Effects of military noise on wildlife: a literature review

Ronald P. Larkin
Center for Wildlife Ecology
Illinois Natural History Survey
607 E. Peabody Drive
Champaign, Illinois, USA 61820
r-larkin@uiuc.edu

(500-word abstract for cover)

Effects on wildlife of noise associated with military training activities, especially vehicle noise, artillery, small-arms and other blast noise, and helicopter noise, are reviewed, but not effects on aquatic animals and effects of fixed-wing aircraft engine noise and sonic booms. Because directly relevant studies are few, some similar non-military sources of noise are discussed. Physical (acoustic) and biological principles are briefly reviewed and traumatic, physiological, and behavioral effects are discussed in relation to population-level effects.

Noise affects wildlife differently from humans and the effects of noise on wildlife vary from serious to nonexistent in different species and situations. Risk of hearing damage in wildlife is probably greater from exposure to nearby blast noise from bombs and large weapons than from long-lasting exposure to continuous noise or from muzzle blast of small arms fire. Direct physiological effects of noise on wildlife, if present, are difficult to measure in the field; telemetric measurement of physiological variables such as heart rate has met with more success technically than as an indicator of health and survival. Behavioral effects that might decrease chances of surviving and reproducing include retreat from favorable habitat near noise sources and reduction of time spent feeding with resulting energy depletion. Serious effects such as decreased reproductive success have been documented in some studies and documented to be lacking in other studies on other species. Decreased responsiveness after repeated noises is frequently observed and usually attributed to habituation.

Vehicle noise can interfere with animal communication essential for reproduction. On the other hand, people afoot may cause stronger behavioral reactions than people in vehicles. Noise from helicopters (rotary-winged aircraft) is complex and varies especially with aspect and model of helicopter. Responses to helicopters from several kilometers distant are documented; however, both the response to helicopters and the degree to which such a response may habituate with time vary greatly. Vehicles and helicopters pose difficulty for researchers trying to separate acoustic from visual and other indications of their presence.

Military and civilian blast noise had no unusual effects (beyond other human-generated noise) on wildlife in most studies, although hearing damage was not an issue in the situations studied and animals were often probably habituated to blasts. Shock waves from projectiles are poorly studied in relation to wildlife. Firearms are probably salient to hunted species, via learning.

Research is hampered by a preponderance of small, disconnected, anecdotal or correlational studies as opposed to coherent programs of controlled experiments (reaffirming Bowles, et al. 1991). Comparability among studies is complicated by terms lacking generally-accepted definitions (e.g. “disturbance”) and by species differences.

Future research should stress quantification of exposure of subjects to noise, experimental

approaches such as broadcasting accurate recordings of sounds, and observer effects. When possible, researchers should separate acoustic from other cues and should build practicable management measures into the research design. Such a young and interdisciplinary field invites narrowly-focused management-oriented studies when fundamental issues of natural history, bioacoustics, and technique still remain poorly understood. Several unexplored areas, such as performance aftereffects and effects mediated by natural selection and associative conditioning, represent fertile territory for research.

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Scientific literature is reviewed on effects on wildlife of noise associated with military training activities, especially vehicle noise, artillery, small-arms and other blast noise, and helicopter noise. Physical (acoustic) and biological principles and traumatic, physiological, behavioral , and population-level effects are discussed. Military blast noise from bombs and large weapons poses greater risk, if any, of hearing damage in wildlife than does continuous noise or small arms fire. Telemetric measurement of physiological effects has met with success primarily technically. Behavioral effects include habitat shifts and reduction of time spent feeding. Serious effects such as decreased reproductive success depend on species. Decreased responsiveness after repeated noises is usually attributed to habituation.

Literature on military and related civilian noise sources includes rotary-winged aircraft (helicopters, a complex noise source), vehicles (including ORV's), muzzle blast, projectile shock waves (nearly unstudied), and firearms (including hunting).

Small-scale studies, anecdotal reports, inherent variability including species differences, and lack of fundamental knowledge hamper progress in this field. Future research should stress quantification of noise stimuli, solid experimental design, separation of cues, and management implications.

FOREWORD

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1 INTRODUCTION

Background

The U.S. military is responsible for preservation of wildlife, particularly threatened and endangered species, on large amounts of public land (Boice 1992, Olmstead 1991). Military activities, including training programs essential to readiness, affect wildlife on these lands both indirectly by degradation of habitat and directly via physical damage or behavioral disturbance.

“Noise” has been used in at least three different ways:

Field	Definition	Reference
signal processing theory	That which increases uncertainty on a communication channel	Shannon and Weaver 1949:20
acoustic engineering	Unwanted sound	Harris 1991b
medicine, occupational health	Sound that produces pathology Sound harmful to health	Welch and Welch 1970 Welch 1973

“Signal/noise ratio” and similar usages will assume the signal processing definition in this review. Otherwise, “noise” will refer to human-generated sound that is unwanted by the wildlife in question; that is, that may be hypothesized to have deleterious effects on wildlife.

Objective

Although there are published reviews of bioacoustics, effects of general noise on animals including wildlife, and effects of military fixed-wing aircraft on domestic animals and wildlife, much less research has been performed on the effects of other military noise on wildlife. Animals can be extraordinarily sensitive to sounds in some circumstances and quite insensitive to sounds in other circumstances. Noises generated by military equipment, having particular and, in some cases, unusual characteristics, cannot necessarily be assumed to have effects similar to noises generated by civilian activities. For these reasons, it is desirable to better understand the effects of military noise on wildlife.

Given knowledge of how military noise effects animals, USACERL may assess the potential impacts of sound from their activities on local wildlife populations and act to minimize possible disturbances. A literature survey should address concerns of the public sector as to the effects of military noise on wildlife and to aid in designing future research in this area if desired.

Approach

This review is concerned with documented and putative sound-mediated disturbance of wildlife by military activities, principally U.S. Army training activity. Because noise from fixed-wing aircraft and sonic booms are the subject of recent literature reviews (see following paragraphs) and ongoing research programs of the U.S. Air Force, these noise sources are mentioned only when they can aid our understanding of effects of other military noise sources. Articles appearing prior to mid-1994 are reviewed.

A recent review, “Responses of wildlife to noise” (Bowles in press, 1995), includes both airborne and underwater noise and is in some respects complementary to the present report.

Like other related fields such as effects of vehicles or recreation on wildlife (Berry 1980, Boyle and Samson 1985, Knight and Gutzwiller 1994), effects of noise on wildlife often appear in the “gray literature” of conference proceedings and unpublished reports and manuscripts, rather than in the refereed scientific literature. Related fields are reviewed elsewhere and are discussed only inasmuch as they contribute directly to understanding of effects of noise on wildlife: underwater noise and strictly aquatic animals (Richardson, et al. 1991); domestic and other confined animals (Gamble 1982, Manci, et al. 1988, Peterson 1980b, Pfaff 1974); auditory physiology and anatomy (Evans 1992, Fay 1988b, Guinan 1986, Klinke and Smolders 1993, Lim 1986, Møller 1972, Pickles 1985, Pickles and Corey 1992, Roberts, et al. 1988, Wever 1971, Wever 1973); comparative psychology of perception (Dooling and Hulse 1989); reviews of effects of various kinds of general noise and recreational activities on wildlife (Awbrey and Bowles 1990, Boyle and Samson 1985, Dahlgren and Korschgen 1988, Dufour 1980, Fletcher 1980, Petit 1991, Ruth 1976, York 1994); off-road vehicles (Berry 1980, Boyle and Samson 1985, Manci, et al. 1988, Reimers 1991) and effects of military and civilian fixed-wing aircraft and sonic booms on domestic animals and wildlife (Awbrey and Bowles 1990, Bowles, et al. 1991, Bowles, et al. 1990, Gladwin, et al. 1988b, Kull and Fisher 1986, Manci, et al. 1988). Recent pioneering U.S. Air Force work on effects of aircraft overflights on wildlife is succinctly reviewed in Kull (1993b).

We searched computer-accessible databases and sometimes their paper versions: AGRICOLA, BEAST, Biological Abstracts, Current Contents, Dissertation Abstracts, Engineering Index, Enviroline, INSPEC, MedLine (Index Medicus), NTIS, Science Citation Index, VETCD, Wildlife Worldwide, Wilson Index, and Zoological Record. We used the resources of the Illinois Natural History Survey in Champaign, Illinois, its parent University of Illinois Library, especially the Life Sciences Collection and the online catalog, and Larkin’s office file of references; looked through the acoustics library at the U.S. Army Construction Engineering Laboratory in Champaign, Illinois; and visited Maj. Robert Kull , then at Wright-Patterson Air Force Base, Dayton, Ohio, and took advantage of the two computerized databases (PAPER and IBAN) and the paper copy collection he kindly made available.

Several inquiries on the internet yielded helpful leads and suggestions. Telephone contacts, followups, and a few visits in person were particularly helpful in discovering in press and gray literature publications. Of course, many publications came to our attention from the Literature Cited sections of later publications.

Mode of Technology Transfer

2 MATTERS ACOUSTICAL

Acoustic background

More complete information on the fundamentals of acoustics is found in Peterson (1980a) and Harris (1991a). For further definitions see Harris (1991a:Chapter 2 and Acoustical Society of America 1994).

Animals respond to sound as pressure. The corresponding subjective measure of sound intensity, "loudness", is closely proportional to pressure as long as the person or animal is appropriately sensitive to the frequencies in the sound. For repetitive or continuous sound, a sound pressure level (SPL) is expressed as an average over a certain period of time. SPL in decibels (dB) is computed:

$$\text{dB SPL} = 20 \cdot \log_{10} \left(\text{pressure} / \left(20 \cdot 10^{-6}\ \text{Pa}\right) \right).$$

20 μPa, is the sound pressure level at which responses of a young adult human to a 1 kHz tone are nominally at threshold, i.e. 70% positive, and takes the value 0 dB SPL in the above expression. For humans, tone pulses and continuous noise that differ in sound pressure level by about 3 dB SPL are judged to be the same loudness and subjective ratings of annoyance are similar for sounds differing by less than about 10 dB SPL. Increased average SPL and loudness of noise is associated with increased percentage of humans "annoyed" by noise (Berrens, et al. 1988). "The terms 'overpressure' and 'sound pressure' are essentially equivalent," the former in the study of high-amplitude pressure waves, the latter in general acoustics (Pater 1981).

Sound levels decrease with distance from a sound source due to several factors. The most pervasive of these, inverse-square spreading loss, is a geometrical decrease of SPL by 6 dB with every doubling of distance from a point source. Therefore, when the SPL of a sound source is specified, the distance from the source should be given. If the distance is not given, the SPL measurement is nearly useless because of spreading of the sound and other factors discussed below. In addition, the aspect of the sound source (if not omnidirectional), movement of the source, if any, and details of the methods of measurements should be given. Many or most wildlife publications reviewed for this report neglected such crucial supporting data for sound level measurements.

The decibel scale is nonlinear, as is the inverse-square decrease of sound pressure level with distance from the source. These nonlinear relationships can deceive. For instance, a comparison of natural Tungara frog calls with broadcast recordings of calls showed only a 1.9 dB (1.24-fold) difference in one case, statistically significant but supposedly "so small that [it] may not be meaningful biologically" (Ryan 1986a). However, even such a small difference in SPL corresponds to approximately 1.4 times increase in the three-dimensional spatial volume reached by the call of an arboreal frog at a given signal/noise ratio -- probably a biologically meaningful difference in efficacy for such an acoustic display.

Measurements of sound necessarily must take frequency into account. A sonagram is a plot of sound frequency as a function of time, usually with the darkness of a trace indicating acoustic intensity. Proper production of sonagrams and specification of their parameters is a technical challenge (Hopkins, et al. 1974, Miller 1992:7).

The audiogram is a plot of an animal's acoustic absolute intensity threshold as a function of log frequency. It can be measured behaviorally, recording conditioned or unconditioned responses by the whole animal, or electrophysiologically, recording changes in e.g. activity of eighth nerve auditory neurons. In research on hearing, pure tones or other stimuli may be presented to a subject together with masking noise (rather than in isolation) to study more complex psychoacoustic parameters such as the critical band and masked auditory thresholds (Okanoya and Dooling 1988).

Ears respond differently to different frequencies of sound. To better approximate sound as perceived by the auditory system, various filtering or weighting systems are used to modify the readings of sound measurement instruments. The human auditory system is the standard in constructing these weighting systems. The particular weighting chosen varies according to the purpose of the measurement and the type of sound to be measured. The most commonly used are A-weighting, approximating human thresholds; C-weighting, which begins to cut off low frequencies ("roll off") only below about 50 Hz; and the unweighted, or flat system. Reported measurements of sound therefore must include reference to the weighting system applied, e.g., "dBA" for measurements made using A-weighting.

Some other measures attempt to express concisely the overall dose of noise that produces a certain effect on the subjects. Equivalent continuous sound level[1] (L_{eq}) refers to the level of a hypothetical continuous steady sound that has the same average energy as a measured varying sound at the stated level. Sound Exposure Level (SEL, also Noise Exposure Level) refers to a cumulative exposure to sound equivalent in energy to one second of sound at the stated level.

Infrasound and ultrasound

The audiogram of young humans determines our concept of sound: airborne compression waves of frequency roughly 20 Hz to 20 kHz. Compression waves of frequency above about 20 kHz we call ultrasound; those below 20 Hz we call infrasound; those in between we can hear and we call them audio frequencies. Although many songbirds (Dooling 1982) and terrestrial mammals (Fay 1988a) have audiograms similar to those of humans, many other species of animals do not. Many or most mammals with body size smaller than humans have useful auditory sensitivity above 20 kHz and use ultrasound in communication or location of predators and prey. Some animals, such as bats, have their peak auditory sensitivity above 20 kHz. However, because high-frequency sound attenuates very rapidly in air with distance from the source (Lawrence and Simmons 1982), high-frequency components of noise likewise diminish rapidly as distance from the noise increases. On military installations, animals close enough to a noise source to experience detrimental effects of ultrasonic components of noise are probably also close enough to risk more general damage, for instance from shrapnel and "flyrock" (Wyllie 1987). Nor is it likely that audio-frequency sound would interfere with animals' use of ultrasound. For example, because even ultrasonic noise can little interfere with bat echolocation (Griffin 1974, Simmons, et al. 1975), it is most unlikely that audio-frequency noise could do so. Probably for these valid reasons, ultrasound receives little attention in discussions of effects of noise on wild animals.

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[1] Frequency weighting systems may be used in these measurements just as they are in determining SPL; thus, "L_{eq}A" refers to an equivalent level determined using the A-weighting system of frequency filtering.

Infrasound attenuates less in air than audible sound, implying that infrasonic components of military noise, which are present in both blast and helicopter noise, could have effects on wildlife at long distances. Infrasound presents practical difficulties in research not only because the researcher cannot hear it but also because generating and controlling infrasonic sound is cumbersome. So far, sensitivity to infrasound is known in two different groups of terrestrial animals. Birds (Rock Doves) have almost 40 dB more auditory sensitivity than do humans to sounds in the region 1 to 10 Hz (Kreithen and Quine 1979, Kreithen 1979, Schermuly 1990a, Warchol and Dallos 1989, Yodlowski, et al. 1977), can discriminate different frequencies of infrasound (Quine and Kreithen 1981), and appear to be remarkably sensitive even to the extent of perceiving changes in static atmospheric pressure (Kreithen 1974). Sensitivity to infrasound in birds is mediated by the basilar membrane in the inner ear and thus is truly “auditory” (Schermuly 1990b). The extent to which this sensitivity is general in birds is speculative, as is the actual function of infrasound sensitivity in birds in nature. Infrasound may or may not be used by birds for communication (Moss and Lockie 1979). However elephants (Langbauer, et al. 1991, Payne, et al. 1986) and possibly other large terrestrial animals do use infrasound for intraspecific communication[2].

Thus it is possible that wildlife may be affected by infrasonic components of military noise, both by direct response or damage to the ears by infrasound (Lim, et al. 1982) and by masking of biologically-meaningful infrasound signals by infrasonic military noise. The nervous systems of pigeons (at least) respond phasically to infrasound, via pulse frequency modulation, (Schermuly 1990a). Therefore, they may respond to the exact waveform of sounds such as helicopter rotor noise and large explosions (Paakkonen 1991), rather than to the frequency content, repetition rate, or other more commonly-presented parameters per se. Two infrasonic noises with identical power spectra, durations, and amplitude signatures but different waveforms are probably discriminable to pigeons and perhaps other birds.

Recent work on anurans (Hetherington 1992) and rodents (Plassmann and Kadel 1991) shows that animals can be sensitive to sounds of much lower frequency than would be suggested by conventional dimensional constraints of body size.

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[2] Based on pachyderms’ use of infrasound, known infrasonic sensitivity by present-day birds and the use of low-frequency audible sound for long-distance communication by crocodilians, one might speculate that dinosaurs made extensive use of infrasound and also sensitivity to substrate vibration. In that case the asteroid impact that coincided with the end of the Cretaceous era about 65 million years ago may have produced the most extensive effects thus far of impulse noise on wildlife.

Military sources of noise and their potential civilian analogs

Effects of "noise" from terrestrial military activities[3] per se are poorly studied but many military noises are similar to more widespread civilian noises:

Military noises	Civilian analogs
Fixed-wing aircraft	
Sonic boom	
Turbine noise	civilian aircraft (in part)
Propeller noise	civilian aircraft
Exploding bombs/missles	construction, mining, thunder
Helicopters (rotary-wing aircraft)	
rotor blade	civilian helicopters
turbine	civilian helicopters
Artillery, tanks	
engine & road noise	railroad trains, vehicles including off-road vehicles
guns	
muzzle blast	fireworks
shock wave of projectile	
explosion (airborne)	construction, mining
explosion (substrate-borne)	earthquake, construction, mining
Infantry	
small arms (aircraft and tanks are also sources of similar sounds)	game hunting, other shooting

Studies on possible effects of the above classes of military activity on wildlife are reviewed in "Stimuli", below. Except for some literature on sonic booms, which are similar in some respects to sounds generated by large guns and bombs, the present review excludes effects of fixed-wing aircraft, which are reviewed by articles listed in the introduction.

Animals are often exposed to noise from more than one exemplar of the same kind of noise source such as the turbine noise of a platoon of tanks or the quasi-simultaneous explosion of a cluster of bombs. Although SPL's in such cases should exceed those from single sources, they

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[3] "Noise" is placed in quotes because, although some of the sounds made by military equipment -- propeller noise of aircraft, for instance--is an undesired side-effect, other sounds of battle are desired for their value to startle and intimidate the enemy and to habituate one's own personnel during training.

are not linearly additive because of effects such as shadowing of more distant vehicles by closer ones, non-simultaneity of impulse noises, and destructive interference of sound waves from different sources. Therefore measured SPL's from multiple sources will often fall short of computed summed SPL's from the individual noise sources.

Military noise can be clumped in space as well as in time. For some noise sources such as artillery and firearm practice and stationary electrical generators, the noises emanate from nonrandom, often fixed positions and wildlife with home ranges small in comparison with the installation will experience very different noise intensities depending on the exact geography. In other situations, such as tank maneuvers, the noise sources will be more spatially pervasive and less spatially predictable.

Classes of sounds

Literature on effects of noise discriminates based on the timing of sounds. Continuous noise lasts for a long time without interruption. Impulse noise lasts for a short duration, often as short as one primary overpressure wave and its sequelae. Trains of impulses such as helicopter rotor noise and bursts from rapid-fire weapons represent intermediate or hybrid instances; if the repetition is rapid enough, they may resemble continuous noise in their effects. Evidence is accumulating that impulse noise and continuous noise differ both in their potential physical effects, namely hearing damage, and in their sensory-mediated physiological and behavioral effects (see Effects on individual animals, below). Former attempts to estimate the continuous noise level "equivalent" to a given impulse noise (the equal energy hypothesis) have been abandoned or redirected (Arlinger and Mellberg 1980, Roberto, et al. 1985). It should be emphasized that continuous noise, although one of the most common experimental conditions that is used in the laboratory, is seldom encountered by wildlife (exceptions: see Effects on populations, below). Continuous noise is nevertheless a useful tool to investigate the etiology of harmful effects of shorter-duration noises.

Impulse noise is difficult to characterize (Hamernik, et al. 1993; Schomer, 1994) and we do not know exactly which parameters of impulse noise are relevant to its biological effects (Nábelek 1980). The physics of impulse noise is discussed in Hamernik and Hsueh (1991).

Noise from explosions is the best-investigated kind of impulse noise (Voigt, et al. 1980). Exploding projectiles and bombs can be expected to vary in their sound depending on their type and their height above or below ground at detonation. Sound levels generated by the equivalent of small projectiles (60 g TNT) exploding were 144 dB peak and larger projectiles (20 kg TNT) 163 dB peak, both at 100 m distance (Paakkonen 1991). In principle, impulse noise is easier to measure and quantify at a distance from the noise source, because the atmosphere disproportionately attenuates rapid transients (see Noise in the natural environment, below). Therefore, some complications of measuring military impulse noise in animals' habitats are reduced because the source of explosions and muzzle blast is usually at a distance, unlike measuring noise levels to which gun crews are exposed, for instance (Henderson and Hamernik 1986, p. 570). Projectile bow waves (see below) provide an important exception because shells can travel past animals, sometimes repeated for many rounds, without killing them.

The rapid onset of intense noise may cause such noise to sound less loud than is indicated by its power spectrum and to act as if it has effects at high audio frequencies disproportionate to their representation in its spectrum (Coles 1980). Therefore, rapid-onset impulse noise may be potentially more damaging than would be predicted strictly from its physical characteristics.

"Impact" noise results from one object striking another, is often reverberant, and obeys the elementary laws of acoustics because it seldom exceeds about 140 dB SPL peak pressure (Hamernik and Hsueh 1991). At levels < 140 dB, impact noise and impulse noise (e.g. from blasts) behave similarly (Hamernik and Hsueh 1991).

"Blast" noise is impulse noise from an explosion and results in shock waves with pressures (> 150 dB SPL) that no longer conform to the laws of ordinary acoustics (Henderson and Hamernik 1986). Blasts from military activities include the noise of detonating propellant from a gun (muzzle blast) and the noise of exploding shells or bombs at the target. Peak sound pressure level alone is often used to describe blast waves but is an inadequate descriptor for many purposes (Pater 1981). Muzzle blast is louder in the direction toward which the weapon is pointed, by up to 14 dB SPL (Pater 1981).

"Bow" shock waves from large projectiles (shells) flying through the air can generate peak pressures that exceed those from the muzzle blast , especially along the line of fire (Pater 1981, p. 24-26). Artillery projectiles typically travel at roughly Mach 2 and the shock waves from their travel are characterized by higher frequency sound than sonic booms from supersonic aircraft both because audible projectiles are closer and because projectiles are smaller in size. Close to the trajectory of an artillery projectile, its shock wave is "a sharp crack" (Pater 1981). Mortar projectiles, on the other hand, are subsonic (L. Pater, pers. comm.) and travel on a high, curving trajectory; therefore, the sound of explosions as heard near their impact is not preceded by a bow shock wave but can be preceded by the sound of the muzzle blast. Effects of projectile shock waves on animals are poorly studied.

Rotary-wing aircraft (helicopter) noise consists of a complex mixture of continuous engine (usually turbine) noise and rapidly repeating impulse noise from the rotor blades, sometimes including nonlinear noise of rotor tips travelling near Mach 1.

Substrate vibration behaves quite differently from airborne pressure waves. Although low-frequency overpressure waves from sonic booms and blasts do, of course, affect hollow objects such as closed buildings, airborne sound at frequencies audible to humans seldom transfers efficiently into vibration of solid objects. Rather, outdoor substrate-borne vibration is generally due to direct mechanical coupling of an explosion, recoil, or vehicle motion with the ground. Such vibration can differ markedly from airborne sound in its rate of propagation and frequency and in the sensory apparatus with which animals perceive it. Some animals use substrate-borne vibrations for intraspecific communication; in at least one case Rayleigh waves have been implicated as the form of the communication (Narins, et al. 1992). In the Arctic, polar bear dens are well-damped from vibratory disturbance by the substrate of packed snow (Blix and Lentfer 1992). In humans, vibration "over a certain level may cause annoyance", nearly independent of the intensity of the vibration over that level (Schuemer-Kohrs, et al. 1993). Vibratory disturbances are unlike airborne sound in at least this respect.

Noise in the natural environment

Embleton (1986) is an excellent short introduction to outdoor sound propagation and related topics.

Wind noise represents an important yet little-measured source of background noise outdoors (Peterson 1980a), even in forested habitats (Eve 1991). Common in daytime and nearly ubiquitous in some habitats, wind noise is composed of (1) non-laminar flow over microphone, ear, or other sensor and (2) flow over or wind-induced motion of other objects, propagated to the sensor. Wind noise from flow over the ears of animals is very difficult to measure although probably quite significant, especially for flying animals. Natural ambient noise such as wind noise can presumably mask or otherwise reduce the effect of human-produced noise; however, in some cases wind noise can mask gradual increase of noise such as approaching aircraft or vehicles, thereby converting gradual-onset sound into rapid-onset sound (Harrington and Veitch 1991) capable of startling.

Attenuation of propagated sound in air is dominated by heating of air and water molecules by high frequency sound, which is why low frequencies predominate over high frequencies at a distance (reviewed in Bass, et al. 1972, Canard-Caruana, et al. 1990, Hartley 1989, Kulichkov 1992). Larger weapons and vehicles generate noise with much energy at low frequencies, so that their noises will propagate with little loss due to attenuation in air. Wind speed and direction have important effects on outdoor sound propagation (Canard-Caruana, et al. 1990).

Propagation of sound in natural environments is difficult to measure (Michelson 1978). In particular, propagation of impulse noise through forests and other dense vegetation is poorly understood. Studies of outdoor sound propagation typically measure excess attenuation, i.e., attenuation in excess of that expected from inverse-square spreading loss. Excess attenuation is attributed to heating of the air, refraction in the air, and absorption and scattering of sound by topography, ground, and vegetation (Embleton 1986, Marten and Marler 1977, Marten, et al. 1977, Saunders 1990). Additionally, habitat characteristics sometimes distort sounds, due primarily to differing arrival times of direct and scattered waves (Dabelsteen, et al. 1993). Regardless of the so-called "sound channel" or "ground effect" (Cosens and Falls 1984, Martin 1981, Roberts, et al. 1981), the height of the source and listener are important variables in outdoor acoustics (Dabelsteen, et al. 1993; Pater, et al. 1994). Songs of forest birds tend to contain less temporal detail than songs of birds in other habitats (Wiley 1991), probably as a result of natural selection in an environment that blurs sound in vegetation. That is to say, the brief and rapid acoustic features characteristic of many bird songs are less prevalent in forest birds, although turbulence of the air may have a similar blurring effect in open habitats in some meteorological conditions. Research on sound propagation outdoors implies that noise measurements should be taken in the same habitat and at the same height above ground, and preferably in the same individual location, as occupied by wildlife possibly impacted by the noises. A further implication, in most habitats, is that wildlife listening from a vantage above the ground may hear more noise and louder noise than wildlife listening from very close to the ground.

The natural acoustic environment extends in three dimensions and includes sounds heard by flying animals. Sounds from the ground can be heard clearly from overhead (D'Arms and Griffin 1972, Griffin 1976, Griffin and Hopkins 1974).

2 MATTERS BIOLOGICAL

Biological background

Many diurnal species and large carnivores use sound in advertising displays and dominance interactions; many nocturnal species use sound in detecting prey, predators, or conspecifics (e.g. see Strasser and Dixon 1986); and many anurans and nocturnal animals use sound in communication. Communication via sound, along with electrical and light discharges and substrate vibration, has been the subject of extensive experimental work because of the ease of reproducing the communication signals. Animal communication in general, including information-theoretic approaches, graded vs. discrete signals, ontogeny, and phylogeny is reviewed in Green and Marler (1979), Sebeok (1977), Kroodsma and Miller (1982), Ryan (1986b), and Brenowitz (1986).

It is helpful to identify information-containing features of animal sounds (Ryan 1988). Such features of sounds may include frequency and amplitude and modulations of each, temporal features including duration and spacing of notes, and other attributes. For instance, Rose and Capranica (1983) and Allan and Simmons (1994) show that amplitude modulation information is used by some species of anurans. Because amplitude of sounds is discriminated more coarsely by vertebrate ears than frequency and because noises can additively modify amplitudes of sounds with which they share spectral components, noise should mask amplitude information more than frequency information. Therefore, such a communication system should be more sensitive to interference by noise or to acoustic impairment of the participants than one relying on frequency information. As another example, individual recognition by voice of Emperor Penguins in an environment of noisy conspecifics appears to be accomplished partly by mutual recognition of the beat frequency arising from concurrent vocalizations of the two communicating partners (Robisson, et al. 1993). Without such knowledge, one might minimize the importance of noise similar in frequency to the beat frequency in the lives of these birds. Some species of swallows show adaptations for communication between parents and young against a “high-noise” background of conspecifics’ vocalizations, whereas others do not (Beecher, et al. 1986).

Considering the delicacy of a well-functioning ear (in which displacements of about 0.1 Å are detected at the tympanum, Harris 1986:20-21) or a well-functioning member of an ecosystem, we expect subtle effects of environmental noise. Communication sounds can be used for making complex distinctions such as the number of members of rival social groups (McComb, et al. 1994). Kangaroo rats detect minor temporal variations in foot-drumming patterns when distinguishing between drumming of familiar neighboring conspecifics and that of strangers (Randall 1994). Hunting Barn Owls localize rodent prey in two dimensions to less than 1° by hearing the sounds of the rodents’ locomotion over the ground (Payne 1971) and selectively detect moving as opposed to stationary sounds (Takahashi and Keller 1992).

Nevertheless, despite such finely-tuned acoustic abilities in wildlife, we cannot always assume that human-generated noise will necessarily have a negative effect. One reason is that, although natural environments can be quiet (e.g. low 20’s dBA in desert, Brattstrom and Michael 1983), natural noise is part of the natural world (Eve 1991, Ryan and Brenowitz 1985, Waser and Waser 1977) and adaptations to a noisy existence predate modern weapons and conveyances. For instance, certain speies of frogs avoid vocalizing during loud calling by cicadas (Páez, et al. 1993) or other frogs (Matsui, et al. 1993), time their calls to use brief silent periods (Schwartz

1991), adapt their calling to circumvent cacophonies of conspecifics (Narins 1992), and possibly geographically exclude competitive sibling species acoustically (Odendaal, et al. 1986); other references on noise interference with anuran communication are given in Barrass (1985:4-5, 29-31) and Gerhardt 1988. Similar avoidance of acoustic interference is found in songbirds (Popp 1989).

Bowles (in press, 1995, "Effects of noise on behavior") points out that attraction to sources of noise and habituation to noise can have negative effects on wildlife.

Sudden onset of an acoustic stimulus is perhaps analogous to a looming visual stimulus (Hayes and Saiff 1967) and can be especially effective in eliciting flight or other responses (Berrens, et al. 1988, Conomy 1993). Sudden onset of disturbance has been emphasized for cliff-nesting raptors, when experimenters approach unseen and unheard along the cliff edge or above the cliff (e.g. with a helicopter), undetected until they appear close and loud (Platt 1977). In humans, unpredictable or intermittent noise has more serious effects on performance than predictable or continuous noise (Sundstrom 1987).

Many studies imply that wildlife react to close phenomena more than distant ones (e.g. Grubb and King 1991, Henson and Grant 1991). If so, noise sources that are out of sight may cause greater reaction if they are close than if they are distant, leading to the hypothesis that the animals are using cues contained in the noises themselves to estimate distance. Such cues include altered spectrum, lower intensity, and blurring of sound with increased distance (Canard-Caruana, et al. 1990, Dabelsteen, et al. 1993, Romer and Lewald 1992). That sudden-onset noise is especially apt to cause reactions from animals is consistent with the hypothesis, because distant noises usually have a slurred or rumbling onset rather than a sudden onset.

Generalization across taxonomic boundaries

Biologists often expect phenomena to be species-specific. Responses to noise are no exception. For instance, at the physiological level, some birds show different hearing deficits than mammals do when exposed to the same kinds of loud noise (Saunders and Dooling 1974). It is not safe to make exact predictions about hearing thresholds of particular species based on data from another species; for instance, although many species of birds have similar audiograms (Dooling 1982), two species of North American sparrows in the genus *Melospiza* differ by about 10 dB in hearing threshold at 2-3 kHz (Okanoya and Dooling 1988). The two species differ in mass by only about 20%. Similarly, generalization across species holds for a measure of audio frequency resolution for several bird species but not for Budgerigars (Okanoya and Dooling 1987b).

At the behavioral level, whereas some medium-sized diurnal raptors flee from approaching helicopters (Andersen, et al. 1989, Platt 1975, Platt and Tull 1977), others refuse to be flushed from the nest (Poole 1989), and larger ones sometimes attack helicopters, presumably in defense against a flying intruder (Mooney 1986, Watson 1993). Variability of response by raptors to disturbance in general is also noted in Awbrey and Bowles (1990) (although the authors make repeated generalizations concerning "raptors"). Similar within- and between-species variation in response of raptors to explosions is noted by Holthuijzen and Eastland (1985:278-279) and in responses of species and populations of waterfowl to human disturbance by (Dahlgren and Korschgen 1988).

Differences among species tend to be qualitative and therefore may be passed over in the rush toward statistical significance. However the perilousness of taxonomic generalizations such as "reactions of wildlife" is readily demonstrated in the field as noted in the following anecdotal account of reactions of arctic wildlife to fixed-wing aircraft and helicopters.

> Moose showed a much greater indifference to aircraft than caribou, and this was equally true of animals encountered in the open or in partial cover. Those moose that ran from the aircraft were in most cases cows with young calves. Grizzly bears, on the other hand, reacted very strongly to the aircraft, often starting to run while the aircraft was still some distance away, apparently trying to outrun the aircraft. In most cases, as the aircraft overtook the running bears, they would veer sharply away from the flight path of the plane. Often when bears were surprised on the tundra, they would try to reach willows in the stream bottoms or other cover before the aircraft overtook them.
>
> Wolves appeared least disturbed by low-flying aircraft of any of the large mammals observed. This is somewhat surprising in view of the fact that they were legally hunted from aircraft in the study areas as late as [ca. 4 years earlier], and at that time, aerial hunters commented on the extreme alarm shown by wolves to aircraft. Currently, aircraft are common in the study areas, and wolves have apparently rapidly adapted to the discontinuance of the threat from this source. (Klein 1973)

The above qualitative accounts of species differences of arctic wildlife were given firm quantitative support by later experiments on caribou and muskoxen in the Canadian Northwest Territories (Miller and Gunn 1979). Ward (1985, cited in Andersen, et al. 1990) describes species differences between two species of cervids in reaction to disturbance.

In addition, group-specific differences occur. Three herds of muskoxen studied by Miller and Gunn (1980) were consistently "calm", "excitable", and of intermediate responsiveness to helicopter overflights. Such group differences could be mediated by heightened responsiveness on the part of certain individual members of the group combined with social facilitation of response within the group. For instance, flight responses of herds of Roosevelt elk in response to noise and other disturbance were attributed to "a decision of flight made by one animal. Almost always, flight of the entire herd followed. ...smaller herds were less likely to contain an animal that would break for cover." (Czech 1991)

Learned responses to noise

Habituation is a kind of learning ubiquitous in the animal kingdom (Peeke and Petrinovich 1984). A biologist's definition is "the elimination of the organism's response to often recurring, biologically irrelevant stimuli without impairment of its reaction to others" (Lorenz 1965:50). No study takes place without subjects habituating to their natural or experimental environments. Even fetuses in utero habituate to fluid-borne acoustic stimuli (Leader, et al. 1988). Habituation is an active process, as demonstrated by experiments on playbacks of alarm calls to caged Chaffinches (Zucchi and Bergmann 1975). The anti-predator behavior of freezing waned and disappeared after about 12 repetitions of the stimulus but partially reappeared with change of any parameter of the recorded call (except simple reduction in its intensity). This dependence of habituation on stereotypy of stimulus presentation (Hinde 1966: 205-209) is well-demonstrated in field studies of birds' reaction to attempts to scare them away from airfields and agricultural areas (discussed below). Similarly, more predictable sources of disturbance can lead to greater apparent habituation in field situations than less predictable ones (Murphy et al. 1989, in Ward and Stehn 1989:120). Military training situations in which similar noise-producing exercises are carried out in the same habitat at frequent intervals may therefore affect locally-breeding wildlife less than less-frequent or less-predictable activities.

Context, including acoustic context, is an important influence on habituation and other learning (Shalter 1984: 378-381), as is illustrated in a series of laboratory experiments on sensitization, which is the reverse of habituation . Davis (1974) presented albino rats with sudden-onset loud tones (110-120 dB) in the presence of a background of continuous white noise. When the background noise was moderate (60 dB), the rats' startle response diminished after a few presentations of the tone, showing habituation. However with only 20 dB louder background noise, the rats showed successively stronger startle responses, or sensitization. The laboratory studies are borne out by data on human performance in the workplace when different sources of noise are combined (Ahroon, et al. 1993). Such nonintuitive, synergistic interaction of two quite different noise sources may merit looking for in field situations.

Habituation is seldom defined operationally but it is often invoked to explain differential responsiveness to disturbance by animals in the field that are regularly exposed to human intrusion and those that are not (e.g. summary in Postovit and Postovit 1987:205-206). Such "habituation" is usually suggested by anecdotal observations rather than demonstrated by a controlled experiment. This is not to say that habituation is not responsible for the observed changes in behavior, but rather that other explanations of a change in behavior have not been ruled out. Field researchers deal with this problem in various ways. One investigator noted that Red-cockaded Woodpeckers successfully raised young near a highly active bombing range in Mississippi but breeding failures by other birds at other sites appeared to be associated with human noises (Jackson 1983). The author suggests that noises novel to the latter birds had effects whereas louder noises to which the bombing range birds were habituated had no effects; the tentativeness of the conclusion is reflected in the title of the report. Other investigators recognize the problem by correctly noting that their results are consistent with the hypothesis that the subjects habituated, without claiming that habituation has been demonstrated (Andersen, et al. 1989, Grubb and King 1991).

Certainly habituation is a likely explanation for diminished responsiveness to stimuli; however, other mechanisms are easy to imagine. For instance, areas with frequent human intrusion may be selected by individual animals with a higher threshold for response to human disturbance, for instance via a greater flight distance (Hediger 1964) or impaired sensory or perceptual capacity to detect disturbance. If these phenotypic traits are heritable, one might expect local evolution of resistance to susceptibility to disturbance.

Military noises probably become salient through classical conditioning. An animal that experiences a noise in conjunction with an aversive unconditioned stimulus, for instance whose nest tree is bumped by a military vehicle or one that experiences a projectile impact at short distance and survives, will likely associate the sound of the vehicle, muzzle blast, or projectile with the trauma. The resulting conditioned response to the noise will be more extreme and more resistant to habituation than the response of animals not conditioned to the noise.

It is possible that the special salience of gunshots (see Firearms, below) for some wildlife is a result of associative conditioning, perhaps, in fact, observational learning. More generally, learned association of human-generated noise with other, more directly fear-producing human activities may be the principal mechanism of many noise effects on wildlife.

Time: susceptibility to noise over the diel, season, and life history

The diel (24-hour) cycle affects acoustically-mediated behavior of animals. Differing effects of noise on wildlife may be expected at different times. The risk of damage to human hearing from workplace noise appears to be affected by time of day (Voigt, et al. 1980). Natural noise, including wind noise and rain, varies greatly over the diel and appears to influence when acoustically-specialized predators hunt (Anisimov and il'ichev 1975). Different species partition the “resource” of quiet by calling at different times of the day to reduce acoustic interference with one another (Ryan 1988:641-642). Herbold (1992) found that two species of deer reacted to experimentally-generated stimuli including noises differently at different times of day. Coyotes changed their daytime activity in response to military training maneuvers (Gese, et al. 1989). Such results strongly suggest that scheduling military noise (e.g. training activities) to avoid certain times of the diel would reduce effects of noise on certain selected species (albeit perhaps diferently affecting other species with different diel use of sound).

Published studies of effects of noise and other disturbance have favored diurnal rather than nocturnal wildlife (see also Awbrey and Bowles 1990:12, regarding owls) and have often favored daytime conditions when animals can be more easily observed visually. Whatever the reasons for such a bias, the bias may be inappropriate for two reasons. First, much military activity, especially maneuver training, takes place at night because of emphasis on preparedness for night warfare. Second, animals may rely more on or attend more to auditory cues at night than in daytime.

Season and the reproductive cycle also affect acoustically-mediated behavior. Field experiments by Platt (1977) are consistent with the hypothesis that Gyrfalcons flee from helicopter overflights much more readily when nesting than during winter, in the same area. This result might be attributed to the severe cost of flight at winter temperatures on the North Slope of the Yukon Territory. However, nest success the following spring diminished at most sites of winter disturbance, indicating that the negative finding in winter was misleading. In experiments investigating the influence of stage of nesting cycle on responsiveness of Red-tailed Hawks, Andersen, et al. (1989) found no tendency (i.e., alpha probability high; no power analysis) on the part of adult hawks to flee from a helicopter at later stages as opposed to earlier in the nesting cycle.

Some seasonal differences in responsiveness of Alaskan caribou to aircraft overflights are attributed by Klein (1973) to “preoccupation of the animals with [biting] insects” in summertime on those days when weather favors insect activity. Similarly, desert bighorn sheep reacted to overflights by recreational helicopters differently in different seasons (Stockwell and Bateman 1987, Stockwell, et al. 1991).

On a longer time scale, the ontogeny of individual species must always be considered; for instance, young ferrets may be considered pre-adapted to noise trauma. The larger weasels and ferrets (including domestic European ferrets and endangered black-footed ferrets) show a profound hearing deficit until they are about 32 days of age because their external auditory meati remain closed (Moore and Hine 1992).

One of the clearest examples of critical periods in ontogeny is the development of song in many species of birds. Songs heard during only a specific few months of the life of a young bird exert an abiding influence on adult song (Mayfield 1966, Miller 1982, Nottebohm 1975,). We have not found published reports on the possible influence of intermittent noise during such a critical period.

There is some evidence that young animals are more susceptible than adults to hearing loss from exposure to loud sounds (Abrams 1980).

3 EFFECTS ON INDIVIDUAL ANIMALS

As pointed out by Petit (1991), results showing effects of noise on animals are more apt to be published and noticed in the literature than results showing no effects.

Stress and other general physiological effects

"Stress" (Selye 1956) effects of noise on animals are reviewed in (Clough 1982 and Tromberg, et al. 1994, in press). Autonomic responses to noise are widespread, occurring widely in birds and mammals, including sleeping human infants in their first year (Anderssen, et al. 1993, Prabhakaran, et al. 1988). The ubiquitous nature of such responses has made noise a popular experimental tool for inducing stress in biomedical research (e.g. Antov, et al. 1985, Wright, et al. 1981). Noise and other noxious stimuli can act synergistically to produce stress (Busnel, et al. 1975). As pointed out by Bowles, et al. (1991), stress is not necessarily indicative of negative consequences to individual life histories or to populations.

Research on humans may be of value in predicting possible stress-like effects of noise on wildlife. For instance, whereas behavioral studies on animals usually examine immediate reactions such as flight, psychological tests on humans clearly indicate that noise affects performance on tasks conducted after the noise ceases. This occurs even if no effects appear during the noise. Such behavioral aftereffects of noise are well-documented for both steady and time-varying noises (Cohen 1980, Glass and Singer 1972). We are not aware of any directly comparable studies on nonhuman animals.

Geist (1971) has argued for estimation of the energetic cost to animals of being disturbed. Heart rate, monitored via telemetry in captive or wild animals exposed to noise (Diehl 1992, Krausman, et al. 1993a, Krausman, et al. 1993b, Krausman, et al. 1993c) is used as a physiological index of energy expenditure (reviewed in MacArthur, et al. 1979), but also as an indication of "alarm" or "excitement". Heart rate increases (tachycardia) or decreases (bradycardia) (MacArthur, et al. 1979) in response to noise; however, tachycardia is merely transient and conssequently any effect on the day-to-day energy balance of the animal is difficult to demonstrate (Anderssen, et al. 1993, Krausman, et al. 1993b, MacArthur, et al. 1979). Recording and quantifying heart rate can be easier than placing specific biological interpretations on resulting data (Espmark and Langvatn 1985), especially when the telemetry package and the necessity to capture and restrain the subjects may themselves sensitize the subjects to subsequent disturbance. Bowles (in press, 1995) provides a valuable perspective on heart rate as a dependent variable.

Research on humans into audiogenic diseases (Irwin, et al. 1989) and even anatomical studies of effects of noise on the ears of laboratory rodents (Cody and Robertson 1983) are characterized by high variability. Nevertheless, various physiological effects of noise are documented (Welch 1973). Laboratory investigations of effects of noise on the immune system have not produced a consensus (Bly, et al. 1993).

Even when habituation to a stimulus has occurred, significant physiological effects may nevertheless still be taking place. For instance, long-term habituation to acoustic cues affects metabolic activity of several areas of the brain (Gonzalez-Lima, et al. 1989).

The energetic (metabolic) cost of reacting to disturbance is discussed below under

"Behavioral and physiological effects in relation to population-level effects".

Noise-induced hearing loss

Most researchers have concluded that direct trauma to wildlife by noise is likely to be auditory, since "The ear is the most vulnerable structure because of its function, i.e. as a transducer for even weak airborne pressure waves" (Zajtchuk and Phillips 1989). Therefore, noise-induced hearing loss deserves special consideration. This section attempts to place human-oriented research on noise-induced hearing loss in phylogenetic perspective, emphasizing loud sounds similar to those likely to be encountered on military installations.

Although sound transduction in mammals differs in fundamental ways from that e.g. in birds (Klinke and Smolders 1993), generic references in the literature to "the inner ear" and "the effects of noise upon hearing" almost always refer to a small number of kinds of mammals, especially house mouse, chinchilla, guinea pig, and human (exception: Cotanche and Dopyera 1990). Such phylogenetic shallowness is especially prevalent in specifically medical research on hearing loss. (Research on non-auditory damage from blast noise frequently uses sheep, pigs and other similar-sized mammals.) There is some indication that species differences in susceptibility to noise-induced hearing loss are due more to anatomical differences in the middle ear than to differences in transduction in the inner ear (Dancer and Decory 1993). Considerable variability is encountered in studies of noise-induced hearing loss, even in a single species in the laboratory (Hamernik, et al. 1980).

In many situations, wildlife is more apt to be exposed to low-frequency intense sound than to high-frequency intense sound because of greater atmospheric attenuation of high-frequency components (Bass, et al. 1972, Hartley 1989, Kulichkov 1992). Therefore, sounds of most concern from the standpoint of human injury are not necessarily those of most concern to wildlife. For example, noise-induced hearing loss is the single largest category of military disability (Bennett and Kersebaum 1993). Those concerned with hearing damage to humans from firearms (Paakkonen, et al. 1991) are often careful to examine effects of high-frequency audible components (> 500 Hz) of muzzle blast. However few if any animals close to the gun will receive the dose of high-frequency sound experienced by the infantry soldier or gun crew. Therefore, hearing damage from small-arms fire is of concern for humans (Paakkonen, et al. 1991) but probably not for wildlife, although small arms fire may be expected to have other effects, notably with respect to its similarity to the sound of shooting of animals (see Firearms, below).

Permanent Threshold Shift (PTS) is lifelong hearing loss. It is usually not equal at all frequencies and is usually accompanied by decreased sharpness of frequency discrimination. Temporary Threshold Shift (TTS) is hearing loss that ameliorates with time (Clark 1991b). Noise causes PTS by at least two kinds of mechanism, one metabolic (physiological) and the other mechanical. The distinction is important for understanding how different kinds of intense noise affect the ear. Continuous or repetitive loud noise appears to cause metabolic stress (Gilloyzaga, et al. 1993) and vascular alteration (Axelsson and Dengerink 1987) to the inner ear. The cumulative effect is TTS, perhaps leading to PTS depending on the intensity of sound, duration of exposure, blood flow in the inner ear, and other variables. Therefore, continuous noise and repetitive loud noise are potentially more harmful in situations in which animals experience metabolic challenge (Fechter, et al. 1988). Unfortunately, dose-response and other information on which to draw more firm conclusions about this relationship are presently lacking.

The time course of short-term to medium-term recovery of the auditory system from impulse noise is spectacularly nonmonotonic when TTS > 30 dB is produced (Hamernik, et al. 1988). The TTS peaks about a half day after exposure to loud impulse noise, rather than immediately. Therefore studies (perhaps e.g. Counter 1985) that measure TTS immediately after exposure to loud noise probably underestimate the effect of the noise. The curious shape of the curve seems to be because the auditory system begins recovering from metabolic damage while edema from structural damage is still advancing. Subsequent PTS resulting from the exposure is predictable from the later peak TTS, not the immediate TTS, as shown in the laboratory for rhesus macaques (Luz 1970), chinchillas (Henderson and Hamernik 1986) and guinea pigs (Gao, et al. 1991). Hearing damage and other direct effects of loud impulse noise should be measured after a suitable interval, which is about 10 hours in those animals (all mammals) studied thus far (Melnick 1991). The laboratory findings also demonstrate that normal sensitivity returns prior to complete structural regeneration of the sensory epithelium and that repeated acoustic trauma may prolong the time course of recovery of normal hearing sensitivity.

Longer-term recovery from hearing loss can occur as a result of hair cell regeneration in birds (Niemiec, et al. 1994, Saunders, et al. 1991, Stone and Cotanche 1992; see also references in Klinke and Smolders 1993: 32). Research on mammalian hair cells exposed to ototoxic agents suggests that regeneration is also possible in mammals, at least in some circumstances (Bohne and Harding 1992, Duckert and Rubel 1993, Forge, et al. 1993, Warchol, et al. 1993).

Physical trauma to the ear caused directly by noise is more commonly associated with impulse noise than with continuous noise, partly because impulse noise loud enough to do physical damage is more common than continuous noise that is loud enough (Hamernik, et al. 1993). Severe noise, even brief in duration, can rupture the tympanum (Eames, et al. 1975), fracture the ossicles, damage various parts of the cochlea (Saunders, et al. 1991), in particular subjecting the tectorial membrane to shear forces sufficient to tear the tissue (Gao, et al. 1992, Vertes, et al. 1984, Ylikoski 1987), cause deterioration of auditory nuclei in the brain (Mattox 1991) resulting in hearing loss (Hamernik, et al. 1987) and/or distorted hearing (Abdul-Baqi 1984), or several of the above (Roberto, et al. 1989). At least in mammals distorted hearing may be related to damage to mechanical “sharp tuning” mechanisms of the cochlea (Pickles 1985, Saunders, et al. 1991), sometimes called the “outer hair cell amplifier”. In most or all mammals and birds (Counter and Borg 1982) middle ear reflexes such as the stapedius and tympanic reflexes (Borg 1970, Borg 1972, Kevanishvili and Gvacharia 1972) dampen the motion of the middle ear ossicles by as much as 10 dB, providing some degree of protection from continuous noise. However, like all reflexes, the stapedius reflex occurs with a certain latency and this latency permits sudden-onset loud sounds to rattle the ossicles before the stapedius muscle contraction takes effect. In this way rapid transients can cause physical damage to the hearing organs at a lower intensity than continuous or rapidly-repeating noise (about 10 dB lower, in fact, in many cases). Henderson and Hamernik (1986:576 ff) review the parameters describing impulse noise and their relation to impulse-noise-induced PTS. The clinical and physiological implications in mammals of rapidly-repeated vs. spaced loud impulse noises are specifically addressed in Dancer, et al. (1991) and Devriere, et al. (1992).

PTS began to occur at lower peak pressures for impulse noise from rifle fire than for impulse noise for artillery fire in one study using cats (Price 1983). If this result holds for other species, then results from experiments using one kind of impulse noise should not be generalized to other kinds of impulse noise, even for the most severe and basic kinds of effects of noise.

Marler et al. (1973) found that Common Canaries treated long-term with 95-100 dB SPL continuous broadband noise showed increased hearing thresholds and flattening of single auditory unit response curves. Thresholds at high frequencies were especially affected. Birds of different ages did not show differential hearing impairment. That the strain of canaries used in these studies were apparently slightly hearing-impaired (Okanoya and Dooling 1985) does not invalidate the findings of Marler et al. (1973).

Hashino (1988) exposed two Budgerigars to 169 dB (peak SPL) impulse noise and found that PTS was emphasized at low frequencies and nearly absent at higher (4 kHz) frequencies. About half the duration of noise is required to cause PTS in birds compared with mammals (Saunders and Dooling 1974).

Both PTS and TTS can decrease viability or reproductive success when wild animals' hearing is damaged. Long-term ontogenetic effects may vary; some species of birds appear normal in singing behavior despite being deafened at an early age, whereas other species cannot sing normally (Dooling, et al. 1987, Marler, et al. 1973).

Brattstrom (1983) reported TTS for lizards and kangaroo rats after 500-s exposures to ORV (dune buggy) sounds at 95 dBA. An indirect physiological measure of hearing suggested to the authors that "dune buggy sounds are inherently damaging to the hearing sensitivity of fringe-toed lizards." Surprisingly, the lizards appeared to be vulnerable to noise-induced TTS even when buried beneath shallow layers of sand. In separate experiments, direct and convincing behavioral measures on desert kangaroo rats showed that these animals' ability to detect predators at a distance via audition is significantly diminished for about three weeks after noise exposure. (However the effect of hearing loss on the detection-distance appears to be overestimated by the authors.) The kangaroo rat hearing deficit appears to have been classic continuous-noise-induced TTS. The authors speculate that these desert animals may suffer hearing deficits after less noise exposure and/or intensity than adult humans do, in the case of the kangaroo rat because the animals have highly specialized ears.

Anecdotal accounts describe terrestrial wildlife living with noise loud enough to cause pain in humans. These include seabirds at airports (Burger 1983), warblers in Texas (T. Hayden and D. Tazik, pers. comm. 1994), Wild Turkeys near a rocket testing plant in Florida (Williams 1981:60), and Ospreys at the Naval Surface Warfare Center, Dahlgren Laboratory (L. Pater, pers. comm.). Other anecdotal reports of wildlife breeding or coexisting near military noise are summarized in Tennesen (1993).

"Disturbance"

Sometimes researchers confuse hypothetical constructs with dependent variables, a practice that may obscure important issues. The often-vague concept of "disturbance" (Awbrey and Bowles 1990, van Rooijen 1984) is a case in point. Some define disturbance in terms of physical objects or events occurring in the surroundings of the animal: "Disturbance... was determined by recording the number of vehicles passing during the observation period." (Plumpton and Lutz 1993) Similarly, Conomy (1993) defines disturbance as "aircraft activities occurring in and around the study area".

Others define disturbance operationally in terms of behavioral response of animals. For instance, Kushlan (1979) defines "drastic disturbance": "...if a bird left its nest and failed to return within five minutes." Holthuijzen and Eastland (1985) measured percentages of subjects that flushed off the nest and also "readjustment time, ...the time elapsed before a falcon resumed the activity it was engaged in immediately prior to the blast". Harmata, et al. (1978) define disturbance in stimulus-response terms: "any stimulus causing responses that change normal behavior." Miller and Gunn (1979) make the distinction explicit in their definition of harassment, which they use as equivalent to deliberate disturbance:

> "Harassment" is assumed to be the phenomenon which resulted from the introduction of unidentified stimuli into the animal's environment brought about by a harassing agent (helicopter). Our only measure of harassment was through overt responses by the supposedly harassed animals.

Defining disturbance in terms of behavioral response rather than manipulations has clear advantages when the effects on the animals are not well-known beforehand. For example, Weinstein (1978, cited in Berry 1980) describes a pair of Say's Phoebes that flushed at the approach of ORV's but did not flush when 15-20 trains/day passed over the railroad trestle on which they nested. The birds' behavior rather than the size, loudness, or other immediate characteristics of the conveyances indicated disturbance. Williams (1981:69) reports similar anecdotal evidence of a nesting wild turkey ignoring a nearby train. In contrast, Platt (1977) reports separately responses of Gyrfalcons to helicopters flying nearby and to humans on the ground. However, because of expense and extreme logistical difficulties (field work at -40°), numbers of observations were small and the author calls both kinds of approach to the birds together "disturbance". Although a human approaching a nest site on foot and a helicopter flying overhead may indeed have similar and perhaps even additive effects on birds, it is premature to lump effects together under one anthropocentric concept until this is demonstrated.

Awbrey and Bowles (1990) define "severe disturbance" of raptors as those kinds of disturbance that produce "serious effects", stating that "The only behavioral response that is known to be associated with serious effects is flying from the nest...." Considering the rather meager state of our knowledge of a diverse group of birds with varying degrees of parental investment, this narrow definition is cavalier in its implication that no adult raptor is severely disturbed as long as it remains on the nest.

Migrating and other flying birds

Experiments on the reactions of nocturnally-migrating songbirds to sounds played from the ground (Larkin 1978) suggest that migrants might react to military noise. The flight paths of birds were observed using a tracking radar. Sounds of bird vocalizations sometimes elicited changes in height and other reactions. The recorded sound of thunder elicited turns away from the source of the sound and such turns were more likely in cloudy weather, suggesting that the birds responded in a biologically meaningful way. Although sometimes birds were observed to re-correct their course after the sound had ceased, sometimes the course changes endured to the edge of the range of the radar unit. The species of night-migrating birds could not be determined, although most were songbirds.

Similarly-conducted pilot experiments using intense tone bursts emanating from directly below migrating birds showed very few responses to the sound (Larkin, unpublished observations 1977-1979). The sound was a 400-ms 2-kHz tone with a 50% duty cycle, lasting 3 s. Only three of 96 birds deviated from a straight and level path, a rate not much above the background rate; each of the possible "reactions" was merely a slight change in height or rate of climb.

These limited studies of migrating birds suggest that the birds do not show frequent reactions to loud sounds *per se* but that noise from large blasts resembling thunder could have short- or longer-term effects on their oriented behavior.

Flying waterfowl may also respond to noise. Gollop, et al. (1974b) show that, when presented with gas compressor station noise, individual snow geese will alter their flight direction (61% by more than 90 degrees). In addition, snow goose flocks will avoid landing in response to decoys while in the presence of such noise. Similar data are presented in Wiseley (1974).

Intentional use of noise to disperse wildlife

An extensive literature describes scaring wildlife away from farms, orchards, airport runways, and other places where they are not wanted (Blokpoel 1976, Murton and Wright 1968:108-109). For instance, firearms, pyrotechnics, ignited-gas cannons, and tape recorded sounds of various kinds are employed to try to prevent depredation on crops or collisions between birds and aircraft. The stimuli usually have sudden onset and are loud but not so loud that they cause complaint from humans in neighboring areas. In many cases, such acoustic stimuli lose their effect as birds habituate to them (Larkin 1976). One infamous example is that of Red-winged Blackbirds initially routed by chemical exploders (gas cannons) (Dr, R. Defusco, pers. comm. 1994). After repeated firings, the birds became so inured to the sound that they rested on the cannons, learning to fly a short distance away when they heard the click of the mechanism that released the gas and signalled an impending explosion. (Neither the hearing acuity of the birds nor the sound intensity at the distance to which the birds fled was measured.) As one would expect, repetitive and predictable sounds are less effective in moving birds than human- or randomly-produced sounds. The loudness of sounds per se sometimes can be increased to the point of pain (for humans) without deterring birds from frequenting a favored feeding place (Blokpoel 1976). Presenting sounds in conjunction with visual stimuli that have biological relevance (such as dead conspecifics) also reduces the tendency of target animals to habituate. When wildlife are successfully eliminated from an area for a long period of time by scaring techniques, it is usually via conscientious and diligent scaring, repeated whenever the animals return to the area until they no longer return.

These endeavors to intentionally affect wildlife using noise can be extrapolated to effects of military noise on wildlife only with caution. The species of birds are not endangered and are usually pest species, already adept at living alongside humans and their insults, although sometimes raptors or other birds not usually considered pests become problems at airports. The stimuli are seldom as loud as blast noise from military ordnance. In many cases conspecific distress calls and other specifically biological sounds are the most effective sounds to use in scaring birds. Finally, long-term biological effects are not addressed in most studies--success in a bird scaring program may or may not affect the biological fitness of the population.

Nevertheless, the bird scaring literature suggests some methods of mitigating possible effects of military noise. For instance, regular intervals between firings or overflights and noises that are perceived to be invariant should have less effect on wildlife than haphazardly-timed and varied sounds. Cues appearing just before loud sounds might permit animals to learn to vacate an area or otherwise reduce the potential stressful effect of a sudden noise. Contrariwise, sudden-onset sounds that are even occasionally paired with biologically-meaningful events (such as injuring conspecifics) may strongly affect wildlife for a long time.

Domesticated and confined animals

The selective forces producing domestication often lead to decreased response to degrees of disturbance that would otherwise have negative effects on reproductive potential (Richter 1954, Stoskopf and Gibbons 1994). There is not much scientific literature on responses of zoo animals to noise. However, of course, we have not found publications on the response to noise of those animals that do not adapt to captivity.

Price, et al. (1993) found that farm-confined red deer were especially vulnerable to noise as opposed to other disturbance. Stephan (1993), studying farm animals and game-farm mink, found strain-specific differences in reactions to overflights by helicopters and fixed-wing aircraft.

5 EFFECTS ON POPULATIONS

Management concerns populations, not individual animals. This concern with populations is manifested at three levels, discussed in the sections below.

- Effects on populations may be measured via long-term census and genetic analysis.
- Effects on populations may be deduced from evidence that the agent alters viability or overall reproductive success on the part of a meaningful proportion of individuals of the population. The evidence may be behavioral, physiological, epidemiological, and so on.
- Effects on populations may occur through selection for traits that permit members of the population having those traits to survive and reproduce better in the continuing presence of the agent.

Measurement of population-level effects

The management argument for studying impacts on wildlife at the population level is stated in Tazik, et al. (1992:47):

> "In evaluating impacts of military activities..., it is important to take a population-based view. If population trend data indicate that the local population is stable and relatively abundant, then adverse impacts that affect only a few individual [animals] should be considered insignificant."

A similar point of view is expressed in Bowles et al. (1993):

> ...great caution should be used in interpreting short-term responses as evidence of stress.... In free-ranging animals, the results of stress, such as effects on reproduction, habitat use, general health, and longevity, must be measured directly.

One assumes that the population is stably reproducing, rather than maintaining stable numbers though immigration. Such population-based views as the above are implicit in most biological studies of adverse impacts, although most studies measure immediate effects of noise on individuals or groups rather than attempting to measure population-wide effects, partly for obvious reasons of expediency.

Measuring populations directly requires long-term data over many years. Several or many generations are often necessary to document population-level effects, especially in species in which breeding success is known to be highly variable such as the Red-cockaded Woodpecker (Lennartz and Henry 1985). Time will be a problem when management decisions cannot be postponed long enough.

Behavioral and physiological effects in relation to population-level effects

Immediate effects and potential population-level effects are often correlated. For instance, both efficacy of acoustically-mediated mate attraction and reproductive output (egg masses) of two species of anurans were reduced in areas near highway traffic noise (Barrass 1985). Mule deer subjected to repeated approaches ("harassment") by all-terrain vehicles in October showed both immediate behavioral responses and decreased reproductive success (1 fawn total for N=5 females) the following season (Yarmoloy, et al. 1988). In a study on caribou, calves' later survival was negatively correlated to degree of experimenter-controlled exposure to low-level overflights of military jet aircraft (Harrington and Veitch 1992). Spearman rank correlations were about -0.7 during summer stress periods. Other similar long-term effects on caribou are listed in Klein (1973).

In some cases, such as the following summary of Adelie Penguin reactions to the sight and sound of aircraft, immediate effects and population-level effects are clearly correlated.

> Aircraft caused birds to panic at distances greater than 1,000 m and 3 days exposure to a helicopter inhibited birds that had been foraging from returning to their nests, caused bird numbers in the colonies to decrease by 15% and produced an active nest mortality of 8%. Wilson, et al. 1991

Even when studying only immediate effects upon individual animals, researchers usually emphasize behaviors and circumstances that affect their survival and reproductive success and therefore serve as mediators of population-wide effects (see also Andersen, et al. 1990, Luz and Smith 1976). Many studies quantify immediate behavioral reactions of animals to noise, usually by establishing ordinal scales of increasing magnitude of effect on the animals. Often such rankings are implicitly or explicitly based on assumed or demonstrated longer-term effects on the animals, for instance, on reproductive potential or energetic expenditure. Such rankings must be based on intimate knowledge of the behavior of the animals. For instance, disturbances often cause increases in respiration rate in lizards, which appears to be a benign effect. But lizards that breathe rapidly do not eat (Avery 1993).

In other cases careful quantitative measures of behavior are needed to distinguish trivial from nontrivial effects. Incubating or other nesting parent birds sometimes vacate the nest following a loud sound or other disturbance and return only after some time interval. Meanwhile, eggs or young can die from heat, cold, and predation. The time the eggs or young are exposed is the critical variable and is usually short for raptors (Awbrey and Bowles 1990:31):

> Raptors ... did not expose their nests for more than 10 minutes after flushing in response to an overflight, so there is little chance of death due to overheating or chilling. Multiple exposures to very low-altitude overflights spaced 5-10 minutes apart would be required to cause lethal exposures of eggs. The chances of repeated exposures of this sort during normal aircraft operations are vanishingly small [the authors cite a personal cummunication].

This last generalization does not hold for military operations. Touch-and-go landings, bombing runs, helicopter sorties, and artillery practice are examples of military activities that do indeed tend to repeat at a short enough interval to constitute a cumulative exposure.

Changes in animals' home ranges as a result of disturbance (Geist 1971) constitute behaviorally-mediated population-level effects whenever available suitable habitat is diminished. Because of the continuing exponential growth of human numbers and shrinking of relatively undisturbed habitat for wildlife, exclusion of wildlife from suitable habitat via disturbance is often equivalent to human-caused mortality.

In a study using "simulated mine noises" played back from loudspeakers, elk cows and calves withdrew "from previously favorable areas to more marginal habitats", although little quantification of habitat favorableness was performed (Kuck, et al. 1985). Movements of desert bighorn sheep responding to helicopters also affected home range:

> Adult males and females with radio collars moved about 2.5 times farther the day following a helicopter survey than on the previous day. Further, 35-52% of these animals changed [home range] polygons (8-83 km^2) following sampling from a helicopter, whereas only 11% did so on the day prior to the survey. Likewise, some animals left the study area following surveys. (Bleich, et al. 1990)

Changes in home range can be enormously variable and difficult to quantify. For example, although it was clear in a detailed study that coyotes' home ranges were affected by military training activity (Gese, et al. 1989), the difficulty of quantifying the stimulus of training maneuvers combined with the puzzling variety of home range changes (expansion, retraction, abandonment) precluded succinct summarization. Similarly, apparent abnormalities in use of habitat by Sage Grouse were difficult to substantiate without long-term comparison data in similar conditions (Eberhardt and Hofmann 1991). Such difficulties are amplified when dealing with large, mobile animals (as in Andersen, et al. 1990).

Results of Czech (1991) on elk are discussed below under "Vehicles and traffic".

Selection-mediated effects on populations

Artificial selection for decreased reactivity to noise is discussed above under "Domesticated and confined animals" and suggests that natural selection also occurs, although clear examples appear to be lacking. The remainder of this section will discuss one particular possible outcome of such selection, hearing impairment, that is of particular interest because we stand a good chance of observing it in nature.

Wildlife in areas of repeated high-intensity sound could become seriously hearing-impaired by either developmental mechanisms or population-level genetic mechanisms. Developmentally, normal young could incur a PTS and develop into hearing-impaired adults. Some species of songbirds, when raised in continuous noise loud enough that they cannot hear themselves sing, do not sing normally as adults, having deficiencies in the loudness and stability of notes and the size of the song repertoire (Marler, et al. 1973). The present review found no reports of analogous situations in nature.

Population-level genetic mechanisms are more likely. Evolutionarily, hearing-impaired or high-startle-threshold animals could immigrate into a loud area and out-compete conspecifics that have full auditory function but are continually being distracted or wasting energy reacting to the sounds. The latter kind of effects provide a basis for selection to occur and are plausible or perhaps likely, although such effects have not appeared in the literature thus far. Domestication (discussed above) provides a solid basis for such speculation, but hearing disability is a less-well-explored possibility. We know that congenital (or at least hereditary) deafness and/or sensitivity to noise are taxonomically widespread, occurring for instance in rabbits (Bartual, et al. 1991), rodents (Bock, et al. 1983, Conlee, et al. 1986, Rybak, et al. 1991, Woolf, et al. 1989), mink (Flottorp and Foss 1979), cats (Stewart and Starr 1970), Dalmatian dogs (Holliday, et al. 1992, Shelton, et al. 1993), and humans (Woolf, et al. 1989). More subtly, different strains of domestic canaries have different audiograms (Okanoya and Dooling 1987a). These numerous examples of hereditary auditory disfunction suggest that evolution of a local subpopulation of hearing-impaired individuals could occur rapidly. Such an aberrant subpopulation might or might not be easy to recognize in the field. One possibility for discovering such a population suggests itself if, in some species, abnormal vocalizations (Marler and Sherman 1983, Romand and Ehret 1984) occur and are observable by acoustic census.

Selection for hearing-disabled terrestrial animals in noisy environments may already have taken place at the species level. Suggestive evidence is found in unusual vocal behavior in some such species. For instance, tailed frogs live nearly all their lives in and near fast-flowing mountain streams. They lack the vocal displays characteristic of most anurans and indeed the males lack vocal chords (Noble and Putnam 1931, Nussbaum, et al. 1983). Dippers (Cinclidae) live near noisy mountain streams, seldom venture far therefrom (Hewson 1967, Muir 1913, Price 1975), and have a loud song similar to that of wrens. The song is usually heard above background noise of rapids or waterfalls but sometimes (Moody 1955) in flight displays away from the water. Torrent Ducks and Harlequin Ducks also live in noisy aquatic habitats. We do not have information on the audiogram of any of these species.

We have one clear example of evolutionary adaptation to auditory trauma, albeit self-produced auditory trauma, in woodpeckers, the ears of at least some which are specialized to dampen mechanical shock, presumably an adaptation to striking trees with the beak (Kohlloffel 1984) during feeding and for auditory communication in the form of drumming (Wallschläger 1985).

6 STIMULI

Cue separation: noise vs. other modalities

Difficulty separating auditory, visual, and other cues complicates interpretation of experiments and observations on responses to military noise, especially when helicopters are used. Cue separation is not usually such a problem in interpreting animals' behavioral responses to military low-level jet aircraft, because they fly so fast that their visual advent almost always presages their sound (Harrington and Veitch 1991:322).

Sometimes the cues to which the animals attend can be inferred from their behavior. For example, in many studies animals are observed to orient the body and/or head toward noises or to head-scan their surroundings following noise onset (e.g. "alerted" (Miller and Gunn 1979), "alerting behavior" Grubb and King 1991, "alert posture" Henson and Grant 1991, "stand at attention" Lynch and Speake 1975, "attention posture" MacArthur, et al. 1979). Krausman, et al. (1993b) offer a useful distinction between "alerted responses", in which the animals merely oriented toward or showed other evidence of having heard reproduced sounds and "alarmed responses", in which the animals also startled and engaged in other behavior in addition to alerting. Similarly, Brown (1990) carefully documents a graded series of behaviors of sea birds in response to aircraft. Covert responses such as heart rate increase can accompany orienting behavior (MacArthur, et al. 1979). Relationships between immediate behavior and longer-term energetic effects are discussed in (Ward and Stehn 1989:4).

Pointing the head in the direction of a sound directs the eyes, but it can also aid hearing and optimize binaural localization. Therefore, head orientation does not necessarily indicate of use of a certain sensory modality. If, however, animals are shown to train the eyes on a noise source, such orienting behavior suggests that the animals first detect the noise, then seek to use multiple modalities (e.g. audition + vision) to obtain further information.

Young (1994) found that red squirrels reacted to the noise of helicopters only when the helicopters were also in sight (see also below under Helicopters).

Czech (1991) relates an anecdote of an unintentional playback experiment on human noise effects on Roosevelt elk, implicating a specific auditory cue:

> [A herd of elk "spooked'] early one morning from the area [of logging], although humans had not yet arrived at the logging site.... It was later discovered that the operator occasionally left a two-way radio switched on in [a vehicle]. The volume was high so that transmissions could be heard above the noise of yarding operations, and radio traffic by loggers usually began earlier in the morning than logging.

However, even when sound is implicated, the auditory cue is often still in doubt. For instance, Murphy, et al. (1993) found that, of three models of jet aircraft used in experimental overflights of caribou, one model, the loudest in SEL, caused "stronger reactions" than the other two; however, no attempt was made to rule out the spectral characteristics of the sounds as opposed to their loudness.

Vehicles and traffic

Most civilian vehicles are much lighter than military vehicles and on-road ones are usually quieter. Because vehicles, particularly off-road vehicles, can move at different speeds and distances, have aspect-dependent noise emissions, and differ from one another in sound and appearance, vehicles are difficult to quantify as stimuli. Much research has been performed on the role of vegetation and topography in reducing vehicle (traffic) noise (Alexandre, et al. 1975, Ringheim 1986). Many studies on effects of vehicle noise suffer from ignorance of the prior history of exposure of the populations to noise and other stimuli associated with vehicles. The commonly-noticed phenomenon of disturbance of wildlife when vehicles stop as compared with when they continue at a steady speed (Czech 1991 and references therein) may represent learning, perhaps habituation that generalizes poorly across rates of travel.

Dorrance, et al. (1975) studied radio-collared deer and found evidence of temporal and spatial avoidance of both heavy and light snowmobile use. Noise of snowmobiles per se was not investigated.

Plumpton and Lutz (1993) found that Burrowing Owls largely ignored road traffic. The birds sometimes became alert or moved when nearby road traffic increased, but nesting productivity was unaffected.

Berry (1980) reviewed the effects of off-road vehicles on wildlife. Off-road vehicles are loud--often by design. Brattstrom and Bondello (1983) measured 90 dB SPL at 30 m from a single Volkswagen ORV in studies described above on TTS following exposure to recorded noise from ORV's. A study in desert riparian habitats found "birds were observed...to fly at the sound of the approach of the vehicles, even if vehicles were at a considerable distance and if they were out of sight" (Weinstein 1978). The birds flew out of vegetation across open areas, up to 3.2 km distance from the noise. The degree of the birds' previous exposure to human-generated noise was not known.

Moen, et al. (1982) studied telemetered heart rates of penned deer subjected to approaches by snowmobiles. Interestingly, heart rate reactions were elicited reliably even though overt behavior was unchanged by appearance of a snowmobile. No habituation was seen, although statistical evidence of this is not presented. The authors speculate about possible generalization by the deer from frequently-heard sounds of chain saws and other motors to less-frequently-heard sounds of snowmobiles. No evidence is given that the deer reacted to the noise of the snowmobiles as opposed to their sight or odor.

Barrass (1985) found that acoustically-mediated reproductive behavior of two species of anurans was negatively affected by noise from highway traffic. Females localized calling males less effectively, males failed to form into calling groups, and egg mass output was reduced with higher noise levels. Playback experiments indicated that the localization effects were a result of noise, not pollution or other effects of vehicles, and spatial proximity to noise suggested that noise was responsible for the other effects as well.

Reijnen, et al. (1986) list previous studies in the United States and The Netherlands on effects of roads and civilian traffic on bird populations. In a mensurative experiment, Reijnen, et al. established 16 carefully-matched pairs of study plots, with one member of each pair adjacent to a major road and the other member > 300 m. from a road. Several species of birds showed significant differences in density and several more species nonsignificant differences; all differences were in the direction of lower breeding densities close to the roads. The authors attribute these consistent effects to noise of traffic near the road, but only weak correlational evidence is given to implicate noise as opposed to other factors related to distance from the road.

The experiments of Freddy, et al. (1986) showed mule deer to respond more strongly to people approaching on snowshoes than in slow-moving snowmobiles, consistent with previous results on ungulates (cited in Freddy, et al. 1986). Stronger responses to snowshoers occurred despite a shorter flight distance for snowshoers. Deer approached by snowshoers were estimated to expend roughly 3% of their background daily energy expenditure in each flight response.

Dwyer and Tanner (1992) found that nesting Sandhill Cranes were undisturbed by highway traffic as close as 4 m from the nest and by "large trucks" travelling within 200 to 300 m of the nest; the lack of response was attributed to "acclimation" to the situation.

The results of Young (1994) on reactions to vehicles as well as helicopters are summarized below (under Helicopters).

Czech (1991) studied herds of elk subjected to logging activity and road traffic. He speculates that elk showed less behavioral reaction to disturbance when forested habitat ("cover") was available nearby than in more uniformly open habitat. Opening a road to tourist traffic was associated with elk's apparent avoidance of areas near (< 250 m from) the road. Only one year's data were available before and one year after the opening of the road but observations of behavioral reactions--flight from vehicles--supported the conclusion that opening the road affected use of habitat.

Additional material on animals' responses to traffic is reviewed elsewhere (Bowles in press, 1995).

Helicopters (rotary-winged aircraft)

Noise from helicopters is complex, consisting primarily of engine noise (usually turbine), gearbox noise, blade loading noise, and a host of interaction noises (including noise caused by interaction between rotors, rotor-vortex interaction noise, and turbulent flow-rotor interaction noise (Chan and Hubbard 1985, George and Chou 1984, Lyrintzis and George 1989). These noises are anisotropic when mapped at different radial angles from the aircraft, a fact seldom taken into account by noise researchers.

Pulsatile noise from rotor blades occurs at characteristic frequencies depending on the number of blades and their rotation speed. The blade-passing frequency (BPF) for a simple rotor is the rotor shaft rotation frequency times the number of rotor blades. Although engine and gearbox noise tends to be broadband and flat, blade loading noise is impulsive, occurring at the fundamental and at harmonics of the BPF (George and Kim 1977). However, Schlinker and Amiet (1983) have shown in highly controlled experiments that rotor-vortex interactions increase the number of above-ambient impulsive BPF harmonics which occupy higher bandwidths and therefore that such interactions may add to annoyance of wildlife depending on the model of helicopter.

Each source of helicopter noise varies between models with respect to the number, type, and design of rotors, the number of blades/rotor, and the number and type of engines. Within models, blade load, blade speed, weather conditions, tilt of the rotor, speed of the aircraft, and aircraft activity (taking off, landing, etc.) are additional sources of variation which influence the spectral content of helicopter noise. Few wildlife related studies reviewed here have actually investigated the spectral content of a noise source.

Whether harmonics or frequency-multiples of blade-slap sound extend into a frequency range more audible to or more annoying to an animal is determined by the number of blades, blade tip speed (True and Rickley 1977), and load. As such, reaction to helicopter noise by wildlife will likely depend on what model of helicopter is used. Many studies examine reactions to only one model of helicopter. Of studies that did compare more than one model, few used models likely to have differed from one another substantially in spectral noise content (Ward and Stehn 1989). Most studies cited below comparing more than one helicopter use the Hughes 500 and Bell 206. These models have nearly identical overall loudness at distances out to 10 km (Newman, et al. 1982).

Military combat exercises often require helicopters to fly close to the ground. Manufacturers' efforts to equip some models of military helicopters with quieter components imply that actual measurement of noise signatures and specification of helicopter model designations are important in noise research. We are not aware of studies attemping to determine to which helicopter noise sources or types of sounds emitted by helicopters (impulse, broadband) wildlife may be especially sensitive (Ward and Stehn1989 come closer than any other) although Magliozzi et al.(1975) report noise control has been directed in part toward eliminating/reducing both rotor (impulse) noise and engine (broadband) noise generation by helicopters as sources of human annoyance. Operational and other stratagems to reduce noise from helicopters are given in Berrens, et al. (1988).

Unless otherwise stated all studies on helicopters used civilian helicopters (some are similar to military helicopters). A "flyover" in the material below can refer either to an aircraft that flies within sight or hearing of the subjects at considerable horizontal distance ~~and~~ one that passes directly over the subjects. Some reports do not distinguish line-of-sight distance (slant range) from horizontal distance. A few studies address whether observing and counting wildlife from helicopters (usually small ones) affects the observed animals; other studies not cited here tacitly assume that the wildlife does not respond to helicopters.

Helicopter noise might affect communication in animals using pulsatile acoustic signals of similar pulse repetition rate. To further investigate this possibility, playback experiments using recorded or simulated helicopter sounds identical except for their rotor-generated pulse rates would provide definitive information. One possibly suggestive result is that pulsatile noises (rapid series of clicks) at certain rates delay hatching in chick embryos (Vince, et al. 1984).

One of the most well-documented instances of wildlife response to helicopters occurs in a sea bird, Brünnich's Guillemot (Thick-billed Murre), which incubates the eggs by placing them on the top surface of the feet. If the incubating parent is disturbed while in this position, the eggs are extremely vulnerable to being broken. Fjeld, et al. (1988) summarize prior studies of seabirds, especially Brünnich's Guillemot, reportedly suffering brood mortality from flushing off the nest in response to fixed-wing aircraft and helicopters. In colonies where aircraft overflights are frequent, guillemots do not usually react to them, which the authors attribute to habituation. In ambitious experiments, the authors arranged experimental overflights with a Bell 212 helicopter and playback experiments with unaltered and with bass- and treble-heavy helicopter noise. None of N=89 breeding Brünnich's Guillemots lost eggs as a result of the experimental overflights; however the authors speculate that the late stage of the breeding season and small colony size may have reduced the birds' reactions compared to other situations. Claimed reactions to recorded frequencies as low as 24 to 48 Hz in the helicopter sounds were not supported by adequate quantitative spectrographic data. The authors note the technical difficulty of obtaining high-fidelity reproductions of the noise of helicopters. Nevertheless, the auditory, as opposed to visual, component of the helicopter caused reactions from the guillemots. The birds sometimes responded to the helicopter at a distance of 6 km and always by a distance of 2.5 km. Reactions were correlated primarily with the sound levels from the helicopter, only secondarily with its distance. No indication of habituation to the helicopter was seen in these infrequently-repeated experiments.

Followup work with Brünnich's Guillemot and a somewhat smaller helicopter (AS 350 Ecureuil) was performed on a large (9×10^4 birds) and remote colony (Olsson and Gabrielsen 1990). Results were similar to the earlier (Fjeld, et al. 1988) study except that sound could not be specifically implicated, partly because spectra and SPL's were not measured in these followup experiments. Eggs or chicks were not lost as a result of the flybys, according to the observations.

Temple (1993) found that pre-hatching reproduction in penned Black Ducks was largely unaffected by aircraft disturbance, but survival of chicks was lower in a noisy than in a control area. Only one experimental and one control area were used and no determination could be made whether the various military helicopters and fixed-wing aircraft to which the birds were exposed had differing effects. This thesis also reviews other studies of aircraft noise and waterfowl.

Other studies report on the effects of aircraft noise/overflights on reproduction in various birds. Gollop, et al. (1974a) concluded that helicopters and fixed-wing aircraft did not impact reproduction in Glaucous Gulls. Henson 1991 observed Trumpeter Swans subjected to aircraft pass-bys. The birds reacted to both fixed-wing and rotary-wing aircraft (19 of 21 trials) and the authors noted potential effects on reproductive success. No noise measurements were taken and the kind of helicopter was not reported. Platt (1975, Platt 1977) observed small numbers of Gyrfalcons and other arctic raptors during experimental overflights by small helicopters. He concluded that more overt responses were elicited by helicopters at 300 m above ground level (AGL) than at 150 m AGL and that immediate behavioral responses of fleeing etc. did not carry over into immediate effects on reproductive success. Delayed effects on nesting success in these studies are discussed above (Time: susceptibility to noise over the diel, season, and life history). In Florida, Sandhill Cranes "remained on their eggs in 82% (N=259) of the cases in which [a helicopter of undocumented model] flew as low as 40 m above them" during nest surveys (Dwyer and Tanner 1992).

Molting arctic geese in a remote area reacted strongly to noise of Bell 206 and 212 helicopters (Mosbech and Glahder 1991). The authors state that the larger 212 helicopter caused reactions at great distances (ca. 9 km), where the helicopters were not visible. Pink-footed Geese "probably did not get enough food" because of disruptions to feeding caused by the helicopters.

Schroeder, et al. (1992) surveyed leks of prairie chickens with a Bell 47 Soloy helicopter at 50-100 m AGL. Although no description of responses to the helicopter is provided, "Leks were easiest to locate when birds were flushed and flying birds were silhouetted against the horizon, rather than directly below". (p. 111) Watson (1993) reviews Bald Eagle responses to helicopters and conducted nest surveys of this species "from a 3-seat Hiller/Soloy UH-12E and a 4-seat Bell 206-BIII", avoiding passing directly over the nests. Distances from the nests and eagles (N=270 perched birds) were carefully noted when responses of various types occurred. Unfortunately, the brief tabular presentation of distances is insufficient to interpret the interesting result that disturbance rates of adult eagles were nonmonotonically related to distance approached in the helicopters. The author attributes the effect to the tendency of eagles perched near the nest to remain perched except when helicopters approach very closely. No breakdown of results by model of helicopter is presented and no noise levels are reported.

Studies prior to 1990 on responses (and lack of response) of raptors to helicopters are reviewed and tabulated in Awbrey and Bowles (1990). Helicopters elicited more responses and a higher proportion of flight responses, as opposed to merely alerting, than most other stimuli. Specifically, Andersen, et al. (1989) experimentally approached 35 nests of Red-tailed Hawks with an Army UH-1 Huey (the military version of a Bell Model 205). Overall, 40% of birds flushed, all at short line-of-sight distances (mean for different groups about 40 to 110 m).

Beyer (1983) studied physiological and other reactions of pregnant dairy cows during experimental low-altitude helicopter overflights. Vigorous behavioral, heart rate, and glucocorticoid increases occurred in response to early overflights. The results are of interest because the cows did not injure themselves by running and there were no indications of reproductive problems.

Reindeer were once herded by helicopter in Russia, a practice discontinued because of "detrimental effects experienced by the reindeer" (Andreev, in Klein 1973). Controlled overflights of caribou by a Fairchild-Hiller 1100 helicopter (Klein 1973) showed stronger responses to lower-height helicopters than higher ones (no statistical analyses are presented). Sound levels produced by the helicopter at different heights are presented but reported details of the recording methods are insufficient to permit conclusions to be drawn from the measurements. No attempt was made to separate responses to noise from responses to other cues.

Miller and Gunn (1979) report that muskoxen and caribou responded more strongly to a circling helicopter (Bell 206B at < 400 m AGL) than to simple overflights by the helicopter. The authors speculate about the behavioral mechanism(s) of this result (p. 17). Extensive experiments ($N \cong 1{,}000$ overflights) permitted the authors to analyze helicopter height, ungulate group composition, sun position, wind, and other factors that modulated the response of these large ungulates to helicopters.

Lenarz (1974) studied reactions of bands of dall sheep, also in response to a Fairchild-Hiller 1100 helicopter, flying at ca. 100-150 m distance in mountainous terrain. Reactions were independent of whether the helicopter was above, even in height with, or below the sheep. Ewes with lambs reacted more strongly to the helicopter than rams or (effectively) sheep of unknown gender. Apparently the same sheep were used indeterminate numbers of times in the experiments and no evidence was obtained indicating whether the sheep reacted to auditory versus visual cues. MacArthur et al. (1979) found that bighorn sheep showed little change in heart rate in response to humans on foot, vehicles on a road, low-flying fixed-wing aircraft, or helicopters 0.5 to 1.5 km distant, but one of the sheep increased heart rate 3.5-fold and began to run when a Bell-206 helicopter flew directly overhead at 150 to 200 m AGL. (The temporal details of the onset of tachycardia and onset of running are not shown in the published report.) Some persisting elevation in heart rate after the flyover was noted as long as the helicopter was audible (to the observers, extrapolated to the sheep), possibly suggesting some learned response to the noise after being subjected to the flyover. During recreational helicopter overflights at the Grand Canyon in Arizona, desert bighorn sheep decreased the time they spent foraging 17% but the magnitude of the effect and the interaction with the altitude of the sheep varied strongly according to season (Stockwell and Bateman 1987, Stockwell, et al. 1991).

Miller and Gunn (1981) flew a Bell 206B helicopter over groups of Peary caribou, observing behavior of calves from the ground before, during, and after overflights. The authors do not report the height of the overflights nor any indication of whether sight, sound, or both played a part. Caribou calves played more during overflights than in control periods, which the authors attribute to increased "excitement" on the part of calves. The authors speculate about "stress" and play behavior in caribou.

Luz and Smith (1976) observed one herd of pronghorn that reacted to an Army OH-58 helicopter when the sound level (slow response setting on B & K Model 2209 SLM) was about 60 to 77 dBA, at a slant range of 150 m. No attempt was made to distinguish whether the pronghorn used visual cues, auditory cues, or both to detect the helicopter. The animals had had little prior experience with helicopters.

Young (1994) studied responses of Mt. Graham red squirrels, an endangered species in a formerly remote area, to helicopters and other sources of noise near areas of human construction activities. The squirrels reacted more to helicopters, bulldozers that came close, and people on foot than to bulldozers at a distance, blasting, and large non-tracked vehicles. Noise levels were not quantified.

Many studies examined fixed- versus rotary-wing aircraft effects on wildlife. Usually distances and noise levels vary between the two types of aircraft. Helicopters usually elicit more vigorous behavioral responses and/or responses at greater distances than fixed-wing aircraft (Watson 1993).

Ward and Stehn (1989) succinctly review responses of Black Brant to aircraft including helicopters and present results of an extensive study at a Brant stopover point at Izembeck Lagoon, Alaska. They studied responses by Pacific Black Brant and other geese to unplanned and experimental flyovers. Various eagles, helicopters and fixed-wing aircraft provided infrequent (1.1 hr^{-1}) unplanned flyovers. Brant both oriented the head and took flight in response to aircraft (fixed-wing and helicopters) at much greater distances--about double--than the distances to which they reacted to or fled from Bald Eagles (p. 104). A large Bell 205 and two smaller helicopters, Bell 206 and Hughes 500-D, were used in experimental flyovers. The large Bell 205 helicopter produced the highest proportion of responses of any aircraft. Helicopters showed no uniform trend of probability of response with height--the relationship was positive in some cases. Ward and Stehn (1989) attribute this phenomenon to wind induced "shadow zones that reduce noise transmission of aircraft at low altitudes." These experiments took place largely over open water, so that terrain did not often obscure the helicopters from being seen by the settled geese.

Grubb and King (1991) found that, for a Bald Eagle population exposed regularly to fixed-wing aircraft but not to helicopters, helicopters elicited more response than did the fixed-wing aircraft -- an unsurprising result.

Snow geese flushed sooner in response to a helicopter (Bell 206 and Hughes 500) but flew farther in response to small fixed-wing aircraft (Davis and Wiseley 1974). The birds had had experience with both rotary- and fixed-wind aircraft; only 14 flocks were involved in the experimental (as opposed to ongoing) flights over the geese.

Kushlan (1979) compared short-term responses of wading birds (mainly Ardeids) to a propeller-driven fixed-wing aircraft and a Bell 47G-2 helicopter. Only two colonies were studied. Although data presented are insufficient to determine the degree to which different species were disturbed by the helicopter, it caused less disturbance than the fixed-wing aircraft. In all cases, birds that were disturbed and left their nests returned within five minutes. Possible previous experience of these birds with helicopters is not mentioned.

Harrington and Veitch (1991) monitored locomotory and other behavior of caribou during and after military jet aircraft and helicopter overflights. The animals responded more strongly to the helicopter (shorter latency, longer and farther locomotion) than to the jets, although the rate of approach, the sequence of stimulus type (jet vs. helicopter), and the prior experience of the caribou with the two types of aircraft all differed, as well as their sounds. The authors discuss visual vs. auditory cues with respect to approaching jet and rotary-winged aircraft. For a caribou herd whose prior exposure to fixed- vs. rotary-wing aircraft (small propeller airplanes vs. small Bell 206 helicopter) was not documented, different investigators report conflicting results on which type of aircraft produced stronger reactions from the animals (Calef, et al. 1976, McCourt, et al. 1974), although statistical analysis was lacking from these studies and the visual vs. auditory component of the disturbance was not investigated.

Brach (1983) and Stephan (1993) subjected game-farm mink to aircraft approaches when the mink could see the aircraft and when the aircraft was hidden from view. The results indicated that game-farm mink show little response when subjected to fixed- and rotary-winged ("BO

105") aircraft noise in the absence of visual cues; however, when that noise is coupled to a visual stimulus, mink orient to the stimulus. Previous anecdotal reports of more severe reactions such as reproductive failure were not confirmed in these studies.

Gladwin, et al. (1988a) provide very brief summaries of 47 anecdotal reports of effects of helicopters (or mixed helicopters and fixed-wing aircraft) at U.S. Fish and Wildlife Service areas. Helicopters are reported to disturb wildlife, especially waterfowl, more than fixed-wing aircraft, although the proximity of the different types of aircraft to the wildlife and other factors are taken into account poorly, if at all. More research on effects of aircraft noise on wildlife was recommended.

Edwards, et al. (1979) conducted brief observations of wildlife reacting to a Bell 47-G helicopter at Aransas National Wildlife Refuge. Species differences were noted and some species were considered by the authors to be intolerant of helicopter noise. More recently however, a nationwide survey of noise of military aircraft over national wildlife refuges has not yet been reported in enough depth to contribute to our understanding of military noise and wildlife (United States Fish and Wildlife Service 1994).

Blast noise

Extensive literature on sonic booms (see Introduction) is not reviewed here. The idea that sonic booms can break birds' eggs or reduce the hatchability of the embryos presently is largely discredited (Awbrey and Bowles 1990), although, curiously, the possibility that embryonic birds' hearing (Gottlieb 1971) could be damaged appears not to have been addressed.

Blast noise from military activity includes muzzle blast and detonation of projectiles, both of which have loose analogs in civilian situations. Shock waves from projectiles (see Classes of Sounds), although probably at least as important, are not as clearly similar to any civilian noises and are very poorly studied in their effects on wildlife.

Prairie Falcons responded to ongoing construction blasting and to experimental charges placed at fixed distances from nest sites not normally exposed to blasting at such distances (Holthuijzen, et al. 1990). No evidence of habituation or sensitization was found, although several reasons may account for this lack of effect. Problems with this study included small numbers of nests, drastically different acoustic environments (mean depth 3 m for construction vs. on surface of rock slabs for experimental blasting), pseudoreplication (Hurlbert 1984), unknown sound levels from construction blasting with a 74-fold range of explosive loads, failure to measure the readjustment time in the absence of any blasting, and failure to specify the weighting used in SLM measurements. In a different, mostly-anecdotal, account, "sudden loud noises generally disturb[ed] Prairie Falcons" (Harmata, et al. 1978), sometimes causing the fleeing parents to knock eggs from the nest.

The closely related Peregrine Falcon has been reintroduced into many urban locations, indicating it is not often sensitive to noise. Remote Alaskan peregrines reared young close to blasting activity and, in other instance, tolerated construction activity near the nests, according to an anecdotal account (Haugh 1982). Early anecdotal accounts of disturbance of Peregrine Falcons by humans are summarized in Platt (1975, 1977).

Jackson et al. (1977) report that a low-flying female Northern Harrier seemed to prefer to hunt close (60 m) to locations where 11-kg practice bombs fell. They speculate that the harrier hunted small mammals flushed by the bombs. If so, the behavior is reminiscent of Northern Harriers' practice of hunting rodents flushed by prairie fires (Bent 1937). Harriers are specialized to use their acute hearing to locate prey (Rice 1982) and therefore may face an unusually high risk of noise-induced hearing loss when they hunt near blast noise.

Bednarz (1984) conducted a 1-year correlational study of two areas, one of which was subject to industrial blasting during mining operations. The mined area supported fewer raptors but the reason for the difference was not further investigated.

A study on Bald Eagles at Aberdeen Proving Ground (Russell and Lewis 1993) is summarized below ("Monitoring animals' exposure to noise").

Reynolds, et al. (1986) monitored a few denning grizzly bears using telemetry and found that underground blasts 1-2 km distant caused brief periods of movement in the dens but did not cause the bears to leave the dens or otherwise disrupt their winter torpor. The bears were accustomed to light aircraft but not other kinds of human disturbance.

The results of Young (1994) on squirrels are summarized above (" Helicopters").

Firearms

Although firearms often damage the ears of those who fire them (Clark 1991a, Price, et al. 1989), animals are at little risk from hearing loss because they are seldom close enough. The sound of gunshots is more likely to affect hunted species for the obvious reason that it acquires salience from association with hunting (e.g. Postovit and Postovit 1987).

Stalmaster and Newman (1978) conducted experimental field studies on Bald Eagles, with care to avoid pseudoreplication. Flight distances (Hediger 1964) in response to approach by humans were related to habitat type and birds' age class. Stalmaster and Newman's remarks on noise do indicate a special salience of gunshots in contrast to other noises, which were often ignored by the eagles:

> Normally occurring auditory disturbances were not unduly disruptive to eagle behavior. Gunshots were the only noises that elicited overt escape behavior..... Eagles were especially tolerant of auditory stimuli when the sources were partially or totally concealed from view.

Game species are reported to move into sanctuaries during hunting season. This phenomenon is apparently widespread but not well-researched, with some exceptions (e.g. Meltofte 1982). The sound of gunshots likely plays a role in seasonal or even date-specific range changes by game species.

7 METHODOLOGICAL ISSUES IN DESIGNING STUDIES

Monitoring animals' exposure to noise

Ideally, each researcher would document the time course, loudness, spectrum, onset time, and other pertinent acoustic measures of the same acoustic stimulus heard by the animals in the field. Most studies have lacked the resources to approach this ideal and many have lacked any formal description of the sounds involved or perhaps have used a few readings from hand-held sound level meters. Perhaps the present state of the art is represented by U.S. Air Force-sponsored pilot research on development of self-contained noise monitoring devices that may be attached to suitable-size animals in the field and used to collect long-term data on the noise environment of individual animals (Kugler and Barber 1993, Kull 1993b, Murphy, et al. 1993). Present versions of this device were designed to be mounted on a collar carried by a caribou-sized animal. Especially with large subjects, noise monitors whose acoustic transducer is mounted on the animals' heads are worth considering (Håkanson, et al. 1980).

Russell and Lewis (1993) monitored sounds including "weapons firing up to and including the 203-mm howitzer" on Aberdeen Proving Ground, Maryland. The area is intensively used by Bald Eagles for nesting and roosting. Simultaneous monitoring with slow-response (A-weighted) and impulsive (peak response, C-weighted and unweighted) settings was conducted at two nest and two roost sites. Although measured noise levels obviously depend heavily on the locations of the monitors relative to the noises, the report does not mention how the four sites were selected nor what the distances were to the noise sources ("weapons firing activity near each site", Russell and Lewis 1993:6). In most cases, little documentation is presented to permit specific noise levels to be associated with specific events in the acoustic environment. For instance, although slow-response readings appear to reflect vaguely-defined noises such as "distant traffic", the authors speculate that vocalizations of the eagles themselves constitute some of the "noise". Peak levels, however, appeared to reflect some combination of muzzle blast ("propellant blast noise"), projectile bow wave ("ballistic wave"), and possibly explosion of rounds on arrival at the target. Unweighted peak levels of about 100 to 135 dB are reported at all of the four sites. Four-year nesting productivity, although near the U.S. “national average of 0.92 young per nest” and therefore not seriously adversely affected by the noise, was not compared with any sort of conventional control population. This study illustrates the limitations of using commercial noise monitors and stochastic descriptions when the acoustic environment is not well-known beforehand.

Both research on effects of noise on wildlife and actual operational changes in military activities to reduce such effects may require assessing the degree of compliance, especially considering the stress and hubbub of military training. Compliance could be assessed in at least two ways. Stochastically, one can determine the rate of overall compliance to similar regulations or orders in similar tactical and geographical situations and extrapolate to the situation in question. Observationally, one can monitor at several levels. In increasing order of directness and confidence, one can review orders, training schedules, and range maps; detect and record military activities such as vehicle movements or weapon firing; or measure and record noise levels in the habitat.

Choice of variables to measure

Research on wild animals has focused on (1) immediate behavioral responses of wildlife to noise, (2) immediate and medium-term measurements of heart rate and other easily-telemetered physiological variables, and (3) numbers of offspring produced and other direct measures of reproductive success. Occasional studies draw inferences about time budgets (e.g. Murphy, et al. 1993) and energy expenditures based upon a combination of behavioral sampling and theoretical extrapolation. Long-term studies on habitat selection and home range with reference to environmental noise are few and often rely on descriptive sampling (Eberhardt and Hofmann 1991) with small sample sizes. Awbrey and Bowles (1990:15, and references therein) mention that nest site fidelity in raptors is fickle early in the nesting period because the birds usually have alternative nest sites available. The point underscores the importance of adequate background data and controlled observations.

The preceding sweeping generalizations are incomplete. They oversimplify the work of many skilled field workers. Nevertheless, the reader is likely to draw the implicit conclusion from published literature that earnest and skilled measurement of one or more of behavioral reactions, heart rate, and breeding success is sufficient. However, they are not necessarily the most appropriate variables. For example, an earlier review and analysis for raptors points out that “aircraft activity could cause greater population-level effects if it increased adult mortality or decreased the abundance of prey items” than if it influenced reproductive success (Awbrey and Bowles 1990).

This situation stands in contrast to what is known about effects of noise on free-ranging humans, where immediate behavioral effects such as annoyance are often of secondary importance to direct measures of occupational (trophic) productivity, longevity-related physiological variables (blood pressure, carcinogenesis), and residential and occupational preference (home range and habitat selection). Without making too much of this contrast, one wonders whether investigations of effects of noise on wildlife are capitalizing effectively on what we know about humans. It is perhaps not too pollyannish to encourage more wildlife studies of effects of noise on less-frequently-studied but relevant phenomena such as diseases, telemetry of less-facile information than heart rate, habitat selection, migratory and homing behavior, and predatory feeding efficiency.

Other methodological issues

Several authors call for experimental as opposed to observational studies of effects of disturbance (e.g. Postovit and Postovit 1987:206). Gutzwiller (1991, 1993) provides extensive discussion of experimental approaches to impacts of human recreational activity on wildlife, a discussion which applies to military activity as well. The many helpful suggestions in these articles need not be recapitulated here.

Experimental evidence is almost always more convincing than observational evidence but may not always be practical in field studies. For instance, Lieb (1981) concluded from observational data on free-ranging elk that: "Except during the spring when moderately noisy, low elevation sites associated with early green-up were used, elk preferred areas with low noise levels." Experimental evidence would be preferable. In the laboratory, choice experiments usually indicate an animal's preference for otherwise-nominally-identical chambers that are insonated with different sounds or noises. For instance, in one series of experiments, mice preferred quiet to familiar noise except during the latter half of preweaning development, when the reverse was true (Jouhaneau and Bagady 1984). Mackenzie, et al. (1993) allowed hens to terminate playbacks of recorded sounds by moving to another part of the laboratory apparatus, permitting the quantification of the aversiveness of different sounds and different intensities of the same sound. Kavanaugh (1967) and Mollenauer, et al. (1992) performed similar experiments on mice. This sort of paradigm has something to offer as an analog of "annoyance" measures in humans, especially if an ingenious investigator implements it in a field situation. Controlled experiments in the field would be possible by using multiple natural sites instead of laboratory enclosures, possibly with AB/BA or ABAB alternation of noise conditions by site.

Experiments and observations should be designed to minimize effects of the experiments and observers on the wildlife (Manci, et al. 1988:73, Grier and Fyfe 1987, Gutzwiller, et al. 1994). Such designs can be challenging if researchers wish to rule out synergistic interactions between observer effects and effects of noise. Providing proper controls are in place, radio tracking or telemetry can sometimes provide a means of completely eliminating observer effects during actual noise trials (Harrington and Veitch 1991). Visual observations can be recorded on video media (Harrington and Veitch 1991) or can be conducted from a greater distance if more easily visible behaviors are chosen for study (e.g. fleeing as opposed to orienting; Watson 1993).

In wildlife field studies reviewed here, sample sizes for documenting population-level effects are usually either pseudoreplicated (Hurlbert 1984), for example N=1 experimental and 1 control area, or small (see also Awbrey and Bowles 1990). Even behavioral data are often afflicted with small sample sizes because of budgetary and other restrictions of carrying out full-scale experiments in nature. Power analysis (Cohen 1988) has been rare in studies of reactions of animals to human disturbance, as has prior definition of effect sizes and setting alpha and beta probability levels together to determine significance. Because negative results are common in studies of wildlife response to noise, it is wise to anticipate them by specifying effect sizes in advance and by planning for sufficient sample sizes when possible.

The unit of behavioral observation may be either the individual animal or the social group. In a group, social facilitation of the behavior, especially fleeing, may make it impossible to conduct independent observations of different members of the group. An excellent example documenting such a situation is given in Ward and Stehn (1989:93), in which 0% or 100% of geese in a flock responded to various disturbances more often than only part of a flock responded.

Playbacks of recorded noise are an indispensible technique for unravelling cues to which animals respond. The subjects can be confined, partly confined, or free-ranging. Carefully-designed experiments use a predetermined experimental protocol and dummy trials, perhaps with the observers blinded with respect to stimulus events (Balph and Balph 1983), as in Larkin (1978). Video tapes of subjects' responses can be scored by observers unaware of noise onset (R. Kull, pers. comm. April 1994). Only the acoustic cue should differ between experimental and control trials. Kroodsma (1990) discusses pseudoreplication and related issues with regard to playback experiments. Richardson, et al. (1985) describe playback of ocean drilling noises to bowhead whales; the whales avoided the source of the recordings. Ljungblad, et al. (1988) and Richardson, et al. (1986) describe use of controlled approaches and noise production in experiments with bowhead whales. Playbacks could also be used as a crude audiometric technique in the field, especially to discriminate deaf from hearing-unimpaired animals. Tests involving experimental deafening would need to use surrogate species.

One should examine both potential deleterious and potential beneficial effects of exposure to noise. In the absence of evidence for a deleterious effect of noise, 2-tailed tests should be used.

For instance, noise could make prey of the study species more vulnerable to predation, interfere with a competitor species more than the target species, or could decrease territory size by masking acoustic displays, thereby increasing density. In addition, a dependent variable may respond in one direction to one kind of disturbance but in the opposite direction to another (MacArthur, et al. 1979).

This review has discussed individual- and population-level effects of noise but not community-level effects except with respect to certain situations such as predator-prey complexes. Sometimes it may be possible to look for community-level effects directly. In fact, it may be easier to observe community-level effects (or lack thereof) than to conduct narrower, species-specific studies. For instance, species diversity estimates can be made in noise-exposed and control areas (Bowles, et al. 1993). In many habitats mixed-species flocks of songbirds (Davis 1946) are a characteristic part of the fauna. Does the species composition of such flocks change when their foraging habitat is subjected to noise? Positive results imply effects on the individuals and presumably the populations of the species in question. As another example, one could investigate what species of prey are taken by predators within and distant from noisy habitats, or for several seasons before and after introduction of a noise source. A difference would indicate a noise effect of some kind. One should use many individual predators, replicated in several pairs of sites or several noise introductions, because the animal is the unit of statistical analysis.

Threatened and endangered species are difficult to study experimentally because negative effects on their populations are not tolerable. When necessary, surrogate species can be found for many noise-exposed threatened and endangered species, for instance, White-eyed Vireo in place of Black-capped Vireo, Prairie Warbler in place of Golden-cheeked Warbler.

Most research on noise effects on wildlife is designed to investigate a particular kind of noise. Part of the research effort goes into characterizing the noise, frequently by measuring SPL and qualtatively describing prominent frequencies or tonal quality. Sometimes effort is also made to separate auditory cues from visual and other cues associated with the source of noise. How much research should be directed at characterizing the stimulus or stimuli to which animals react in such studies? Presumably, characterizing the stimulus is more important after deleterious effects of noise are known to exist than when no noise effects are known.

There exist both a general need for more understanding of noise effects on wildlife and specific needs for understanding of magnitude and mechanisms of effects in particular species, locales, and situations. As is evident throughout this review, our current knowledge of noise effects on wildlife is often fragmentary and largely lacking in predictive power. In a situation where possible effects of noise cannot be avoided, it may be more useful to direct research money into contributing to our general knowledge rather than targeting a specific situation for which no mitigation is going to be performed anyway.

Research aimed at a particular noise situation may profit from a practical orientation, namely by studying independent variables that are related to measures that would be feasible to undertake if elimination or mitigation of noise effects were attempted. For instance, if restrictions in routes taken by military vehicles are the most likely method to be used in avoiding disturbance of wildlife, then research might examine whether eliminating the visual component of the disturbance by screening was effective or what degree of acoustic attenuation, achievable with what minimum distance, would reduce disturbance to acceptable levels. Although many current studies ask similar questions, the parameters of the research are not usually explicitly selected on the basis of what actions would be practical in an operational context.

Helicopters pose an especially difficult stimulus to characterize. When conducting and analyzing experiments on reactions of wildlife to helicopters, it is not clear for any species how the degree or probability of response is related to position of the helicopter in the sky as opposed to its distance from the animals. Although some studies (notably Ward and Stehn 1989) ambitiously analyze the stimuli in two dimensions (height and distance), it is not clear that we understand the problem in terms of vision, audition, or the combination of these cues, for any species. (Other cues such as air motion from rotor blade downwash come into play at shorter distances.) An animal may attend to distance cues (loudness, sound spectrum, retinal image size, apparent radial speed), angular location cues (apparent bearing, elevation off the horizon, visual or possibly acoustic aspect), cues indicating approaching or receding stimuli (looming, rate of change of loudness, elevation, or aspect), unknown cues, or some combination of these. For experimentation or for analysis of observational data, presenting such cues involves careful design of experimental protocols, which is usually complicated by needing to work in a biologically unsuitable coordinate system such as feet above sea level and latitude-longitude. Perhaps recent behavioral ecology research on responses of wildlife to aerial predators will throw light on this issue (Lima 1993) .

The preexisting behavioral context can be decisive in interpreting responses to human-produced noise and other human activity. For instance, wintering Bald Eagles have greater flight distances when in groups (perhaps due to social facilitation) and when on the ground (Knight and Knight 1984).

A small number of the publications cited in this review stand out in terms of relevance and value for designing future studies:

- Useful introductions to noise are (Harris 1991b) and (Peterson 1980a).
- A thorough, scholarly review of raptors' response to disturbance is given in (Awbrey and Bowles 1990); the authors point out may pitfalls of performing research on disturbance of wildlife and include previously-unpublished data on California Condors.
- Brattstrom and Bondello (1983) ask incisive questions of lizards, kangaroo rats, their predators, and the hearing of each species.
- Freddy, et al. 1986 performed careful field experiments with mule deer and succeeded in identifying several differences between the deer's response to different stimuli.
- CART models, which are presently popular as analysis tools, are used effectively in a field study on eagles (Grubb and King 1991).
- Krausman, et al. (1993b) used focal-animal sampling in a careful, quantitative monitoring of animals' behavior before, during, and after exposure to playbacks of sounds of aircraft.
- Kull (1993a) reviews effects of aircraft on wildlife with remarkable conciseness and precision.
- Manci, et al. (1988) provide a wide-ranging review of effects of aircraft noise and sonic booms on wildlife.
- Remarkably large N's (with some pseudoreplication) were achieved in thorough and difficult field studies on muskoxen and caribou (Miller and Gunn 1979).
- Instructive methods to provide control over extraneous variables in measurements of blast noise are given in (Pater 1981:8).
- Experimental field work with helicopters provided the basis for quantitative findings (Ward and Stehn 1989); noise was implicated but not proven to be an important factor.

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> Impacts of aircraft noise on raptor hearing, reproduction, nesting and fledging success, feeding, and demography were discussed. The authors concluded that, to a small extent, nesting and fledging success may be affected by aircraft activity as may reoccupancy. In addition, a disturbed raptor's tendancy to flush was based largely on previous experience and "stage of the breeding season." Given many presumptions, the authors built a "straw-man" model and suggested machanisms for modeling the varying ways in which noise effects raptors.

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> Study of the effects of traffic noise on acoustic communication important in mating in two species of anurans, Bufo woodhousei and Hyla cinerea. The experiments and observations were carried out at the Attwater Prairie Chicken National Wildlife Refuge in Texas. Three sites were selected for different levels of average traffic noise. Phonotaxis of female anurans was assessed with and without background playbacks of highway traffic noise. The females showed "significant decreases in the rate, distance, and time of reaction to male calls" when noise was introduced. In these experiements, females from the quietest location showed evidence of less adaptation to ambient noise than females from the locations nearer highways. Marked male anurans were observed in the three sites. Some indication was found that aggregations of calling males failed to occur at locations with more ambient traffic noise. Importantly, reduced spatial densities of egg masses were found in locations close to highway noise.

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> At the time of writing, investigations of the impacts of ORV's on wildlife were relatively scant, with much of the effort studying species of desert scrub habitats. Still fewer papers explored the effects of ORV noise specifically. Much of the author's review highlighted the work of Weinstein (1978). The author concluded ORVs negatively impact vertebrate abundance, diversity, and biomass. ORV noise was shown to damage the hearing of some desert scrub inhabitants.

Beyer, D. 1983. *Studies of the effects of low-flying aircraft on endocrinological and physiological parameters in pregnant cows*. Unpublished D.V.M. Dissertation, Hanover Veterinary College, Hanover, Germany. pp.

Bleich, V. C., Bowyer, R. T., Pauli, A. M., Vernoy, R. L., and Anthes, R. W. 1990. Responses of mountain sheep to helicopter surveys. *California Fish and Game*, 76:197-204.

Blix, A. S. and Lentfer, J. W. 1992. Noise and vibration levels in artificial polar bear dens as related to selected petroleum exploration and developmental activities. *Arctic*, 45:20-24.

> Breul and Kjaer Sound Level Meters and Vibration Meters (with accelerometers) were used to measure noise and vibration within artificial poar bear dens. At a distance of 300 m, both noise and vibration levels from seizmic tests were undetectable. At 100 m, noise levels were approximately 40 dB (lin.) (15 dB above ambient levels) and minute vibrations were detectable. During a helicopter takeoff 3 m from the artificial den, noise level dropped from 115 dB (lin.) outside the den to 77 dB (lin.) inside the den through 1 m of dry snow. Because ambient noise levels may vary from 0 to 50 dB (lin.) depending primarily on wind conditions, and because of the high sound absorptive quality of the dry snow near Prudhoe Bay, Alaska, the authors conclude that if the exploration activities studied here are >100 m from a den, polar bears will not likely be disturbed.

Blokpoel, H. (Ed.). 1976. *Bird Hazards to Aircraft*. Ottawa,Canada: Clarke,Irwin, & Co., Ltd.pp.

Bly, S., Goddard, M., and McLean, J. 1993. A review of the effects of noise on the immune system. Paper presented at the 6th International Congress on Noise as a Public Health Problem, Nice, France.

Bock, G. R., Frank, M. P., Steel, K. P., and Deol, M. S. 1983. The quivering mutant mouse: hereditary deafness of central origin. *Acta Otolaryngol*, 96:371-377.

Bohne, B. A. and Harding, G. W. 1992. Neural regeneration in the noise-damaged chinchilla cochlea. *Laryngoscope*, 102:693-703.

Boice, L. P. 1992. The Department of Defense's natural resources management program: Integrating stewardship and mission requirements. *Environ. Prof.*, 14:84-87.

Borg, E. 1970. On the dynamic properties of the middle ear reflexes. *Acta Physiologica Scandinavica*, 80.

Borg, E. 1972. Excitability of the acoustic m. stapedius and m. tensor tympani reflexes in the nonanesthetized rabbit. *Acta Physiology Scand.*, 85:374-389.

Bowles, A., Tabachnick, B., and Fidell, S. 1991. *Review of the effects of aircraft overflights on wildlife* (7500): National Park Service.

Bowles, A. E. in press, 1995. *Responses of wildlife to noise*. In Knight, R. L. and Gutzwiller, K. J. (Eds.), Wildlife and recreationists, (pp. 154-212). Washington, D.C.: Island Press.

Bowles, A. E., McClenaghan, L., Francine, J. K., Wisely, S., Golightly, R., and Kull, R. 1993. Effects of aircraft noise on the predator-prey ecology of the kit fox (*Vulpes macrotis*) and its small mammal prey. Paper presented at the 6th International Congress on Noise as a Public Health Problem, Nice, France.

> Three kinds of military jet aircraft traveled repeatedly (up to 167 overflights/day) over three 1.4 ha study plots in Arizona. Small mammal (especially *Dipodomys* sp.) densities were compared with similar plots distant from aircraft disturbance. Small-mammal predator densities were indexed using three methods which posed varying methodological problems. Two kinds of noise monitoring instruments were posted in the study areas to measure exposures. Qualtitative summaries of data are presented, indicating that small mammal densities were not materially affected by overflights and values for kit fox densities were probably confounded by coexistence of gray foxes in the experimental areas.

Bowles, A. E., Yochem, P. K., and Awbrey, F. T. 1990. *The effects of aircraft noise and sonic booms on domestic animals: A preliminary model and a synthesis of the literature and claims* (NSBIT Technical Operating Report #13): Noise and Sonic Boom Impact Technology, Advanced Development Program Office, Wright-Patterson AFB, Ohio.

> This report reviewed literature regarding the effects of aircraft activity on domestic animal reproduction, behavior, egg production, milk production, trauma, and habituation. Claims against the USAF were also summarized. The authors found that controlled studies often conflicted with anecdotal reports and claims. Data in the literature is used to build a "dose-response model for effects of aircraft overflights on domestic animals."

Boyle, S. A. and Samson, F. B. 1985. Effects of nonconsumptive recreation on wildlife: a review. *Wildlife Society Bulletin*, 13:110-116.

> The authors summarized a subset of their review of 536 references in a table identifying that nonconsumptive outdoor recreation more often that not negatively impacts birds, mammals, and herps. They concluded that increasing outdoor recreation is straining natural resources, and cite complex relationships and incomplete knowledge as reasons for impeded proper management. Off-road-vehicles have "the most serious potential impacts."

Brach, W. 1983. *Studies of the effects of aircraft noise on the peri-partal and post-partal losses in farm-raised minks (Mustela vison f. dom.).* Unpublished D.V.M. Dissertation, Hanover Veterinary College, Hanover, Germany. 161 pp.

> Mink exposed to simulated and real aircraft (F4F "Phantom" jet and BO 105 helicopter) noise exhibited no extraordinary reaction. However, when exposed to aircraft both audibly and visually, mink reacted by orienting toward the source. Reproduction in the exposed group did not differ from that of the controls.

Brattstrom, B. H. and Michael, C. B. 1983. *Effects of off-road vehicle noise on desert vertebrates*. In Webb, R. H. and Wilshire, H. G. (Eds.), Environmental effects of off road vehicles: Impacts and management in arid regions, (pp. 200).

> Conditions in desert environments make desert inhabitants especially sensitive to ORV noise. ORVs in the California desert impacted wildlife causing permanent hearing loss, a decrease

in the ability to detect predators, and the emergence of aberrant behavior exposing the animal to higher risk of mortality. The authors make several management recommendations based on their results.

Brenowitz, E. A. 1986. Environmental influences on acoustic and electric animal communication. *Brain, Behavior, and Evolution*, 28:32-42.

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

Burger, J. 1983. Jet aircraft noise and bird strikes: Why more birds are being hit. *Environmental Pollution (Series A)*, 30:143-152.

Busnel, R. G., Busnel, M. C., and Lehmann, A. G. 1975. Synergic effects of noise and stress on general behavior. *Life Sci*, 16:131-137.

Calef, G. W., DeBock, E. A., and Lortie, G. M. 1976. The reaction of barren-ground caribou to aircraft. *Arctic*, 29:201-212.

Canard-Caruana, S., Lewy, S., Vermorel, J., and Parmentier, G. 1990. Long range sound propagation near the ground. *Noise Control Engineering Journal*, 34:111-119.

Chan, D. C. L. and Hubbard, J. E., Jr. 1985. Model helicopter blade slap at low tip speeds: theoretical and experimental correlations. *Annual Forum Proceeding, American Helicopter Society*, 1:289-295.

Clark, W. W. 1991a. Noise exposure from leisure activities: a review. *Journal of the Acoustical Scociety of America*, 90:175-181.

Clark, W. W. 1991b. Recent studies of temporary threshold shift (TTS) and permanent threshold shift (PTS) in animals. *Journal of the Acoustical Scociety of America*, 90:155-163.

Clough, G. 1982. Environmental effects on animals used in biomedical research. *Biological Reviews*, 57:487-523.

Cody, A. R. and Robertson, D. 1983. Variability of noise-induced damage in the guinea pig cochlea: electrophysiological and morphological correlates after strictly controlled exposures. *Hearing Research*, 9:55-70.

Cohen, J. 1988. *Statistical power analysis for the behavioral sciences*. (2 ed.). Hillsdale, N.J.: Lawrence Erlbaum Associates. pp.

The text everybody refers to in recommending power analysis. It is written for scientists (albeit in psychology, economics, and so on), rather than for statisticians. Introductory chapters are especially readable and persuasive on usefulness of power analysis.

Cohen, S. 1980. Aftereffects of stress on human performance and social behavior: a review of research and theory. *Psychological Bulletin*, 88:82-108.

Coles, R. B., Guppy, A., Anderson, M. E., and Schlegel, P. 1989. Frequency sensitivity and directional hearing in the gleaning bat, *Plecotus auritus* (Linnaeus 1758). *Journal of Comparative Physiology [a]*, 165:269-280.

Coles, R. R. A. 1980. International symposium on effects of impulse noise on hearing. Paper presented at the International symposium on effects of impulse noise on hearing, Malmo, Sweden.

(Summary of Introduction) Impulse noise needs to be more specifically defined than "a general descriptor of noises characterized by discrete or repetitive rises of sound pressure that have very rapid onset." Rapidly repeated impulses seem to have essential equivalence of effect to similar quantities of energy from steady state noise. Impulses don't sound loud because the time constant is below the auditory system time constant. Note that though much impulse noise has its most prominent components at 200-1000 Hz, the power spectrum concentrates toward the high frequency range, due to the short duration, so hearing loss is at the higher frequencies, not the lower frequencies. Current measures (A-weighting) correspond to perceived loudness and Central Nervous System time constants. The author argues that high SPL's are lost in L_{eq} and average SPL measurements; he presents a new instrument.

Committee on Classification and Nomenclature. 1983. *Check-list of North American birds*. Lawrence, Kansas: American Ornithologists' Union. 876 pp.

Conlee, J. W., Abdul-Baqi, K. J., McCandless, G. A., and Creel, D. J. 1986. Differential susceptibility to noise-induced permanent threshold shift between albino and pigmented guinea pigs. *Hearing Research*, 23:81-91.

Conomy, J. T. 1993. *Habitat use by, and effects of aircraft noise on the behavior and energetics of wintering dabbling ducks in Piney and Cedar Islands, North Carolina*. Unpublished M.S. Thesis, North Carolina State University, Raleigh, North Carolina. 125 pp.

Cosens, S. E. and Falls, J. B. 1984. A comparison of sound propagation and song frequency in temperate marsh and grassland habitats. *Behavioral Ecology and Sociobiology*, 15:161-170.

Cotanche, D. A. and Dopyera, C. E. J. 1990. Hair cell and supporting cell response to acoustic trauma in the chick cochlea. *Hearing Research*, 46:29-40.

Counter, S. A. 1985. Brain-stem evoked potentials and noise effects in seagulls. *Comp. Biochem. Physiology, A.*:837-845.

Counter, S. A. and Borg, E. 1982. The avian stapedius muscle: influence on auditory sensitivity and sound transmission. *Acta Oto-Laryngologica*, 94:267-274.

Classical electrophysiology using nembutalized adult chickens, *Gallus gallus.* A cochlear microphonic-based audiogram is given. "...tension produced in the ipsilateral stapedius muscle causes a significant reduction in the acoustic energy reaching the ipsilateral inner ear at all frequencies...." The authors speculate on the function of this relationship in attenuating loud sounds and localizing sounds.

Czech, B. 1991. Elk behavior in response to human disturbance at Mount St. Helens National Volcanic Monument. *Applied Animal Behaviour Science*, 29:269-277.

Mt. Saint Helens in the State of Washington became overrun with tourists following the volcanic eruption in 1980 and opening of an additional road to traffic was suggested. Eight elk total were monitored in 1986 and 1987 by radio location and by visual observation. (The marked animals served to locate their "herds" or "bands". These two terms are not defined in the paper.) Reactions to logging activity and to use of the road by tourists are described. Intensity of vehicle use increased about 30 times in 1987. Elk were hunted in the area, seasonally.

D'Arms, E. and Griffin, D. 1972. Balloonists' reports of sounds audible to migrating birds. *Auk*, 89:269-279.

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

Dahlgren, R. B. and Korschgen, C. E. 1988. *Human disturbances to waterfowl: an annotated bibliography* : United States Fish and Wildlife Service.

Dancer, A. and Decory, L. 1993. Predictions of NIHL based on animal studies: species differences and their implication. Paper presented at the 6th International Congress on Noise as a Public Health Problem, Nice, France.

Dancer, A., Grateau, P., Cabanis, A., Lejeau, J., and Lafont, D. 1991. Influence of the spacing of

impulse noises (weapon noises) on the amplitude of the TTSs in man. *Journal d'Acoustique*, 4:421-434.

Davis. 1946. A seasonal analysis of mixed flocks of birds in Brazil. *Ecology*, 27:168-181.

Davis, M. 1974. Sensitization of the rat startle response by noise. *Journal of Comparative Physiology Psychology*, 87:571-581.

Davis, R. A. and Wiseley, A. N. 1974. *Normal behaviour of snow geese on the Yukon-Alaska North Slope and the effects of aircraft-induced disturbance on this behaviour, September, 1973* (Volume 27, Chapter Two): Canadian Arctic Gas Study, Ltd.

Devriere, F., Dancer, A., and Vassout, P. 1992. Approach of the intracochlear acoustic reflex in the guinea pig. *Journal De Physique Iv*, 2:237-240.

Diehl, P. 1992. Radiotelemetric measurements of heart-rate in singing blackbirds (*Turdus merula*). *Journal of Ornithology*, 133:181-195.

Dooling, R. J. 1982. *Auditory perception in birds*. In Kroodsma, D. E. and Miller, E. H. (Eds.), Acoustic communication in birds, (Vol. 1, pp. 95-130). New York: Academic Press.

Dooling, R. J., Gephart, B. F., Price, P. H., McHale, C., and Brauth, S. E. 1987. Effects of deafening on the contact call of the budgerigar, *Melopsittacus undulatus*. *Animal Behaviour*, 35:1264-1266.

Dooling, R. J. and Hulse, S. H. (Eds.). 1989. *The comparative psychology of audition: perceiving complex sounds*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.482 pp.

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

> Negative correlation between numbers of radio-collared deer along the trail and numbers of snowmobiles (registered, not counted) suggests deer respond to relatively low intensities. Deer were displaced away from trails in areas of snowmobile activity. In addition, deer were sensitive to low intensity human intrusion on foot and by vehicles. Two day home range size of radio-collared animals did not differ significantly between low and high intensity snowmobile activity. However, radio-collared deer activity near trails increased signficantly from days to nights.

Duckert, L. G. and Rubel, E. W. 1993. Current concepts in hair cell regeneration. *Otolaryngol Clin North Am*, 26:873-901.

> Reviews findings in avian hair cell regeneration 1987-93. No mention of mammalian or other vertebrate findings. First observed in neonatal chicks following aminoglycoside administration; 10 d post treatments, no hair cells; 1 wk post-treatment, partial repopulation. Later studies indicate repopulation is via a stem cell precursor in supporting tissues (receptor epithelium). Ultrastructural morphology during the process reviewed, with pics. HC regeneration is not equivalent to functional recovery: other tissues may be structurally damaged (e.g. in trauma); and other sensory components may degenerate after HC loss, and not regenerate; also, regeneration may not yield functional HC. In cochlea as a whole, though HC reappear, orientation etc. is very disorganized, and functional connections to afferent nerves missing. Micromorphology recovery takes a few weeks, whereas gross cochlear morphology, neural recovery, and hearing recovery takes 20+ weeks. Some concluding mention of HC regeneration in the vestibule (where there's normally some turnover), and proliferation in culture. Mammalian regeneration apparently not observed as of 1993.

Dufour, P. A. 1980. *Effects of noise on wildlife and other animals, review of research since 1971* (EPA-550/9-80-100): U. S. Environmental Protection Agency.

> "This report represents a survey of the most significant studies since EPA issued its first report concerning noise effects on wildlife in 1971."

Dwyer, N. C. and Tanner, G. W. 1992. Nesting success in Florida sandhill cranes. *Wilson Bulletin*, 104:22-31.

Eames, B. L., Hamernik, R. P., Henderson, D., and Feldman, A. 1975. The role of the middle ear in acoustic trauma from impulses. *Laryngoscope*, 85:1582-1592.

Eberhardt, L. E. and Hofmann, L. A. 1991. *Sage grouse on the Yakima Training Center: A summary of studies conducted during 1989 and 1990* (PNL-7647): Battelle Pacific Northwest Labs., Richland, WA.

Edwards, R. G., Broderson, A. B., Barbour, R. W., McCoy, D. F., and Johnson, C. W. 1979. *Assessment of the environmental compatibility of differing helicopter noise certification standards; final report* (FAA Technical Report FAA-AEE-79-13): Federal Aviation Administration, Washington, DC. Office of Environment and Energy.

Embleton, T. F. W. 1986. Sound propagation mechanisms, topography, surface impedance and meteorology. Paper presented at the Workshop on sound propagation in forested areas and shelterbelts, Nijmegen, the Netherlands.

Erlandsson, B., Håkanson, H., Ivarsson, A., Karlsson, E., and Nilsson, P. 1980. Estimation of impulse noise from cumulative time distribution with a new sound pressure time analyzer. Paper presented at the International symposium on effects of impulse noise on hearing, Malmo, Sweden.

Reports a new meter which measures cumulative time during which 10 specified SPLs have been exceeded. Nothing of relevance vis-a-vis IN noise measures or effects per se.

Espmark, Y. and Langvatn, R. 1985. Development and habituation of cardiac and behavioral responces in young red-deer calves (*Cervus elaphus*) exposed to alarm stimuli. *Journal of Mammalogy*, 66:106-113.

Evans, E. F. 1992. Auditory processing of complex sounds - an overview. *Philosophical Transactions Of The Royal Society Of London Series B Biological Sciences*, 336:295-306.

Eve, R. 1991. The sound environment of a tropical forest bird community - order or chaos. *Revue D Ecologie La Terre Et La Vie*, 46:191-220.

Fay, R. R. 1988a. Comparative psychoacoustics. *Hearing Research*, 34:295-306.

Fay, R. R. 1988b. *Hearing in vertebrates: a psychophysics databook*. Winnetka, Illinois: Hill-Fay Associates. 621 pp.

Fechter, L. D., Young, J. S., and Carlisle, L. 1988. Potentiation of noise induced threshold shifts and hair cell loss by carbon monoxide. *Hearing Research*, 34:39-48.

Fjeld, P. E., Gabrielsen, G. W., and Orbek, J. B. 1988. *Noise from helicopters and its effect on a colony of Brunnich's Guillemots (Uria lomvia) on Svalbard* (Rapportserie NR 41): Norsk Polarinstitutt.

Fletcher, J. L. 1980. Effects of noise on wildlife: A review of relevant literature 1971-1978. Paper presented at the Proceedings of the Third International Congress on Noise as a Public Health Problem.

Flottorp, G. and Foss, I. 1979. Development of hearing in hereditarily deaf white mink (Hedlund) and normal mink (standard) and the subsequent deterioration of the auditory response in Hedlund mink. *Acta Otolaryngol*, 87:16-27.

Forge, A., Li, L., Corwin, J. T., and Nevill, G. 1993. Ultrastructural evidence for hair cell regeneration in the mammalian inner ear. *Science*, 259:1616-1619.

Freddy, D. J., Whitcomb, M. B., and Martin, C. F. 1986. Responses of mule deer to disturbance by persons afoot and snowmobiles. *Wildlife Society Bulletin*, 14:63-68.

Controlled disturbance trials were conducted in the winters of 1979 and 1980 in winter conditions in Colorado. One or two people on snowshoes or in snowmobiles approached mule deer. Deer reactions were coded in four ordinal categories of intensity of reaction. Deer responded for longer durations and expended more energy when reacting to showshoers than to snowmobiles but low-intensity reactions occurred at shorter distances for showshoers than for snowmobiles. Energy expenditure estimates were based on time feeding was interrupted and estimated cost of locomotion for different speeds of locomotion.

Fride, E., Soreq, H., and Weinstock, M. 1986. Are the effects of gestational stress on motor development and cerebellar cholinesterase activity mediated prenatally? *Int. J. Dev. Neurosci.*, 4:407-414.

Fride, E. and Weinstock, M. 1989. Alterations in behavioral and striatal dopamine asymmetries induced by prenatal stress. *Pharmacol. Biochem. Behavior*, 32:425-430.

The authors investigated the effects of maternal noise and light stress, randomly applied throughout pregnancy, on the development of behavioral and neurochemical asymmetries in the rat offspring. The findings from this study are consistent with the possibility that the alterations in cerebral asymmetries induced by prenatal stress may underlay the decrease in the ability of the offspring to cope with anxiety provoking situations.

Fuzessery, Z. M., Buttenhoff, P., Andrews, B., and Kennedy, J. M. 1991. Prey capture behavior in the desert pallid bat *Antrozous pallidus pallidus* : passive sound localization of terrestrial insects. *Bat Research News*, 33:71.

Gamble, M. R. 1982. Noise and laboratory animals. *J. Inst. Anim. Tech.*, 33:5-15.

Gao, W. Y., Ding, D. L., Zheng, X. Y., and Ruan, F. M. 1991. Changes in the stereocilia and non-monotonic pattern of threshold shift after exposure to impulse noise. *Hearing Research*, 54:296-304.

Gao, W. Y., Ding, D. L., Zheng, X. Y., Ruan, F. M., and Liu, Y. J. 1992. A comparison of changes in the stereocilia between temporary and permanent hearing losses in acoustic trauma. *Hearing Research*, 62:27-41.

Geist, V. 1971. *A behavioural approach to the management of wild ungulates*. In Duffey, E. and Watt, A. S. (Eds.), The scientific management of animal and plant communities for conservation, (pp. 413-424). Oxford: Blackwell Scientific Publications.

George, A. R. and Chou, S.-T. 1984. *Broadband rotor noise analysis* (NASA CR-3797): National Aeronautics and Space Administration.

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Gerhardt, H. C. 1988. Masking of acoustic signals by the chorus background noise in the green tree frog: a limitation on mate choice. *Animal Behaviour*, 36:1247-1249.

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

Gilloyzaga, P., Fernandezmateos, P., Vicentetorres, A., Remezal, M., Cousillas, H., Arce, A., and Esquifino, A. 1993. Effects of noise stimulation on cochlear dopamine metabolism. *Brain Research*, 623:177-180.

Gladwin, D. N., Asherin, D. A., and Manci, K. M. 1988a. *Effects of aircraft noise and sonic booms on fish and wildlife: results of a survey of U.S. Fish and Wildlife Service endangered species and ecological services field offices, refuges, hatcheries, and research centers* : National Ecology Research Center, Ft. Collins, Colorado.

Gladwin, D. N., Manci, K. M., and Villella, R. 1988b. *Effects of aircraft noise and sonic booms on domestic animals and wildlife: bibliographic abstracts* (bibliography NERC-88/32; AFESC-TR-88-14): National Ecology Research Center, Fort Collins, Co.

Glass, D. C. and Singer, J. E. 1972. *Urban stress: experiments on noise and social stressors.*

New York: Academic Press. pp.

Gollop, M. A., Black, J. E., Felske, B. E., and Davis, R. A. 1974a. *Disturbance studies of breeding black brant, common eiders, glaucous gulls and arctic terns at Nunaluk Spit and Philips Bay, Yukon Territory, July, 1972*. In Gunn, W. W. H. and Livingston, J. A. (Eds.), Arctic Gas Biological Report Series: Disturbance to Birds by Gas Compressor Noise Simulators, Aircraft and Human Activity in the MacKenzie Valley and North Slope, 1972, (Vol. 14, pp. 153-202): L. G. L. Limited, Environmental Research Associates.

Gollop, M. A., Davis, R. A., Prevett, J. P., and Felske, B. E. 1974b. *Disturbance studies of terrestrial breeding bird populations: Firth River, Yukon Territory, June, 1972*. In Gunn, W. W. H. and Livingston, J. A. (Eds.), Arctic Gas Biological Report Series: Disturbance to Birds by Gas Compressor Noise Simulators, Aircraft and Human Activity in the MacKenzie Valley and the North Slope, 1972, (Vol. 14, pp. Chapter III, 97-153): L.G.L. Limited, Environmental Research Associates.

Gollop, M. A., Goldsberry, J. R., and Davis, R. A. 1974c. *Aircraft disturbance to moulting sea ducks, Herschel Island, Yukon Territory, August, 1972* (Arctic Gas Biological Report Series, Volume Fourteen, Chapter Five): Canadian Arctic Gas Study, Ltd and Alaskan Arctic Gas Study Company.

Gonzalez-Lima, F., Finkenstadt, T., and Ewert, J. P. 1989. Neural substrates for long-term habituation of the acoustic startle reflex in rats: a 2-deoxyglucose study. *Neurosci Lett*, 96:151-156.

Gottlieb, G. 1971. *Development of species identification in birds*. Chicago, Illinois: University of Chicago Press. pp.

Green, S. and Marler, P. 1979. *The analysis of animal communication*. In Marler, P. and Vandenbergh, J. G. (Eds.), Social Behavior and Communication, (Vol. 3, pp. 73-158). New York: Plenum Press.

Grier, J. W. and Fyfe, R. W. 1987. *Preventing research and management disturbance*. In Giron Pendleton, B. A., Millsap, B. A., Cline, K. W., and Bird, D. M. (Eds.), Raptor management techniques manual., (pp. 173-182). Washington, D.C.: National Wildlife Federation.

Griffin, D. 1976. The audibility of frog choruses to migrating birds. *Animal Behaviour*, 24:421-427.

Griffin, D. and Hopkins, C. 1974. Sounds audible to migrating birds. *Animal Behaviour*, 22:672-678.

Griffin, D. R. 1974. *Listening in the dark: the acoustic orientation of bats and men*. New York: Dover Publications, Inc. 413 pp.

Griffin, D. R. and Thompson, D. 1982. High altitude echolocation of insects by bats. *Behavioral Ecology and Sociobiology*, 10:303-306.

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

The authors apply CART (classification and regression tree) models to quantify the degree to which distance, duration, visibility, number, position, and/or sound of different human disturbances incite bald eagle response.

Guinan, J., Jr. 1986. Effect of efferent neural activity on cochlear mechanics. *Scand. Audiol. Suppl.*, 25:53-62.

Gutzwiller, K. J. 1991. Assessing recreational impacts on wildlife: the value and design of experiments. *Transactions of the 56th North American Wildlife and Natural Resources Conference*:248-255.

The author discusses the value of recreational impact studies and sites major statistical and biological considerations of their design.

Gutzwiller, K. J. 1993. Serial management experiments: an adaptive approach to reduce recreational impacts on wildlife. Paper presented at the 58th North American Wildlife and Natural Resources Conference.

Gutzwiller, K. J., Wiedenmann, R. T., Clements, K. L., and Anderson, S. H. 1994. Effects of human intrusion on song occurrence and singing consistency in subalpine birds. *Auk*, 111:28-37.

Håkanson, H., Erlandsson, B., Ivarsson, A., and Nilsson, P. 1980. Differences in noise doses achieved by simultaneous registrations from stationary and ear-borne microphones. Paper presented at the International symposium on effects of impulse noise on hearing, Malmo, Sweden.

Compared ear borne and stationary dosimeters; the former are preferable because there was a large difference between avg dB exposures meaured by each method. Recommend a several day measurement period to get a true picture of avg exposure, and note that good response of the dosimeter to different types of noise (esp impulse) is much more important than high accuracy for sinusoidal sound. Also noted dBSPL approx equal to dbA (A-weighted) measures in this (industrial) setting.

Hamernik, R. P., Ahroon, W. A., Hsueh, K. D., Lei, S. F., and Davis, R. I. 1993. Audiometric and histological differences between the effects of continuous and impulsive noise exposures. *Journal of the Acoustical Scociety of America*, 93:2088-2095.

Hamernik, R. P., Ahroon, W. A., and Patterson, J., Jr. 1988. Threshold recovery functions following impulse noise trauma. *Journal of the Acoustical Scociety of America*, 84:941-50.

Hamernik, R. P., Henderson, D., and Salvi, R. J. 1980. Contribution of animal studies to our understanding of impulse noise-induced hearing loss. Paper presented at the International symposium on effects of impulse noise on hearing, Malmo, Sweden.

Advantages and disadvantages of chinchillas as experimental animal. General findings: TTS increases post-exposure, followed by log-linear recovery speculated to represent combination of metabolic and structural recoveries proceeding at different rates. Poor correlations between hearing thresholds (by conditioned behavior) and hair cell disruptions, with mean thresholds returning to normal despite severe morphological damage remaining. EEH inadequate in that even small changes in impulse waveform produce very different damage patterns and impairments. Interaction occurs between IN and SSN such that sum effect > parts. Vibration plus IN also increases damage (several citations on these points in article). Susceptibility to SSN is highly variable, but to IN even more so. Rate of energy delivery also a factor, w/higher rates giving greater damage.

Hamernik, R. P. and Hsueh, K. D. 1991. Impulse noise: some definitions, physical acoustics and other considerations. *Journal of the Acoustical Scociety of America*, 90:189-196.

Hamernik, R. P., Patterson, J. H., and Salvi, R. J. 1987. The effect of impulse intensity and the number of impulses on hearing and cochlear pathology in the chinchilla. *Journal of the Acoustical Scociety of America*, 81:1118-1129.

Harmata, A. R., Durr, J. E., and Geduldig, H. 1978. *Home range, activity patterns and habitat use of prairie falcons nesting in the Mojave Desert* (Contr. YA-512-CT8-43): U.S. Bureau of Land Management, California Desert Program, Riverside, CA.

Harrington, F. H. and Veitch, A. M. 1991. Short-term impacts of low-level jet fighter training on caribou in Labrador. *Arctic*, 44:318-327.

The effects of both fixed- and rotary-wing aircraft were studied. All flight speeds were subsonic. Caribou activity was monitored using satellite telemetry and video taped observations. Sound level was recorded with an omni-directional microphone, and peak SPL measured using a Bach-Simpson model 886 Sound Level Meter on C scale. The authors conclude that initial response is caused by sound, not sight. Because rise times of noise were fast enough (in jets) to be considered impulse, caribou usually responded with a "startle reflex", therefore, habituation is not likely. Caribou reactions to rotary-wing aircraft were longer, initiated upon sight of the aircraft, and more physically demanding than those caused by fixed-wing aircraft noise. Several minutes after the last overpass, caribou behavior returned to its original level. Overflights did not cause greater daily travel distances.

Harrington, F. H. and Veitch, A. M. 1992. Calving success of woodland caribou exposed to low-level jet fighter overflights. *Arctic*, 45:213-218.

The authors study the potential for long-term population impacts with respect to the effects of overflights on calf survival. For methods, see Harrington and Veitch (1991). A number of "biologically relevant" periods within which to estimate calf survival were outlined by the authors. During calving, post-calving, and high insect pressure periods, calf survival was significantly negatively correlated with the number of low-level overflights (where the jet is >1 km from the animal) . The authors suggest excessive overflights may account in part for the lack of population growth despite a 20 year old hunting ban.

Harris, C. M. 1991a. *Definitions, abbreviations, and symbols*. In Harris, C. M. (Ed.), Handbook of acoustical measurements and noise control, (3rd ed., pp. 2.1-2.23). New York: McGraw-Hill.

In addition to providing definitions to terminology and commonly used symbols in the fields of acoustic measurements and noise control, the author

Harris, C. M. (Ed.). 1991b. *Handbook of acoustical measurements and noise control*. New York: McGraw-Hillpp.

An introduction to and reference work on applied acoustics. It contains chapters on terminology, fundamental concepts, and topics in acoustics and noise measurement and noise abatement.

Harris, J. D. 1986. *Anatomy and physiology of the peripheral auditory mechanism*. In Halpern, H. (Ed.), The PRO-ED studies in communicative disorders, (pp. 110). Austin, Texas: PRO-ED, Inc.

Hartley, D. J. 1989. The effect of atmospheric sound absorption on signal bandwidth and energy, and some consequences for bat echolocation. *Journal of the Acoustical Scociety of America*, 85:1338-1347.

Hashino, E., Sokabe, M., and Miyamoto, K. 1988. Frequency specific susceptibility to acoustic trauma in the budgerigar (*Melopsittacus undulatus*). *Journal of the Acoustical Scociety of America*, 83:2450-2453.

PTS and TTS to impulse noise in budgerigars (N=2) differed from those seen in mammals. In particular, PTS were pronounced below 1 kHz and negligible above 4 kHz. The observations' generality beyond the particular waveform of the impulse noise used in the experiments (a starter's pistol, 169 dB SPL peak) was not studied.

Haugh, J. R. 1982. Responses of raptors to exploration and construction activities in the National Petroleum Reserve in Alaska. Paper presented at the Proc. symp. and workshop on raptor management and biology in Alaska and western Canada.

Hayes, W. N. and Saiff, E. I. 1967. Visual alarm reactions in turtles. *Animal Behaviour*, 15:102-106.

Hediger, H. 1964. *Wild animals in captivity* (Sircom, G., Trans.). New York: Dover. pp.

Henderson, D. and Hamernik, R. P. 1986. Impulse noise: critical review. *Journal of the Acoustical Scociety of America*, 80:569-584.

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

> Nineteen of 21 overflights by either fixed-wing or rotary-wing aircraft or commercial jets (all <615 m) caused swans to react, often before the aircraft came into view. The authors noticed no difference in the swans' reaction between the types of aircraft. Nesting swans closest to a highway carrying heavy gravel trucks and/or having the least vegetative cover experienced greater disturbance. Human disturbance induced nest departures may effect habitat suitablity, female energy budgets, and egg exposure (as relates to increased predation or impaired development). That the birds reacted to sounds of vehicles and aircraft was deduced from their behavior. No noise measurements are reported.

Herbold, H., Suchentrunk, F., Wagner, S., and Willing, R. 1992. The influence of anthropogenic disturbances on the heart frequency of red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*). *Zeitschrift Fur Jagdwissenschaft*, 38:145-159.

Hetherington, T. E. 1992. The effects of body size on functional properties of middle ear systems of anuran amphibians. *Brain, Behavior, and Evolution*, 39:133-142.

Hewson, R. 1967. Territory, behaviour and breeding of the dipper in Banffshire. *British Birds*, 60:244-252.

Hinde, R. A. 1966. *Animal behaviour: a synthesis of ethology and comparative psychology*. New York: McGraw-Hill Book Company. 534 pp.

Holliday, T. A., Nelson, H. J., Williams, D. C., and Willits, N. 1992. Unilateral and bilateral brainstem auditory-evoked response abnormalities in 900 dalmatian dogs. *Journal Of Veterinary Internal Medicine*, 6:166-174.

Holthuijzen, A. M. A. and Eastland, W. G. 1985. Responses of breeding prairie falcons (*Falco mexicanus*) to experimental blasting. Paper presented at the Raptor Research Foundation Symposium on the Management of Birds of Prey. International Meeting.

Holthuijzen, A. M. A., Warren, G. E., Allan, R. A., Michael, N. K., Richard, D. W., and Leonard, S. Y. 1990. Effects of blasting on behavior and productivity of nesting prairie falcons. *Wildlife Society Bulletin*, 18:270-281.

Hopkins, C., Rossetto, M., and Lutjen, A. 1974. A continuous sound spectrum analyzer for animal sounds. *Z. Tierpsychol.*, 34:313-320.

Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecol. Monogr.*, 54:187-211.

> Brought the problem to the attention of field biologists and introduced the term; made a big splash. Nevertheless, pseudoreplication continues to plague whole-organism studies.

Irwin, M. R., Segal, D. S., Hauger, R. L., and Smith, T. L. 1989. Individual behavioral and neuroendocrine differences in responsiveness to audiogenic stress. *Pharmacol. Biochem. Behavior*, 32:913-917.

Jackson, J. A. 1983. Possible effects of excessive noise on red-cockaded woodpeckers. Paper presented at the Red cockaded Woodpecker Symposium II Proceedings, Panama City, Florida.

Jackson, J. A. and McDaniel, T. H. 1977. Opportunistic hunting of a marsh hawk on a bombing range. *Raptor Research*, 11.

Jouhaneau, J. and Bagady, A. 1984. Effect of early auditory stimulation on the choice of acoustical environment by adult Swiss albino mice (*Mus musculus*). *Journal of Comparative Psychology*, 98:318-326.

Kavanaugh, J. L. 1967. Behavior of captive white-footed mice. *Science*, 155:1623-1639.

Kevanishvili, Z. S. and Gvacharia, Z. V. 1972. On the role of the tensor tympani muscle in sound conduction through the middle ear. *Acta Otolaryngol*, 74:231-239.

Klein, D. R. 1973. The reaction of some northern mammals to aircraft disturbance. Paper presented at the XIth Conference, International Union Of Game Biologists., Stockholm.

> Moose showed a much greater indifference to aircraft than caribou, and this was equally true of animals encountered in the open or in partial cover. Those moose that ran from the aircraft were in most cases cows with young calves. Grizzly bears, on the other hand, reacted very strongly to the aircraft, often starting to run while the aircraft was still some distance away, apparently trying to outrun the aircraft. In most cases, as the aircraft overtook the running bears, they would veer sharply away from the flight path of the plane. Often when bears were surprised on the tundra, they would try to reach willows in the stream bottoms or other cover before the aircraft overtook them. Wolves appeared least disturbed by low-flying aircraft of any of the large mammals observed. This is somewhat surprising in view of the fact that they were legally hunted from aircraft in the study areas as late as November, 1969, and at that time, aerial hunters commented on the extreme alarm shown by wolves to aircraft. Currently, aircraft are common in the study areas, and wolves have apparently rapidly adapted to the discontinuance of the threat from this source.

Klinke, R. and Smolders, J. W. T. 1993. Performance of the avian inner ear. *Progress in Brain Research*, 97:31-43.

Knight, R. L. and Gutzwiller, K. J. (Eds.). 1994. *Wildlife and recreationists.* Covelo, California: Island Press.384 pp.

Knight, R. L. and Knight, S. K. 1984. Responses of wintering bald eagles to boating activity. *Journal of Wildlife Management*, 48:999-1004.

Kohlloffel, L. U. 1984. Notes on the comparative mechanics of hearing. I. A shock-proof ear. *Hearing Research*, 13:73-76.

Krausman, P. R., Wallace, M. C., De Young, D. W., Weisenberger, M. E., and Hayes, C., L. 1993a. The effects of low-altitude jet aircraft on desert ungulates. Paper presented at the 6th International Congress on Noise as a Public Health Problem, Nice, France.

Krausman, P. R., Wallace, M. C., Weisenberger, M. E., and Maughan, O. E. 1993b. *Effects of simulated aircraft noise on heart-rate and behavior of desert ungulates* (Technical Report): School of Renewable Natural Resources, College of Medicine/University Animal Care, University of Arizona.

> Animals becoming excited or alarmed briefly (usually for < 2 minutes) experienced increased heart-rates, although repeated exposure to aircraft noise does result in "short term habituation" and reactions vary with experience, age, and season. Although no corrections were performed for multiple comparisons, most of the 30 differences reported were significant at $p < 0.001$.

Krausman, P. R., Wallace, M. C., Zine, M. J., Berner, L. R., Hayes, C. L., and DeYoung, D. W. 1993c. *The effects of low-altitude aircraft on mountain sheep heart rate and behavior* (Technical Report): School of Renewable Natural Resources, College of Medicine/University Animal Care, University of Arizona.

Kreithen, M. 1974. Detection of changes in atmospheric pressure by the homing pigeon *Columbia livia. Journal of Comparative Physiology*, 89:73-82.

Kreithen, M. and Quine, D. 1979. Infrasound detection by the homing pigeon: a behavioral audiogram. *Journal of Comparative Physiology*, 129:1-4.

Kreithen, M. L. 1979. Detection of sound and vibration by birds. Paper presented at the Abnormal Animal Behavior Prior to Earthquakes. Second Conference., Galveston, Texas.

Kroodsma, D. E. 1990. Using appropriate experimental designs for intended hypotheses in 'song' playbacks, with examples for testing effects of song repertoire sizes. *Animal Behaviour*, 40:1138-1150.

Kroodsma, D. E. and Miller, E. H. 1982. *Acoustic communication in birds*. New York:

Academic Press. pp.

Kuck, L., Hompland, G. L., and Merrill, E. H. 1985. Elk calf response to simulated mine disturbance in southeast Idaho. *Journal of Wildlife Management*, 49:751-757.

> To test the effects of surface mining activity on calving area affinity, elk were exposed to three levels of disturbance: simulated mine noise, human, and none (control). Investigators walked 6.4 km transects playing mining activity noise through a loudspeaker at 100 dbA at 3 m. Compared to undisturbed calves, disturbed calves traveled farther over larger areas and occupied a greater variety of vegetation types (having different mean temperatures), slope aspects, and elevations. Disturbed elk did not habituate to simulated mine noises but rather moved so as to position geographic barriers between themselves and the disturbance. The authors found no difference in survival between disturbed and undisturbed calves.

Kugler, B. A. and Barber, D. S. 1993. A method for measuring wildlife noise exposure in the field (abstract). *Journal of the Acoustical Society of America*, 93:2378.

> Animal noise monitor designed for a collar mount, storing noise statistics for later recovery. Abstract only.

Kulichkov, S. N. 1992. Long-range sound propagation in the atmosphere (review). *Izvestiya Akademii Nauk SSSR, Fizika Atmosfery i Okeana*, 28:339-360.

Kull, R. C., Jr. 1993a. Summary of Team 7. (Noise and Animal Life). Paper presented at the 6th International Congress on Noise as a Public Health Problem, Nice, France.

> The author cites technology as instrumental in moving foward studies on the effects of noise on animals and indicates the need to incorporate into Team 7's membership more biologists studying these effects. Goals for Team 7 include: further study of habituation, creation of noise effects models, and "determine long-term effects of noise on populations."

Kull, R. C. and Fisher, A. D. 1986. *Supersonic and subsonic aircraft noise effects on animals: a literature survey; final rept. 15 Oct 85-15 Oct 86* (AAMRL-TR-87-032): Harry G. Armstrong Aerospace Medical Research Lab., Wright-Patterson AFB, OH.

Kull, R. C. J. 1993b. Overview of USAF studies on the effects of aircraft overflight noise on wild and domestic animals. Paper presented at the 6th International Congress on Noise as a Public Health Problem, Nice, France.

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

Langbauer, W. R., Charif, R. A., Payne, K. B., and Martin, R. B. 1991. Vocalizations of African elephants recorded by radiotelemetry. *American Zoologist*, 31:A98.

Larkin, R. P. 1976. The theory and practice of scaring birds away from airports and aircraft. Paper presented at the Bird Hazards to Aircraft Training Seminar and Workshop, East Point, Georgia.

Larkin, R. P. 1978. *Radar observations of behavior of migrating birds in response to sounds broadcast from the ground*. In Schmidt-Koenig, K. and Keeton, W. T. (Eds.), Animal Migration, Navigation, and Homing, . New York: Springer-Verlag.

Lawrence, B. D. and Simmons, J. A. 1982. Measurements of atmospheric attenuation at ultrasonic frequencies and the significance for echolocation by bats. *Journal of the Acoustical Scociety of America*, 71:585-590.

Leader, L. R., Stevens, A. D., and Lumbers, E. R. 1988. Measurement of fetal responses to vibroacoustic stimuli. Habituation in fetal sheep. *Biol. Neonate*, 53:73-85.

Lenarz, M. 1974. *The reaction of Dall sheep to an FH-1100 helicopter* (Arctic Gas Biological Report Series, Chapter 3.): Canadian Arctic Gas Study Ltd. and Alaskan Arctic Gas Study Company.

> Reactions of a Fairchild-Hiller 1100 helicopter flying at 300-500 feet from bands of dall sheep were recorded. Degree of response was independant of aircraft location, season, and group size, but not sex. Ewes reacted more strongly than rams. It was unknown whether the animals were responding to visual or audible cues.

Lennartz, M. R. and Henry, V. G. 1985. *Red-Cockaded Woodpecker Recovery Plan (Revision)* : U.S. Fish and Wildlife Service, 88 pp.

Lieb, J. W. 1981. *Activity, heart rate, and associated energy expenditure of elk in western Montana*. Unpublished Ph.D. Dissertation, University of Montana, Missoula, Montana. 239 pp.

Lim, D. J. 1986. Functional structure of the organ of Corti: a review. *Hearing Research*, 22:117-146.

Lim, D. J., Dunn, D. E., Johnson, D. L., and Moore, T. J. 1982. Trauma of the ear from infrasound. *Acta Otolaryngol*, 94:213-231.

Lima, S. L. 1993. Ecological and evolutionary perspectives on escape from predatory attack - a survey of North American birds. *Wilson Bulletin*, 105:1-47.

Ljungblad, D. K., Wuersig, B., Swartz, S. L., and Keene, J. M. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. *Arctic*, 41:183-194.

Lorenz, K. 1965. *Evolution and modification of behavior*. Chicago: University of Chicago Press. 121 pp.

Luz, G. A. 1970. Recovery from temporary threshold shift in monkeys exposed to impulse noise: evidence for a diphasic recovery process. *Journal of the Acoustical Scociety of America*, 48:48.

Luz, G. A. and Smith, J. B. 1976. Reactions of pronghorn antelope to helicopter overflight. *Journal of the Acoustical Scociety of America*, 59:1514-1515.

> Pronghorn antelope subject to the approach of an OH-58 helicopter exhibited no reaction and strong reaction at 60 dbA and 77 dbA respectively. The animals typically experience 36 to 40 dbA wind noise.

Lynch, T. E. and Speake, D. W. 1975. *The effect of sonic boom on the nesting and brood rearing behavior of the Eastern wild turkey* (US Govt FAA-RD-75-2): US DOT / FAA.

Lyrintzis, A. S. and George, A. R. 1989. Use of the kirchhoff method in acoustics. *Aiaa Journal*, 27:1451-1453.

MacArthur, R. A., Johnston, R. H., and Geist, V. 1979. Factors influencing heart rate in free-ranging bighorn sheep: a physiological approach to wildlife harassment. *Canadian Journal of Zoology*, 57:2010-2021.

Mackenzie, J. G., Foster, T. M., and Temple, W. 1993. Sound avoidance by hens. *Behavioural Processes*, 30:143-156.

Manci, K. M., Gladwin, D. N., Villella, R., and Cavendish, M. G. 1988. *Effects of aircraft noise and sonic booms on domestic animals and wildlife: a literature synthesis* (NERC-88/29): U.S. Fish and Wildlife Service, National Ecology Research Center, Ft. Collins, CO.

> While not assessing the qualtiy of literature reviewed, this report comprehensively reviewed effects of aircraft noise on both domestic and wild fanua. Authors discussed the potential impacts of aircraft noise on animals as understood by the current literature and acknowledged a lack of controlled studies. They proceded to identify areas needing further study.

Marler, P., Konishi, M., Lutjen, R., and Waser, M. S. 1973. Effects of continuous noise on avian hearing and vocal development. *Proceedings of the National Academy of Science, US.*, 70:1393-1396.

Marler, P. and Sherman, V. 1983. Song structure without auditory feedback: emendations of the auditory template hypothesis. *Journal of Neuroscience*, 3:517-531.

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

Marten, K., Quine, D. B., and Marler, P. 1977. Sound transmission and its significance for animal vocalization. II. Tropical forest habitats. *Behavioral Ecology and Sociobiology*, 2:291-302.

Martin, G. 1981. Avian vocalizations and the sound interference model of Roberts et al. *Animal Behaviour*, 29:632-633.

Matsui, M., Wu, G. F., and Yong, H. S. 1993. Acoustic characteristics of 3 species of the genus *Amolops* (*amphibia anura, ranidae*). *Zoological Science*, 10:691-695.

Mattox, D. E. 1991. Central nervous system changes associated with noise-induced hearing loss - an electron microscopic and freeze-fracture study of the chick nucleus magnocellularis. *Laryngoscope*, 101:1063-1075.

Mayfield, H. 1966. Hearing loss and bird song. *Living Bird*, 5:167-176.

McComb, K., Packer, C., and Pusey, A. 1994. Roaring and numerical assessment in contests between groups of female lions, *Panthera leo*. *Animal Behaviour*, 47:379-387.

> When recordings of three lions roaring were played, responding lions were more apt to approach than when recordings of groups of three lions were played. Authors conclude the listeners could assess the number of lions that were vocalizing.

McCourt, K. H., Feist, J. D., Doll, D., and Russell, J. J. 1974. *Disturbance studies of caribou and other mammals in the Yukon and Alaska, 1972* (Arctic Gas Biological Report Series, Volume 5): Canadian Arctic Gas Study Ltd. and Alaskan Arctic Gas Study Company.

Melnick, W. 1991. Human temporary threshold shift (TTS) and damage risk. *Journal of the Acoustical Society of America*, 90:147-154.

Meltofte, H. 1982. Shooting disturbance of waterfowl. *Dansk Ornithologisk Forening. Tidsskrift*, 76:21-36.

> In Denmark, hunted birds prefer sanctuaries free from hunting. For instance, in western Jutland 90% of ducks are found in the 20% of the area that is closed to shooting. Waterfowl and hunted shorebirds use hunting areas more during those parts of fall when hunting is proscribed and during spring . (restated from the English summary)

Michelson, A. 1978. *Sound reception in different environments*. In Ali, M. (Ed.), Sensory Ecology: Reviews and Perspectives., (pp. 345-373). New York: Plenum Press.

Miller, E. H. 1982. *Acoustic communication in birds*. New York. pp.

Miller, E. H. 1992. *Acoustic signals of shorebirds*. Victoria, British Columbia: Royal British Columbia Museum. 44 pp.

> A review of sounds (vocalizations and some wing noises) produced by shorebirds (waders, Charidriidae). Includes remarks on the proper use of spectra in bioacoustics.

Miller, F. L. and Gunn, A. 1979. *Responses of peary caribou and muskoxen to helicopter harrassment, Prince of Wales Island, Northwest Territories, 1976-77* (Occasional Papers No. 40.): Canadian Wildlife Service.

> Response of both muskoxyn and caribou depends, in part, on the altitude of helicopter (Bell 206b turbo) overflights, distance of a helicopter landing, terrain, and climate. Sex, group size and content, and number of calves/group also influence response. Each species reacts differently under varying conditions. The authors attribute this difference in response to variations in social structure and foraging and defense behavior.

Miller, F. L. and Gunn, A. 1980. Behavioral responses of muskox herds to simulation of cargo slinging by helicopter, Northwest Territories. *Canadian Field Naturalist*, 94:52-60.

The authors used a Bell 206-B "Jet Ranger turbo-helicopter", flown at 114 to 400 m AGL, in experimental passes over muskox herds, noting behavioral responses such as locomotion. Evidence for habituation was inconsistent and circumstantial but differences among three different herds were documented. No evidence for long-lasting effects was obtained.

Miller, F. L. and Gunn, A. 1981. Play by peary caribou calves before, during, and after helicopter harassment. *Canadian Journal Of Zoology*, 59:823-827.

Moen, A. N., Susan, W., and Bonnie, B. 1982. Effects of disturbance by snowmobiles on heart rate of captive white-tailed deer. *N.Y. Fish and Game Journal*, 29:176-183.

Mollenauer, S., Bryson, R., Robison, M., and Phillips, C. 1992. Noise avoidance in the c57bl/6j mouse. *Animal Learning & Behavior*, 20:25-32.

Møller, A. R. 1972. *The middle ear*. In Tobias, J. V. (Ed.), Foundations of Modern Auditory Theory., (Vol. 2, pp. 135-152). New York: Academic Press.

Moody, C. 1955. Display-flight of dipper. *British Birds*, 48:184.

Mooney, N. 1986. Reactions of raptors to aircraft. *Australasian Raptor Association News*, 7(4).

Moore, D. R. and Hine, J. E. 1992. Rapid development of the auditory brainstem response threshold in individual ferrets. *Developmental Brain Research*, 66:229-235.

Mosbech, A. and Glahder, C. 1991. Assessment of the impact of helicopter disturbance on moulting pink-footed geese, *Anser brachyrhynchus*, and barnacle geese, *Branta leucopsis*, in Jameson Land, Greenland. *Ardea*, 79:233-237.

Smaller (Bell 206) and larger (Bell 212) helicopters at < 120 m AGL but at considerable lateral distances affected time budgets of molting Pink-footed Geese more than those of molting Barnacle Geese. The former species "probably did not get enough food." Larger helicopters elicited reactions from geese at an average 9 km distance. In most cases, the helicopters were not visible to the geese, thus implicating noise as the cue being used. The authors consider low-flying helicopters to be less disturbing to the birds in this circumstance because they are less audible than high-flying helicopters.

Moss, R. and Lockie, I. 1979. Infrasonic components in the song of the capercaillie *Tetrae urogallus*. *Ibis*, 121:95-97.

Muir, J. 1913. *The mountains of California*. New York: Centurn. 389 pp.

Murphy, S. M., White, R. G., Kugler, B. A., Kitchens, J. A., Smith, M. D., and Barber, D. S. 1993. Behavioral effects of jet aircraft on caribou in Alaska. Paper presented at the 6th International Congress on Noise as a Public Health Problem, Nice, France.

Murton, R. K. and Wright, E. N. (Eds.). 1968. *The problems of birds as pests (Proceedings of a symposium held at the Royal Geographical Society, London, on 28 and 29 September 1967).* London: Academic Press.254 pp.

Nábelek, I. V. 1980. On some aspects of impulse noise measurement. Paper presented at the International symposium on effects of impulse noise on hearing, Malmo, Sweden.

The risk of PTS with impulse noise is substantially higher than continuous noise "dose equivalent" would predict. The article discriminates between perceived loundess and peripheral auditory response to impulse noise.

Narins, P. M. 1992. Evolution of anuran chorus behavior: Neural and behavioral constraints. *American Naturalist*, 139:S90-S104.

Narins, P. M., Reichman, O. J., Jarvis, J. U., and Lewis, E. R. 1992. Seismic signal transmission between burrows of the Cape mole-rat, Georychus capensis. *Journal of Comparative Physiology* *[a]*, 170:13-21.

Newman, J. S., Rickley, E. J., and Bland, T. L. 1982. *Helicopter noise exposure curves for use in environmental impact assessment* (DOT-FAA-EE-82-16): Department of Transportation, Federal Aviation Administration.

Niemiec, A. J., Raphael, Y., and Moody, D. B. 1994. Return of auditory function following structural regeneration after acoustic trauma - behavioral measures from quail. *Hearing Research*, 75:209-224.

Noble, G. K. and Putnam, P. G. 1931. Observations on the life history of *Ascaphus truei* Stejneger. *Copeia*:97-101.

Nottebohm, F. 1975. *Vocal behavior in birds*. In Farner, D. S. and King, J. R. (Eds.), Avian Biology, (Vol. 5, pp. 289-332). New York: Academic Press.

Nussbaum, R. A., Brodie, E. D., Jr., and Storm, R. M. 1983. *Amphibians and reptiles of the Pacific Northwest.* Moscow, Idaho: University Press of Idaho. 332 pp.

Odendaal, F. J., Bull, C. M., and Telford, S. R. 1986. Influence of the acoustic environment on the distribution of the frog *Ranidella riparia. Animal Behavior*, 34:1836-1843.

> Two species of Australian Leptodactylid frogs abut in distribution. The authors posit that the loud species prevents invasion by the soft-voiced species by masking its species-specific mating call.

Okanoya, K. and Dooling, R. J. 1985. Colony differences in auditory thresholds in the canary (*Serinus canarius*). *Journal of the Acoustical Scociety of America*, 78:1170-1176.

> One particular laboratory colony of canaries has hearing loss characteristic of a sensorineural deficit: mid- to high-frequency threshold elevations of 30 to 40 dB. The deficit probably does not affect the ability of the birds to hear or learn conspecific song in the confines of laboratory enclosures in which song experiments are conducted.

Okanoya, K. and Dooling, R. J. 1987a. Strain differences in auditory thresholds in the canary (*Serinus canarius*). *Journal of Comparative Psychology*, 101:213-215.

Okanoya, K. and Dooling, R. J. 1988. Hearing in the swamp sparrow, *Melospiza georgiana*, and the song sparrow, *Melospiza melodia. Animal Behaviour*, 36:726-732.

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

Olmstead, T. 1991. Proceedings of the Department of Defense Natural Resources Leadership Conference. Paper presented at the Department of Defense Natural Resources Leadership Conference, Colorado Springs, CO.

> The Defense Natural Resources Leadership Conference was called to bring together the men and women who are concerned with the stewardship of the 25 million acres of Departmental of Defense land - land rich in wildlife, wetlands, forests, deserts and coastal resources.

Olsson, O. and Gabrielsen, G. W. 1990. *Effects of helicopters on a large and remote colony of Brunnich's Guillemots (Uria lomvia) in Svalbard.* (N.R. 64.): Norsk Polarinstitutt.

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> A Bell 206 turbine-powered helicopter (apparently) was used in experiments to examine flight responses, productivity, and nest abandonment by Gyrfalcons in response to helicopters flying nearby. Numbers of trials in various conditions (distance, stage of nesting cycle,

gender of birds) were small and little attempt was made to unconfound the sight from the sound of the aircraft stimulus. After lumping other conditions, height of overhead flights was a significant factor during the nesting season, with no birds reacting to the helicopter at 600 m overhead and all reacting at 150 m. In winter (-35 to -40°), these distances were reduced to "approximately 100 m or less". Multiple nonsignificant statistical tests are reported without power analysis and on small N; the tentative nature of the results are emphasized by the author.

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> Footdrummings recorded with a geophone were later, during playback, broadcast through a fiberglass horn buried face down 1.5 m from the main burrow entrance. Territory owners responded to playbacks of footdrumming by neighbors differently than to those of strangers. Strange footdrumming patterns were met by higher footdrumming rates from territory owners.

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> Level of disturbance was determined by flight distance which was measured with a Rangematic, Mark V optical range finder. While adults reacted more readily than younger birds to disturbances, human activity had a significant effect on feeding behavior of all age classes. With the exception of gunshots, eagles were more toleratnt of disturbances obscured from their view.

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> Four kinds of fixed-wing military jet aircraft and two kinds of helicopters (Alouette 11, Bo 105, Bell UH1-D) were flown over farm animals and farm-raised mink at low level. The author provides brief verbal summaries of the behavior of each species and describes effects such as habituation to the stimuli. Mink from two strains were reported to differ in "sensitivity" to the noise, however no data are presented in this short paper.

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Tazik, D. U., Sherman, R. A., and Courson, J. A. 1991. *Annotated directory of threatened and endangered wildlife on selected U.S. Army installations east of the Mississippi river; final rept* (CERL-TR-N-91/26): Construction Engineering Research Lab. (Army), Champaign, IL.

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New River USMC Air Station at Jacksonville NC uses helicopters: AH-1, UH-1, CH-46, CH-53. The study tests 7 hypotheses comparing one high-use with one-low-use natural area, each having multiple-pen duck enclosure.

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Information was obtained mid-1993 from refuge managers at 41 refuges out of 491 total refuges. Military overflights are addressed specifically. Noise issues are not separated from other issues in most of the accounts and no scientific evidence is presented. Types of "aircraft" are not distinguished in the report. It is not apparent from the report how many of the 450 non-responding refuges did or did not have problems with military activities.

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Peak levels in "apparently identical" impulse noise events can differ substantially. The "fluctuation pattern of noise, and not simply its peaks" should be considered in evaluating effects of impulse noise. The kinds of impulse noise arising from different sources are discussed in detail.

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Ward, D. H. and Stehn, R. A. 1989. *Response of brant and other geese to aircraft disturbances at Izembek Lagoon, Alaska* (Final rept MMS-90/0046): Minerals Management Service, Anchorage, AK. Alaska Outer Continental Shelf Office.

Responses of Black Brant, Emperor Geese, and Canada Geese to both fixed- (Piper Navajo twin-engine) and rotary-wing (Bell 205) aircraft were investigated. Flocks exhibited higher percent response to the Bell 205 than to the Piper Navajo. The Bell 205 in particular produced increases in both noise levels and behavioral response of brants when flying at increasing altitudes at a fixed distance. This implicated audible rather than visual cues as the disturbing factor. The authors developed a model to predict the energetic cost (or reduction of weight gain) of aircraft disturbance.

Ward, J. and Sharp, P. L. 1974. *Effects of aircraft disturbance on moulting sea ducks at Herschel Island, Yukon Territory, August 8 1973* (Arctic Gas Biological Report Series, Volume Twenty-nine, Chapter Two.): Canadian Arctic Gas Study Ltd. and Alaskan Arctic Gas Study Company.

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> From Intro: Munitions changes have increased the hazard of direct blast injury (as opposed to from fragments, heat, etc.). The ear is the most vulnerable structure because of its function as a transducer for even weak airborne pressure waves. Injury to the ear is a common blast injury, ranging from trivial to major disruption of middle and inner ear structures; hearing loss with or without eardrum rupture, with other sequelae being much less common. By itself rupture is not usually a cause of significant acute disability (in combat setting vis-a-vis other wounds?). 10-20% will require surgical closure; and a small percentage of pt's have chronic problems. Rupture also indicates probable cochlear damage; following such a blast, can be functional deafness for minutes, measurable loss for hours if not permanently. Note in passing "common noise-induced hearing loss associated with the impulse noise of weapon

firing and the high-intensity continuous noise of engines, armored vehicle tracks, and helicopter blades."

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APPENDIX A: Taxonomic names

(Prepared with Jennifer Roth.)

Bird names are from the A.O.U. Committee on Classification and Nomenclature (1983).

Adelie Penguin	*Pygoscelis adeliae*
American Dipper	*Cinclus mexicanus*
Asian elephant	*Elephas maximus*
Bald Eagle	*Haliaeetus leucocephalus*
banner-tailed kangaroo rat	*Dipodomys spectabilis*
Barn Owl	*Tyto alba*
bat	Chiroptera
bighorn sheep (Rocky Mountain)	*Ovis canadensis canadensis*
Black-capped Vireo	*Vireo atricapillus*
black-footed ferret	*Mustela nigripes*
bowhead whale	*Balaena mysticetus*
Brunnich’s Guillemot (=Thick-billed Murre)	*Uria lomvia*
Budgerigar	*Melopsittacus undulatus*
Burrowing Owl	*Speotyto cunicularia*
California Condor	*Gymnogyps californianus*
caribou (=reindeer)	*Rangifer tarandus*
Chaffinch	*Fringilla coelebs*
chicken	*Gallus domesticus*
chinchilla	*Chinchilla laniger*
cicada	Cicadidae
common lizard	*Lacerta vivipara*
Common Canary	*Serinus canarius*
cow	*Bos domesticus*
coyote	*Canis latrans*
Dall sheep	*Ovis dalli dalli*
desert bighorn sheep	*Ovis canadensis nelsoni*
desert kangaroo rat	*Dipodomys deserti*
desert tortoise	*Gopherus agassizii*
dog	*Canis familiaris*
domestic cat	*Felis catus*
elk (Rocky Mountain)	*Cervus elaphus nelsoni*
egret	Ardeidae
Emperor Penguin	*Aptenodytes forsteri*
Eurasian Dipper	*Cinclus cinclus*
European ferret	*Mustela mustela*
frog	Anura
Glaucous Gull	*Larus hyperboreus*
Golden-cheeked Warbler	*Dendroica chrysoparia*
gopher tortoise	*Gopherus polyphemus*
gray wolf	*Canis lupus*
green treefrog	*Hyla cinerea*
grizzly bear	*Ursus arctos*
guinea pig	*Cavia porcellus*
gull	Laridae
Gyrfalcon	*Falco rusticolus*
Harlequin Duck	*Histrionicus histrionicus*
heron	Ardeidae
homing pigeon (=Rock Dove)	*Columbia livia*
house mouse	*Mus musculus*

human	*Homo sapiens*
kangaroo rat	*Dipodomys*
Kirtland’s Warbler	*Dendroica kirtlandii*
kit fox	*Vulpes marcrotis*
mink	*Mustela vison*
Mohave fringe-toed sand lizard	*Uma scoparia*
moose	*Alces alces*
mule deer	*Odocoileus hemionus*
muskox	*Ovibos moschatus*
Northern Harrier	*Circus cyaneus*
Osprey	*Pandion haliaetus*
pelican	Pelecanidae
Peregrine Falcon	*Falco peregrinus*
pigeon	Columbidae
polar bear	*Ursus maritimus*
prairie chicken	*Tympanuchucs*
Prairie Falcon	*Falco mexicanus*
Prairie Warbler	*Dendroica discolor*
pronghorn	*Antilocapra americana*
rat (laboratory)	*Rattus norvegicus*
red deer	*Cervus elaphus*
Red-cockaded Woodpecker	*Picoides borealis*
Red-tailed Hawk	*Buteo jamaicensis*
Red-winged Blackbird	*Agelaius phoeniceus*
reindeer (caribou)	*Rangifer tarandus*
rhesus macaque	*Macaca mulatta*
Rock Dove (homing pigeon)	*Columbia livia*
roe deer	*Capreolus capreolus*
Roosevelt Elk	*Cervus elaphus roosevelti*
Sage Grouse	*Centrocercus urophasianus*
Sandhill Crane	*Grus canadensis*
Say’s Phoebe	*Sayornis saya*
Snow Goose	*Chen caerulescens*
songbird	Passeriformes (roughly speaking)
sparrow	Emberizinae
swallow	Hirundinidae
tailed frog	*Ascaphus truei*
Thick-billed Murre (=Brunnich’s Guillemot)	*Uria lomvia*
Torrent Duck	*Merganetta armata*
Trumpeter Swan	*Cygnus buccinator*
tungara frog	*Physalaemus pustulosus*
weasel	Mustelidae
White-eyed Vireo	*Vireo griseus*
white-tailed deer	*Odocoileus virginianus*
Wild Turkey	*Meleagris gallopavo*
woodland caribou	*Rangifer tarandus caribou*
woodpecker	Picidae
wren	Troglodytidae

APPENDIX B: Examples of potentially vulnerable ecological or life-history situations

Situation	Examples
Predators that detect prey by sound	owls Taylor 1994, Kit Fox, insectivorous bats (passive Anderson and Racey 1993, Fuzessery, et al. 1991 and active Coles, et al. 1989, Griffin and Thompson 1982 sonar)
Prey that detect predators by sound or alert conspecifics to predators by sound	*Dipodomys* (Brattstrom and Michael 1983, Randall 1994)
Critical times in animals' life cycle	Fledging in birds, a time of high stress as evidenced by high natural mortality; molting for waterfowl (Gollop, et al. 1974c, Ward and Sharp 1974); critical period for song learning in birds; prenatal period in mammals (Fride, et al. 1986, Fride and Weinstock 1989).
Immigrants to an area or migrants through an area might be at a disadvantage from not being habituated to noise and might keep moving or suffer reproductively. Dispersing from surrounding areas into areas of intense noise might be easier, because animals would already be long-term habituated.	<hypothetical>

List of Acronyms and abbreviations

See also Harris 1991a.

AEP	Auditory Evoked Potential
AER	Auditory Evoked Response *or* Averaged Evoked Response
AGL	Above Ground Level
ATOC	Acoustic Thermometry of Ocean Climates (Anderson 1991)
ATS	Asymptotic Threshold Shift, the threshold shift resulting from very long-duration exposure to continuous loud sound
B & K	The Bruel and Kjaer Company
BAER	Brainstem Auditory Evoked Response
BPF	Blade Passing Frequency of helicopters
CART	Classification and Regression Tree models, a descriptive statistical technique
CF	Characteristic Frequency
CM or CMP	Cochlear Microphonic Potential
CNS	Central Nervous System
CSEL	C-weighted Sound Exposure Level
dBA	Decibels SPL, A-weighting
dBL	Decibels SPL, unweighted (Linear)
DNL	day/night noise Level, the L_{eq} with a 10 dB penalty added for nighttime exposures.
DRC	Damage-risk Criterion
EEH	Equal Energy Hypothesis, a largely-discredited idea (Erlandsson, et al. 1980, Henderson and Hamernik 1986) that equal amounts of cumulative sound energy over a time period produce equal amounts of damage to hearing, independent of their distribution in time.
EQL	see L_{eq}
FSEL	Flat-weighted Sound Exposure Level
EP	Endocochlear Potential or Endolymphatic Potential
HL,HTL	Hearing threshold Level
ISO	International Organization for Standardization
L_{dn}	See dnL
L_{eq}	Equivalent noise Level over a specified period of time
ORV	Off-Road Vehicle
NIPTS	Noise-Induced PTS
OSHA	U.S. Occupational Safety and Health Administration
Pa	The Pascal, S.I. unit of pressure

PSPL	Peak Sound Pressure Level
PTS	Permanent Threshold Shift.
SEL	Sound Exposure Level, a measure of the cumulative acoustic energy of a sound during a specified time period, computed as the total energy in a hypothetical 1-s exposure equivalent to the energy in a longer actual exposure.
SLM	Sound Level Meter
SPL	Sound Pressure Level
TES	Threatened and Endangered Species
TTS	Temporary Threshold Shift

INDEX

In this index, peoples' names and ubiquitous terms such as "noise", "weapon", and "statistics" are omitted. No attempt has been made for taxonomic or geographical comprehensiveness--the reader may have to look under "ungulate", "elk", and "cervid" to find a reference to Roosevelt elk. And synonymy is minimal--"deafness" and "auditory deficit" are neglected in favor of "hearing loss", for instance.