aircraft overflight.[20] In this case the about of coyote predation was also shown as having a negative effect and the noise levels were not indicated. Dark bellied Brant geese (*Branta bernicla bernicha*) were disturbed by aircraft overflights at altitudes of 500 m up to 1.5 km and also by nearby pedestrian activity.[93] Similarly, snow geese (*Chen caerulescens atlantica*) also could be disturbed by hunting and aircraft overflights. In a study of trumpeter swans (*Cygnus buccinator*) there was no significant effect of traffic as long as

vehicles did not stop.[63] However, louder vehicles are noted as causing a greater disturbance although the noise levels are not indicated.

Conomy et al.[29] found that black ducks (*Anas rubripes*) did become habituated to aircraft noise when housed in an aviary. However, wood ducks (*Aix sponsa*) did not become habituated to the noise (actual or simulated jet aircraft with a equivalent of 63.2 dB(A)). Oetting and Cassel[90] studied dabbling ducks along interstate 95 in North Dakota and found numbers of nesting mallards (*Anas platyrhynchos*), pintails (*A. acuta*) and gadwalls (*A. Strepera*) with more success in unmowed ROW. The preference may be related to fewer predators (red foxes) in the ROW. A subsequent study of the same species along the same highway found the birds preferred to nest in unmowed ROW over adjacent wetland areas, again perhaps due to a reduction in predation.[121] A field study of dabbling ducks including black ducks, American wigeon (*Anas americana*), gadwall (*A. Strepera*) and green-winged teal (*A. crecea carolinensis*) found no effect on the time-activity budgets at a mean sound level of 85dB(A) when exposed to low-flying aircraft (L_{eq} 24 hr. = 63 dB(A)).[28] Pacific eiders (*Somateria mollisima – v – nigra*) did not appear to react to aircraft overflights (mainly helicopters) and these did not have a measurable effect on the number of nests on the island.[66] Indeed the authors reported that the birds were more disturbed by experimental observers. Burger and Gochfeld[22] found that the common gallinule, Sora rail, glossy ibis, little blue heron and Lousiana heron were disturbed by the presence of visitors and that loudness was as significant as the number of people in this effect, however, loudness was measured on only a subjective scale and was not quantified.

Crested terns (*Sterna bergii*) in Australia showed escape behaviors following exposure to pre-recorded aircraft noise at levels of 85 dB(A).[19] This study also found that the visual presence of balloons could trigger an escape response. Wading birds (great egret, snowy egret, Lousiana heron, wood stork and cormorant) in Florida showed no reaction to most overflights by small aircraft.[73] The sound levels in this study were not given. Black et al.[12] also reported no significant effect of jet overflights on wading birds (egrets) at levels of 55-100 dB(A). In addition it is noted that nesting success was independent of

overflights and that humans on airboats (sound levels not given) caused greater disturbance.

Other species

Crows have been reported to make increased use of roadside verges as a source of food (worms).[113] Thus, there appears to be no deleterious effect of noise on their behavior. Ring-necked pheasants (*Phasianus colchius*) were found to nest in farming areas on undisturbed roadside cover especially if small grains along with hay were being farmed.[123] The noise levels encountered were not given in the study, however it does indicate that broader landscape factors can influence the utilization of roadside vegetation. Subsequently, Warner et al.[124] reported that ring-necked pheasants utilized roadside plots for nesting to a greater extent than adjacent control areas if the roadsides were seeded. It is suggested that such ROW plots could be used to buffer year to year variability in surrounding habitats. While noise was not addressed directly it is apparent that noise was not interfering with nesting in these areas. This confirmed the result of an earlier study which had indicated the utility of ROW seedings for pheasant nesting.[67] Further, Joselyn et al.[67] found no indication that predation was greater in ROW vegetation than adjacent hayfields eliminating this as a potential cause of the difference in nest success.

Gutzwiller and Barrow[59] studied birds in a Chihuahuan desert and found the abundance and species richness within 21 of 26 species to be reduced and that significant predictors were (generally) being within 1-2 km of the nearest road as the length of road increased, distance to the nearest road, distance to the nearest development or a two-way interaction of these variables. It is important to note that landscape factors in conjunction with the road factors were found in many models to be significant (e.g. distance to nearest development, areas covered by different types of vegetation). The traffic density was reported to be between 407-459 vehicles/day with a speed limit of 45 mph. The noise levels were not measured; however, the effect is postulated by the authors to be related to the roads or the associated development.

Noise carries many properties with it including the number, size and speed of vehicles.[100] The noise levels were about 59 dB(A) adjacent to roads and 38 dB(A) in remote areas with a threshold for response of between 27-61 dB(A).

Mammals

Large mammals

For mammals the impact of traffic noise has not been as closely studied as in birds. It has been found that various mammals will avoid roads and (in some cases) this has been attributed to noise (see overview in Liddle[76]). For example, mountain goats (*Oreamos americanus*) would hesitate to cross the road if they heard a truck changing gears over 1 km away.[108] Passing vehicles in this study were perceived as a threat (speed limit 50 mph). Interestingly, the goats did not seem to be disturbed by the noise from trains. Rost and Bailey[102] found that deer and elk avoided coming within 200 m of roads (paved, gravel and dirt). The visibility of the road alone did not appear to be the causative factor based on pellet densities (from which presence was estimated). They speculated that there may be an effect of hunting being associated with vehicles. This conclusion accords with the study of Dorrance et al.[33] that found white tailed deer (*Oedocoileus virginianus*) to avoid snowmobiles, but that they would habituate to these in areas where they had not been hunted. Elk in Rocky mountain national park were not greatly disturbed by road traffic although there was some evidence of avoidance early in the winter when food was more abundant.[107] In a study of elk movement along interstate 80 in Wyoming traffic noise was an average of 54-62 dB(A) for cars and 58-70 dB(A) for trucks with little evidence of avoidance up to distances of 300 yards.[122] At the same time there did appear to be a physical barrier imposed by the road. Adams and Geis[2] reported that elk generally avoided roads while deer showed little difference in distribution around interstate highways (monitored at distances up to 400 m from the road). A more general model of the effects of roads on elk found that as the density increased to 5.5 miles per square mile, the use declined to only 8-18%.[78] Finally, white

tailed deer have been found to use interstate 84 ROW extensively presumably due to the available forage.[36] In contrast, Forman and Deblinger[44] found some indication that white-tailed deer preferred to use habitat in areas relatively undisturbed by roads. Again there is no discussion of the effect of noise directly. The opening of Denali national park (Alaska) to traffic did not cause a decline in the numbers of large mammals found (caribou, grizzly bear, Dall sheep) with the exception of moose and grizzlies tended to be found closer to the road.[109] Taken together the evidence from large ungulates suggests that there is little evidence for a direct avoidance of roads due to noise. The presence of people was found to cause avoidance in mule deer (*Odocoileus hemionus*), however the effect of noise, if any was not measured.[47] Desert mule deer (*Odocoileus hemionus crooki*) could be habituated to low flying Cessna aircraft at an average altitude of 80 m.[72] Moutain sheep were not greatly disturbed at overflights of >50 m and moose by flights >100 m above ground.[71] Again, the specific noise level is not given.

Badgers were found to avoid higher traffic roads, but this was attributed to an avoidance of crossing without noting specific noise levels.[27] Bobcats were found to cross four-lane highways (more frequently through culverts), but the effect of noise is not discussed.[23] Coyotes (*Canis latrans*) were found to expand (if less cover was available) or reduce (if more cover available) their home range in response to military maneuvers (including overflights, vehicle and truk activity).[52] The degree to which noise was a factor in these movements is not indicated. In a study of mountain lions (*Felis concolor*) the use of areas for timber had a greater negative effect than road density.[117] However, the potential for distant machine noise to have a negative impact is suggested at distances between 100 m and < 1 km. The intensity or frequency of these sounds is not given. Wolves (*Canis lupus*) showed no clear avoidance of highways with one pack's range straddling it for several years.[114] Further, wolves were less likely to use smaller roads (to an oilfield) possibly due to a more visible human presence. For larger mammals, the barrier imposed by roads is generally indicated as the major cause of differences in animal distribution; however noise may be a component at least for some species. Further study would greatly help to elucidate the effect of noise on large mammals.

Small mammals

For small mammals the situation is more complex because, while roads do present barriers to movement [25, 92], they have also provided the means for dispersal for small rodents (voles) that utilize the continuous strips of vegetation and would otherwise be restricted to roadsides [53] and the use of areas such as the median strip has provided habitat for some species.[1] Small mammals that prefer grassland habitat were found to utilize ROW habitat and several other species preferred right of way or adjacent areas.[2] Adams[1] reported small mammal (rodent) density in an unmowed median strip was similar to that in surrounding wooded areas at distances up to 400 m. Species that preferred ROW habitat include golden mouse, dusky-footed wood rat, brush mouse and pinion mouse and more species were found in the ROW than in adjacent habitat. A number of additional species were found to be more common in ROW than adjacent areas including the eastern harvest mouse, white footed mouse, meadow vole and prairie vole. Shrews and opossums were also found along the ROW and cottontail rabbits used areas adjacent to the interstate. The presence of these small mammals is attributed to a low number of predators (foxes, raccoons, skunks, coyotes) in the ROW. However, in this study, ROW was found to inhibit movement of 11 of 40 small mammal species studied. In the case of forest dwelling species, areas of clearance appear to be more important barriers than the road surface although noise is not discussed as a factor.[92] In a study following the construction of a highway there was no effect on the distribution of several mammalian game species (rabbit, squirrel, fox, deer).[85] In any case there appears to often appear a barrier effect due to roads with noise being of lesser importance for most small mammals. However, Mader[79] reported that two species of forest mice were inhibited from crossing a two lane highway. Although noise was not specifically analyzed as a contributing factor, it is suggested as a possibility by the author. It should be noted that the presence of small mammals has been implicated as a reason for the use of roadside verges by raptors.[38]

CONCLUSIONS

It is clear that roads have definite effects on wildlife populations for a variety of reasons including habitat fragmentation, runoff, pollution, visual disturbance and increased mortality. Owing to the consistent and pervasive nature of noise and its apparent or at least potential widespread effects, it is clearly an area that needs to be addressed (see Forman and Alexander[43] Forman et al.[46] for reviews on this subject). Indeed in many cases it appears that noise may have a significant effect on both numbers of individuals, species diversity and breeding.

Invertebrates are too poorly studied at present for any definitive conclusions. Some significant use of roadside areas by some species (e.g. butterflies, bees) is indicated, but there are also many other species that should be investigated (particularly the aquatic species that may decline as road density changes). Although sparse, the studies that have looked at the response of fish would suggest that normal traffic noise would not be sufficiently great to disturb those species that have been looked at so far. Roads do provide a barrier to the movement of reptiles and amphibians; however the effect of noise is less clear. Recent work suggesting that vehicle noise can arouse toads from their burrows is of concern since this could affect survival and is one area that could be looked at in a series of controlled studies where sound levels and the associated behavioral response are more systematically studied.

The most comprehensive experimental studies on the subject [41, 96-100] demonstrate that many (although not all) species of small breeding birds in both grassland and forest habitats appear to avoid areas in proportion to the traffic noise and volume at distances up to three thousand meters. It is also important to note that the other studies that review an extensive number of species found some to be negatively affected by the presence of roads, but most species were neutral and a few species to increase in numbers presumably due to food or habitat provided by rights-of–way [2] (see also Appendix A). Further, several studies have found that roadside verges can provide breeding habitat for birds – however, without more information on the populations at greater distances from the road

it is difficult to determine if the same effect reported in the Netherlands was also present. What these studies do suggest is that the situation may be more complex than roads simply providing a barrier to all breeding. As an illustration, the review by Way[126] records that (in Britain) roadsides have been recorded as breeding habitat for 20 of 50 mammal species, all 6 reptiles, 40 of 200 bird species, 25 of 60 butterfly species, 8 of 17 bumblebee species and 5 of 6 amphibian species. Road noise would appear an unlikely impediment to species that are able to successfully breed so close to the source (it should be noted that the numbers relative to adjacent areas would be important in indicating their relative importance and this information is not provided in this study). A summary of some of the major findings with respect to birds shows little, if any contradiction in results, rather some species are negatively effected and others occur more frequently nearer roads due factors such as prey availability or vegetation type (see Appendix A).

A further example of the complexity involved is shown by the study of Gutzwiller and Barrow[59] where a number of bird species densities were influenced by the presence and/or number of roads; however, a number of landscape factors including the amount of development and vegetation type were also found to be significant predictors in many of the models.

RECOMMENDATIONS

It is clear that there are large gaps in the existing knowledge of the impact of noise on wildlife populations. In invertebrates and lower vertebrates (fish, reptiles, amphibians) there is relatively little study on the effects of road noise with no clear indication of a strong adverse response, at least for the levels of noise likely to be encountered from road traffic. For reptiles and amphibians, effects appear to be localized and likely due to mortality or a barrier to movement. Recent studies on the effect on toads in burrows near roads strongly indicate that further study on this or similar behaviors is warranted. For birds, noise can apparently have a significant effect; however, the results are not universal with some species being adversely affected, many unaffected and still others becoming more common near even interstate highways. Mammals (particularly large

species) may avoid noise, however, there is evidence (particularly for smaller species) that additional habitat and corridors for movement are provided by roadways.

The most urgent requirement is to determine why noise - the presumptive cause – has such variable effects and to determine if the effect is attributable to noise alone or if other factors and/or interactions are present. This could be addressed through introduction of appropriate noise levels into naïve areas or through studies of individual responses in controlled laboratory settings to determine where background noise is having an effect (e.g. distance of transmission of calls, ability of birds to locate others, patterns of behavior, reproductive success etc.).

Since direct masking of vocalization is unlikely to be the significant factor in many cases, future studies could also look at other indicators of stress including physiological indices such as an increase in sympathetic nerve activity affecting pupils, heart, digestive system, adrenal medulla, blood vessels and musculature (Borg and Møller c.f. Algers et al.,[(3)]). In stressed animals, the hypothalamus would signal an increase in ACTH (adrenocorticotropic hormone) and TSH (thyroid stimulating hormone) from the pituitary gland and the resultant changes (e.g. corticosteroid levels, blood glucose levels, electrolyte balance) could be measured either field or laboratory studies to determine the level of stress. A number of additional physiological effects of noise on animals have been summarized including changes in endocrine, digestive, blood, immune and reproductive function (see Algers et al[(3)]; Manci et al.[(81)] and references therein) and could be looked at as indicators of stress and deviations in any of these (from control or reference populations) could help to explain the results seen. This approach has been suggested as a possible course of action recently.[(99)]

Two important points to consider in the design of studies are 1) the density of a given species is not necessarily an absolute indicator of the best habitat (i.e. sometimes individuals are relegated in significant numbers to less desirable habitat because of territoriality by dominant individuals)[(118)], and 2) greater behavioral response (i.e. movement away from highway) does not necessarily indicate species that are at greatest

need of protection.[55] Thus, any plans for conservation must consider the quality of the habitat and the sensitivity of the population or community under consideration as well as the degree of the effect on a given species.

APPENDIX A

Table – Summary of some bird species found to be affected by the proximity of roads or road noise.

Negative effect = reduced density nearer roads; Positive effect = increased density near roads unless otherwise indicated

Source	Location	Species	Effect
Gutzwiller and Barrow, 2003	Breeding season (February – May) Chihuahuan desert 407-459 vehicles/day (average)	Turkrey vulture (*Cathartes aura*) Scaled quail (*Callipela squamata*) Say's phoebe (*Sayornis saya*) Ash-throated flycatcher (*Myiarchus cinerascens*) Cactus wren (*Campylorhynchus brunneica*) Bewick's wren (*Thyromanes bewickii*) *Black-throated sparrow (*Amphispiza bilineata*) House finch (*Carpodacus mexicanus*)	Negative
		Lesser nighthawk (*Chordeiles actuipennis*) Bell's vireo (*Vireo bellii*)	Positive
		All species showed effect for one year of three year study *Negative effect for two years of study, positive effect in one year	
Adams and Geis, 1981	Breeding Season Southeast	Wood thrush (*Hylocichla mustelina*) Indigo bunting (*Passerina cyanea*) Field sparrow (*Spizella pusilla*) Blue jay * (*Cyanocitta cristata*)	Negative
	Midwest	Horned lark (*Eremophila alpestris*)	Negative
		House sparrow (*Passer domesticus*)	Positive
	Northwest	Chestnut-backed chickadee* (*Parus rufescens*) Nashville warbler (*Vermivora ruficapilla*) Hermit Warbler* (*Dendroica occidentalis*) Savannah sparrow (*Passerculus sandwichensis*)	Negative
		Song sparrow (*Melospiza melodia*)	Positive
	California	Lark sparrow (*Chondestes grammacus*)	Negative
		Brewer's blackbird (*Euphagus cyanocephalus*) Red-winged blackbird (*Agelaius phoeniceus*)	Positive

Adams and Geis, 1981 (cont.)	Non-breeding (wintering) Southeast Midwest Northwest	Cardinal (*Cardinalis cardinalis*) White-throated sparrow (*Zonotrichia albicollis*) Blue jay (*Cyanocitta cristata*) Horned lark (*Eremophila alpestris*) House sparrow (*Passer domesticus*) Chestnut-backed chickadee* (*Parus refescens*) Golden-crowned kinglet* (*Regulus satrapa*) * = species affected by both county roads and interstates; other species only affected by interstates	Positive Negative Positive Negative
Forman et al., 2002	Grassland Breeding season 15-30,000 vehicles/day ≥ 30,000 vehicles/day	Bobolink (*Delichonyx oryzivorous*) Eastern meadowlark (*Sturnella magna*) (possibly- upland sandpiper (*Bartramia longicauda*), Henslow's sparrow (*Ammodramus henslowii*), grasshopper sparrow (*A. savannarum*))	Negative to 700 m Negative to 1200 m (effect applies to all species)
Reijnen et al., 1996	Grassland Breeding season 5,000 vehicles/day 50,000 vehicles/day	Black-tailed godwit (*Limosa limosa*) Oystercatcher (*Haematopus ostralegus*) Lapwing (*Vanellus vanellus*) Shoveler (*Anas clypeatal*) Skylark (*Alauda arvensis*) Black-tailed godwit (*Limosa limosa*) Oystercatcher (*Haematopus ostralegus*)	Negative to 100 m Negative to 1500 m Negative to 1500 m
Reijnen and Foppen, 1994	Woodland Breeding season 50,000 vehicles/day	Willow warbler (*Phylloscopus trochilus*)	Negative to 200 m

Reijnen et al., 1995	Woodland Breeding season 10,000 vehicles/day 60,000 vehicles/day	Ring-necked pheasant (*Phasianus colchicus*) Common cuckoo (*Cuculus canorus*) Lesser spotted woodpecker (*Dendrocopus minor*) Marsh warbler (*Acrocephalus plaustris*) Icterine Warbler (*Hippolais icterina*) Greenish warbler (*Phylloscopus trochilus*) Gold crest kinglet (*Regulus regulus*) Golden oriole (*Oriolus oriolus*) Hawfinch (*Coccothraustes coccothraustes*)	Negative 40-1500 m Negative 70-2800 m (effects given as a range for all species at given traffic level)
van der Zande et al., 1980	Grassland Breeding season Rural road Highway	Lapwing (*Vanellus vanellus*) Black-tailed godwit (*Limosa limosa*) Redshank (*Tringa tetanus*)	Negative to 500-600 m Negative to 1600-1800 m (effects are combined for all species)
Ferris, 1979	Woodland Breeding season Interstate highway	Bay-breasted warbler (*Dendroica castanea*) Blue jay (*Cyanoeitta cristata*) Blackburnian warbler (*Dendroica fusca*) Winter wren (*Troglodytes troglodytes*)	Negative to 300-400 m
	Interstate highway	Chestnut sided warbler (*Dendroica pensylvanica*) White-throated sparrow (*Zonotrichia albicollis*) Wood thrush (*Hylocichla mustelina*) Common yellowthroat (*Geothlypis trichas*) Robin (*Turdus migratorius*) Tennessee warbler (*Vermivora peregrina*)	Positive
Clark and Karr, 1979	Row crop fields Winter and Breeding Interstate and county roads	Horned lark (*Eremophila alpestris*) Red-winged blackbird (*Agelaius phoeniceus*)	Negative to 500 m Positive to 500 m

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SYNTHESIS OF NOISE EFFECTS ON WILDLIFE POPULATIONS

ANNOTATED BIBILIOGRAPHY

1. Adams, L.W. 1984. Small mammal use of the interstate highway median strip. Journal of Applied Ecology 21:175-178.

The author reports that density of small mammals in an unmowed median strip adjacent to an interstate highway to be as great as that in wooded adjacent habitat to a distance of 400m. The report does not address noise directly, however, the relativity density of mammals adjacent to roads would argue against a similar to that reported by Reijnen and colleagues and Forman et al. (2002).

2. Adams, L.W. and A.D. Geis. 1981. Effects of highways on wildlife. Federal Highway Administration Technical Report No. FHWA/RD-81/067.

This report details the use of areas adjacent to roadways by a variety of animals. It is significant in that it covers a diverse number of species in a variety of regional habitats in the United States. Amphibians (salamanders) were found adjacent to roadsides and ROW in the southeast and northwest although they appeared not to cross indicating a barrier effect. A number of small mammal species are reported to prefer ROW habitat and, in some cases, they are more common along large interstate ROW than those of smaller county roads. It is suggested that this may be due to the low number of predators in these ROW areas. Further road size and traffic volume were not critical to deer distribution, however elk were found to avoid areas adjacent to roads.

3. Algers, B., Ekesbo, I. And S. Strömberg. 1978. The impact of continuous noise on animal health. Acta Veterinaria Scandinavica (Supplementum) 67:1-26.

The authors present a review including the sound sensitivities of many major animal species and the physiological response of animals to noise (including major organs, blood, and endocrine function). This provides a good overview of some of the responses, beyond interference with vocalization that would indicate a deleterious effect of noise exposure and explain aversion to this effect.

4. Andersen, D.E., O.J. Rongstad and W.R. Mytton. 1986. The behavioral response of red-tailed hawk to military training activity. Raptor research 20:65-68.

The authors report that red-tailed hawks shifted their activity away from military training activities returning when the activity had ceased. The levels of noise associated with these activities are not given and it is not possible to discern how much of the disturbance is due to noise and how much due to the presence of humans.

5. Andersen, D.E., O.J. Rongstaf and W.R. Mytton. 1990. Home range changes of raptors exposed to increased human activity. Wildlife Society Bulletin 18:134-142.

The authors look at four different raptor species (hawks, eagle) during periods of military activity (including vehicles, camps and helicopter overflights). The birds were found to increase home range size presumably to avoid the activity. Unfortunately, the levels of noise are not measured and it is difficult to determine the impact of the presence of persons in comparison to the noise from vehicles and flights.

6. Anderson, D.W. 1988. In my experience...Dose-response relationship between human disturbance and brown pelican breeding success. Wildlife Society Bulletin 16:339-345.

The author describes the response of breeding brown pelicans to humans walking along trails. A negative effect was reported at distances up to 600 m. The specific levels of noise are not given, however, the presence of humans may be an important factor.

7. Awbrey, F.T., D. Hunsaker and R. Church. 1995. Acoustical responses of California gnatcatchers to traffic noise. Inter-noise 65: 971-974.

The authors report on the number of breeding California gnatcatchers in a variety of locations. The calls of this species are recorded between 3 and 6 kHz with a sound level of about 50 dB. The noisiest field location where the birds were located was interstate 15 with a sound level of 69 dB. The masking distance was calculated at 15.2 m from the outer edge of the slow lane. The authors point out that one of the most successful breeding sites for this species is near an airport where noise levels often exceed 70 dB.

8. Banner, A. and M. Hyatt. 1973. Effects of noise on eggs and larvae of two estuarine fish. Transactions of the American Fisheries Society 102:134-136.

The authors measured the effect of a range of frequencies a pressure levels on the hatching and fry survival of two estuarine fish. It is significant that the authors note that this is above the levels of sound usually caused by traffic.

9. Baur, A. and B. Baur 1990. Are roads barriers to the dispersal of the land snail *Arianta arbustorum*? Canadian Journal of Zoology 68:613-617.

The authors determine that the snail will not crossed wide paved roads. This confirms that roads may pose a barrier to movement rather than repel these organisms by sound.

10. Belanger, L. and J. Bedard. 1990. Energetic cost of man-induced disturbance to staging snow geese. Journal of Wildlife Management 54:36-41.

> The authors report that snow geese are disturbed by both hunting and aircraft overflights. The noise levels associated with the disturbance are not given. This is one of a number of studies that indicate human presence, with low levels of noise can also be disturbing particularly to waterfowl.

11. Benson, R.H. 1995. Unpublished. The effect of roadway traffic noise on territory selection by Golden-cheeked warblers.

> The author reports on the golden-cheeked warbler in a state park in Texas. The sound equivalent per hour varied between 30 and 59 dB. The areas in which the bird sang showed no effect of noise exposure. The song of the bird was at about 5.2 kHz, a higher frequency than road noise.

12. Black, B.B., M.W. Collopy, H.F. Percival, A.A. Tiller and P.G. Bohall. 1984. Effects of low level military training flights on wading bird colonies in Florida. Florida Cooperative Fish and Wildlife Research Unit, School for Research and Conservation, University of Florida. Technical Report No. 7.

> The authors report on the effect of jet fighter overflights on wading birds (egrets) in Florida. Sound levels from 55-100 dB(A) caused no significant effect. The entrance of humans and airboats are reported as more disturbing. Nesting success is also indicated as independent of overflights.

13. Blaxter, J.H.S. and D.E. Hoss. 1981. Startle response in herring Clupea harengus: The effect of sound stimulus. Journal of the Marine Biological Association of the United Kingdom. 61:871-880.

> The authors report on the hearing sensitivity of herring (*Clupea harengus* L.) giving the pressure and frequency range. There is no discussion of application to levels of noise or sound encountered by this species in the field.

14. Bond, J. 1971. Noise: its effect on the physiology and behavior of animals. Agricultural Science Review 9:1-10.

> The author provides a review on the effect of noise on a variety of domesticated animals. Responses to noise (primarily aircraft overflights and sonic booms) are included for cattle, poultry, mink and sheep. The report does not provide significant detail on noise levels or frequencies, but does summarize several studies and includes references to source materials.

15. Borg, E. and A.R. Møller. 1973. Våra omedvtena reaktioner på buller. Forskning och Framsteg 7:5-9.

The authors summarize findings that describe the physiological responses to stress (including noise). These results are summarized (in English) in the report by Algers et al.[3]

16. Bowles, A.E. 1995. Responses of wildlife to noise. pp. 109-156. In: Knight, R.L. and K.J. Gutzwiller. (eds.) Wildlife and Recreationists: Coexistence through Management and Research. Island Press: Washington, D.C.

The author presents a fairly comprehensive review of the responses of various wildlife groups to noise from previously published work including detailing the range of frequencies and sound intensities for terrestrial vertebrates (amphibians, reptiles, birds, mammals). The frequencies of peak sensitivity are also indicated. This provides a good overview of the areas that would be of concern for the various groups.

17. Brackenbury, J.H. 1979. Power capabilities of the avian-producing system. Journal of Experimental Biology 78:163-166.

The author reviews the sound producing capabilities of a number of bird species. It is concluded that larger birds are able to produce greater intensities. This can be important in considering the effect of noise particularly with respect to masking vocalization in birds.

18. Brattstrom, B.H. and M.C. Bondello. 1983. Effects of Off-Road vehicle noise on desert vertebrates. pp.167-204. In: Environmental Effects of Off-Road Vehicles. R.H. Webb and H.G. Wilshire (eds.) Springer-Verlag: New York.

The authors found that "dune buggy" noise can affect lizard hearing and that motorcycle noise could cause emergence of spadefoot toads during a period of estivation. The latter effect is of particular concern since emergence at the wrong time could be fatal to these species. Sustained (500 seconds) dune buggy noise was found to impair the hearing of kangaroo rats. This type of environment has not apparently been investigated elsewhere.

19. Brown, A.L. 1990. Measuring the effect of aircraft noise on sea birds. Environment International 16:587-592.

The authors report on the effect of pre-recorded aircraft noise on the crested tern in Australia. It is noted that levels of 85 dB(A) were required to cause escape behavior and that balloons (i.e. visual disturbance) could also have an effect. It is notable that both visual and auditory stimuli can trigger a similar response.

20. Bunnell, F.L., D. Dunbar, L. Koza and G. Ryder. 1981. Effects of disturbance on the productivity and numbers of white pelicans in British Columbia - observations and models. Colonial Waterbirds 4:2-11.

The authors note a decline in white pelican breeding in areas of low overflight by aircraft and also suggest that coyote predation may have played a role. There is no quantification of the level of noise or its impact on breeding although it is certainly a possible contributor to the observations.

21. Burger, T. 1981. The effect of human activity on birds at a coastal bay. Biological Conservation 21:231-241.

The author reports that human activites (jogging and lawn mowing) disturbed herons, egrets and shorebirds with some effect on ducks. Both gulls and terns are reported to show little response. The levels of noise associated with these activities are not given. The results demonstrate that responses to disturbance including noise can be species specific.

22. Burger, J. and M. Gochfield. 1998. Effects of ecotourists on bird behaviour at Loxahatchee National Wildlife Refuge, Florida. Environmental Conservation 25:13-21.

The authors report on the effect of visitors on several species of waterfowl including herons, rails and ibises. It was found that the loudness of the visitors had as great an effect as the number of people. The scale for loudness was subjective and thus cannot be quantified. The conclusion is that noise can be disturbing to these species.

23. Cain, A.T., V.R. Tuovilla, D.G. Hewitt and M.E. Tewes. 2003. Effects of a highway and mitigation projects on bobcats in Southern Texas. Biological Conservation 114:189-197.

The movement of bobcats across a four-lane highway was recorded. They were observed to cross more frequently using culverts or bridges. The effect of noise is not discussed specifically, however, the more frequent crossing suggests a barrier effect of the road itself rather than a noise induced avoidance.

24. Campbell, H.W. 1969. The effect of temperature on the auditory sensitivity of vertebrates. Physiological Zoology 42:183-210.

The author reviews the auditory sensitivity of a number of species (lizards) making the important point that this can change with ambient temperature (usually that at which activity is maximal). This is an important consideration in the study and modeling of road effects on ectotherms, particularly noise.

25. Clark, B.K., B.S. Clark, L.A. Johnson and M.T. Hayne. 2001. Influence of roads on the movements of small mammals. Southwestern Naturalist 46:338-344.

> The movements of small animals in relation to roads are discussed based on a variety of techniques including radio-tracking, capture/recapture and pigment markers. The width of the roads was 6m and this was sufficient to prevent crossing, however the role of noise specifically is not given.

26. Clark, W.D. and J.R. Karr. 1979. Effects of highways on red-winged blackbird and horned lark populations. Wilson Bulletin 91:143-145.

> The authors report on the number of birds at distances up to 500 m from both county roads and interstates. The horned lark increased in numbers away from both types of road and were generally more common along county roads. In contrast red-winged blackbirds were greater in numbers nearer to roads especially in May and June. This result is attributed to the horned lark requiring larger areas of open ground and the preference of blackbirds for grass habitat found along the ROW. The level of noise or its potential effect are not discussed. The juxtaposition of these two species in the same area is significant in indicating the importance of other habitat factors along with noise or traffic in the response of wildlife.

27. Clarke, G.P., P.C.L. White and S. Harris. 1998. Effects of roads on Badger *Meles meles* populations in southwest England. Biological Conservation 86:117-124.

> The movement of badgers across high traffic roads in England is attributed to a barrier effect. The role of noise in the results is not discussed. This result is consistent with that of several other mammals that also tended to avoid crossing roads (e.g. Cain et al., 2003; Oxley et al., 1974)

28. Conomy, J.T., J.A. Collazo, J.A. Dubovsky and W.J. Fleming. 1998. Dabbling duck behavior and aircraft activity in coastal North Carolina. Journal of Wildlife Management 62:1127-1134.

> The authors report on the effect of aircraft noise for a number of dabbling duck species (black ducks, teal, wigeon). The average sound equivalent was 63 dB(A) and did not appear to alter overall time-activity budgets. It is indicated that there is no major disturbance to normal behavior for these species.

29. Conomy, J.T., J.A. Dubovsky, J.A. Collazo and W.J. Fleming. 1998. Do black ducks and wood ducks habituate to aircraft disturbance? Journal of Wildlife Management 62:1135-1142.

> The response of black ducks and wood ducks to jet aircraft overflights (both real and simulated) is discussed. Black ducks became habituated whereas wood ducks did not. The sound levels had a 24 hour equivalent of 63 dB.

30. Debelsteen, T., O.N. Larsen and S.B. Pedersen. 1993. Habitat induced degradation of sound signals: Quantifying the effects of communication sounds and bird location on blur ratio, excess attenuation and signal to noise ratio in blackbird song. Journal of the Acoustical Society of America 93:2206-2220.

This study of blackbirds reports on how quickly high-pitched sounds degrade and that this is fairly rapid. Further the sounds travel better from a high perch. This may be important information in looking at the distance sounds need to travel to the size of the birds territories.

31. Delaney, D.K., T.G. Grubb, P. Beiber, L.L. Pater and M.H. Reiser. 1999. Effects of helicopter noise on Mexican spotted owls. Journal of Wildlife Management 63:60-76.

The authors detail the response of Mexican spotted owls to aircraft and chainsaw noise. The birds were found to flush if exposed to lower sound levels from chainsaws than helicopter overflights. The reason for the difference between sound sources is not given.

32. Dooling, R.J. 1982. Auditory perception in birds. In: Acoustic communication in birds (volume 1):95-129. Academic Press, New York.

The author an expert on avian auditory systems presents an overview of perception in a number of species. It is pointed out that species must be able to discriminate their vocalizations from others and background noise and that the thresholds for hearing are greater in birds than for humans at all frequencies. The fact that masking is most effective if in the same region of the spectrum as the vocalization is also indicated. Finally, the fact that signal must exceed background by ~ 20 dB in order to be detected.

33. Dorrance, M.J., P.J. Savage and D.E. Huff. 1975. Effects of snow-mobiles on white-tailed deer. Journal of Wildlife Management 39:563-569.

The authors discuss the impact of snowmobiles on white tailed deer finding that they tended to avoid these. Because it was found that they could be habituated, but not in areas where they had been hunted it is suggested that there may be an effect of this experience. Noise is not discussed as a specific factor in causing avoidance.

34. Evink, G. 2002. Interaction between roadways and wildlife ecology: A synthesis of highway practice. National Cooperative Highway Research Program Synthesis 305. Transportation Research Board, Washington, D.C.

The authors present an NRC estimate of the amount of land in the United States that has been converted to highway, street and right of way. Their estimate is about 20 million acres.

35. Fahrig, L., J.H. Pedlar, S.E. Pope, P.D. Taylor and J.F. Wenger. 1995. Effect of road traffic on amphibian density. Biological Conservation 73:177-182.

The authors report that frog and toad density is reported to decrease with increasing traffic density between 8,500 and 13,000 vehicles per day. The authors conclusion is that this is due to increased mortality and noise is not posited as a possible cause.

36. Feldhamer, G.A., Gates, J.E., Harman, D.M., Loranger, A.J. and K.R. Dixon. 1986. Effects of interstate highway fencing on white-tailed deer activity. Journal of Wildlife Management 50:497-503.

The authors report on the distribution of white-tailed deer along interstate 84 indicating a greater amount of activity along the ROW. This is attributed to the greater amount of forage available in the ROW. The effect of noise is not discussed, however the presence of significant numbers in the ROW would suggest no strong aversion to noise.

37. Fernández-Juricic, E., Jimenez, M.D. and E. Lucas. 2001. Alert distance as an alternative measure of bird tolerance to human disturbance: implications for park design. Environmental Conservation 28:263-269.

The authors report on the response of house sparrow to human pedestrian activity along a pathway. In response they increased the alert distance. No similar effect was seen for blackbirds, woodpigeons or magpies. The level of noise is not indicated, but it does indicate that the responses of species to disturbance are not uniform.

38. Ferris, C.R. 1974. Effects of highways on red-tailed hawks and sparrow hawks. M.S. Thesis, West Virginia University, Morgantown, WV.

The author reports on the use of roadside areas by two species of raptors finding that they can make fairly extensive use of these areas as they provide habitat for several species of small rodents that are their prey. There is no indication of the levels of noise or the impact of noise on the birds.

39. Ferris, C.R. 1979. Effects of interstate 95 on breeding birds in northern Maine. Journal of Wildlife Management. 43:421-427.

The author reports on a study along an interstate highway that looked at the density of ten species of breeding birds. Four species were found to become less abundant near the road (bay-breasted warbler, blue jay, Blackburnian warbler and winter wren). Six species were found to become more abundant near the road (especially within 100 m) (chestnut-sided warbler, white-throated sparrow, wood thrush, common yellowthroat, robin and Tennessee warbler). It is noted that both the chestnut-sided warbler, yellowthroat and robin tend to prefer edge habitat and this might explain the results. It is significant that some species can show a negative relationship with the road while others due not.

40. Findley, C.S. and J. Houlahan. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. Conservation biology 11:1000-1009.

The authors report on the numbers of reptiles and amphibians that appear to decline in both number and diversity up to 2000m from two and four lane highways. The decline is attributed to barriers to dispersal rather than to noise, although the latter is not addressed directly.

41. Foppen, R. and R. Reijnen. 1994. The effects of car traffic on breeding bird populations in woodland. II. Breeding dispersal of male willow warblers (*Phylloscopus trochilus*) in relation to the proximity of a highway. Journal of Applied Ecology 31:95-101.

The authors continue with the second portion of a study on willow warblers near a major highway (50,000 cars/ day) (see also Reijnen and Foppen, 1994). It is reported that dispersal of the males was actively away from the road. The greatest number of individuals were found in the control zone beyond 400 m from the road.

42. Forman, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology 14:31-35.

The research is by an authoritative worker in the field from Harvard University. The land area of the United States potentially affected by roads is given as much as one-fifth. The estimate is based on a convoluted pattern of roads and on the accuracy of sensitive zones presented by studies in the Netherlands for grassland and woodland birds (see Reijnen, Foppen and others).

43. Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207-231.

The authors review a number of the important of effects of roads on the ecology of surrounding areas. Topics discussed include the impact of noise, road

mortality, and habitat fragmentation as well as the effect on plant species, water, sediment chemicals and sections dealing with road planning and design. It does reference several major works dealing with the effect of noise.

44. Forman, R.T.T. and R.D. Deblinger. 2000. The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. Conservation Biology 14:36-46.

The authors report on the response of various wildlife species (moose, deer, forest and grassland birds, amphibians) to a four lane highway near Boston. The traffic density is between 34,000 and 50,000 vehicles / day. There was some avoidance of by all groups up to 100 m or more. Booth moose corridors and grassland bird avoidance appears at distances up to and beyond 1 km. It is noted that the data on grassland birds are scattered and that woodland bird data are based on expectations from the studies of Reijnen et al. (see associated references). The suggestion is that the road serves as a barrier to the movement of amphibians.

45. Forman, R.T.T., B. Reineking and A.M. Hersperger. 2002. Road traffic and nearby grassland bird patterns in a suburbanizing landscape. Environmental Management 29:782-800.

The authors report on the effect of roads with varying traffic volumes on species of grassland birds in a suburban/rural area near Boston. The principle species are the bobolink and Eastern meadowlark. There was no effect on distribution in areas of low traffic volume (3,000-8,000 vehicles / day). At moderate traffic levels (8,000 – 15,000 vehicles / day) the numbers were not reduced, but the number of breeding birds was reduced up to a distance of 400 m. At higher traffic volume (15,000-30,000 vehicles / day) both the presence and breeding of birds is reduced to 700 m. At the highest traffic volume (>30,000 vehicles / day) both presence and breeding are reduced to 1,200 m). There is essentially no breeding birds found in areas near roads with >15,000 vehicles / day. The levels of noise are not given in this study although further studies that manipulate the level of noise are suggested.

46. Forman, R.T.T., D. Sperling, J.A. Bissonette, A.P. Clevenger, C.D. Cutshall, V.H. Dale, L. Fahrig, R. France, C.R. Goldman, K. Heanue, J.A. Jones, F.J. Swanson, T. Turrentine and T.C. Winter. 2003. Road Ecology: Science and Solutions. 481pp. Island Press: Washington, D.C.

A volume dealing with the developing field of road ecology including sections on roads, vegetation and wildlife, water chemicals and the atmosphere and landscape planning. It reviews the effects of noise on wildlife briefly, but does discuss the major effects found in the studies to deal with noise (especially those dealing with birds by Reijnen and colleagues).

47. Freddy, D.J., W.M. Brenough and Fowler. 1986. Responses of mule deer to disturbances by persons afoot and snowmobiles. Wildlife Society Bulletin 14:63-68.

> The authors report that mule deer were more disturbed by the presence of people afoot than snowmobiles. This was shown by running and greater associated energy expenditure when responding to the presence of pedestrians. The level of noise encountered in this study is not given.

48. Free, J.B., D. Gennard, J.H. Stevenson and I. Williams 1975. Beneficial insects present on a motorway verge. Biological Conservation 8:61-72.

> Collected a large number of insect species (67) on a major highway roadside verge. The authors note that passing traffic did not appear to distract the insects, however, there is no indication of the noise levels encountered.

49. Frings, H. and M. Frings. 1959. Reactions of swarms of *Pentaneura aspera* (Diptera: tendipedidae) to sound. Annals of the Entomological Society of America 52:728-733.

> A report detailing the frequency and sound intensity to which a species of small fly (Diptera) are sensitive. Low frequencies are reported to cause greatest sensitivity.

50. Frings, H. and J. Jumber. 1954. Preliminary studies on the use of a specific sound to repel starlings (*Sturnus vulgaris*) from objectionable roosts. Science 119: 318-319.

> The authors report that starlings can, to some extent, be repelled with distress calls from the same species. The sound level is rather high (85 dB) and indicates that this species can tolerate some significant noise without effect. The relation to highway noise is not discussed.

51. Frings, H. and F. Little. 1957. Reactions of honey bees in the hive to simple sounds. Science 125:122.

> Report that details the sound frequency and levels at which honeybee activity ceases. This type of information may be important in suggesting responses of invertebrates to noise.

52. Gese, E.M., O.J. Rongstad and W.R. Mytton. 1989. Changes in coyote movements due to military activity. Journal of Wildlife Management 53:334-339.

The authors report on the response of coyotes to military activity including maneuvers by vehicles (including tanks) and overflights by helicopters and jet aircraft. Individuals with home ranges that had more cover retreated to smaller areas whereas those that were more exposed increased their range. The specific noise levels were not measured and it is difficult to determine how much of the response was due to the presence of traffic versus noise alone.

53. Getz, L.L., F.R. Cole and D.L. Gates. 1978. Interstate roadsides as dispersal routes for *Microtus Pennsylvanicus*. Journal of Mammalogy 59:208-212.

The authors report that roadside strips of vegetation could be used by a small rodent for dispersal. The roads were large interstates and, while the impact of noise is not addressed directly it can be concluded that there is no extreme barrier to the use of these areas as a result of road noise.

54. Gill, J.A., W.J. Sutherland and A.R. Watkinson. 1996. A method to quantify the effects of human disturbance on animal populations. Journal of Applied Ecology 33:786-792.

The authors report on a study of pink-footed geese that were found to be disturbed from feeding near roads. A method for quantifying the difference in amount of food consumed as an indicator of the decrease in geese presence is given. The effect of noise is not given, disturbance events ranging from overflights to farming and pedestrian activities were recorded. Only distance to the nearest road was a significant predictor of the response.

55. Gill, J.A., K. Norris and W.J. Sutherland. 2001. Why behavioural responses may not reflect the population consequences of human disturbance. Conservation Biology 97:265-268.

The authors discuss whether the degree of behavioral disturbance a population shows is a good indicator of the species that require greatest concern for conservation. The paper does not address noise specifically, but raise the important point that species showing the greatest effect are not necessarily those that need to be considered first in road planning.

56. Green, R.E., G.A. Tyler and C.G.R. Bowden. 2000. Habitat selection, ranging behaviour and diet of the stone curlew (*Burhinus oedicnemus*) in southern England. Journal of Zoology (London) 250:161-183.

The authors report on the numbers of stone curlews (nocturnal bird) near major roads. The populations were found to be diminished within 3 km of the road. The authors conclude that traffic noise or movement are the most likely cause although the levels of noise encountered are not given. Because this species it is suggested the visual stimuli could have a greater effect although this is not tested. There is no evidence of a lessening of this effect if the habitat nearby is less abundant (i.e. do not appear near the road if habitat may be more suitable than that at a distance).

57. Grubb, T.G. and R.M. King 1991. Assessing human disturbance of breeding bald eagles with classification tree models. Journal of Wildlife Management 55:500-511.

The authors look at the effect of both pedestrian activity and aircraft overflights on breeding bald eagles. They report that pedestrians were more disturbing. The levels of noise are not given, but this demonstrates that noise alone is not the only factor causing disturbance.

58. Grubb, T.G., L.L. Pater and D.K. Delaney. 1998. Logging truck noise near nesting northern goshawks. USDA Forest Research Service Note RMRS-RN-3.

The authors report on the effect of logging trucks on a breeding female and juvenile goshawk. There was no discernable effect on either bird with peak noise about 80 Hz and ~ 50 dB(A).

59. Gutzwiller, K.J. and W.C. Barrow. 2003. Influences of roads and development on bird communities in protected Chihuahuan desert landscapes. Biological Conservation 113:225-237.

The authors looked the abundance and species richness of 26 species of birds in the desert. The average number of vehicles was 400-459 per day with a speed limit of 45 mph. Both abundance and species richness were reduced for 21 of 26 species within 1-2 km of the road. Other variables were said to be controlled for in the study. The levels of noise were not measured.

60. Hastings, M.C. 1995. Physical effects of noise on fishes. Inter-noise 95, the 1995 International congress on noise control Engineering Vol 2: 979-984.

This report presents a summary of the frequencies and sound pressure levels f a number of fish species. It includes the threshold levels for sensitivity and a summary of frequencies that are best for fish sensitivity. It is a useful summary for prediction of response of species to anticipated noise levels.

61. Hawkins, A.D. 1986. Underwater sounds and fish behaviour. pp. 114-151. In: The behaviour of teleost fishes. T.J. Pitcher (ed.) The Johns Hopkins Press, Baltimore, MD. 553 pp.

The author presents a review of the levels of sound perceived by a variety of fish species. This can be useful for obtaining data to make predictions about how fish in a given area may respond to noise.

62. Hendriks, R.W. 1989. Traffic noise attenuation as a function of ground vegetation. California Department of Transportation Report FHWA/CA/TL-89/09.

The author describes the physics of noise attenuation in various types of environment (e.g. forest, open field) indicating the rate at which different environments affect distance of transmission. There is no discussion of the needs of a particular species, but does provide a useful background in considering the environment in the impact of noise.

63. Henson, P. and T.A. Grant. 1991. The effects of human disturbance on trumpeter swan breeding behavior. Wildlife Society Bulletin 19:248-257.

The authors describe the response of trumpeter swans to road traffic and report that it did not greatly alter behavior as long vehicles did not stop. Louder vehicles were reported to cause a greater disturbance. There is no measurement of the traffic or noise levels so the threshold for a response is not given.

64. Hienz, R.D. and M.B. Sachs. 1987. Effects of noise on pure-tone thresholds in blackbirds (*Agelaius phoeniceus* and *Molothrus ater*) and pigeons (*Columbia livia*). Journal of Comparative Psychology 101:16-24.

This study reports on the critical ratios (the sound level above background) required for sounds to be audible in several species of birds. It is indicated that these ratios are greater for birds than for humans at all levels. It is important to have background information on the auditory requirements of birds in assessing the impact of noise on these species.

65. Jackson, J.A. 1976. Rights-of-way management for an endangered species: the red-cockaded woodpecker. pp. 248-252 In: Symposium on environmental concerns in rights-of-way management, Mississippi State University, January 6-8.

The author discusses the fact that the red-cockaded woodpecker (an endangered species) has some populations located along interstate ROW and that many colonies are found adjacent to roads. It is suggested that interstate ROW can be used to link populations. Although the level of noise is not indicated it is clear that this population is not greatly disturbed by the adjacent noise.

66. Johnson, S.R., D.R. Herter, M.S.W. Bradstreet. 1987. Habitat use and reproductive success of Pacific eiders *Somateria mollissima v-nigra* during a period of industrial activity. Biological Conservation 41:77-89.

The authors describe the response of Pacific eiders to industrial activity and to aircraft overflights (mainly helicopters). The overflights did not appear to have any negative effect on the birds or the number of nests on the island. The presence of experimental observers appear to have a greater effect.

67. Joselyn, G.B., J.E. Warnock and S.L. Etter. 1968. Manipulation of roadside cover for nesting pheasants – a preliminary report. Journal of Wildlife Management 32:217-233.

The authors report on the use of roadsides by pheasants for nesting. They report that roadsides are more successful than other habitats (including unseeded controls) and that levels of predation were not greater in the ROW. Noise levels are not given, but a deleterious effect would be argued against by the large numbers of breeding birds found in this area.

68. Knight, T.A. 1974. A review of hearing and song in birds with comments on the significance of song in display. Emu 74:5-8.

The author reviews both hearing and vocalization in a number of bird species and discusses the various uses of vocalization in birds including isolation of species, pair-bond, pre-copulatory display, territorial defense, signaling danger, food sources and flock cohesion.

69. Knight, R.L. and K.J. Gutzwiller. 1995. Wildlife and Recreationists: Coexistence through Management and Research. 372 pp. Island Press: Washington, D.C.

The authors provide an overview of the interactions between wildlife and human activity. There is only a brief overview of the effect of roads and noise and this is probably more useful as a general reference.

70. Knudsen, F.R., P.S. Enger and O. Sand. 1992. Awareness reactions and avoidance responses to sound in juvenile Atlantic salmon. *Salmo salar* L. Journal of Fish Biology 40:523-534.

This study reports on the sensitivity of Atlantic salmon smolts to sound including the frequency and pressure levels that caused an effect and avoidance. This could be used if this or a similar species were under consideration, particularly if areas where juveniles would be found were under consideration.

71. Krausman, P.R. and J.J. Hervert. 1983. Mountain sheep responses to aerial surveys. Wildlife Society Bulletin 11:372-375.

The response of mountain sheep to overflights by small aircraft (Cessna) at altitudes of greater than 50 m was not great. Likewise, moose exposed to overflights at altitudes above 100 m showed no particular disturbance. The levels of noise are not given in this study.

72. Krausman, P.R., B.D. Leopold and D.L. Scarborough. 1986. Desert mule deer response to aircraft. Wildlife Society Bulletin 14:68-70.

The authors report that desert mule deer could become habituated to overflights by small aircraft (Cessna) at an average altitude of 80 m. The level of noise generated by these flights is not given.

73. Kushlan, J.A. 1979. Effects of helicopter censuses on wading bird colonies. Journal of Wildlife Management 43:756-760.

The author discusses the response of a number of wading birds in Florida (egrets, herons, storks, cormorants) to aircraft overflights. There are no significant responses indicated to most overflights although the sound levels are not given making it difficult to quantify the level of disturbance.

74. Langowski, D.J., H.M. Wight and J.N. Jacobson. 1969. Responses of instrumentally conditioned starlings to aversive acoustical stimuli. Journal of Wildlife Management 33:669-677.

The study details the response of starlings to sounds over a range of sound frequencies and intensities and that there is a relationship between the intensity and level of disturbance. The range of effect is between about 50-100 dB. This forms part of a body of information indicating the level of sounds that can be disturbing to birds.

75. Laurensen, K. 1981. Birds on roadside verges and the effect of mowing on frequency and distribution. Biological conservation 20:59-68.

The author reports on the use of roadside verges in Denmark by the skylark finding that the birds preferred to forage in this area as compared to adjacent fields. The ROW was also found to be a favored site for nesting when compared to adjacent areas. The roadside areas varied between 1 and 5m. A similar response is reported for the house sparrow and tree sparrow although these are not discussed to the same extent. The level of noise and traffic volume were not measured although the studies occurred outside of major urban areas.

76. Liddle, M. 1997. Recreation ecology: The ecological impact of outdoor recreation and ecotourism. 639 pp. Chapman and Hall: New York.

The author describes a wide variety of interactions between human activity and the response of all animal groups (fish, reptiles, amphibians, birds, mammals). The level of disturbance is qualified at three levels from mild to extreme. There is discussion of a variety of effects, however only a small portion is actually devoted to the effects of noise and is included under different sections for various species.

77. Luce, A. and M. Crowe. 2001. Invertebrate terrestrial diversity along a gravel road on Barrie Island, Ontario, Canada. The Great Lakes Entomologist 34:55-60.

The report looks at the numbers of terrestrial arthropods (insects) at distances up to 15 m from a gravel road finding no significant changes in numbers. This is one of the few studies that deals with invertebrate numbers at varying distances from a roadway although it does not address noise specifically.

78. Lyon, L.J. 1983. Road density models describing habitat effectiveness for elk. Journal of Forestry 81:592-595.

The authors present a method for determining the amount of elk use based on the amount of roaded area. The study does not directly address noise, but does predict significant reductions in use of areas with a density of more than 5.5 miles of road per square mile of area. The fact that roads can cause an effect is important, however the extent to which this reflects a physical barrier versus a noise effect remains to be determined.

79. Mader, H.J. 1981. Animal habitat isolation by roads and agricultural fields. Biological Conservation 29:81-96.

Report on the effect of emissions from roads (including noise) as having a potential effect on inhibiting movement of carabid beetles near the road. It is one of few studies to mention noise with respect to these invertebrates. This study also reports on two species of forest mice that were inhibited from crossing a two-lane highway. In this case noise is included in a suite of possible causes for the effect, however the specific levels of noise or traffic are not given.

80. Malar, T. and H. Kleerkoper. 1968. Observations on some effects of sound intensity on the locomotor pattern of naïve goldfish. American Zoologist 8:741-742.

This study reports on the sound frequency and pressure level that caused avoidance reaction in goldfish. The study does not detail a range of frequencies and intensities to give a broader indication of the response of this species.

81. Manci, K.M., D.N. Gladwin, R. Vilella and M.G. Cavendish. 1988. Effects of aircraft noise and sonic booms on domestic animals and wildlife: a literature synthesis. National Ecology Research Center Report# NERC-88/29.

The authors provide a review the effects of noise (mainly from aircraft or simulated sonic booms) on a variety of wildlife. The report deals with all major wildlife groups, but the sound levels are generally louder and of shorter duration than road noise. The overview of material is quite extensive.

82. Marten, K. and P. Marler. 1977. Sound transmission and its significance for animal vocalization. Behavioral Ecology and Sociobiology 2:271-290.

The authors report on factors that can effect sound transmission including the height of transmission (close to ground attenuates faster) and frequency. Thus, perch height may be important in the amount of transmission.

83. McGurk, B.J. and D.R. Fong. 1995. Equivalent roaded area as a measure of cumulative effect of logging. Environmental Mangement 19: 609-621.

Studied the effect of the effective roaded area on the numbers of aquatic invertebrates. Although the index is developed based on a model it does show a diversity decline as the effective roaded area increase above 5%.

84. Memphis State University. 1971. Effects of noise on wildlife and other animals. United States Environmental Protection Agency Office of Noise Abatement and Control Washington, D.C. Document NTID300.5.

The authors review the effect of noise on wildlife. At the date of publication most of the information dealt with domesticated birds and mammals. There is some material on the effects of noise on livestock, but much of the information deals with the sensitivities of species or the sound levels that can physical damage the hearing apparatus of species. There is very little information on roads or the sound levels that are likely to be encountered near roadways. The review of material as of the date of preparation is quite extensive.

85. Michael, E.D. 1975. Effects of highways on wildlife. West Virginia Department of Highways Report FHWA-WV-76-09.

A review of the response of vertebrate species to an adjacent highway at distances up to 1 mile into the surrounding woods. The study is able to compare distributions of species prior to and one year following the construction of a highway. The effect of noise is not addressed specifically, however, the effect on the numbers of several and species are given both before and following construction of a highway in the Appalachians. No game animal showed a difference in distribution following the road construction including rabbits, squirrels, foxes and deer. Rabbits are reported to increase in numbers near the

road. The numbers of birds and species diversity is reported to be greater in the ecotone than in either the ROW or native forest. None of the bird species were adversely affected and the authors speculate that numbers of species that prefer ecotone or ROW vegetation may increase including starlings, indigo buntings, red-winged blackbirds and goldfinches.

86. Michael, E.D., C.R. Ferris and E.G. Haverlack. 1976. Effects of highway rights of way on bird populations. Proceedings of the First National Symposium on Environmental Concern. pp. 253-261.

The authors report on the use of planted ROW habitat by bird species. More bird species were found in the ecotone compared to the surrounding forest up to one mile from the road. It is noted that the ROW supports both insects and rodents as food sources and that species requiring forest habitat would be expected to be reduced. The fact that some species occur in significant numbers indicates that noise was not sufficient to repel them.

87. Minton, Jr. S.A. 1968. The fate of amphibians and reptiles in a suburban area. Journal of Herpetology 2:113-116.

An early study of the effect of roads on a number of amphibians and reptiles (snakes, turtles). It does not address noise directly suggesting that this was not recognized as significant, but does discuss some of the initial observations of barrier effects of roads themselves.

88. Munguira, M.L. and J.A. Thomas. 1992. Use of road verges by butterfly and burnet populations and the effect of roads on adult dispersal and mortality. Journal of Applied Ecology 29:316-329.

A side ranging study of the numbers of butterfly species present on the roadside verges of major roads in England. The large number of species (23 or 40% of total found in England) suggests little effect of noise. The noise levels are not given in the study.

89. Norén, O. 1987. Noise from animal production. pp. 27-46. In: Animal Production and Environmental Health. D. Strauch (ed.). Elsevier Science Publishers: New York.

The author provides a good basic introduction to the principles of sound production and measurement. He further discusses the principles of sound propagation and attenuation. This is useful in understanding the principles that affect sound.

90. Oetting, R.B. and J.F. Cassel. 1971. Waterfowl nesting on interstate right of way in North Dakota. Journal of Wildlife Management 35:774-781.

The authors report on the use of interstate-94 ROW areas by dabbling ducks (mallard, pintails, gadwalls) for nesting. The amount of breeding was greater in unmowed ROW than in mowed areas. The level of noise is not measured and there is no comparison to control areas away from the ROW. However, numbers of birds were found to breed in the ROW and it is suggested that the road may have served as a barrier to the movement of predatory foxes.

91. Okanoya, K. and R.J. Dooling. 1987. Hearing in passerine and psittacine birds: a comparative study of absolute and masked auditory thresholds. Journal of Comparative Psychology 101:7-15.

authors measured the auditory threshold of several species (starling, sparrow, finch) and determined the critical ratio necessary for audibility over a range of frequencies. From a range of 0.4 Hz to 6 kHz the ratio rises from ~ 20-35 dB. This information may be important in determining the levels of vocalization necessary for detection against background noise.

92. Oxley, D.J., M.B. Fenton and G.R. Carmody. 1974. The effects of roads on populations of small mammals. Journal of Applied Ecology 11:51-59.

The movement of small mammals (rodents) adjacent to roads is described including 4 lane interstate highways. The results show that the large highways are as effective as bodies of water twice as wide preventing distribution of these species. The effect is described as a barrier and noise is not discussed as contributing factor.

93. Owens, N.W. 1977. Responses of wintering Brent geese to human disturbance. Wildfowl 28:5-14.

This report details the disturbance of Brant geese to overflights (at altitudes between 500 m and 1.5 km) and to human pedestrian activity. The levels of sound associated with the disturbance are not quantified. The results do indicate that human presence can be as disturbing as the much louder noise of aircraft.

94. Popper, A.N. and R.R. Fay. 1993. Sound detection and processing by fish: a critical review and major research questions. Brain, Behaviour and Evolution 41:14-39.

The authors present a review of hearing in fish. It contains a fairly extensive review of the anatomy of sound detection in fish and presents some information on the range of detection possible by fish. It provides less of an indication of the

frequencies and sound levels detected by a variety of fish species that are found in other reviews.

95. Räty, M. 1979. Effect of highway traffic on tetraonid densities. Ornis Fennica 56:169-170.

The author conducted one of the first studies to look at the distribution of birds usiung a series of transects away from a roadway. The study looked at grouse species at distances up to 1 km from a road with a traffic density of 700-3,000 cars / day. A reduction in density of two thirds was reported at a distance up to 250 m from the road and some reduction in density was found up to 500 m. The study began at a distance of 25 m from the roadway so there is no information about use of the ROW for comparison. The cause of this "highway effect" is not given and the levels of noise are not measured.

96. Reijnen, M.J.S.M., J.B.M. Thissen and G.J. Bekker. 1987. Effects of road traffic on woodland breeding bird populations. Acta Ecologia/Ecologia Generalis 8: 312-313.

This is the first study by the research group in the Netherlands that looked at the effect of traffic on nearby breeding birds. It was found that the numbers of breeding birds declined at distances up to 300 m from the road (the greatest distance measured). The road was heavily traveled with traffic levels of 30,000-40,000 vehicles / day. The level of noise was not measured in this study.

97. Reijnen, R. and R. Foppen. 1994. The effects of car traffic on breeding bird populations in woodland I. Evidence of reduced habitat quality for willow warblers (*Phylloacopus trochilus*) breeding close to a highway. Journal of Applied Ecology 31:85-94.

The authors, in the first of a series of studies, looked at willow warbler numbers and in particular, older, territorial males at distances of up to 400 m from a busy highway (50,000 cars /day). It was found that the numbers of the older birds were greatest at the farthest distance from the road (400 m) indicating a preference for this area. The authors suggest that noise may be an important factor (estimated at 50 dB(A) at a distance of 500 m) in this effect.

98. Reijnen, R. and R. Foppen. 1995. The effects of car traffic on breeding bird populations in woodland. IV. Influence of population size on the reduction of density close to the highway. Journal of Applied Ecology 32:481-491.

This study conducted in the Netherlands looked at the numbers of 43 species of woodland birds in both deciduous and coniferous forests. It is found that 26 species (60%) showed some negative effect. This study reports that noise is the best independent variable for predicting the "effect distances". The numbers of individuals were found to be reduced between 40-1,500 m at a traffic density of

10,000 cars/day and 70 -2,800 m at a density of 60,000 cars/day. The frequency range of noise was between 100 Hz and 10 kHz but loudest at 100-200 Hz and 0.5 to 4 kHz. The threshold for an effect seemed to be between 20-56 db(A). The authors note that if the level of noise is held constant there was no apparent difference in areas of high and low vehicle visibility.

99. Reijnen, R., R. Foppen, C. Ter Braak and J. Thissen. 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction in the density in relation to the proximity of main roads. Journal of Applied Ecology 32: 187-202.

The authors report on 23 species of woodland birds adjacent to a highway with relatively high density (40-52,000 cars / day). Of the total species 17 showed some reduction in numbers nearer to the road. The effect was found to be diminished in years when the overall population was high presumably due to some individuals being forced into less desirable areas. It is suggested that measurements be made over several years to increase the accuracy of this measurement. The importance of looking at more than just density is supported by other reports such as that of van Horne (1983).

100. Reijnen, R., R. Foppen and H. Meeuwsen. 1996. The effects of car traffic on the density of breeding birds in Dutch Agricultural Grasslands. Biological Conservation 75:255-260.

The authors report on the numbers of grassland bird species adjacent to roads where 7 of 12 species studied showed some effect. Roads with moderate traffic volume (5,000 cars/day) showed a 12-56% of most species within 100 m of the road beyond 100 m only the black-tailed godwit and oystercatcher showed an effect. Roads with higher density (50,000 cars/ day) showed a reduction of 12-52% at distances up to 500 m. The lapwing, shoveler, black-tailed godwit and oystercatcher were reduced between 14 and 44% at distances up to 1500 m. The authors note that noise as the best predictor of these results carries a number of factors with it including number, size and speed of vehicles. Noise levels adjacent to the road were about 59 dB(A) and 38 dB(A) in more remote areas. It is worth noting that the surrounding habitat in the study was relatively undisturbed with no farmhouses within 250 m of the measured transect.

101. Roach, G.L. and R.D. Kirkpatrick. 1985. Wildlife use of woody plantings in Indiana. Transportation Research Record 1016:11-15.

The authors report on a number of bird species (red-winged blackbird, goldfinch, and song sparrow) using plantings in ROW (mainly in interstate highways). Plantings were found to significantly increase the use of the habitat compared to control areas.

102. Rost, G.R. and J.A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. Journal of Wildlife Management 43:634-641.

The authors report on the effect of roads on deer and elk distribution and looked at paved, gravel and dirt roads. Their conclusion is that both attempted to avoid areas within 200m of the road and that the effect was greater for mule deer than for elk. They also note that road visibility did not apparently play a role in the density of either species. Whether there is an effect if noise is not discussed although the potential of an effect due to experience with hunting is discussed.

103. Rucker, R.R. 1973. Effect of sonic boom on fish. Department of Transportation, Federal Aviation Admininstration Report No. FAA-RD-73-29.

The author presents the results of sonic booms on the trout and salmon eggs and fry. The report does not detail the effect of lesser sound levels and thus is probably of more use in conjunction with other findings detailing the response of these and related species.

104. Rudolph, D.C., S.J. Burgdorf, R.N. Conner and R.R. Schaefer. 1999. Preliminary evaluation of the impact of roads and associated vehicular traffic on snake populations in eastern Texas. pp. 129-136. In: Proceedings of the third international symposium on wildlife ecology and transportation. G.L. Evink, P. Garrett and D. Ziegler (eds.). Florida Department of Transportation, Tallahassee, FL. Report No. FL-ER-73-99.

The author reports on the increased mortality of large snakes crossing roads. The similarity in effect in a range of road sizes and traffic volumes from interstate to county roads suggests that noise alone is not having a significant effect.

105. Scott, G.B. and P. Moran. 1993. Effects of visual stimuli and noise on fear levels in laying hens. Applied Animal Behaviour Science 37:321-329.

The author reports that there is no significant impact of noise from conveyor belts on laying hens. Sound levels were in the range of 70 dB. This is important in providing an indication of the levels of noise that can be tolerated by various birds.

106. Seabrook, W.A. and E.B. Dettmann. 1996. Roads as activity corridors for cane toads in Australia. Journal of Wildlife Management 60:363-368.

This report details the use of roads to dispersal by cane toads in Australia. The numbers of individuals were greater near the edge of the road or vehicle track. Although the traffic density is not given it appears to have been low. The impact of noise is not discussed although it did not appear to impair the use of roads by this species.

107. Shultz, R.D. and J.A. Bailey. 1978. Responses of national park elk to human activity. Journal of Wildlife Management 42:91-100.

The authors report on a study of Elk in Rocky Mountain national park finding that the presence of traffic resulted in only a slight avoidance in early winter. The specific effect of noise is not addressed.

108. Singer, F.J. 1978. Behavior of mountain goats in relation to US Highway 2, Glacier Park, Montana. Journal of Wildlife Management 42:591-597.

The author reports on the effect of a highway crossing a national park on mountain goat distribution (speed limit 50 mph). Both vehicles and highway noise are reported as perceived threats and would prevent animals moving toward salt licks. This is one of few studies of large ungulates to address noise as having an effect as opposed to road as barrier.

109. Singer, F.J. and J.B. Beattie. 1986. The controlled traffic system and associated wildlife responses in Denali National Park. Arctic 39:195-203.

The effect on several large mammals (caribou, grizzly, Dall sheep, moose) following the opening of a national park to a roadway is detailed. There was no significant decline in the sightings of any species except moose. Grizzly bears were reported to move closer to the road after construction. The level of noise is not given, but the presence of numbers of individuals suggests that there was no significant disturbance with the possible exception of moose.

110. Stadelman, W.J. 1958. The effect of sounds of varying intensity on hatchability of chicken egg. Poultry Science 37:166-169.

The author reports that there is no measurable effect on hatchability of chicken eggs or chick quality following exposure to noise in incubators. This is significant in that potential deleterious effects of noise on birds would include those on reproductive efficiency.

111. Stadelman, W.J. 1958. Observations with growing chickens on the effects of sounds of varying intensities. Poultry Science 37:776-779.

The author indicates that broiler chickens could be grown in areas of significant noise (~120 dB) without loss of weight. The potential effects of noise on both growth and development of birds is critical in evaluating the impact on wildlife.

112. Stalmaster, M.V. and J.R. Newman 1978. Behavioral responses of bald eagles to human activity. Journal of Wildlife Management 42:506-513.

The authors studied the effect of human activities on wintering bald eagles and report that normal activities such as boating and fishing did not disturb the birds.

Normal sounds from these activities are reported as not having an effect. However, gunshots did disturb them causing flight (escape behavior). This study does not give the levels of noise encountered or the effects of greater levels of noise.

113. Tabor, R. 1974. Earthworms, crows, vibrations and motorways. New Scientist 62:482-483.

Reports on the numbers of earthworms emerging near a major motorway and provides some explanation for the behavior. The report notes that birds (crows) may be attracted to roadside verges if food is available.

114. Thurber, J.M., R.O. Peterson, T.D. Drummer and S.A. Thomasma. 1994. Gray wolf response to refuge boundaries and roads in Alaska. Wildlife Society Bulletin 22:61-68.

The authors report on a survey of several wolf packs. The presence of the road alone appeared to no have a significant effect as the home range of one pack straddled the highway for several years whereas a less traveled road to an oilfield was less used possibly due to the human presence.

115. Trombulak, S.C. and C.A. Frissell. 2000. Review of the ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

The authors provide a general review of the effects of roads on the ecology of a variety of species. The study does not address the impact of noise extensively and is more useful as a general overview of factors to be considered in the environmental impact of roads most particularly disruption of the physical and chemical environment including fragmentation and mortality.

116. van der Zande, A.N., W.J. ter Keurs and W.J. Van der Weijden. 1980. The impact of roads on the densities of four bird species in an open field habitat-evidence of a long distance effect. Biological Conservation 18:299-321.

The authors report on a reevaluation of data gathered originally by Veen (1973) in the Netherlands. It is found that three species (lapwing, godwit and redshank) were reduced in density and numbers of nests at distances up to 500-600m from rural road and 1,600 to 1,800 m from a busy highway. A fourth species, the oystercatcher did not appear to show the same response. The level of noise was not measured for either type of road.

117. van Dyke, F.G., R.H. Brecke, H.G. Shaw et al. 1986. Reactions of mountain lions to logging and human activity. Journal of Wildife Management 50:95-102.

The activity of mountain lions in different levels of human activity is given. Areas where timber was being harvested had a more negative effect on the

presence of individuals than the overall road density. There is a potential avoidance zone for machine noise given between 100 m and 1 km. However, the specific levels of noise are not given.

118. van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47:893-901.

The author discusses the importance of using more than density as an indicator of the suitability of habitat by giving examples of cases in which density was high, but habitat less desirable due to some individuals being forced into marginal areas by older, more dominant ones. This is an important consideration in studies that wish to indicate whether there is an effect of noise or roads based on density alone.

119. Veen, J. 1973. De verstoring van weidevogelpopulaties. Stedebouw en Volkshuisvesting 53:16-26.

The author published original data on four species of bird in the Netherlands and the impact of roads on their density and nesting. The data are reevaluated in English by van der Zande et al. (1980) and are discussed there.

120. Vickery, P.D., M.L. Hunter, Jr. and S.M. Melvin. 1994. Effects of habitat area on the distribution of grassland birds in Maine. Conservation Biology 8:1087-1097.

The authors report on the amount of habitat area required for ten grassland bird species. The results range from 200 ha for the upland sandpiper to 10 ha for the savanna sparrow. The effect of noise is not discussed although the potential of using airports as sites for species conservation in more developed areas is made. It is important to note that some species require larger areas of habitat and that this may effect their utilization of areas nearer roadsides. The studies by Clark and Karr (1979), Ferris (1979) and some by Reijnen and colleagues suggest that habitat factors in addition to traffic and noise may be important in the utilization of roaded areas by birds.

121. Voorhees, L.D. and F.J. Cassel. 1980. Highway right-of-way: mowing versus succession as related to duck nesting. Journal of Wildlife Management 44:155-163.

The authors report on the use of interstate 94 ROW habitat in North Dakota by dabbling ducks. The same species are looked at as in an earlier study (Oetting and Cassel, 1971) and the preference for unmowed sections is the same as the earlier study. It is noted that nest success declined in areas where the vegetation was older perhaps due to increased predation. The levels of noise encountered are not mentioned and the response to noise can only be estimated from the frequent use of the ROW for nesting.

122. Ward, A.L., J.J. Cupal, A.L. Lea et al. 1973. Elk behavior in relation to cattle grazing, forest recreation and traffic. North American Wildlife National Research Conference Transactions 38:327-337.

The authors report on the effect of interstate 80 on elk behavior indicating both the noise level for both cars and trucks. There is little effect reported within 300 yards due to noise, however the road did act as a barrier to crossing.

123. Warner, R.E. and G.B. Joselyn. 1986. Responses of Illinois ring-necked pheasant populations to block roadside management. Journal of Wildlife Management 50:525-532.

The authors report on the breeding of ring-necked pheasants using roadsides and makes the important observation that in areas where much of the landscape is being used for agriculture (especially small grains) the ROW may provide a more suitable breeding area. The noise levels along the road are not given.

124. Warner, R.E., G.B. Joselyn and S.L. Etter. 1987. Factors affecting roadside nesting by pheasants in Illinois. Wildlife Society Bulletin 15:221-228.

The authors report on ring-necked pheasants using roadside plots where nest densities exceed those found in even control areas away from the road. It is also suggested that ROW can act as a buffer for other areas that experience greater variability. The effect of noise is not directly addressed the presence of significant numbers of breeding birds argues against a significant effect in this species.

125. Warner, R.E. 1992. Nest ecology of grassland passerines on road rights-of-way in central Illinois. Biological Conservation 59:1-7.

The author studied grassland birds along a (four-lane) interstate highway and secondary ROW in rural Illinois. The number of nests and species increased with roadside width being greatest on heavily trafficked interstates. Traffic densities on secondary roads also did not influence the density of nests. The vast majority of nests belonged to red-winged blackbirds. The levels of noise were not measured. It is notable that as surrounding farmland became more diverse the numbers of nests could also vary indicating that broader landscape factors also play a role in site selection.

126. Way, J.M. 1977. Roadside verges and conservation in Britain: A review. Biological Conservation 12:65-73.

The author provides a review of the use of roadsides for breeding by all major wildlife species in England. Both county roads and major highways were included. It is reported that 20 of 50 mammal species, 40 of 200 birds, 25 of 60 butterflies, 8 of 17 bumble bees and 5 of 6 amphibian species are found to use the

roadsides. It appears that the quantity of herb-rich grassland without scrub is particularly in the importance of the utilization of ROW habitat. The specific levels of noise are not discussed, but is in agreement with studies that have found species to breed in the ROW in numbers.

127. Wenz, G.M. 1962. Acoustic ambient noise in the ocean: spectra and sources. Journal of the Acoustical Society of America 34:1936-1956.

This paper presents a review of the levels of background noise encountered in the ocean including a review of sounds from ocean traffic. It presents a potentially useful overview of levels of sound and frequencies that are often encountered for comparison to other measurements.