Highway Traffic Noise

Noise Effect on Wildlife

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/m2 and a value of 120 dB corresponds to about 20 N/m2 – a level at which pain will be experienced.

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

where I = intensity of actual sound, Io = intensity of sound Io 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 Leq = 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 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/m2) 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/cm2 and 1 Hz; where 1 Pa = 1 N/m2 = 10 µbars = 10 dynes/cm2). (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/cm2 (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 little. 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 (Leq = 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 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 (Leq 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 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 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)