

Here are MDIFW responses to Commission Questions, I have also attached the requested materials.

Question 1a:

MDIFW response:

We are aware of multiple studies conducted to assess human noise disturbance impacts on wildlife. Since the 1970s, many studies have been conducted to assess how noise from roads, aircraft, and snowmobile/ATV use influence a variety of wildlife species. A few recent studies have focused research on noise effects to wildlife at industrial-type facilities similar to the proposed Kibby Windpower Expansion project. Findings from these studies indicate that wildlife will either respond behaviorally (avoiding adjacent habitats, increase vigilance, etc.) or will habituate and adapt to the noisier environment and that responses are taxa-specific.

MDIFW recognizes that noise produced from operating wind facilities may have negative effects on certain species, but the full impact of these effects are unknown. The effect of anthropogenic noise on wildlife populations is difficult to measure and often confounded by other variables that cannot be teased out in the study. Therefore most studies can only speculate about the impact of noise and the resulting survival and reproduction of specific study species. The challenge is to determine what level of impact is expected, but more importantly, what level of effect is acceptable. When reviewing large-scale wind projects, MDIFW has concentrated on protecting habitats for species with special conservation needs. The Department will adapt and continue to refine the questions we ask of applicants, as technology changes or new information emerges.

Here are some recent peer-reviewed papers focused on noise and wildlife:

Barber, J. R. et al. 2009. The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology and Evolution* 25: 180-189.

This paper provides an excellent review of multiple studies and suggests potential impacts to wildlife including communication, predator-prey relationships, and reproductive success.

Rabin, L. A et al. 2006. The effects of wind turbines on antipredator behavior in California ground squirrels (*Spermophilus beecheyi*). *Biological Conservation* 131:410-420.

This study measured noise levels at control sites and turbine sites and found an increase in background noise while turbines were operating. The researchers recorded alarm call sequences from squirrels and played back at both sites. They found that at both sites, when recorded alarm calls were played the squirrels showed an increased alertness and readily returned to the area around their burrows. There were several confounding factors, but overall, ground squirrels showed a higher level of alert behavior at the turbine site.

Flydal, Kjetil, et al. 2003. Effects of wind turbines on area use and behaviour of semi-domestic reindeer in enclosures. *Rangifer* 24:55-66.

The researchers for this study observed reindeer activities in a control enclosure away from a wind facility and an enclosure at a wind facility. Observations of activities were also made while turbine blades were rotating and off. The study found no significant difference in activity of reindeer from either the control site, or while turbine blades were rotating.

Bee, M.A. and E.M. Swanson. 2007. Auditory masking of anuran advertisement calls by road traffic noise. *Animal Behaviour* 74(6): 1765-1776.

An experimental study that suggests that realistic levels of background traffic noise can place constraints on the active space of the acoustic signals of some amphibians, including grey tree frogs (a species native to Maine).

Question 1b:

MDIFW response:

MDIFW utilizes Natural Resources Protection Act- Significant Vernal Pools standards, regardless of actual regulatory jurisdiction (DEP NRPA Chapter 335 Rules; Section 9, Significant Vernal Pools). TransCanada, through consultation with MDIFW, adopted a protocol to identify vernal pools as part of their pre-construction study package based on NRPA standards. The objective of the protocol employed by TransCanada was to identify, map, and characterize all vernal pools that are in proximity to their proposed development. This is typical of vernal pool surveys for large development applications. MDIFW/MDEP have developed a "Maine State Vernal Pool Assessment Form" to aid in characterization of the vernal pools.

Under NRPA rules, only Significant Vernal Pools are subject to habitat management standards. There are several criteria used to determine significance of a vernal pool (outlined in Section 9 of Chapter 335 rules). It is important to note that official determination of pool Significance is made by MDIFW and not the applicant or the certified professional conducting the survey.

TransCanada submitted their vernal pool data forms to MDIFW. All pools submitted were determined to be non-significant, because the vernal pools identified in the survey were all of unnatural origin. Therefore, additional surveys during the identification period for pool-breeding amphibians are unnecessary, and would not change the determination of Significance. In most circumstances, unnatural vernal pools are not determined to be Significant or subject to habitat management standards (under NRPA rules). Regardless of this determination, TransCanada is applying the NRPA habitat management standards to all identified vernal pools.

Thanks,

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The costs of chronic noise exposure for terrestrial organisms

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Growth in transportation networks, resource extraction, motorized recreation and urban development is responsible for chronic noise exposure in most terrestrial areas, including remote wilderness sites. Increased noise levels reduce the distance and area over which acoustic signals can be perceived by animals. Here, we review a broad range of findings that indicate the potential severity of this threat to diverse taxa, and recent studies that document substantial changes in foraging and anti-predator behavior, reproductive success, density and community structure in response to noise. Effective management of protected areas must include noise assessment, and research is needed to further quantify the ecological consequences of chronic noise exposure in terrestrial environments.

Anthropogenic noise and acoustic masking

Habitat destruction and fragmentation are collectively the major cause of species extinctions [1,2]. Many current threats to ecological integrity and biodiversity transcend political and land management boundaries; climate change, altered atmospheric and hydrologic regimes and invasive species are prominent examples. Noise also knows no boundaries, and terrestrial environments are subject to substantial and largely uncontrolled degradation of opportunities to perceive natural sounds. Noise management is an emergent issue for protected lands, and a potential opportunity to improve the resilience of these areas to climate change and other forces less susceptible to immediate remediation.

Why is chronic noise exposure a significant threat to the integrity of terrestrial ecosystems? Noise inhibits perception of sounds, an effect called masking (see [Glossary](#)) [3]. Birds, primates, cetaceans and a sciurid rodent have been observed to shift their vocalizations to reduce the masking effects of noise [4–7]. However, compromised hearing affects more than acoustical communication. Comparative evolutionary patterns attest to the alerting function of hearing: (i) auditory organs evolved before the capacity to produce sounds intentionally [8], (ii) species commonly hear a broader range of sounds than they are capable of producing [9], (iii) vocal activity does not predict hearing performance across taxa [9,10], (iv) hearing continues to function in sleeping [11] and hibernating [12] animals; and (v) secondary loss of vision is more common than is loss of hearing [13].

Masking is a significant problem for the perception of adventitious sounds, such as footfalls and other byproducts of motion. These sounds are not intentionally produced and natural selection will typically favor individuals that minimize their production. The prevalence and characteristics of adventitious sounds have not been widely studied [14–16], although their role in interactions

Glossary

Alerting distance: the maximum distance at which a signal can be perceived. Alerting distance is pertinent in biological contexts where sounds are monitored to detect potential threats.

Atmospheric absorption: the part of transmission loss caused by conversion of acoustic energy into other forms of energy. Absorption coefficients increase with increasing frequency, and range from a few dB to hundreds of dB per kilometer within the spectrum of human audibility.

Audible: a signal that is perceptible to an attentive listener.

A-weighting: A method of summing sound energy across the frequency spectrum of sounds audible to humans. A-weighting approximates the inverse of a curve representing sound intensities that are perceived as equally loud (the 40 phon contour). It is a broadband index of loudness in humans in units of dB(A) or dBA. A-weighting also approximates the shapes of hearing threshold curves in birds [20].

Decibel (dB): a logarithmic measure of acoustic intensity, calculated by $10 \log_{10}(\text{sound intensity}/\text{reference sound intensity})$. 0 dB approximates the lowest threshold of healthy human hearing, corresponding to an intensity of 10^{-12} Wm^{-2} . Example sound intensities: –20 dB, sound just audible to a bat, owl or fox; 10 dB, leaves rustling, quiet respiration; 60 dB, average human speaking voice; 80 dB, motorcycle at 15 m.

Frequency (Hz and kHz): for a periodic signal, the maximum number of times per second that a segment of the signal is duplicated. For a sinusoidal signal, the number of cycles (the number of pressure peaks) in one second (Hz). Frequency equals the speed of sound ($\sim 340 \text{ ms}^{-1}$) divided by wavelength.

Ground attenuation: the part of transmission loss caused by interaction of the propagating sound with the ground.

Listening area: the area of a circle whose radius is the alerting distance. Listening area is the same as the ‘active space’ of a vocalization, with a listener replacing the signaler as the focus, and is pertinent for organisms that are searching for sounds.

Masking: the amount or the process by which the threshold of detection for a sound is increased by the presence of the aggregate of other sounds.

Noticeable: a signal that attracts the attention of an organism whose focus is elsewhere.

Scattering loss: the part of transmission loss resulting from irregular reflection, diffraction and refraction of sound caused by physical inhomogeneities along the signal path.

Spectrum, power spectrum and spectral profile: the distribution of acoustic energy in relation to frequency. In graphical presentations, the spectrum is often plotted as sound intensity against sound frequency (Figure 1, main text).

1/3 octave spectrum: acoustic intensity measurements in a sequence of spectral bands that span 1/3 octave. The International Standards Organization defines 1/3rd octave bands used by most sound level meters (ISO 266, 1975). 1/3rd octave frequency bands approximate the auditory filter widths of the human peripheral auditory system.

Spreading loss: more rigorously termed divergence loss. The portion of transmission loss attributed to the divergence of sound energy, in accordance with the geometry of environmental sound propagation. Spherical spreading losses in dB equal $20 \log_{10}(R/R_0)$, and result when the surface of the acoustic wavefront increases with the square of distance from the source.

White noise: noise with equal energy across the frequency spectrum.

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Box 1. Geographic extent of transportation noise in the USA

Transportation noise is a near ubiquitous component of the modern acoustical landscape. The method used here to estimate the geographic extent of airway (Figure 1a,b), railway (Figure 1c) and roadway (Figure 1d) noise in the continental USA is calculated using the average human 'noticeability' of noise. Noise was deemed noticeable when the modeled noise intensity from transportation [in dB(A)] exceeded the expected noise intensity as predicted from population density [also dB(A)]. Although noticeability is a conservative metric of the geographic extent of transportation noise, this analysis only indicates the potential scope of the problem. How anthropogenic noise changes the temporal and spectral properties of naturally-occurring noise (Figure 1, main text) and the life histories of individual species will be crucial components of a more thorough analysis.

The maps in Figure 1 reflect the following calculations: (i) noise calculations are county-by-county for a typical daytime hour; (ii)

county population density is transformed into background sound level using an EPA empirical formula (see Ref. [84]); higher density implies higher background sound levels; (iii) the geographic extent of transportation noise is determined by calculating the distance from the vehicle track at which the transportation noise falls below the background sound level, multiplying twice that distance by the length of the transportation corridor in the county (giving a noticeability area), and comparing that area with the total area in the county to compute the percentage land area affected. A low percentage noticeability can result if either the population density is high or the number of transportation segments is low in the county. This analysis indicates that transportation noise is audible above the background of other anthropogenic noise created by local communities in most counties in continental USA. See Ref. [84] for more details.

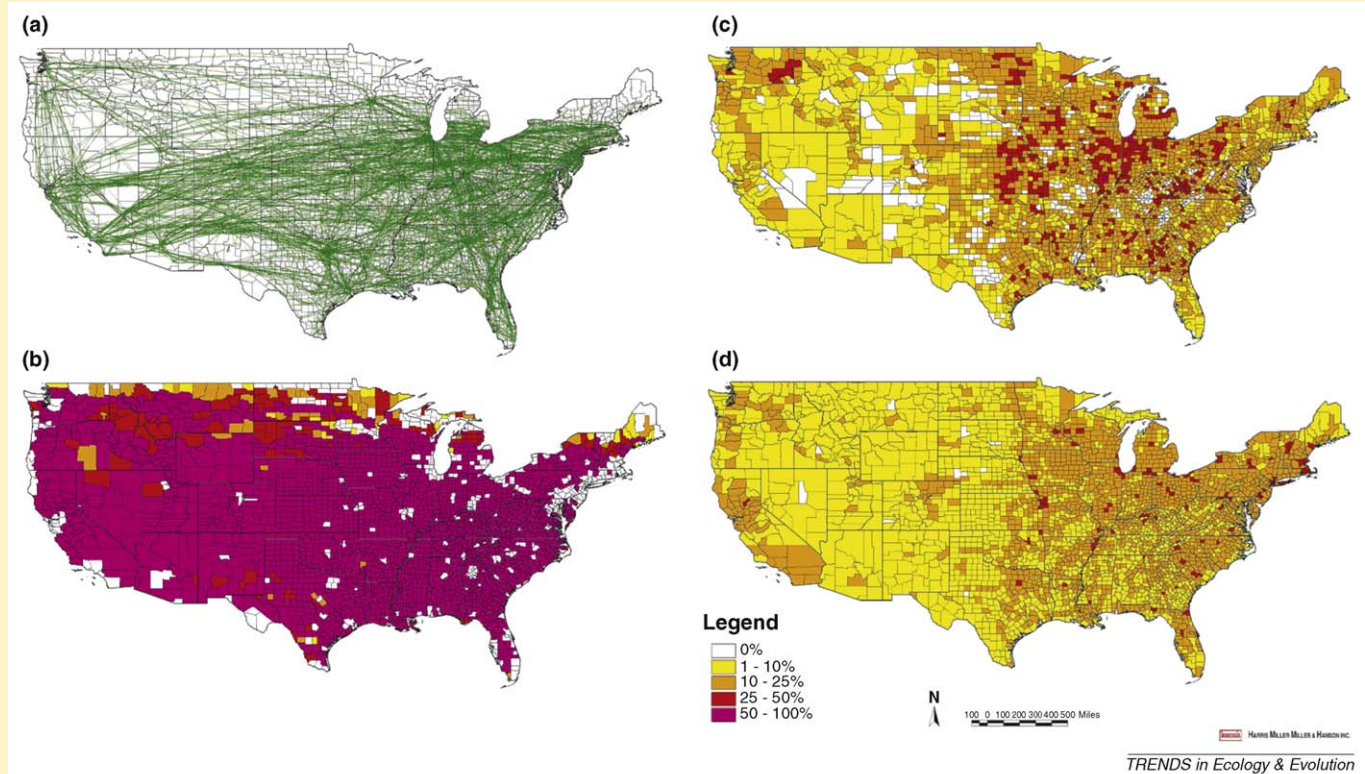


Figure 1. Percent of US county areas in which transportation noise is noticeable. (a) Jet departures that occurred between 3 and 4 pm on Oct. 17, 2000, tracked to first destination. (b) Data from (a) were used to estimate the geographic extent of high altitude airway noise in the USA. The geographic extent of noise from railway and highway networks is depicted in (c) and (d), respectively. The color-coded divisions (see legend; divisions increase in size as the percent increases) were chosen assuming that, as noticeability increases, so do estimate errors due to noticeability area overlap from different transportation segments. Adapted with permission from Ref. [84].

among predators and prey is unquestionable. In animal communication systems, both the sender and receiver can adapt to noise masking, but for adventitious sounds the burden falls on listeners.

Anthropogenic disturbance is known to alter animal behavioral patterns and lead to population declines [17,18]. However, animal responses probably depend upon the intensity of perceived threats rather than on the intensity of noise [19]. Deleterious physiological responses to noise exposure in humans and other animals include hearing loss [20], elevated stress hormone levels [21] and hypertension [22]. These responses begin to appear at exposure levels of 55–60 dB(A), levels that are restricted to relatively small areas close to noise sources [20].

The scale of potential impact

The most spatially extensive source of anthropogenic noise is transportation networks. Growth in transportation is increasing faster than is the human population. Between 1970 and 2007, the US population increased by approximately one third (<http://www.census.gov/compendia/statab>). Traffic on US roads nearly tripled, to almost 5 trillion vehicle kilometers per year (<http://www.fhwa.dot.gov/ohim/tvtw/tvtpage.cfm>). Several measures of aircraft traffic grew by a factor of three or more between 1981 and 2007 (http://www.bts.gov/programs/airline_information/air_carrier_traffic_statistics/airtraffic/annual/1981_present.html). Recent reviews of the effects of noise on marine mammals have identified similar trends in shipping noise (e.g. Refs [23,24]). In addition to transportation,

resource extraction and motorized recreation are spatially extensive sources of noise on public lands.

Systematic monitoring by the Natural Sounds Program of the US National Park Service (<http://www.nature.nps.gov/naturalsounds>) confirms the extent of noise intrusions. Noise is audible more than 25% of the hours between 7am and 10pm at more than half of the 55 sites in 14 National Parks that have been studied to date; more than a dozen sites have hourly noise audibility percentages exceeding 50% (NPS, unpublished). Remote wilderness areas are not immune, because air transportation noise is widespread, and high traffic corridors generate substantial noise increases on the ground (Box 1). For example, anthropogenic sound is audible at the Snow Flats site in Yosemite National Park nearly 70% of the time during peak traffic hours. Figure 1 shows that typical noise levels exceed natural ambient sound levels by an order of magnitude or more.

Roads are another pervasive source of noise: 83% of the land area of the continental US is within 1061 m of a road [25]. At this distance an average automobile [having a noise source level of 68 dB(A) measured at 15 m] will project a noise level of 20 dB(A). This exceeds the median natural levels of low frequency sound in most environments. Trucks and motorcycles will project substantially more noise: up to 40 dB(A) at 1 km. Box 2

provides a physical model of the reduced listening area that can be imposed by these louder background sound levels.

Acoustical ecology

Intentional communication, such as song, is the best studied component of the acoustical world, and these signals are often processed by multiple receivers. These communication networks enable female and male songbirds, for example, to assess multiple individuals simultaneously for mate choice, extra-pair copulations and rival assessment [26]. Acoustic masking resulting from increasing background sound levels will reduce the number of individuals that comprise these communication networks and have unknown consequences for reproductive processes [27].

Reproductive and territorial messages are not the only forms of acoustical communication that operate in a network. Social groups benefit by producing alarm calls to warn of approaching predators [28] and contact calls to maintain group cohesion [29]. A reduction in signal transmission distance created by anthropogenic noise might decrease the effectiveness of these social networks. The inability to hear just one of the alarm calling individuals can result in animals underestimating the urgency of their response [30].

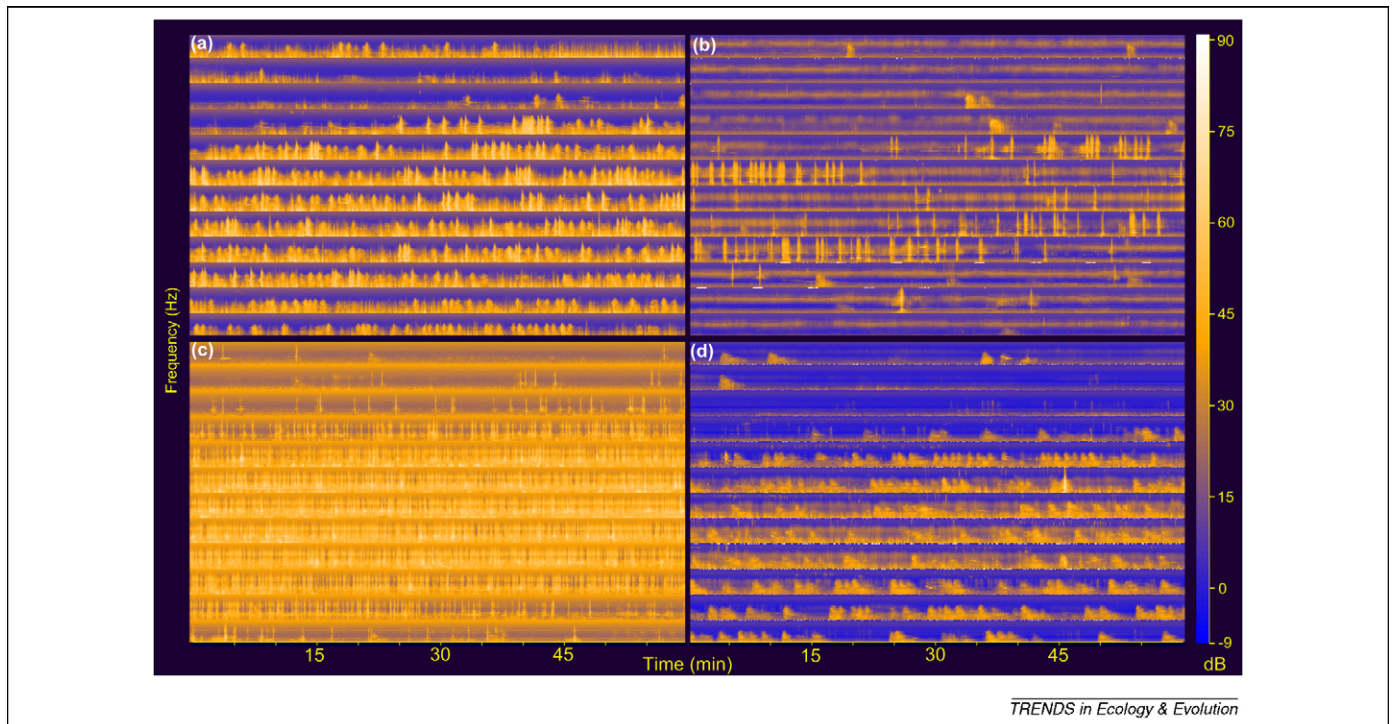


Figure 1. 24-hour spectrograms of Indian Pass in Lake Mead National Recreation Area (a), Madison Junction in Yellowstone National Park (b), Trail Ridge Road in Rocky Mountain National Park (c), and Snow Flats in Yosemite National Park (d). Each panel displays 1/3 octave spectrum sound pressure levels, with two hours represented horizontally in each of 12 rows. The first three rows in each panel represent the quietest hours of each day, from midnight to 6 am. Frequency is shown on the y axis as a logarithmic scale extending from 12.5 Hz to 20 kHz, with the vertical midpoint in each row corresponding to 500 Hz. The z axis (color) describes sound pressure levels in dB (unweighted); the color scaling used for all four panels is indicated by the color bar on the right hand edge. The lowest 1/3 octave levels are below 0 dB, the nominal threshold of human hearing. White dots at the upper edge of some rows in the panels on the right side denote missing seconds of data. Low-frequency, broadband signatures from high altitude jets are present in all four panels. Distinct examples are present just before 6 am in (a), near 12:45 am in (b) and (c), and between midnight and 12:30 am in (d). Fixed wing aircraft signatures (tonal contours with descending pitch) are present in (a) and (d), with a good example at 1:15 am in (d). Broadband signatures with very low frequency tonal components in (a) are due to low-altitude helicopters, that are prominent from ~7 am until 8 pm. Another prominent helicopter signature is at 11:30 am in (d). (b) illustrates snowmobile and snowcoach sounds recorded ~30 m from the West Entrance Road in Yellowstone. (c) illustrates traffic noise recorded 15 m from Trail Ridge Road in Rocky Mountain National Park, during a weekend event featuring high levels of motorcycle traffic. Background sound levels at the Rocky Mountain site were elevated by sounds from the nearby river.

Box 2. Physical model of reduced listening area in noise

The maximum detection distance of a signal decreases when noise elevates the masked hearing threshold. The masked detection distance: original detection distance ratio will be the same for all signals in the affected frequency band whose detection range is primarily limited by spreading losses. For an increase of N dB in background sound level, the detection distance ratio is: $k = 10^{-N/20}$. The corresponding fraction of original listening area is: $k = 10^{-N/10}$. A 1-dB increase in background sound level results in 89% of the original detection distance, and 79% of the original listening area. These formulae will overestimate the effects of masking on alerting distance and listening area for signals that travel far enough to incur significant absorptive and scattering losses. More detailed formulae would include terms that depend upon the original maximum range of detection.

Figure 1 illustrates the expected noise field of a road treated as a line source (equal energy generated per 10 m segment). An animal track is marked by ten circular features, that depict the listening area of a signal whose received level (expressed as a grey-scaled value for each possible source location) decreases with the inverse square of distance from the listener. The apparent shrinkage of the circles is due to masking by the increasingly dark background of sound projected from the road, just as noise would shrink the listening area. The circles span 9 dB in road noise level, in 1-dB steps from the quietest location (upper right) to the noisiest (at the crossing).

Masking effects are reduced with increasing spectral separation between noise and signal. The model presumes that the original conditions imposed masked hearing thresholds, so organisms that are limited by their hearing thresholds will not be as affected by masking. A diffuse noise source is illustrated, but the same results would be obtained if some spatial release from masking were possible, so long as the original conditions implied masked hearing thresholds (see Ref. [85] for a review of release strategies).

These measures of lost listening opportunity are most pertinent for chronic exposures. They imply substantial losses in auditory awareness for seemingly modest increases in noise exposure. Analyses of

transportation noise impacts based on perceived loudness often assert that increases of up to three dB have negligible effects; this corresponds to a 50% loss of listening area.

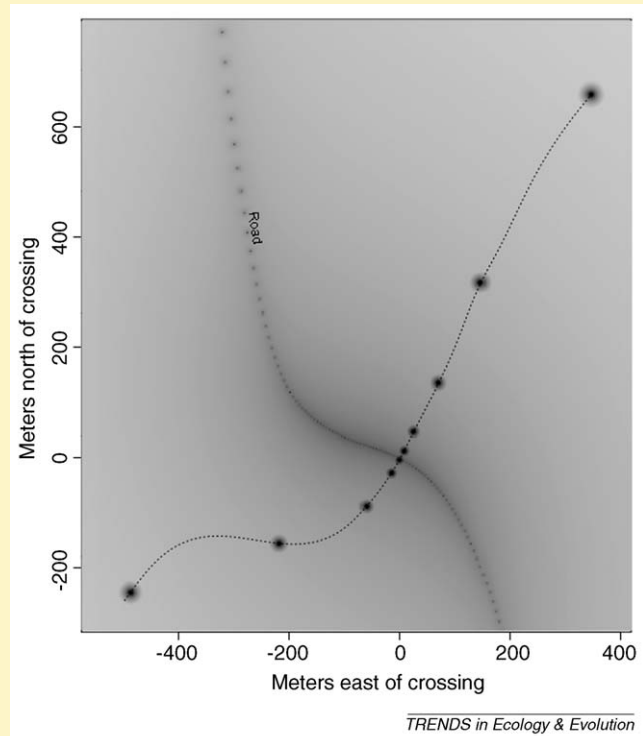


Figure 1. A physical model of reduced listening area as an animal approaches a road.

Many vertebrate and invertebrate species are known to listen across species' boundaries to one another's sexual (e.g. Ref. [31]), alarm (e.g. Ref. [32]) and other vocalizations. Recent examples include gray squirrels, *Sciurus carolinensis*, listening in on the communication calls of blue jays, *Cyanocitta cristata*, to assess site-specific risks of cache pilfering [33]; and nocturnally migrating songbirds [34] and newts (Ref. [35] and Refs therein) using heterospecific calls to make habitat decisions. Reduced listening area imposed by increased sound levels is perhaps more likely to affect acoustical eavesdropping than to interfere with deliberate communication. The signaler is under no selective pressure to ensure successful communication to eavesdroppers and any masking compensation behaviors will be directed at the auditory system and position of the intended receiver rather than of the eavesdropper.

Acoustical communication and eavesdropping comprise most of the work in bioacoustics, but the parsimonious scenario for the evolution of hearing involves selection for auditory surveillance of the acoustical environment, with intentional communication evolving later [8]. Adventitious sounds are inadequately studied, in spite of their documented role in ecological interactions. Robins can use sound as the only cue to find buried worms [36]; a functional group of bats that capture prey off surfaces, gleaners, relies on prey-generated noises to localize their next meal [37]; barn owls (*Tyto alba*; [38]), marsh hawks (*Circus cyaneus*; [39]), and grey mouse

lemurs (*Microcebus murinus*; [15] have been shown to use prey rustling sounds to detect and localize prey; big brown bats, *Eptesicus fuscus*, have the ability to use low-frequency insect flight sounds to identify insects and avoid protected prey [40]. In addition to prey localization, spectrally unstructured movement sounds are also used to detect predators. White-browed scrubwren (*Sericornis frontalis*) nestlings become silent when they hear the playback of footsteps of pied currawong, *Strepera graculina*, their major predator [41]; and tungara frogs, *Physalaemus pustulosus* avoid the wingbeat sounds of an approaching frog-eating bat, *Trachops cirrhosus* [42]. We are aware of only one study that has examined the role of adventitious sounds other than movement noises; African reed frogs, *Hyperolius nitidulus* flee from the sound of fire [43]. It is likely that other ecological sounds are functionally important to animals.

It is clear that the acoustical environment is not a collection of private conversations between signaler and receiver but an interconnected landscape of information networks and adventitious sounds; a landscape that we see as more connected with each year of investigation. It is for these reasons that the masking imposed by anthropogenic noise could have volatile and unpredictable consequences.

Separating anthropogenic disturbance from noise impacts

Recent research has reinforced decades of work [44,45] showing that human activities associated with high levels

of anthropogenic noise modify animal ecology: for example, the species richness of nocturnal primates, small ungulates and carnivores is significantly reduced within ~ 30 m of roads in Africa [46]; anuran species richness in Ottawa, Canada is negatively correlated with traffic density [47]; aircraft overflights disturb behavior and alter time budgets in harlequin ducks (*Histrionicus histrionicus*; [48]) and mountain goats (*Oreamnos americanus*; [49]); snowmobiles and off-road vehicles change ungulate vigilance behavior and space use, although no evidence yet links these responses to population consequences [50,51]; songbirds show greater nest desertion and abandonment, but reduced predation, within 100 m of off-road vehicle trails [52]; and both greater sage-grouse (*Centrocercus urophasianus*; [53]) and mule deer (*Odocoileus hemionus*; [54]) are significantly more likely to select habitat away from noise-producing oil and gas developments. Thus, based on these studies alone, it seems clear that activities associated with high levels of anthropogenic noise can re-structure animal communities; but, because none of these studies, nor the disturbance literature in general, isolates noise from other possible forces, the independent contribution of anthropogenic noise to these effects is ambiguous.

Other evidence also implicates quiet, human-powered activities, such as hiking and skiing, in habitat degradation. For example, a paired comparison of 28 land preserves in northern California that varied substantially in the number of non-motorized recreationists showed a five-fold decline in the density of native carnivores in heavily used sites [55]. Further evidence from the Alps indicates that outdoor winter sports reduce alpine black grouse, *Tetrao tetrix* populations [17] and data from the UK link primarily quiet, non-motorized recreation to reduced woodlark, *Lullula arborea* populations [18]. A recent meta-analysis of ungulate flight responses to human disturbance showed that humans on foot produced stronger behavioral reactions than did motorized disturbance [45]. These studies strengthen a detailed foundational literature suggesting that anthropogenic disturbance events are perceived by animals as predation risk, regardless of the associated noise levels. Disturbance evokes anti-predator behaviors, interferes with other activities that enhance fitness and, as the studies above illustrate, can lead to population decline [44]. Although increased levels of noise associated with the same disturbance type appear to accentuate some animal responses (e.g. Refs [44,48]), it is difficult to distinguish reactions that reflect increasingly compromised sensory awareness from reactions that treat greater noise intensity as an indicator of greater risk.

To understand the functional importance of intact acoustical environments for animals, experimental and statistical designs must control for the influence of other stimuli. Numerous studies implicating noise as a problem for animals have reported reduced bird densities near roadways (reviewed in Ref. [56]). An extensive study conducted in the Netherlands found that 26 of 43 (60%) woodland bird species showed reduced numbers near roads [57]. This research, similar to most road ecology work, could not isolate noise from other possible factors associated with transportation corridors (e.g. road mortality, visual disturbance, chemical pollution, habitat fragmentation,

increased predation and invasive species along edges). However, these effects extended for over a mile into the forest, implicating noise as one of the most potent forces driving road effects [58]. Later work, with a smaller sample size, confirmed these results and contributed a significant finding: birds with higher frequency calls were less likely to avoid roadways than birds with lower frequency calls [59]. Coupled with the mounting evidence that several animals shift their call frequencies in anthropogenic noise [4–7], these data are suggestive of a masking mechanism.

A good first step towards disentangling disturbance from noise effects is exemplified by small mammal translocation work performed across roadways that varied greatly in traffic amount. The densities of white-footed mice, *Peromyscus leucopus* and eastern chipmunks *Tamias striatus* were not lower near roads and both species were significantly less likely to cross a road than cover the same distance away from roads, but traffic volume (and noise level) had no influence on this finding [60]. Thus, for these species, the influence of the road surface itself appears to outweigh the independent contributions of direct mortality and noise.

Recent findings on the effects of anthropogenic noise

Two research groups have used oil and gas fields as ‘natural experiments’ to isolate the effects of noise from other confounding variables. Researchers in Canada’s boreal forest studied songbirds near noisy compressor stations [75–90 dB(A) at the source, 24 hrs a day, 365 days a year] and nearly identical (and much quieter) well pads. Both of these installations were situated in two to four ha clearings with dirt access roads that were rarely used. This design allowed for control of edge effects and other confounding factors that hinder interpretation of road impact studies. The findings from this system include reduced pairing success and significantly more first time breeders near loud compressor stations in ovenbirds (*Seiurus aurocapilla*; [61]), and a one-third reduction in overall passerine bird density [62]. Low territory quality in loud sites might explain the age structuring of this ovenbird population and, if so, implicates background sound level as an important habitat characteristic. In addition to the field data above, weakened avian pair preference in high levels of noise has been shown experimentally in the lab [63]. These data suggest masking of communication calls as a possible underlying mechanism; however the reduced effectiveness of territorial defense songs, reduced auditory awareness of approaching predators (see Box 3 for a discussion of the foraging/vigilance tradeoff in noise), or reduced capacity to detect acoustic cues in foraging, cannot be excluded as explanations of the results.

A second research group, working within natural gas fields in north-west New Mexico, US, used pinyon, *Pinus edulis*-juniper, *Juniperus osteosperma* woodlands adjacent to compressor stations as treatment sites and woodlands adjacent to gas wells lacking noise-producing compressors as quiet control sites [64]. The researchers were able to turn off the loud compressor stations to perform bird counts, relieving the need to adjust for detection differences in noise [62]. This group found reduced nesting species richness but in contrast to Ref.

Box 3. Do rising background sound levels alter vigilance behavior?

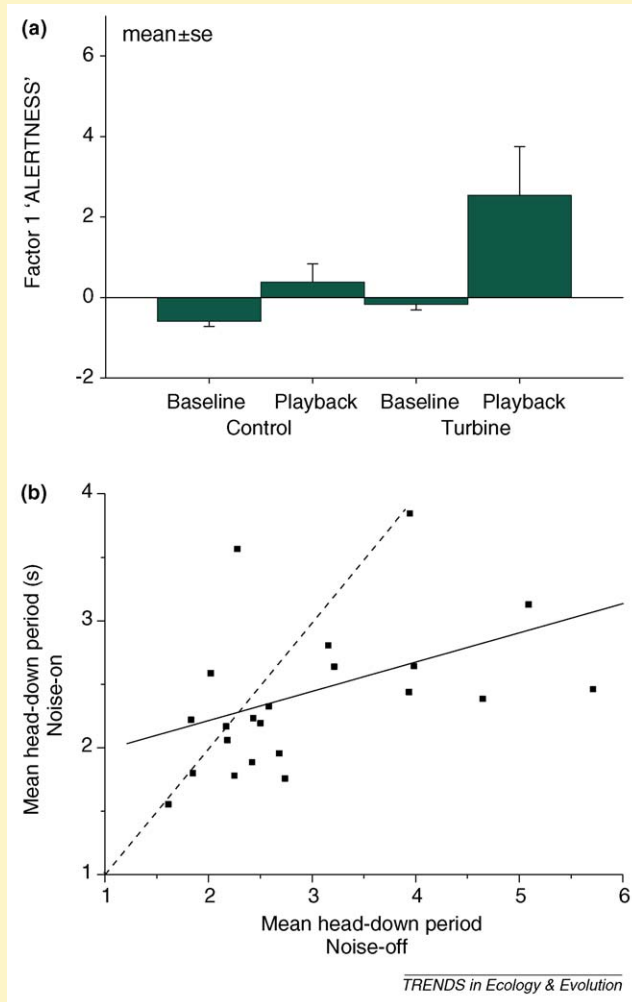


Figure I. Examples of increased vigilance behavior in noise. (a) When predator-elicited alarm calls are played back to California ground squirrels (*Spermophilus beecheyi*), adults show a greater increase in vigilance behavior at a site heavily impacted by anthropogenic noise, under power-generating wind turbines, than in a quiet control site [67]. (b) Further work on vigilance behaviors in noise comes from controlled, laboratory work with foraging chaffinches (*Fringilla coelebs*). In noise these birds decrease the interval between head-up scanning bouts, which results in fewer pecks and, thus, reduced food intake [90]. Dots depict the mean head-down period for each individual with and without white noise playback. Points below the dashed line (slope = 1) document individuals who increased scanning effort in noise. The solid regression line shows that the general trend was a more dramatic response from individuals with the lowest scanning effort. (a) adapted and (b) reproduced, with permission from Refs [67] and [90], respectively.

[62], no reduction in overall nesting density. Unexpectedly, nest success was higher and predation levels lower in loud sites (also see Ref. [52]). The change in bird communities between loud and quiet sites appears to be driven by site preference; the response to noise ranged from positive to negative, with most responses being negative (e.g. three species nested only in loud sites and 14 species nested only in quiet, control sites). However, given the change in community structure, habitat selection based on background sound level is not the only interpretation of these data, as birds might be using cues of reduced competition pressure or predation risk to make habitat decisions [64]. The major nest predator in the study area, the western scrub jay, *Aphelocoma californica*,

was significantly more likely to occupy quiet sites, which might explain the nest predation data [64]. It is probable that nest predators rely heavily on acoustic cues to find their prey. The study also found that the two bird species most strongly associated with control sites produce low-frequency communication calls. These observations suggest masking as an explanatory factor for these observed patterns. This work highlights the potential complexity of the relationship between noise exposure and the structure and function of ecological systems.

Predation risk and human disturbance increase vigilance behaviors (e.g. Refs [50,86]), at a cost to foraging efficiency [87,88]. Habitat features that influence predator detection, such as vegetation height, predict predation risk [88]. If background sound level interferes with the ability of an animal to detect predators, risk can increase. Do animals perceive background sound level as a habitat characteristic that predicts predation risk? Two recent studies document increased vigilance behaviors in high levels of noise (Figure I). It seems probable that these increased anti-predator behaviors are the result of attempted visual compensation for lost auditory awareness. Evidence from ungulates near roads suggests this is the case (Figure II); however, the distinct contributions of traffic as perceived threat and traffic noise as a sensory obstacle are confounded in road studies. Experimental research with birds and mammals suggests that lost visual awareness owing to habitat obstruction reduces food-searching bouts and increases vigilance (reviewed in Ref. [89]). Although no evidence exists (but see Ref. [64]), if noise shifts the spatial distribution of foraging effort, then plant growth and seed dispersal could also be altered.

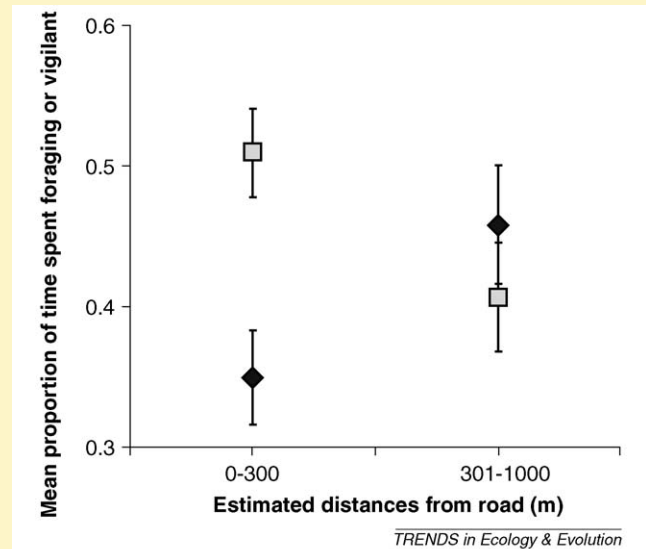


Figure II. An example of the foraging–vigilance tradeoff. Pronghorn (*Antilocapra americana*) spend more time being vigilant (squares) and less time foraging (diamonds) within 300 meters of a road [86]. Future experiments should attempt to separate the roles of traffic as perceived threat and reduced auditory awareness on these tradeoffs. Reproduced, with permission, from Ref. [86].

Adjusting temporal, spectral, intensity and redundancy characteristics of acoustic signals to reduce masking by noise has been demonstrated in six vertebrate orders [4–7,65]. These shifts have been documented in a variety

of signal types: begging calls of bird chicks [66], alarm signals in ground squirrels [67], contact calls of primates [68], echolocation cries of bats [65] and sexual communication signals in birds, cetaceans and anurans [4–7,69]. Vocal adjustment probably comes at a cost to both energy balance and information transfer; however, no study has addressed receivers.

Masking also affects the ability of animals to use sound for spatial orientation. When traffic noise is played back to grey treefrog, *Hyla chrysoscelis* females as they attempt to localize male calls, they take longer to do so and are significantly less successful in correctly orienting to the male signal [70]. Similar studies with the European tree frog, *Hyla arborea* show decreased calling activity in played back traffic noise [71]. *H. arborea* individuals appear to be unable to adjust the frequency or duration of their calls to increase signal transmission, even at very high noise intensities (88 dB(A), [71]); although other frogs have been shown to slightly shift call frequencies upward in response to anthropogenic noise [69]. These are particularly salient points. It is likely that some species are unable to adjust the structure of their sounds to cope with noise even within

the same group of organisms. These differences in vocal adaptability could partially explain why some species do well in loud environments and others do poorly [5,7,72].

Under many conditions, animals will minimize their movement sounds. For example, mice preferentially select quieter substrates on which to move [73]. Adventitious sounds of insects walking contain appreciable energy at higher frequencies (main energy ~3–30 kHz [16]) and are thus unlikely to be fully masked by most anthropogenic noise (<2 kHz [4–7]) but the spectral profile near many noise sources contains significant energy at higher frequencies (e.g. Ref [74]). Foundational work with owls and bats has shown that frequencies between approximately three and eight kHz are crucial for passive sound localization accuracy [38,75]. In fact, a recent laboratory study demonstrated that gleaning bats avoided hunting in areas with played back road noise that contained energy within this spectral band ([74]; Box 4).

Adapting to a louder world

Animals have been under constant selective pressure to distinguish pertinent sounds from background noise. Two

Box 4. Effects of acoustic masking on acoustically specialized predators

Laboratory work has demonstrated that gleaning bats (who use prey-generated sounds to capture terrestrial prey; Figure 1a) avoid noise when foraging (Figure 1b). Interestingly, treefrogs, a favorite prey of some neotropical gleaning bats, tend to call from sites with high ambient noise levels (primarily from waterfalls) and bats prefer frog calls played back in quieter locations [91]. Extinction risk in bats correlates with low wing aspect ratios (a high cost and low wing-loading morphology), a trait that all gleaning bats share [92]. A recent analysis indicates that urbanization most strongly impacts bats with these wing shapes [93]. However, low wing aspect ratio is also correlated with habitat specialization, edge intolerance and low mobility [92,93], obscuring the links between a gleaning lifestyle, louder background sound levels and extinction risk as urbanization reduces available habitat, fragments landscapes and generates noise concomitantly.

A radio-tag study showed that a gleaning bat, *Myotis bechsteinii*, was less likely to cross a roadway (three of 34 individuals) than was a sympatric open-space foraging bat, *Barbastella barbastellus* (five out of six individuals; [94]), implicating noise as a fragmenting agent for some bats. The latter species hunts flying insects using echolocation (an auditory behavior that uses ultrasonic signals above the spectrum of anthropogenic noise) [94]. Similar findings suggest acoustically mediated foragers are at risk: terrestrial insectivores were the only avian ecological guild to avoid road construction in the Amazon [95] and human-altered landscapes limited provisioning rates of saw-whet owls [96]. That these animals plausibly rely on sound for hunting might not be coincidental.

(a)



(b)

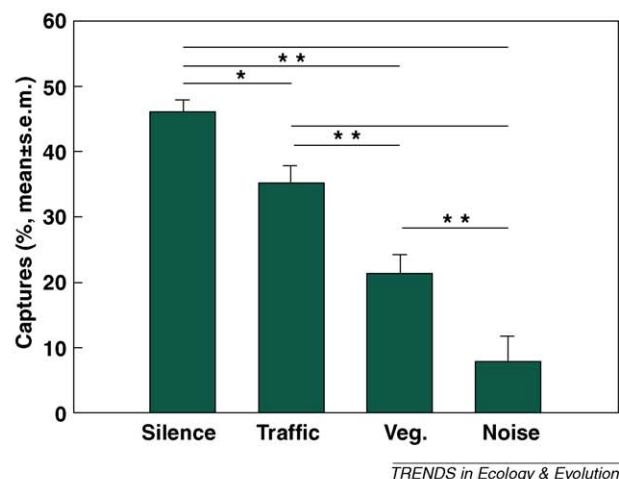


Figure 1. Gleaning bats avoid hunting in noise. The pallid bat, *Antrozous pallidus* (a), relies upon prey-generated movement sounds to localize its terrestrial prey. Recent work demonstrates that another gleaning bat, the greater mouse-eared bat, *Myotis myotis*, avoids foraging in noise [74]. (b) A laboratory two-compartment choice experiment showed that this bat preferred to forage in the compartment with played-back silence versus the compartment with played-back traffic, wind-blown vegetation or white noise. This pattern held true whether the percentage of flight time, compartment entering events, the first 25 captures per session or overall capture percentage were compared across silent and noise playback compartments. Asterisks indicate the results of post repeated-measure ANOVA, paired t-tests (** $P < 0.01$, * $P < 0.05$, $N = 7$ bats). The differences between noise types (traffic, vegetation and white noise) probably reflect increased spectral overlap between prey-generated movement sounds and the spectral profile of the noise. Reproduced with permission from Scott Altenbach (a) and Ref. [74] (b).

Box 5. Outstanding questions

- Multiple studies with birds have demonstrated signal shifts in anthropogenic noise that does not substantially overlap in frequency with the birds' song [4–7,72]. To what extent does low-frequency anthropogenic noise inhibit perception of higher frequency signals? Mammals appear more prone to the 'upward spread' of masking than do birds [85,97]. Noise commonly elevates low frequency ambient sound levels by 40 dB or more, so small amounts of spectral 'leakage' can be significant. Laboratory studies should be complimented by field studies that can identify the potential for informational or attentional effects [98]. This work should use anthropogenic noise profiles and not rely on artificial white noise as a surrogate. Furthermore, we suggest that future studies measure or model sound levels (both signal and background) at the position of the animal receiver (*sensu* Ref. [23]).
- What roles do behavioral and cognitive masking release mechanisms [85] have in modifying the capacity of free-ranging animals to detect and identify significant sounds? Only one study has examined the masked hearing thresholds of natural vocal signals in anthropogenic noise [97]. This work found that thresholds for discrimination between calls of the same bird species were consistently higher than were detection thresholds for the same calls [97]. This highlights the lack of knowledge concerning top-down cognitive constraints on signal processing in noise. Can noise divide attention and reduce task accuracy by forcing the processing of multiple streams of auditory information simultaneously [99]?
- Do animals exploit the temporal patterning of anthropogenic noise pollution (see Ref. [4])? Alternatively, what constitutes a chronic exposure and how does this vary in relation to diel activity schedules?
- Does noise amplify the barrier effects of fragmenting agents, such as roads [94,100]?
- What routes (exaptation, behavioral compensation, phenotypic plasticity and/or contemporary evolution) lead to successful tolerance of loud environments?
- What role does audition have in vigilance behaviors? Are visually mediated predators at an advantage in loud environments when prey animals rely upon acoustical predator detection?
- Do animals directly perceive background sound level as a habitat characteristic related to predation risk? A noise increase of 3 dB(A) is often identified as 'just perceptible' for humans, and an increase of 10 dB(A) as a doubling of perceived loudness. These correspond to 30% and 90% reductions in alerting distance, respectively. Do organisms assess reduced alerting distance by monitoring other acoustical signals?

examples include penguin communication systems being shaped by wind and colony noise [76] and frog systems driven to ultrasonic frequencies by stream noise [77]. A meta-analysis of the acoustic adaptation hypothesis for birdsong (the idea that signals are adapted to maximize propagation through the local habitat) found only weak evidence for this claim [78]. Physiological constraints and selective forces from eavesdropping could explain this weak relationship [78], in addition to variation of noise profiles across nominally similar habitat types (e.g. insect noise, [79]).

Phenotypic plasticity enables one adaptation to anthropogenic noise. The open-ended song learning documented in great tits, *Parus major* helps explain the consistent song shifts observed in all ten comparisons between urban and rural populations [72]. Contemporary evolution (fewer than a few hundred generations) has now been quantified in several systems [80] and we might anticipate similar microevolutionary changes in many species with rapid generation times that consistently experience acoustical environments dominated by noise, particularly in increasingly fragmented landscapes.

Perhaps the greatest predictors of the ability of a given species to succeed in a louder world will be the degree of temporal and spectral overlap of biologically crucial signals with anthropogenic noise (Figure 1), and their flexibility to compensate with other sensory modalities (e.g. vision) when auditory cues are masked. Given known sensory biases in learning [81], many animals will be constrained in their ability to shift from acoustical inputs to other sensory cues for dynamic control of complex behavioral sequences.

Conclusions and recommendations

The constraints on signal reception imposed by background sound level have a long history of being researched in bioacoustics, and it is increasingly clear that these constraints underlie crucial issues for conservation biology. Questions have been raised about the value of behavioral studies for conservation practice (for a review

see Ref [82]), but ethological studies of auditory awareness and the consequences of degraded listening opportunities are essential to understanding the mechanisms underlying ecological responses to anthropogenic noise (Box 5). These studies are more challenging to execute than observation of salient behavioral responses to acute noise events, but they offer opportunities to explore fundamental questions regarding auditory perception in natural and disturbed contexts.

Chronic noise exposure is widespread. Taken individually, many of the papers cited here offer suggestive but inconclusive evidence that masking is substantially altering many ecosystems. Taken collectively, the preponderance of evidence argues for immediate action to manage noise in protected natural areas. Advances in instrumentation and methods are needed to expand research and monitoring capabilities. Explicit experimental manipulations should become an integral part of future adaptive management plans to decisively identify the most effective and efficient methods that reconcile human activities with resource management objectives [83].

The costs of noise must be understood in relation to other anthropogenic forces, to ensure effective mitigation and efficient realization of environmental goals. Noise pollution exacerbates the problems posed by habitat fragmentation and wildlife responses to human presence; therefore, highly fragmented or heavily visited locations are priority candidates for noise management. Noise management might also offer a relatively rapid tool to improve the resilience of protected lands to some of the stresses imposed by climate change. Shuttle buses and other specialized mass transit systems, such as those used at Zion and Denali National Parks, offer promising alternatives for visitor access that enable resource managers to exert better control over the timing, spatial distribution, and intensity of both noise and human disturbance. Quieting protected areas is a prudent precaution in the face of sweeping environmental changes, and a powerful affirmation of the wilderness values that inspired their creation.

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The effects of wind turbines on antipredator behavior in California ground squirrels (*Spermophilus beecheyi*)

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ABSTRACT

Electricity-generating wind turbines are an attractive energy source because they are renewable and produce no emissions. However, they have at least two potentially damaging ecological effects. Their rotating blades are hazardous to raptors which occasionally fly into them. And wind turbines are very noisy when active, a feature that may interfere with the lives of animals beneath them. We studied California ground squirrels (*Spermophilus beecheyi*) in the Altamont Pass Wind Resource Area of Northern California. These squirrels emit vocalizations that alert others to the presence of a predator, and so may be forced to compensate for turbine noise by modifying antipredator behavior. We compared the antipredator behavior of squirrels at two sites, one close to and the other far from turbines, and under two conditions, during baseline and playback of conspecific alarm calls. We generated composite two variables using principle components analysis, one representing vigilance and one representing another cautionary antipredator tactic, for further statistical comparisons. Animals at the Turbine site exhibited elevated levels of vigilance and showed increased caution demonstrated in part, by returning to the area near their burrows during alarm calling. We conclude that this site difference is probably caused by the disparity in turbine noise, since predator abundance, group size, and vegetation type and density were similar for the two sites. Though population level impacts of these behavioral differences remain to be explored, our results indicate that behavioral impacts of turbines on wildlife should be considered during future turbine development.

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1. Introduction

Animals can be important gauges of ecological disturbances (Sullivan and Sullivan, 2001). Under modified conditions, the demographics, dynamics, and phenology of populations can be measured to determine how different environmental perturbations affect species (Miller and Mullette, 1985; Wilson et al., 1997; Blaustein et al., 2001; Beebee, 2002; Waser and

Ayers, 2003). Data from these studies can then be used to make recommendations for mitigation (Thiollay, 1989; Price et al., 1994; Carey and Johnson, 1995; Wilson et al., 1997; Sullivan and Sullivan, 2001) and to measure the efficacy of such mitigation attempts (Miller and Mullette, 1985; Peach et al., 1999).

Installations of electricity-generating wind turbines, or windfarms, create an ecological disturbance that affects both

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resident and transient animals moving through these farms. In the Altamont Pass Wind Resource Area (APWRA) in Northern California, over 7000 wind turbines have been installed since the early 1980s (Davidson, 1998) with close to 4700 still in operation in 2002 (Nakafuji et al., 2002). Some impacts of these windmills are already well documented. Raptors are killed by turbines after flying into rapidly rotating turbine blades. During 1994 for example, 348 raptor fatalities were reported in the APWRA of which 35 were golden eagles (Alameda County, 1998). Decision-makers have identified this as a potential problem and have attempted to mitigate such impacts in the redevelopment of windfarms in the Altamont Pass (Alameda County, 1998).

Though mortality studies and population measurements certainly identify ecological disturbances posed by windfarms, behavioral studies can provide additional sensitive measures of the effects of anthropogenic habitat-modifications on animals (for examples, see Witherington, 1997; Eadie et al., 1998; Pettifor et al., 2000; Rabin et al., 2003; Slabbekoorn and Peet, 2003; Brumm, 2004; Foote et al., 2004; McDonald and St Clair, 2004; Sun and Narins, 2005). Animals living beneath strings of turbines or on hillsides close to turbine installations may be affected by this acoustically challenging environment. For resident wildlife using sound to communicate, high-amplitude noise produced by turbines may interfere with the detection of acoustic signals, a phenomenon known as acoustic “masking” (Patterson and Green, 1978). If turbines create new challenges for resident animals, individuals may modify their behavior to cope. Such a behavioral shift would be indicative of ecological disturbance.

2. Rationale

In this paper we use California ground squirrel (*Spermophilus beecheyi*) antipredator behavior in the APWRA as one gauge of the ecological disturbances caused by electricity-generating wind turbines and the high-amplitude noise they emit during operation. California ground squirrels are an ideal species with which to explore these potential impacts both because *S. beecheyi* is abundant and because California ground squirrels prefer the kind of open grassland habitat in which APWRA turbines have been installed. Ground squirrels are highly vocal in a variety of contexts and depend on acoustic communication to avoid predation (Owings and Hennessy, 1984; Hanson and Coss, 2001). Any interference with communication due to turbine noise has the potential to pose a significant challenge to individual survival. If squirrels have difficulty hearing the antipredator calls of others because of the masking effects of turbine noise, they may detect predators less quickly and so experience higher predation risk. In response, squirrels might change their visual scanning behavior, feeding behavior, and amount of time spent near or in safe refuge through both developmental and evolutionary processes. We will explore how behavior differs between a turbine and a control site during baseline conditions and during playback of ground squirrel alarm vocalizations. We will also assess group size and predator densities at the two sites as potential confounding factors since antipredator

behavior can vary as a function of these two factors (Lima and Dill, 1990).

3. Materials and methods

3.1. Location and study site

The Altamont Pass Wind Resource Area (APWRA) in Northern California spans over 160 km². Approximately 3500 of the turbines currently installed in the APWRA (56% of all turbines installed in this area) are 100 kW Kenetech Windpower, Inc. turbines. The production of wind-generated electricity is seasonal with almost 70% of the annual output being produced in the Spring and Summer quarters (Nakafuji et al., 2002). California ground squirrels are most active during this period of the year.

Research for this experiment was conducted at the approximately 7500 hectare Los Vaqueros Watershed in the APWRA. The watershed consists primarily of oak-savanna habitat with rolling hills and grassland. The height of grasses and other vegetation is kept low by cattle ranching. Squirrels were studied at two field sites. The first, the Turbine site, is located on a hillside immediately adjacent to a string of 6 turbines (lat: 37°48.02'N; long: 121°43.25'W) with strings of wind turbines installed on the surrounding hillsides, as well. All turbines are 100 kW Kenetech turbines. Turbine activity was variable but peaked in the morning. All observations were conducted among the abundant ground squirrel burrows adjacent to the turbines. The Control site is 2.7 km from the Turbine site and is located in an area where turbines are absent (lat: 37°46.64'N; long: 121°43.80'W). Hills bordering the Control site act as a barrier to turbine noise emitted in the surrounding area. As a result, turbine noise was negligible (see below). Grasses and scattered shrubs at each site were cut prior to trials to aid in visibility and to maintain similar patterns of signal degradation and attenuation when alarm calls were broadcast.

3.2. Acoustic characterization of ambient noise at sites

Sound pressure levels were measured at each site using a Bruel and Kjaer 2209 sound-pressure level meter set at Impulse-Hold (flat/linear response) with UA-0237 wind-screen. Twenty readings were taken, each separated by at least 1 min. Each measurement was taken ~0.25 m above the substrate for a period of 5 s. At the Control site, one set of readings was taken. At the Turbine site, two sets were taken, one while turbines were active and one while turbines were inactive. The time average decibel level (L_p) was then calculated for each set with the 20 documented readings.

Recordings of ambient noise at each site were also made at ground level near ground squirrel burrows using an AKG SE5E-10 microphone with omnidirectional capsule (CE2) enclosed in a Rycote windscreens and windsock. Ambient noise at the Turbine site was recorded once when all turbines surrounding the site were active and again when no turbines were active. Recordings were made on the dedicated audio track of a VHS tape using a JVC BR-S405U VHS video cassette

recorder with audio set to Hi-Fi. To produce spectrograms and power spectra, recordings were played from a Panasonic AG-7350 video cassette recorder, digitized via a Sony DVMC-DA2 Media Converter (16 bit, 48 kHz sampling frequency), and saved as uncompressed digital WAVE files using BIAS Peak DV (Berkeley Integrated Audio Software, Inc.). Cool Edit Pro 2.0 (Syntrillium, Inc.) was then used to generate spectrograms and power spectra (sampling rate of 48 kHz; 1024-Point FFT Spectrum with Hamming Filter).

3.3. Characterization and analysis of predator abundance

In order to characterize the predator abundance at each site, normative data on *S. beecheyi* predators were collected during a subset of 10-min experimental trials occurring between July 15 and August 26, 2002. During each trial, the presence of raptors and of predatory mammals (coyotes, badgers, and bobcats) was recorded. A two-tailed Fisher's exact test evaluated differences in predator abundances between the two sites. Because these 10-min experimental trials were short, little opportunity was provided to observe predators. As a result, we also analyzed predator abundances from a previous field season where normative data on predators was collected during 30-min samples. These data were collected at the same two sites between August 13 and Septem-

ber 6, 2001 and were also analyzed using a two-tailed Fisher's exact test.

3.4. Playback stimuli used in playback experiments

Alarm call series were elicited and recorded from ground squirrels in the field during or immediately after exposure to a domestic dog, simulating a canid predator, between August 20 and September 6, 2001. From these series, 5 min playbacks were created that started with a chatter, a call typically given in response to mammalian predators (Owings and Virginia, 1978) and progressed into repetitive calls (chats) known to maintain elevated vigilance (Owings and Hennessy, 1984; Owings et al., 1986; Loughry and McDonough, 1988). Eight different series from squirrels of different age and sex classes were used. Four of these series, referred to hereafter as Turbine-Call-Series, were obtained from 4 different squirrels at two turbine sites during periods of moderate to high turbine activity. Another 4 call series were obtained from 4 different squirrels at a nonturbine site and will be referred to as Nonturbine-Call-Series. Filtering and noise reduction was performed using Cool Edit Pro 2.0 (Syntrillium, Inc.) to remove ambient noise from playbacks while preserving the ground squirrel acoustic signal (see Fig. 1). For additional details on call recording, digitization, and processing, see Rabin (2005).

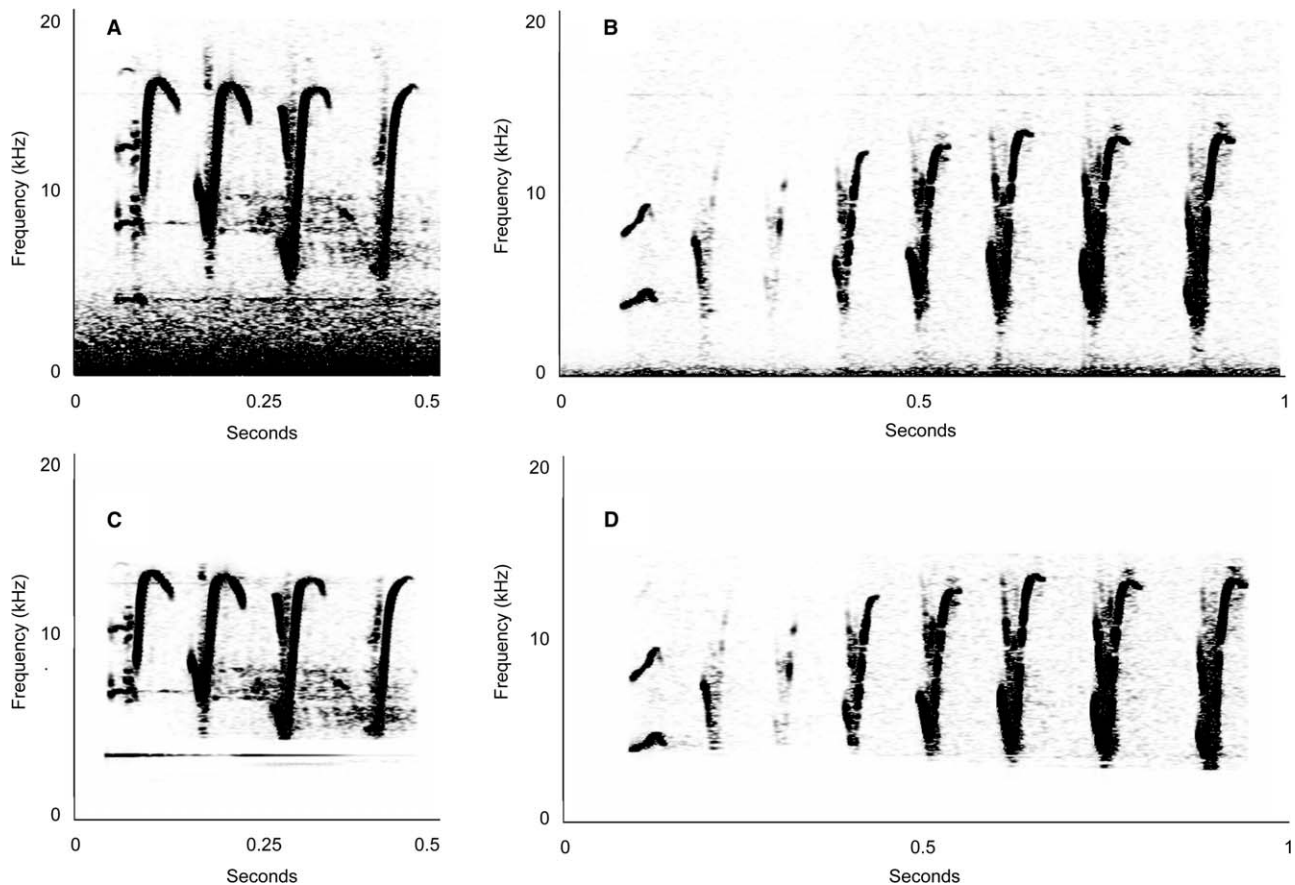


Fig. 1 – Spectrograms of initial chatters in two playback call series: (A) Chatter from a Turbine-Call-Series playback; (B) Chatter from a Nonturbine-Call-Series playback; (C) Chatter in spectrogram A after noise reduction and bandpass filtering and (D) Chatter in spectrogram B after noise reduction and bandpass filtering. Spectrograms were produced using a 512-point FFT with Hamming Filter.

To ensure that calls remained provocative after noise filtering, behavioral responses to playbacks were compared with baseline behavior, as described below, to explore for appropriate antipredator responses to playbacks. Because alarm calls reliably elicit antipredator responses in squirrels (Loughry and McDonough, 1988; Loughry and McDonough, 1989; Hanson and Coss, 2001) a lack of such responses at both the Control and Turbine sites would indicate that the calls were not appropriate for use.

3.5. Playback experiment

Prior to the experiment, 8 adults (2 males and 6 females) and 34 juveniles (17 males and 17 females) from the Turbine site were live trapped, tranquilized, aged (“juvenile” or “adult”), sexed, and dye marked for individual identification as were 7 adults (4 males and 3 females) and 45 juveniles (17 males and 28 females) from the Control site (methods described in Rabin, 2005). Data were collected between July 15 and August 26, 2002 with the first trial beginning 3 days after the last tranquilization.

Focal squirrels were followed for 10 min, beginning with a 5-min baseline sample and ending with a 5-min playback sample. Samples were identical except that during playback samples, a 5-min alarm call series was broadcast. Though turbine activity at the Turbine site was variable, samples were always taken there when at least some of the turbines were active. Squirrels were videotaped from an observer’s blind at a distance of 40–60 m. Videotaping allowed for behavioral coding in the lab using continuous focal animal sampling (Altmann, 1974). The percent of time spent in each of the following behaviors was recorded: Head Up, Head Down, Post, Feed, At Burrow, and In Burrow (see Table 1). Instantaneous focal animal samples (Altmann, 1974) were also taken every 30 s from a subset of squirrels to count the number of squirrels within 3 m of the focal squirrel. Instantaneous data from each squirrel were then averaged to obtain clustering data, a measure used in the past as a surrogate for group size (Metcalf, 1984b; Metcalfe, 1984a; Blumstein et al., 2001). An actual measure of group size could not be made because squirrels did not consistently forage together as a group.

During playbacks, alarm calls were broadcast at ground level from a speaker array made up of four Motorola piezoelectric tweeters driven in pairs by two amplifier channels. Call

series were played from compact disc using a battery powered Sony CD Compact Player, model D-231 attached to a Coustic MP 380 (125 W/channel) amplifier. Gain was set such that the amplitude of the initial chatter in each series was 105 dB SPL at 0.25 m from the speaker array (measured by a Bruel & Kjaer model 2209 SPL meter set at peak amplitude with linear weighting). Trials were separated by at least 1 hour.

Trials were only initiated on squirrels that were within the borders of a 25 m² baited area located 40 m from the speaker array. Prior to the start of trials each day, this area was baited with 600 g of oats to attract squirrels. In between successive trials on the same day, oats were replenished with an additional sprinkling of 300 g. Trials began no less than 30 min after baiting, to allow animals to resume natural patterns of behavior.

Two variants of the experimental design were performed, one in which focal squirrels were played a Nonturbine-Call-Series during playback. In the other, a Turbine-Call-Series was broadcast. Squirrels served as focal animals in each variant no more than once, though not all squirrels were focal animals in both variants. We alternated between playing Turbine-Call-Series and Nonturbine-Call-Series on successive trials to prevent order effects.

3.6. Playback experiment statistical analysis

Because many of the coded behaviors are correlated, we attempted to reduce the analyzed behaviors (Head Up, Head Down, Post, Feed, and At Burrow) into a subset of composite variables indicative of antipredator behavior. To accomplish this, a single principle components analysis (PCA) was performed that included all samples (for baseline and playback as well as for Nonturbine-Call-Series and Turbine-Call Series samples). The behavioral measures, “Average number of squirrels within 3 m” and “In Burrow” were excluded and analyzed separately. We excluded “In Burrow” from the PCA because our primary interest in performing the PCA was to create composite variables indicative of antipredator behavior occurring outside of the burrow. The PCA was generated without rotation and all components with eigenvalues greater than 1 were extracted. Available component scores for individual squirrels could thus be analyzed for comparisons of site, baseline vs. playback conditions, and age class.

Table 1 – Definitions of coded behaviors

Behavior	Definition
Head Up	Animal stands or sits with head oriented so that the animal’s eyes are above the horizontal axis of its body. The animal’s front feet may or may not be off the ground. However, the axis of the body remains horizontal or diagonal relative to the ground. Animal’s body axis is not vertically oriented.
Head Down	Animal stands or sits with head either touching the ground or oriented toward the ground. Animal’s eyes are below the horizontal axis of its body.
Post	Animal sits on hind limbs. Body axis is rotated upwards and oriented vertically. Back is not bent and is perpendicular to the substrate.
Feed	Animal chews on food, manipulates food with mouth, or brings food to the mouth with front paws.
At Burrow	Animal is in view and located within 12 in. of burrow entrance.
In Burrow	Animal is out of view and located inside its burrow.

Unless stated otherwise, type III weighted repeated measures ANOVAs with sample (baseline vs. playback) as the repeated measure and with site (Turbine vs. Control) and age (adult vs. juvenile) as fixed effects were then performed on each principle component (PC) using the generated individual component scores. Analyses were performed separately for Nonturbine-Call-Series and Turbine-Call-Series trials because not all squirrels were sampled in both variants of trials (only 13 out of 32 squirrels were focal animals in both variants). As a result, the two trial series could not be considered a repeated measure.

A weighted ANOVA was used to cope with inherent between-site heteroscedasticity in the data (Neter et al., 1985). Weighted least squares weights were generated by first running the ANOVA without weighting and then using the inverse of the variance of the error term ($1/\sigma_i^2$) at each site as the weight for squirrels at that site. "Average number of squirrels within 3 m" was also analyzed using a Type III repeated measures ANOVA with site as a fixed effect. However, age class was not included as a factor because small sample sizes

forced us to pool adults and juveniles. Weighting was unnecessary because there was no violation of the assumption of homogeneity of variance. For the behavior "In Burrow", two-tailed Mann-Whitney U Tests were performed with site (Turbine vs. Control) as a grouping variable.

4. Results and interpretation

4.1. Acoustic characterization of site noise

The average decibel level for ambient noise at the Control site was substantially lower than at the Turbine site during turbine activity (79.8 dB vs. 110.2 dB, ranges = 70–88 dB and 93–118 dB SPL respectively). Representative spectrograms and power spectra for ambient noise at the sites are presented in Fig. 2. When turbines are active, the Turbine site has a complex spectral signature with high amplitude noise extending as high as ~6–8 kHz. The "swooshing" sound of the sweeping windmill blades are identified on the spectrogram in Fig. 2A by arrows. The ambient noise spectrum at the Control site

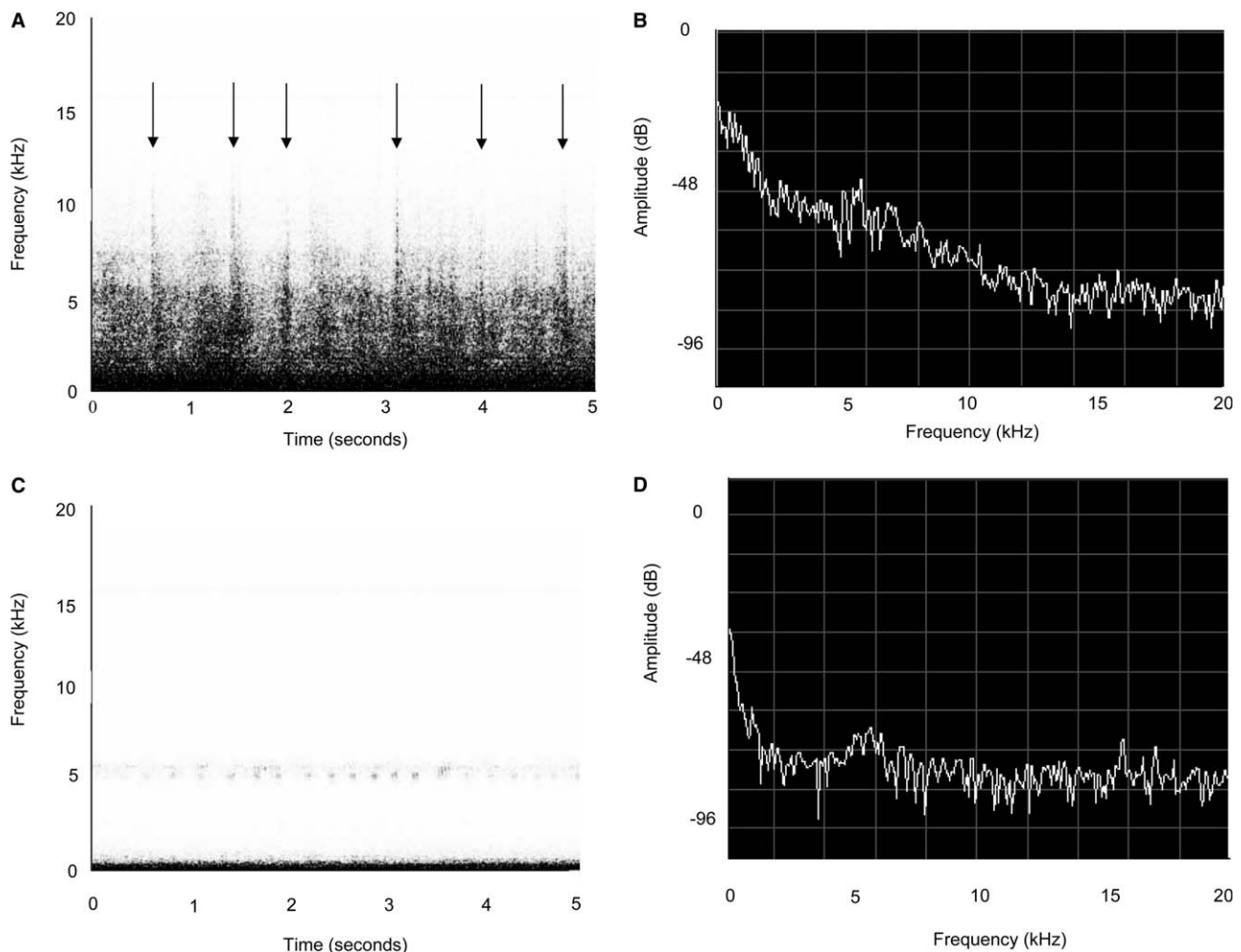


Fig. 2 – Spectrograms and power spectra of ambient noise at Turbine and Control sites: (A) Turbine site ambient noise. Arrows mark the spectral signatures of the turbine blades 'swooshing' as they rotate. (B) Power spectrum of the ambient noise shown in A. (C) Control site ambient noise and (D) Power spectrum of the ambient noise shown in C. Spectrograms and power spectra were produced using 1024-point FFT with Hamming filter. Power spectra were produced by averaging the five second recordings shown in the spectrograms.

is much simpler with noise produced mostly at very low frequencies by wind. Crickets were abundant at the Control site with chirping occurring repetitively at ~5 kHz. When turbines were not in operation at the Turbine site, ambient noise was very similar to that at the Control site both in terms of decibel level (75.8 dB, range = 63.5–83.5 dB) and frequency characteristics. Though a separate spectrogram and power spectrum are not presented here for the Turbine site during turbine inactivity, both look very similar to those in Figs. 2C and D.

4.2. Principle components analysis

Twenty-four Nonturbine-Call-Series trials (n = 6 adults; 18 juveniles) and 21 Turbine-Call Series trials (n = 4 adults; 17 juveniles) were used to generate the PCA. Both the baseline sample and the playback sample from each trial were used in the PCA, for a total of 90 samples. Two PCs were extracted from the PCA (see Table 2). PC 1 explained 64.1% of the variance and can be interpreted as a measure of vigilance. The different individual behaviors loaded on this PC in a general order of increasing alertness (e.g. Posting is more vigilant than Head Up and Head Down is less alert than any other behavior). As a result, we have named PC 1, “ALERTNESS”. PC 2 explained 21.2% of the variance and was indicative of a different tactic that involved staying in close proximity to refuge, and to a lesser extent posting. PC 2 was less a composite score indicative of vigilance and more a score that expressed a squirrel’s return to the area near its burrow (see PC 2 scores in Table 2). Therefore, we have named PC 2, “PROXIMITY TO SHELTER.”

4.3. Behavioral responses during trials

Levene’s tests on component scores of individual squirrels for ALERTNESS and PROXIMITY TO SHELTER determined that in some cases, the variance was not homogeneous across sites. As a result, weighted ANOVAs were performed using site weights that were generated separately for Nonturbine-Call-Series and Turbine-Call-Series trials. Nonturbine-Call-Series trials and Turbine-Call-Series trials were thus analyzed separately in different weighted ANOVAs.

4.3.1. Test of call-series effectiveness

Through statistical analysis of the repeated measure (baseline vs. playback), we were able to assess whether or not the two types of playbacks (Nonturbine or Turbine) were evocative.

Table 2 – Summary of principle component loadings for the two extracted principle components		
Behavior	“ALERTNESS” PC 1	“PROXIMITY TO SHELTER” PC 2
Posting	0.761	0.477
Head Up	0.730	–0.621
At Burrow	0.564	0.638
Feed	–0.910	0.148
Head Down	–0.973	0.138
Eigenvalue	3.024	1.060
Percent of variance	64.1	21.2

In fact, the two types of playbacks did differ in their ability to evoke an antipredator reaction. Squirrels responded to Nonturbine-Call-Series, but not to Turbine-Call-Series. Squirrels responded to Nonturbine-Call-Series (see Fig. 3) by significantly increasing ALERTNESS during playback ($F_{[1,20]} = 21.353$; $p < 0.001$). PROXIMITY TO SHELTER scores changed differentially at the two sites, increasing at the Turbine site on playback but decreasing at the Control site (interaction between site and the repeated measure; $F_{[1,20]} = 9.238$; $p = 0.006$; see Fig. 4). Because behavioral shifts occurred during playback for both PCs, we can conclude that the Nonturbine-Call-Series were behaviorally provocative. In contrast, playbacks of the

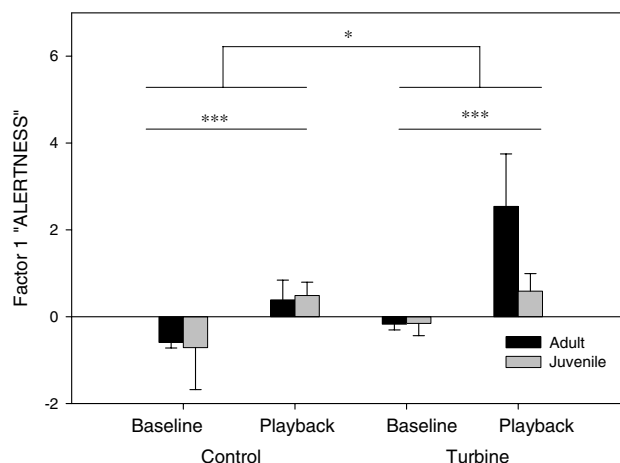


Fig. 3 – Mean (and SE) of PC 1 “ALERTNESS” scores for trials. Asterisks indicate significant differences in the repeated measure and site. The difference in values between baseline and playback is highly statistically significant (***) (weighted repeated measures ANOVA, $p < 0.001$). Values are also significantly higher (*) at the Turbine site than at the Control site (weighted repeated measures ANOVA, $p < 0.05$).

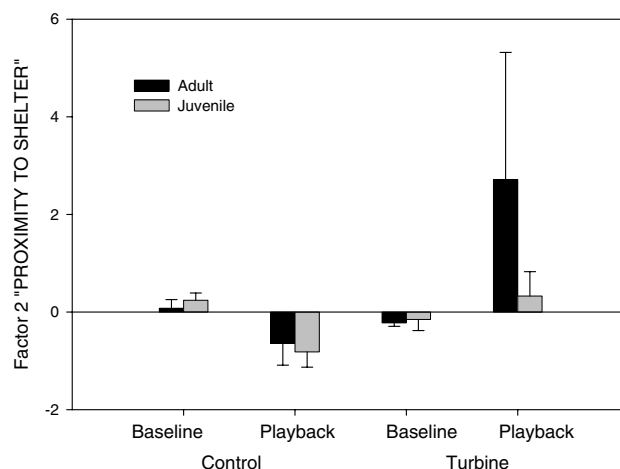


Fig. 4 – Mean (and SE) of PC 2 “PROXIMITY TO SHELTER” scores for trials. Squirrels at the Turbine site increased PROXIMITY TO SHELTER during playbacks. At the Control site, the opposite pattern emerged (interaction between site and the repeated measure, $F_{[1,20]} = 9.238$; $p = 0.006$).

Turbine-Call-Series did not elicit a response from squirrels for either ALERTNESS ($F_{[1,17]} = 2.899$; $p = 0.107$) or for PROXIMITY TO SHELTER ($F_{[1,17]} = 0.203$; $p = 0.658$).

There are a variety of reasons that Turbine-Call-Series may have been ineffective. Although Rabin et al. (2003) reported that the noise reduction feature in Cool Edit Pro can be utilized with minimal signal loss in quantitative acoustic analyses, the high noise-to-signal ratios in the Turbine-Call-Series may have exceeded the noise reduction capabilities of this software. To our ears, Turbine-Call-Series remnant noise (See Fig. 1C) was associated with a slightly artificial quality after noise reduction. Nevertheless, we needed to assess how provocative these calls were through playbacks, an assay in which the squirrels proved to be unresponsive. On the other hand, the low noise content in the Nonturbine-Call-Series may have been in the range in which this noise-reduction feature is effective. Second, recordings taken at turbine sites may have been degraded at the time of recording because high amplitude turbine noise forced us to significantly reduce the gain of our recorder. A third possibility is that squirrels at turbine sites emitted inherently less provocative calls. A systematic analysis of the acoustic properties of these calls could certainly test for that possibility but such an analysis is beyond the scope of this study.

Since squirrels at neither site appeared to recognize Turbine-Call-Series as alarm calls, we reasoned that data obtained during these trials were not relevant to our primary goal of exploring differences in antipredator behavior during baseline and playback. As a result, we have removed those trials from our analyses below. All subsequent analyses will report only on data obtained during Nonturbine-Call-Series trials and will hereafter be referred to simply as 'Playback trials'.

4.3.2. Site differences in antipredator behavior

Adults and juveniles did not differ in ALERTNESS ($F_{[1,20]} = 1.811$; $p = 0.193$; Fig. 3) or in PROXIMITY TO SHELTER ($F_{[1,20]} = 2.007$; $p = 0.172$; Fig. 4) in playback trials. Similarly, there are no significant interactions between age and baseline/playback or between age and location ($p > 0.10$).

Squirrels at the Turbine site showed higher levels of ALERTNESS overall than squirrels at the Control site (main site effects during trials; $F_{[1,20]} = 4.938$; $p = 0.038$; Fig. 3). This statistical difference in the main effect reflects the average of both the baseline and playback samples. The same trend is evident for baseline and playback conditions separately, but the weighted simple effects only approached significance (baseline and playback, respectively: $F_{[1,20]} = 2.803$; $p = 0.110$; $F_{[1,20]} = 3.477$; $p = 0.077$). The lack of any significant differences in simple effects is likely due to the high amount of behavioral variation among squirrels, variation that could be accounted for in the repeated-measures ANOVA but not in the simple effects design.

For PC 2, squirrels at the Turbine site increased their PROXIMITY TO SHELTER during playbacks whereas values at the Control site decreased (interaction between site and the repeated measure, $F_{[1,20]} = 9.238$; $p = 0.006$; Fig. 4).

The percent of time spent In Burrow did not differ significantly between sites for either baseline ($U_{[12,12]} = 60.0$; $p = 0.149$) or for playback ($U_{[12,12]} = 53.0$; $p = 0.241$).

4.4. Group size

Group size data were collected from a subset of 14 focal squirrels during trials ($n = 5$ Control; 9 Turbine). Squirrels reduced clustering significantly during playback (see Fig. 5) when compared with baseline ($F_{[1,12]} = 8.048$; $p = 0.015$). This change in clustering was the result of squirrels scattering during playback. However, there were no differences in clustering between the two sites ($F_{[1,12]} = 0.598$; $p = 0.454$) nor was there an interaction between site and the repeated measure ($F_{[1,12]} = 0.622$; $p = 0.446$).

4.5. Characterization of predator abundance

During 10-min trials in 2002, normative data were collected during 14 samples taken from the Control site and 17 from the Turbine site. Though differences are not statistically significant (two tailed Fisher's exact test, $p = 0.452$), raptors were present at the Control site during 7.1% of trials and were never observed at the Turbine site during data collection (see Fig. 6). Consistent with this trend, aerial predators were observed significantly more frequently during 2001 at the Control site ($n = 23$ thirty-minute trials at each site; two tailed Fisher's exact test, $p < 0.0001$). Raptors were present at the Control site during 52.1% of trials but were never observed at the Turbine site during this time (Fig. 6). Mammalian predators were not observed while collecting quantitative data in 2001 or in 2002 (Fig. 6) though they were observed at other times. At the Turbine site a resident badger, whose large burrow was located near the colony, was observed on one occasion. At the Control site, coyotes were frequently seen when predator data were not being collected.

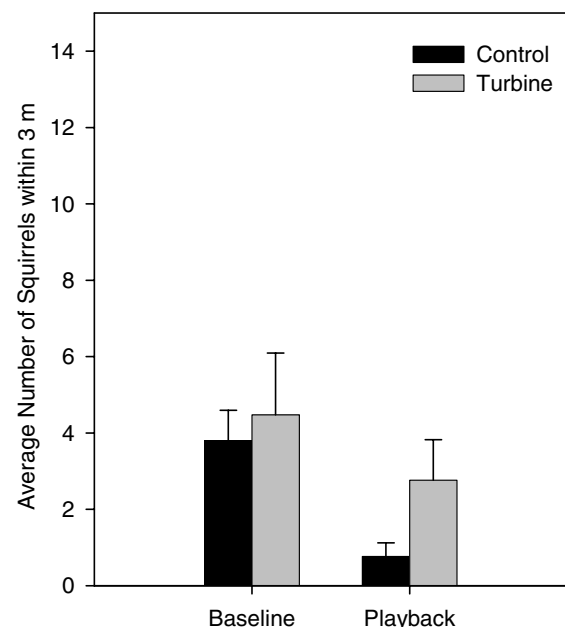


Fig. 5 – Mean (and SE) for the measurement “Average number of squirrels within 3 m of the focal squirrel.” Squirrels clustered less during playback than during baseline samples (Repeated Measures ANOVA, $p < 0.05$). Site differences were not statistically significant.

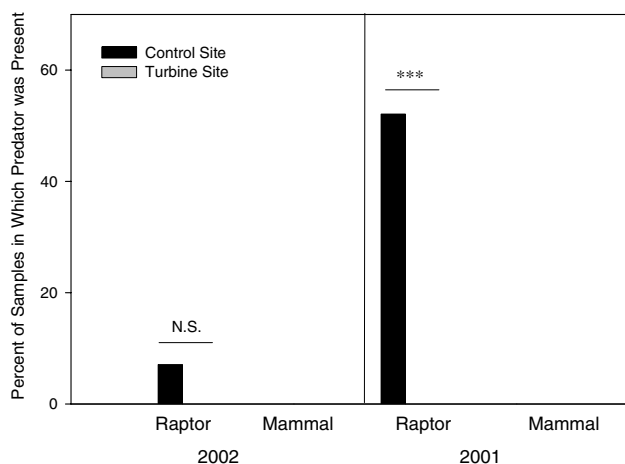


Fig. 6 – Predator abundances at each site during samples collected in 2002 and 2001. No mammals were observed during data collection in 2002 or 2001. In 2001, there were significantly more raptors (*) at the Control site than at the Turbine site (two tailed Fisher’s exact test, $p < 0.001$). In 2002, difference in raptor abundance were not statistically significant (N.S.) (two tailed Fisher’s exact test, $p > 0.1$).**

5. General discussion

5.1. Effects of turbines on california ground squirrel behavior

The expectation that turbine noise would affect the behavior of squirrels was confirmed by behavioral differences between Turbine and Control sites (See Table 3). Three general differences emerged in our study. The first is that noise at the Turbine site, when turbines were active, was much higher in amplitude than at the Control site. The second general result is that, regardless of site, squirrels increased their vigilance in playback samples when compared with baseline (as indicated by the ALERTNESS composite variable, Table 3). However, squirrels at the Turbine site were more vigilant than squirrels at the Control site overall (Fig. 3, Table 3). Elevated Turbine site ALERTNESS occurring prior to playback suggests that site differences in ALERTNESS did not arise simply because broadcast call series were novel at the Turbine site. The third result is that squirrels at the Turbine site had a greater tendency to return to the area immediately around their burrows and post during playbacks (as indicated by the PROXIMITY TO BURROW composite variable). Squirrels at the Control site actually reduced their PROXIMITY TO BURROW during these

same playbacks (Fig. 4, Table 3). At the Turbine site, a return to the burrow area concomitant with posting allowed animals to manage predation risk in a second fashion by providing more immediate access to refuge. The utilization of both responses at the Turbine site, as well as the higher level of overall ALERTNESS at that site, indicates that Turbine squirrels perceived themselves to be under higher risk than Control squirrels.

It is possible that factors other than noise were responsible for these behavioral differences (e.g. site differences in vegetation type and density, predator abundance, group size, and distance from refuge; see Lima and Dill, 1990 for review of those factors’ effects on antipredator behavior). But, those factors probably did not drive site differences for the following reasons: (1) Vegetation type and density were kept similar at both sites by cattle grazing and the removal of tall vegetation by the investigators. (2) During trials at both sites, the distance from focal squirrels to shelter was similar since trials were only initiated on squirrels within a baited area located close to resident ground squirrel burrows. (3) Raptor abundance did not differ between sites and may have even been lower at the turbine site (see Fig. 6). And any heightened levels of vigilance associated with the presence of a badger at the Turbine site were likely balanced at the Control site by repeated encounters with coyotes. (4) Though animals did cluster less during playback than during baseline conditions as a result of scattering to refuge, there were no apparent clustering differences between sites (see Fig. 5, Table 3).

Some other unique factor or combination of factors is likely driving the higher overall ALERTNESS values at the Turbine site and the increased use of PROXIMITY TO BURROW during playback. Our data support the assertion that the turbine installations and their associated noise are one of these factors. California ground squirrels are preyed on by a number of predators (Fitch, 1948) and use acoustic communication to reduce predation. When predators approach *S. beecheyi* colonies, squirrels call using a variety of antipredator vocalizations (Owings and Virginia, 1978; Owings and Hennessy, 1984) and respond to these vocalizations by increasing their levels of vigilance, returning to their burrows, or both (Leger and Owings, 1978; Leger et al., 1979; Loughry and McDonough, 1988; Loughry and McDonough, 1989; Hanson and Coss, 2001). However in a noisy environment, signals are more difficult to detect when the frequency of the signal and noise overlap, or when the amplitude of the noise source is high relative to signal intensity (Patterson and Green, 1978). During turbine activity,

Table 3 – Significant behavioral differences^a

Variable	Baseline vs. Playback		Turbine vs. Control site	
	F value	P value	F value	P value
ALERTNESS	21.353	<0.001	4.938	0.038
PROXIMITY TO SHELTER	Repeated measure/site interaction, $F = 9.238$; $p = 0.006$			
Group size/clustering	8.048	0.015	0.598	0.454

^a Only trials conducted using Nonturbine-Call-Series as playbacks are included because Turbine-Call-Series were not effective in provoking behavioral responses. See text for further explanation.

ambient noise levels at our Turbine site averaged 110.2 dB but reached as high as 118.0 dB SPL. Much of this noise was produced in the spectral band between 100 Hz and 6 kHz (see Fig. 2). Though components of California ground squirrel calls do extend above this spectral band (Fig. 1), the lower frequency components of the calls overlapped with turbine noise. And because the higher-frequency components of calls attenuate more rapidly with distance, it is the lower-frequency components that are most likely to be important for long-range communication. Thus, there is great potential for noise at turbine sites to interfere with the detection and assessment of alarm calls. In turbine environments, animals have shifted their antipredator tactics to utilize the visual modality more as seen by increased levels of ALERTNESS and PROXIMITY TO SHELTER. In doing so, squirrels appeared to attempt to compensate for acoustic masking as a result of turbine noise. One confounding factor could not be controlled for, the low frequency noise associated directly with greater winds at the Turbine site. However acoustic interference from wind noise would be highly unlikely as the frequency of wind noise is well below ground squirrel acoustic sensitivity (Henry and Coss, unpublished data).

It may seem surprising that animals at the Turbine site reacted strongly to playbacks. If alarm signals are completely masked, we would expect to see no behavioral reaction to playbacks when broadcast with simultaneous turbine noise, since noise would prevent animals from hearing calls. Instead, we see that levels of ALERTNESS and PROXIMITY TO SHELTER are both higher at the Turbine site on playback than at the Control site. A number of non-mutually exclusive hypotheses might account for this pattern. First, noise at the Turbine site might not completely mask emitted alarm calls. This would allow squirrels to hear some components of the broadcast calls though the quality of the calls may be degraded and call perception altered. In this case, turbine squirrels may be less effective at extracting subtle information from calls, and may instead use a simple rule of thumb, to be more alert and seek refuge under noisy conditions. Second, animals likely listen, as well as watch for the approach of an incoming predator after detecting an alarm call. Predators quickly approaching on the ground will make noise as their footfalls disturb loose substrate. But during turbine activity, animals may be unable to detect these low-amplitude sounds, warranting an increase in visual vigilance. Finally, animals at the Turbine site may have suffered some degree of hearing loss due to chronic exposure to high-amplitude noise. On hearing salient antipredator signals, those animals would be forced to compensate with visual scanning or a return to refuge. Each of these hypotheses requires further investigation.

Time spent In Burrow did not differ either between baseline and playback samples or between sites. These results follow Leger and Owings (1978), Owings and Leger (1980), and Owings et al. (1986) which suggest that alarm calling or the presence of distant predators does not often drive squirrels underground. Though California ground squirrels are likely to flee inside their burrow after close encounters with a predator (e.g. Hanson and Coss, 1997), hearing alarm calls alone does not appear to induce this behavior.

5.2. Implications for other species of wildlife

Turbine-related impacts on *S. beecheyi* might indirectly affect other species of concern that depend on ground squirrels as a resource. For example, *S. beecheyi* makes up over 25% of the diet of golden eagles (Carnie, 1954). And burrowing owls, red legged frogs, and California tiger salamanders rely on California ground squirrel burrows for shelter (Bente, 1938; Rowe et al., 1986; Jennings and Hayes, 1994; Loredó et al., 1996). Any movement of ground squirrel populations away from turbine installations could also negatively impact these other species. Our study suggests that ground squirrels may be able to cope with turbines and their associated acoustic noise through behavioral modifications in a predatory context. Additional research in non-predator/prey contexts should further test this assertion.

The fact that California ground squirrels appear to be able to adjust their behavior appropriately to cope with the presence of turbines is not surprising since *S. beecheyi* has demonstrated its ability to live in a variety of habitats under a variety of anthropogenic modifications (Marsh, 1998). However, for species of special concern that may be more sensitive to habitat change, studies along these same lines will help to identify the potentially adverse effects of turbines on other wildlife.

The findings presented here are not intended to suggest that turbine development be stopped. Wind-generated power should continue to be considered as an attractive alternative energy source due to its ability to produce energy without emissions. However, as engineers and turbine installers continue to develop new windmills and install new windfarms, consideration should be made towards reducing any impacts that turbines have on California's wildlife.

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Effects of wind turbines on area use and behaviour of semi-domestic reindeer in enclosures

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Abstract: In recent decades, industrial developments have expanded into reindeer ranges in the arctic and adjacent higher latitudes in search for energy, minerals, timber and other resources. Several wind turbine parks are under planning in reindeer ranges in Norway, and there is concern about possible negative effects on behaviour and area use of wild and semi-domestic reindeer. We tested whether a wind turbine and its rotor movement had any effect on area use, activity changes, vigilance bouts, and restless behaviour like running, walking, and standing for enclosed semi-domestic reindeer. Five different groups of reindeer in a 450 m long, 8 hectare, enclosure close to a wind turbine were manipulated by turning the wind turbine rotor on and off, and compared with reindeer in a control enclosure without wind turbine exposure. When exposed to rotor movement, two groups used locations farther from the wind turbine, two groups showed no shift, while one group moved closer to the wind turbine. The reindeer showed no systematic differences in the measured behaviour patterns between the two enclosures that could indicate fright or stress as a consequence of the wind turbine or rotor movement. We conclude that semi-domestic reindeer in an enclosure showed no negative behavioural response and little or no aversion towards a wind turbine. The possibility of rapid habituation in a small enclosure with continuous wind turbine exposure suggests that effects on area use should be studied at a larger scale or with free-ranging reindeer.

Key words: activity changes, aversion, disturbance, exposure, vigilance, wind turbine rotor.

Introduction

In recent decades, industrial developments have expanded into the arctic and adjacent higher latitudes in search for energy, minerals, timber and other resources (Klein, 2000). Reindeer's (*Rangifer tarandus*) dependence on large areas for grazing and regional movement patterns make them vulnerable to increases in human development and activity in their habitats. In Norway, large hydroelectric developments have resulted in loss of pastures for wild and semi-domesticated reindeer (Skogland & Mølmen, 1980; Reimers, 1986). Human infrastructure and activity combined with a rugged terrain with deep valleys and wildlife management decisions

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have resulted in the creation of 26 subpopulations of wild reindeer in southern Norway, some of which are restricted to one range for all seasons (Gaare, 1968; Skogland & Mølmen, 1980). Although anthropogenic development has increased significantly over the last 50 years and is forecasted to continue increasing, there is uncertainty about the separate effect of different types of disturbing factors, and the cumulative effect of several disturbing factors (Klein, 2000; Reimers *et al.*, 2000).

In recent years, alternative energy production from wind turbines has received political support in Norway, with a goal of producing 3 TWh within year

Table 1. Periods with wind turbine (W.t.) rotor turned on and off and number of observations during experimental periods with different groups of reindeer.

Enclosure	Year	Exp. period	Date	Number of reindeer	Group of reindeer	Rotor	Scan obs.	Focal obs.
W.t.	1999		14.09–20.09	five	A	Off	1661	53
W.t.			20.09–28.09	five		On	1975	64
W.t.			28.09–02.10	five		Off	1080	43
W.t.			02.10–07.10	five		On	1219	44
W.t.			07.10–11.10	five		Off	1159	38
W.t.	2000	1	17.09–20.09	three	B	Off	449	14
Control		1	17.09–20.09	three	C	-	466	10
W.t.		1	20.09–23.09	three	B	On	531	10
Control		1	20.09–23.09	three	C	-	474	11
W.t.		2	25.09–27.09	three	C	Off	342	10
Control		2	25.09–27.09	three	B	-	340	11
W.t.		2	27.09–02.10	three	C	On	798	26
Control		2	27.09–02.10	three	B	-	791	36
W.t.		3	04.10–07.10	five	D	Off	779	24
Control		3	04.10–07.10	five	E	-	725	25
W.t.		3	07.10–13.10	five	D	On	1384	49
Control		3	07.10–33.10	five	E	-	1439	44
W.t.		4	15.10–17.10	four	E	Off	660	28
Control		4	15.10–17.10	five	D	-	537	24
W.t.		4	17.10–22.10	four	E	On	1441	37
Control		4	17.10–22.10	five	D	-	1092	38

2010. Currently, numerous wind turbine parks are under planning in semi-domestic reindeer ranges in Norway. Many of the parks that are under planning in Finnmark county (over 10), Northern Norway (Anonymous, 2001), will consist of up to 100 wind turbines per park, with a minimum distance of 250 m between each wind turbine. There will be roads connecting all the wind turbines as well as power lines and converter stations. Consequently, each wind turbine park may directly or indirectly affect reindeer area use for several km².

With the exception of birds (Clausager & Nøhr, 1995), scientific studies on the effects of wind turbines on wildlife are few. To our knowledge, only one systematic study on effects of wind turbines on ungulates has been performed (Johnson *et al.*, 2000), in which no difference in abundance of pronghorns (*Antilocapra americana*) within 800 m of a wind turbine park was found when comparing data from before and after construction. A study on possible effects of wind turbines on reindeer was therefore needed.

We performed an experiment with a number of reindeer groups released periodically in two enclosures. One enclosure was located next to a wind

turbine, while a control enclosure was without wind turbine exposure. *Rangifer* may respond to human development and activity in two main ways (Wolfe *et al.*, 2000); A) they may avoid areas with high levels of development and activity and fail to cross such areas while migrating, or B) they may decrease feeding and increase restless behaviour and energy expenditure near the source of disturbance. If wind turbines were to have a disturbing effect on reindeer, we expected to find:

- 1) Less use of sections of the enclosure that were closest to the wind turbine.
- 2) Increased levels of restless behaviour like running, walking and standing, and increased frequency of activity changes and vigilance bouts for reindeer exposed to the wind turbine.

Since no similar studies of wind turbines and wildlife existed, another purpose of this study was to evaluate the suitability of this type of experiment for future studies.

Methods

The experimental area was located at a wind turbine park at Midtre Vikna (10°57' E 64°52' N), a hilly

Table 2. The frequency min^{-1} (standard error of the mean (s)) of vigilance bouts in relation to enclosure, reindeer group and rotor movement, for period 3 and 4 in 2000.

Reindeer group	Experimental period	Rotor	Wind turbine Mean vigilance bouts (min^{-1})	Control Mean vigilance bouts (min^{-1})
D	3	Off	0.664 (0.093)	0.484 (0.067)
E				
D	4	On	0.744 (0.091)	0.745 (0.073)
E				
D		Off	0.817 (0.098)	0.963 (0.12)
E				
D	On	0.683 (0.066)	0.861 (0.078)	
E				

island with altitudes up to 100 m in Nord-Trøndelag county, in mid-Norway. Vegetation is dominated by birch (*Betula* spp.), graminoids, mosses and lichens. Lichen pasture combined with low snow cover during winter makes it suitable as winter pasture for reindeer, and the Sami reindeer pastoralists have used the area during winter in the 1990s as well as in earlier decades of the 20th century.

In 1991–93, Nord-Trøndelag Electricity Board (NTE) established the wind turbine park, consisting of five wind turbines. The individual wind turbines have a tower height of 39 m, a rotor diameter of 39 m and a rotation speed of 30 min^{-1} at wind speeds above 4 ms^{-1} .

The wind turbine enclosure of approximately 8 hectare was located next to the westernmost wind turbine, while the control enclosure of approximately 7 hectare was located about 3 km away from the park. Both enclosures were fenced with 150 cm fence, including the top of the respective hills and stretching 450 m downhill towards southwest (Fig. 1). Although different in shape due to a highly variable terrain, both enclosures had similar vegetation types and climatic conditions. There was a moisture/altitude gradient from the wind turbine / hilltop at 0–50 m distance from the northeast corner of the enclosures, to a level area of bush, meadow and marsh at a distance of 200–450 m. At 300–400 m distance, both enclosures contained a smaller hill with similar vegetation as the area from 0–150 m. At the highest altitudes from 0–150 m distance, and partly from 300–400 m, there were more lichen and heather and less moss and marsh than in the other areas. In parts of the areas from 200–450 m of the wind turbine enclosure, the reindeer could not see the wind turbine. The reindeer grazed on natural pasture throughout the study period.

Study design

Experiments were performed in two field seasons, autumn 1999 and autumn 2000 (Table 1). The field season of 1999 was primarily a pilot study using the wind turbine enclosure only. The effect of the wind turbine was manipulated by periodically turning the rotor on and off. The other wind turbines in the park were not manipulated. These were located 350 m to 800 m away.

Three, four or five, 16–17 months old, female reindeer were used in each enclosure. In 1999, the same reindeer (group A) were observed in the entire study period, while in 2000, there were four separate periods. New reindeer were used in period 1 (group B and C) and 3 (group D and E), while a crossover of reindeer groups between enclosures was performed in period 2 and 4 (Table 1). This in turn provided us with two test groups and two control groups. Unfortunately, all the animals escaped from a broken fence in the wind turbine enclosure during the first day of period 1 when the rotor was off. One new animal from the main herd and two animals from the control enclosure replaced the escaped animals resulting in three animals per enclosure in period 1 and 2. One animal in the wind turbine enclosure was injured during transfer to the wind turbine enclosure in period 2. As a result, data from period 1 and 2 may be less reliable and should be judged with caution.

Observations

At the start of each experiment, the reindeer were released in the enclosure after lasso selection and lorry transport. Human handling of this kind is physiologically stressful and may reduce the animals' glycogen stores (Wiklund *et al.*, 1996). In order to allow the reindeer time to calm down and behave naturally before observations began, we waited minimum 12 hours after the release of the last animal into the enclosures. The reindeer were observed using telescopes, stop-watches with time-split, dictaphones and video cameras. We used digital video cameras mounted on a tripod. Each video recording was continuous and lasted for about 5 min 3 times per hour. There were two observers each simultaneously recording the respective enclosures. The minimum distance to the reindeer during observation was 200 m, and no behavioural effects of observer's presence took place.

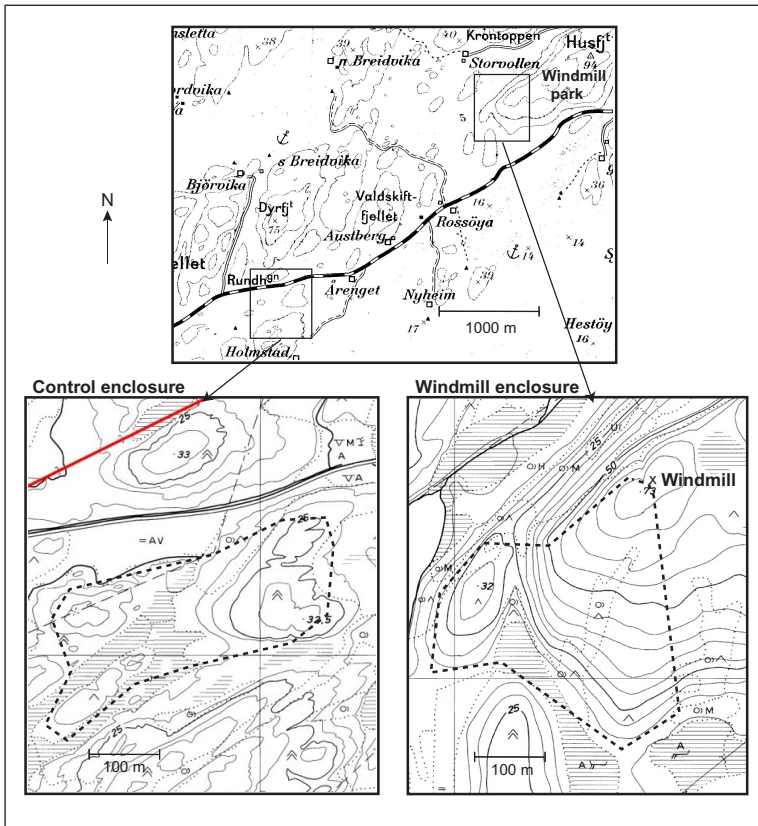


Fig. 1. The enclosures used in the experiment were located at a wind turbine park at Midtre Vikna (lat 64°52'N, long 10°57'E) in North-Trøndelag County, Mid-Norway. (Permission no. Ugland IT Group-MOT44225).

All observations were done during daylight between 7:00 AM and 8:00 PM. The observations were usually done in three-hour shifts, with one-hour break between shifts, *i.e.* three shifts per day.

Reindeer activity and area use in the enclosures were recorded using scan and focal animal sampling (Altman 1974; Murphy & Curatolo, 1986; Mörschel & Klein, 1997; Colman, 2000). A scan was performed every ten minutes by simultaneously observing each reindeer and recording its type of behaviour. During feeding bouts, a focal was performed every twenty minutes by visually observing or video-recording one reindeer closely for 5 minutes. Animal behaviour was categorised into nine types according to Colman (2000). For both scan and focal observations, individual distance to the hilltop/wind turbine in the northeast end of the enclosures was recorded. Animal behaviour during feeding and resting bouts was analysed separately. While resting, the majority of the animals were ruminating at the same location for a lasting period of up to 3 hours. The dominant animal behaviour was lying head up and lying head down. Occasionally, an animal stood while ruminat-

ing or stood up and fed shortly before it continued ruminating. We defined a resting bout to last until the majority of the animals had resumed feeding activity lasting for more than 2 minutes or moved to another location.

The video recordings were examined for vigilant behaviour during feeding bouts using methods from Bøving & Post (1997). In the short time period (0–10 min) after the wind turbine rotor was turned on, the reindeer were observed closely to reveal any short-term change of behaviour that could be related to the rotation and noise of the wind turbine rotor.

Wind speed and wind direction was recorded every ten minutes at an observation post on the hilltop next to the wind turbine of the wind turbine enclosure.

Analyses

Variations in behaviour during resting bouts were not considered of importance. The location of the reindeer during resting bouts was recorded, and use of the favourite bedding site was tested in relation to the wind turbine rotor turned on or off. The location of each separate resting bout was treated as an independent observation.

For feeding bouts, temporal autocorrelation in the scan observations was avoided by using one-hour means consisting of maximum 30 individual observations (five animals \times six scans). Since animals were occasionally out of sight and because observations during resting bouts were not included, the maximum number of individual observations was not always reached. In the analyses, the one-hour means were proportionally weighted according to number of individual observations. From the scan data, two different response variables were used in the analyses, animal location in the enclosure and restless behaviour. Animal location during feeding bouts was calculated as the mean distance to the wind turbine / hilltop in the northeast end of the enclosures of all individual observations of animals in a one-hour period. Restless behaviour during feeding bouts was calculated as the sum of one-hour mean proportions of running, walking and standing.

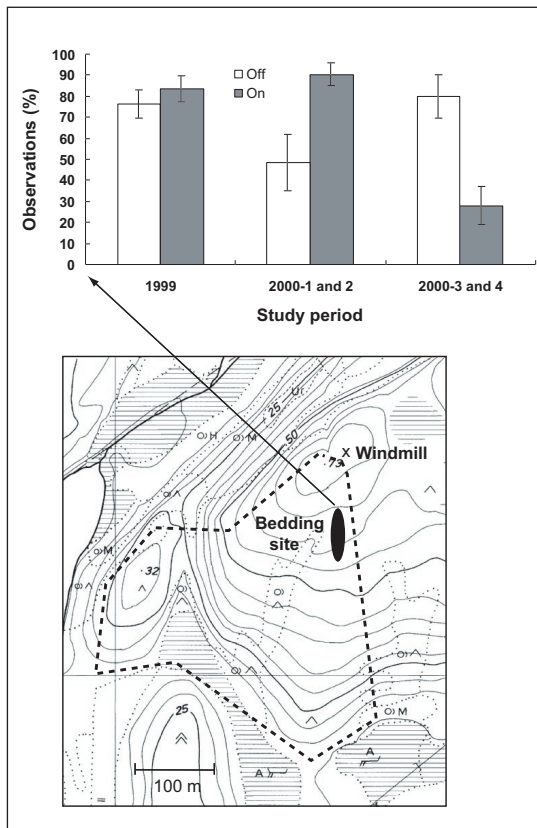


Fig. 2. The total % (bars: standard error of the mean) of observed lying bouts at the most frequently used bedding site of the wind turbine enclosure with rotor movement off and on. (Permission no. Ugland IT Group-MOT44225).

One animal was randomly chosen for each focal observation. The focal observations were not autocorrelated since they were done with 15 minutes separation and only during feeding bouts, *i.e.* the animals changed their behaviour and location for such long time spans that one focal observation did not necessarily depend on the former. If a focal was not 5 minutes long (because the animal occasionally moved out of sight), it was proportionally weighted according to its duration. From focal data, two response variables were used in the analyses: 1) The frequency min^{-1} of activity changes (Mörschel & Klein, 1997; Colman, 2000) and 2) The frequency min^{-1} of vigilance bouts (Bøving & Post, 1997).

Data for 1999, period 1 and 2 in 2000, and period 3 and 4 in 2000 were analysed separately. The following predictor variables were tested for effects on area use and behaviour: Wind turbine, rotor movement, group of reindeer (Table 1), wind speed, wind direction, and interacting effects between the wind turbine rotor movement and wind speed and/or direction. The latter was tested to see if increased

noise from the wind turbine in relation to wind speed and direction would affect the reindeer (Solberg, 2000). The continuous predictor variables of wind speed and wind direction were categorised before the analyses. Wind speed was categorised into three levels: 0–4 ms^{-1} (rotor not moving), 4–8 ms^{-1} (rotor noise higher than background noise) and more than 8 ms^{-1} (background noise higher than rotor noise) (Solberg, 2000). The categorisation of wind direction was chosen based on the direction of the enclosures: Southwest (wind towards the wind turbine/hilltop), northeast (wind from the wind turbine/hilltop), northwest and southeast. The effect of wind direction could not be tested in 2000 because the wind was stable from the same direction during most of the study period. The effect of habituation was examined by testing for changes in area use and behaviour after the reindeer had been in the enclosures for 24 hours, and after the rotor had been on for 24 hours.

Reindeer use of the favourite bedding site during resting bouts in the wind turbine enclosure was tested with Fisher's exact test for differences in preference between periods with the rotor turned on and off. Reindeer location, restless behaviour, and rate of activity changes and vigilance during feeding bouts were analysed with fixed effects, type III ANOVA. A full model including all predictor variables was the starting point of the analyses. The model was reduced stepwise by removing the nonsignificant predictor variables. In the final model, a significance level of 0.05 was chosen.

Fisher's exact test and Analyses of variance (ANOVA) were performed in S-PLUS 2000 Professional. The data were checked for normality and constancy of variance through QQ-plots and residuals *vs.* fit-plots.

Results

Area use

The reindeer mostly rested and ruminated (*i.e.* lying) repetitively at the same location. In the wind turbine enclosure, the majority of all lying activity was concentrated at one bedding site in 1999, in period 1 and 2 combined in 2000, and in period 3 and 4 combined in 2000 (Fig. 2). The site was on level ground dominated by graminoids. It was located at high elevation with a particularly good view, and close (100 m) to the wind turbine. The site was highly preferred, both when the rotor was moving and when it was turned off (Fig. 2). In 1999, no significant difference in use of this site was found between the periods of wind turbine rotor on or off. In period 1 and 2 in 2000, there was a significant increase in use from 49% to 90% ($n = 44$; $\chi^2 = 9.34$, $P < 0.05$) with the rotor turned on,

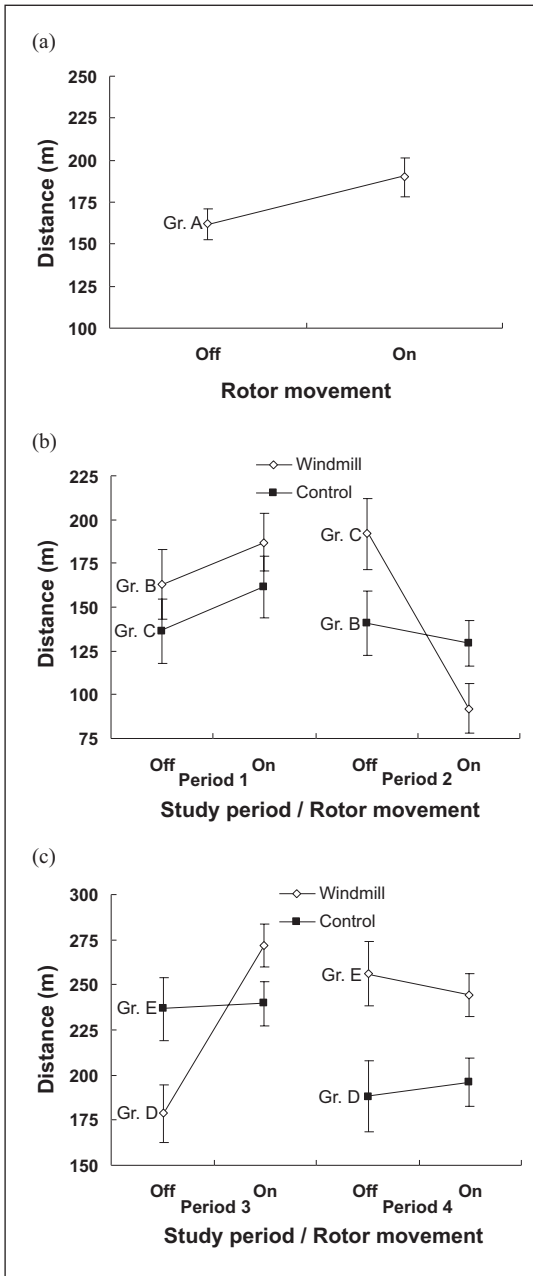


Fig. 3. Reindeer mean distance to the upper part of the enclosures and the wind turbine in relation to enclosure and rotor movement for (a) 1999, (b) 2000 period 1 and 2 and (c) 2000 period 3 and 4. Bars: standard error of the mean.

while in period 3 and 4 the result was opposite, with a decrease from 80% to 28% with the rotor turned on ($n = 39$; $\chi^2 = 8.19$, $P < 0.01$). The favourite bedding sites of the different groups of control reindeer was in similar habitat, with high elevation, a good view and graminoid dominated vegetation.

During feeding bouts, the enclosures were used more uniformly by all groups, and no distinct locations of concentrated activity were registered. In 1999, significant effects were found for rotor movement ($n = 207$; $F = 5.65$, $P < 0.05$), wind direction ($n = 207$; $F = 5.79$, $P < 0.001$) and wind speed ($n = 207$; $F = 6.47$, $P < 0.01$) on the location of the reindeer in the wind turbine enclosure. The reindeer were located on average 28 m farther away from the wind turbine when the rotor was moving than when it was turned off (Fig. 3a). With a southwest wind direction and wind speeds more than 8 ms^{-1} , reindeer were located farther away from the wind turbine (against the wind) than during other wind directions and lower wind speeds.

In period 1 and 2 in 2000, there was a significant interacting effect of enclosure, rotor movement and reindeer group on the location of the reindeer ($n = 215$; $F = 11.44$, $P < 0.001$; Fig. 3b). In period 1, both the wind turbine and control reindeer were located farther down in the enclosure when the rotor was moving. In period 2, there was a marked difference between wind turbine and control, with the wind turbine reindeer being located on average 100 m closer to the wind turbine in the northeast end of the enclosure when the rotor was moving. Among the control reindeer, there was no significant difference in mean distance to the northeast end of the enclosure between periods of rotor movement on and off.

An interacting effect of enclosure, rotor movement and reindeer group on the location of the reindeer was also significant in period 3 and 4 in 2000 ($n = 275$; $F = 5.29$, $P < 0.05$; Fig. 3c). However, the trends in the results were different from period 1 and 2. In period 3, the wind turbine reindeer were located on average 93 m farther away from the wind turbine in the northeast end of the enclosure when the rotor was moving, while there was no significant difference in mean distance to the northeast end of the enclosure between periods of rotor movement on and off among the control reindeer. In period 4, there were only small differences between the wind turbine and control reindeer. Effects of wind speed and days of experiment on location of the reindeer were not found in any of the periods 1 to 4.

In summary, the area use during resting bouts in period 3 and 4 combined in 2000, during feeding bouts in 1999 and in period 3 in 2000 was shifted farther away from the wind turbine during rotor movement. During resting bouts in period 1 and 2 combined, and during feeding bouts in period 2 in 2000, the results were opposite, with area use shifted closer to the wind turbine during rotor movement. During resting bouts in 1999 and feeding bouts in period 1 and 4 in 2000, the rotor movement showed

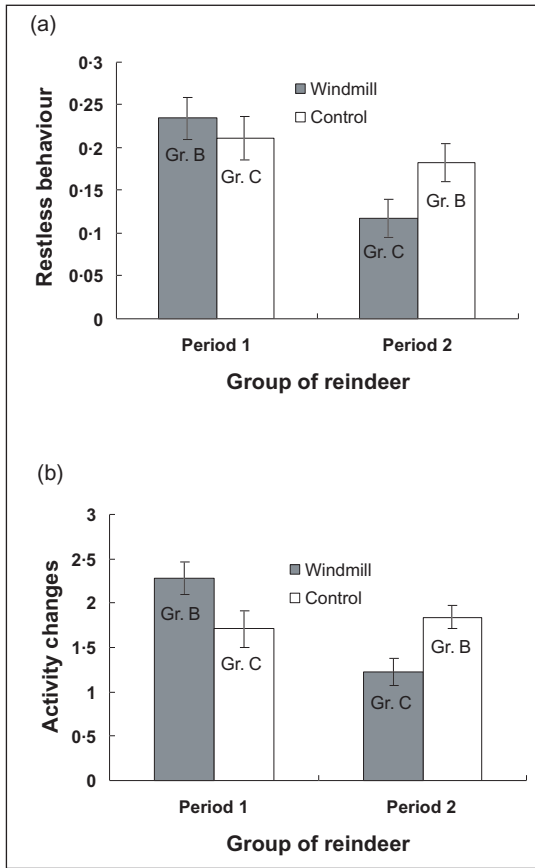


Fig. 4. The proportion of restless behaviour (a) and the frequency min^{-1} of activity changes (b), in relation to enclosure and reindeer group for period 1 and 2 in 2000. Bars: standard error of the mean.

no effect on area use. No combined negative effect of rotor movement and wind speed was found.

There were no indications of habituation with changes in area use from the start and into later days of the experiment.

Behaviour

No instant changes in behaviour were observed in the short time period of 0–10 min directly after onset of the wind turbine rotor in any of the experimental periods. In 1999, the frequency of activity changes was lower when the wind turbine rotor was moving ($n = 236$; $F = 7.46$, $P < 0.01$), and when the wind direction was from northeast (blowing from the wind turbine) ($n = 236$; $F = 4.10$, $P < 0.05$). The frequency (\pm standard error of the mean) was $1.11 \pm 0.073 \text{ min}^{-1}$ at rotor movement and $1.36 \pm 0.066 \text{ min}^{-1}$ when the rotor was off. No variables were found to significantly affect the proportion of restless behaviour in 1999.

In period 1 and 2 in 2000, there was a signifi-

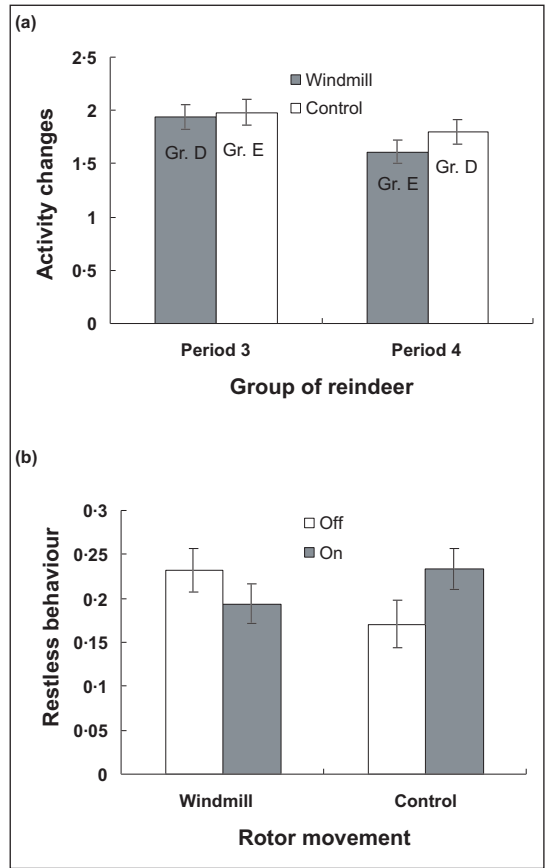


Fig. 5. The frequency (min^{-1}) of activity changes (a) in relation to enclosure and reindeer group, and the proportion of restless behaviour (b) in relation to enclosure and rotor movement for period 3 and 4 in 2000. Bars: standard error of the mean.

cant interacting effect of enclosure (wind turbine and control) and reindeer group (B and D) on both the proportion of restless behaviour ($n = 124$; $F = 7.33$, $P < 0.01$; Fig. 4a) and the frequency of activity changes ($n = 120$; $F = 13.2$, $P < 0.001$; Fig. 4b). In period 1, group B in the wind turbine enclosure had more frequent activity changes and more restless behaviour than group C in the control enclosure. After the cross-over in period 2, group B, now in the control enclosure, maintained more frequent activity changes and restless behaviour than group C. The difference between the two groups of reindeer was larger than the difference between wind turbine and control, with group B having an overall frequency of activity changes of 2.06 min^{-1} and group C having an overall frequency of 1.47 min^{-1} ($n = 124$; $F = 12.1$, $P < 0.001$). No effects on behaviour from wind turbine rotor movement, wind speed or days of experiment were found in period 1 and 2.

In period 3 and 4 in 2000, the reindeer showed

different behavioural responses than in period 1 and 2. A significant interacting effect of enclosure and reindeer group on the frequency of activity changes was found ($n = 258$; $F = 4.86$, $P < 0.05$), but it showed no higher frequency in the wind turbine than in the control enclosure (Fig. 5a). For restless behaviour, a significant interacting effect of enclosure and rotor movement was found ($n = 325$; $F = 5.74$, $P < 0.05$; Fig. 5b). The reindeer were less restless when the rotor was moving than when it was turned off in the wind turbine enclosure. In the control enclosure, this was opposite, with the reindeer behaving more restless in the time periods of rotor movement. For both activity changes ($n = 258$; $F = 4.37$, $P < 0.05$) and restless behaviour ($n = 325$; $F = 4.36$, $P < 0.01$), there were significant effects found for the interaction between rotor movement and wind speed, but the effect of wind and rotor movement was not different in the wind turbine enclosure compared to the control.

Vigilance behaviour was only recorded for group D and E, and we found a significant interacting effect of enclosure, rotor movement and reindeer group on the vigilance frequency ($n = 193$; $F = 6.12$, $P < 0.01$; Table 2). In period 3, group D in the wind turbine enclosure had a higher vigilance frequency with the rotor moving than with the rotor turned off, but the same tendency was stronger with group E in the control enclosure, indicating no increasing effect of rotor movement on the vigilance. In period 4, the tendency was opposite for both the wind turbine and control groups, with lower vigilance frequency when the rotor was moving. No effect of the experimental day was found for the behaviour of the reindeer in period 3 and 4.

In summary, the behaviour of the reindeer was affected by different variables in a nonsystematic way. In general, negative effects of wind turbine and rotor movement were not found. There was no indication of habituation with changed behaviour in later days of the experiment.

Discussion

Effects of the wind turbine

The reindeer showed some indications of a shift towards use of locations at longer distance from the wind turbine when the rotor movement was on. This was observed for resting bouts in period 3 and 4 in 2000 and for active behaviour in 1999 and period 3 in 2000. However, the opposite, with a shift towards use of areas closer to the wind turbine, was observed for resting bouts in period 1 and 2 and for active behaviour in period 2 in 2000. Because of handling problems with the experimental animals in period

1 and 2, the results from these periods should be evaluated with caution. We can not exclude the possibility of confounding effects from different handling of animals prior to the experiment in period 1 and 2, and an injured animal in the wind turbine enclosure in period 2. Reindeer area use in the wind turbine enclosure in period 2 differed from the other periods, but we did not observe any obvious relationship between this result and the hoof injury of the animal.

When considering all the experimental periods and groups of reindeer, the behaviour seemed highly variable, with significant effects of different variables in the different periods of the study. From the hypothesis of a disturbing effect, we expected increased levels of restless behaviour, activity changes and vigilance when the reindeer were exposed to the wind turbine and rotor movement. Overall, this was not observed.

Increased activity and energy expenditure may occur if reindeer continue grazing in an area despite extensive human disturbance. In oil-fields in North-America, caribou have been shown to increase their movement rates and reduce the time allocated to feeding when exposed to roads with vehicle traffic, pipelines and noise from petroleum exploration (Curatolo & Murphy, 1986; Murphy & Curatolo, 1986; Bradshaw *et al.*, 1997). Reindeer respond with fright and flight whenever humans are detected within a certain distance (Eftestøl, 1998; Colman *et al.*, 2001). Behavioural responses of this kind may result in negative effects on the energy budget of the animals (Reimers, 1980; Tyler, 1991; Bradshaw *et al.*, 1998, Colman *et al.*, 2003). If the activity budget is skewed towards energy expending activities with less time spent feeding, the body weight and physical condition of the individual animals will eventually be reduced, as has been shown for reindeer during the hunting (Reimers & Kollé, 1987; Skogland & Grøvan, 1988) and insect (Colman, 2000, Colman *et al.*, 2003) seasons in southern Norway. Since energy expending behavioural responses were generally not observed in connection with the onset of the wind turbine rotor, the reindeer probably did not associate the wind turbine with instant danger. The overall tendencies of our results indicate no effect of the wind turbine on reindeer area use and behaviour.

The wind turbine is a permanent construction that reindeer were continuously exposed to during the experiment. Since we waited minimum 12 hours after release of the reindeer in the enclosures before beginning our observations, habituation towards the wind turbine could already have begun, making it difficult to observe a possible disturbing effect of the wind turbine followed by normalised behaviour later

on. However, onset of the wind turbine rotor began minimum three days after the reindeer had been released in the enclosure, and did not induce any fright or stress response, even though the reindeer had no prior experience with this stimulus. Furthermore, there was a general lack of negative behavioural effects of wind speed that are also related to the noise level of the wind turbine rotation (Wagner *et al.*, 1996).

There have been several studies on *Rangifer* behaviour when exposed to moving and noise generating objects. Among the results are increase in vigilance when exposed to humans on foot (Duchesne *et al.*, 2000), fright and flight responses in exposure of snowmobiles (Tyler, 1991; Mahoney *et al.*, 2001; Reimers *et al.*, 2003) and humans on foot (Colman *et al.*, 2001; Eftestøl, 1998), and startle responses (Harrington & Veitch, 1991), increased movement rates (Maier *et al.*, 1998) and heart rates (Berntsen, 1996) in exposure of overflights from jet-fighters or helicopters.

On the other hand, there are not many studies on *Rangifer* behavioural effects of direct exposure to permanent constructions. In Prudhoe Bay oil field in Alaska, Curatolo & Murphy (1986) and Murphy & Curatolo (1986) found negative effects on the activity budget of caribou, with a decrease in the time spent lying and an increase in time spent standing, walking and running within 600 m of a pipeline paralleled by a road with traffic and within 300 m of a pipeline paralleled by a road without traffic. There was a decrease in the crossing frequency, but only under pipelines that were paralleled by roads with traffic. The effects were not significant in periods with insect harassment. Caribou have been reported to use roads, gravel pads and shading constructions inside the Prudhoe Bay oil field for insect relief on hot days with high levels of insect harassment (Curatolo & Murphy, 1986; Pollard *et al.*, 1996; Noel *et al.*, 1998). Thus, the constructions seem to have a limited or weak disturbing effect that eventually disappears when insects are the dominant disturbing factor. Our results do not indicate disturbing effects of the wind turbine rotation. Although it is a construction with a movable object, it is probably not associated by a direct risk of predation by reindeer. Vehicles, aircrafts or humans on foot are more likely to induce anti-predatory behavioural responses. Human activities in the area of a wind turbine park are likely to have stronger effects on reindeer than the constructions themselves. A short period of construction, concentrated in seasons without reindeer in the area, and limited human activity after establishment of a wind turbine park, is probably essential in order to minimise potential negative effects. If the level of

human activity in an area is high, reindeer may learn to associate the area with danger regardless of the existence of wind turbines.

Johnson *et al.* (2000) found no difference in abundance of pronghorns within 800 m of a wind turbine park when comparing data from before and after construction. Occasional observations from Lammasoivi wind turbine park in Finland (V. Kokkonen, pers. comm.), and from Rodovålen wind turbine park in Sweden (Anonymous, 2000) suggests no negative effects of wind turbines on domestic reindeer in these areas. It should be noted that the windmill park in Lammasoivi is located on a rocky outcrop and reindeer may react differently if windmills were located within preferred habitat. The overall tendencies of our study are in accordance with this, and thus, short-term negative effects of wind turbines on reindeer can not be supported. On the other hand, Sami reindeer pastoralists claim that their herds do not calm down while grazing in the area of Vikna wind turbine park (R. Anti, pers. comm.). In light of this, it is important to keep in mind that the limited knowledge from occasional observations and proximate effects of a wind turbine on reindeer inside an 8 hectares enclosure can not be directly extrapolated to free-ranging reindeer. Free-ranging reindeer will only occasionally be exposed to human constructions, and they are free to move away from the constructions after short exposure times (*e.g.* in connection with migration routes). Thus, their behaviour and reactions towards wind turbine parks may differ considerably from this study.

Cumulative effects of human developments and activity

It is possible that *Rangifer* avoidance responses occur in larger geographical perspective towards human developments, but it is less obvious how much area is likely to be avoided, and whether long-time habituation or population growth may reintroduce animals into temporarily abandoned areas (Bergerud *et al.*, 1984). Although direct exposure to permanent technical constructions without humans being present do not seem to induce major fright or stress responses in *Rangifer*, the animals may learn to associate the constructions, or infrastructure in general, with increased levels of human activity, and thereby avoid or decrease the use of adjacent areas as an anti-predator strategy. The cumulative effect of hunting, tourism, and technical constructions may result in avoidance of large areas. Our study was not designed to reveal such an effect of a wind turbine park.

Future studies

Understanding the implications of human disturbance for reindeer and caribou requires assessment of

cumulative effects at annual, population and regional scales (Wolfe *et al.*, 2000). We show no direct, negative local effects of a wind turbine on reindeer behaviour. Comparable experimental studies are needed to confirm this finding. A main challenge when doing manipulative experiments with reindeer is to reduce eventual negative effects of human handling on these animals. A sample size with enough power to reveal possible effects is also necessary. However, this is costly and time-consuming when doing research on such a large species.

The cumulative effect of a wind turbine park and the human activity associated with such parks, along with previous human disturbance in an area, can not be fully assessed in the type of study presented here. We concentrated at the individual and group level, focusing on specific, short term behavioural aspects of reindeer reactions towards windmills at close range. Future studies should include group and population aspects on a regional scale. In such regional studies, it is also necessary to document the area use of populations before, during, and after establishment of a wind turbine park in order to reveal eventual avoidance, and perhaps re-use after short-term abandonment. Several methods are available for estimating animal distribution in the field, including line transect surveys of animals, tracks, or dung (Marques, *et al.*, 2001), aerial surveys along transects (Pollard, *et al.*, 1996), and GPS/VHF tracking (Haller, 2001). Studies on area use of the animals should be continued in subsequent decades in order to reveal if areas are only temporarily abandoned (Bergerud *et al.*, 1984).

Conclusion

Our study showed ambiguous effects of the movement and noise of the wind turbine rotor on the area use of reindeer in an enclosure located from 10 to 450 m from the wind turbine. Reindeer behaviour was not systematically different when comparing animals in the wind turbine enclosure with those in a control enclosure, suggesting that the level of fright and/or stress was not higher for the exposed reindeer. Since other studies have found negative effects of human developments and activity on regional area use of free-ranging *Rangifer*, future studies on possible effects of wind turbines on reindeer need to include this aspect.

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Abstract in Norwegian / Sammendrag:

I løpet av de senere tiår har industriell utbygging til utnyttning av energi, mineraler, tømmer og andre ressurser ekspandert inn i reinens beiteområder i nordområdene. Flere vindmølleparker er under planlegging i norske reinbeiteområder, og det spekuleres i mulige konsekvenser av disse på atferd og arealbruk hos villrein og tamrein. Vi testet om en vindmølle og dens rotorbevegelse hadde noen effekt på arealbruk, aktivitetsskifter, vaksomhetsatferd, og rastløshetsatferd i form av løp, gange og ståing for tamrein i innhegning. I en 450 m lang innhegning på 8 hektar som var plassert tett opp til en vindmølle, ble fem forskjellige grupper av reinsdyr manipulert ved å slå vindmøllerotoren av og på. Reinsdyrene i innhegningen ved vindmøllen ble sammenlignet med reinsdyr i en kontroll-innhegning som var uten påvirkning fra vindmøller. Når

reinsdyrene ble utsatt for vindmøllerotoren i bevegelse, viste to grupper av dyr et skifte i arealbruk til områder av innhegningen som var lenger unna møllen, to grupper av dyr viste ikke noe skifte i arealbruk, mens en gruppe dyr beveget seg nærmere vindmøllen. Sammenligning av atferden hos reinsdyrene i vindmølleinnhegningen og kontroll-innhegningen viste ingen systematisk forskjell som kunne indikere frykt eller stress som en effekt av vindmøllen eller rotorbevegelsen. Vi konkluderer med at tamrein i innhegning ikke viser negative atferdsresponsen og viser lite eller ingen reduksjon i arealbruken tett opp til en vindmølle. Muligheten for at det skjer en rask tilvenning i en liten innhegning der dyrene er i kontinuerlig påvirkning av vindmøllen betyr at effekter på arealbruk bør studeres i et større arealperspektiv eller på frittgående rein.