

Mackenzie Gas Project

Effects of Noise on Wildlife

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1 Overview

1.1 Introduction

The potential impact of noise disturbance on wildlife in the vicinity of the Mackenzie Gas Project is an issue of concern identified by the proponents, regulators and communities. Noise sources in the production area will include:

- air traffic
- construction vehicles
- production wells
- drilling pads
- compressors
- aerial coolers
- flare stacks
- pumps
- generators

Noise sources at various facilities along the pipeline corridor, such as compressor stations and line heaters, will include:

- air traffic
- construction vehicles
- compressors
- aerial coolers
- fired heaters
- flare stacks
- flow meters
- pumps
- generators

In addition, both areas will have noise associated with each infrastructure site, e.g., barge landing sites, stockpile sites, fuel storage sites, staging and marshalling areas, permanent and seasonal camps, permanent and seasonal roads, airstrips and helipads, as well as noise generated by extraction activities at borrow sites, e.g., by equipment and vehicles.

The literature review in this report focuses on the effects of noise on several wildlife species, including:

- barren-ground caribou (*Rangifer tarandus groenlandicus*)
- woodland caribou (*Rangifer tarandus caribou*)
- moose (*Alces alces*)
- grizzly bear (*Ursus arctos*)
- polar bear (*Ursus maritimus*)
- lynx (*Lynx canadensis*)
- beaver (*Castor canadensis*)

- marten (*Martes americana*)

The literature review also focuses on several species guilds, including:

- marine mammals
- amphibians
- shorebirds and waterbirds
- songbirds
- raptors

1.2 Objectives of Report

The objectives of this report are to:

- provide an overview of the existing knowledge available on the effects of noise on wildlife that might result from constructing and operating the project, including a description of the factors that cause noise effects on wildlife, and the responses to noise by wildlife
- compile and summarize the direct evidence for the effects of noise on each wildlife species. Direct evidence came from studies that followed experimental protocols, such as use of a control group, and included some measure of noise levels, either as decibels or as distance from the source. In some studies, distance from the source is used as a surrogate for noise level (see Section 1.3.1). Direct evidence was specific to the wildlife species itself, not to any related species. Studies that examined the effects of aircraft overflights and snowmobiles were included as direct evidence if some indication of noise level was provided, and if the intent was not just to test the effects of harassment. These studies did not typically address the separation of the visual and noise components of these types of disturbance (see Section 1.3 for further discussion).
- compile and summarize the indirect evidence for the effects of noise on each wildlife species examined. Indirect evidence came from studies on the avoidance of features that might be a source of noise disturbance, such as roads. Under such indirect evidence, there was no specific assessment of noise level. Indirect evidence also includes direct evidence for noise effects obtained for closely-related species.
- describe the hearing characteristics of each wildlife species examined. Information on hearing range (frequency) was deemed particularly important for evaluating the noise assessment and its meaning for wildlife.

1.3 Factors Affecting Noise Effects on Wildlife

It is generally accepted that the effects of noise on most wildlife species are poorly understood (Larkin et al. 1996; Brown 2001; OSB 2003). There are numerous reasons for this, including:

- extrapolating from one species to the next
- measurement problems, e.g., lack of species-specific frequency weighting filters and failure to accurately report measurement parameters (hearing characteristics could be species-specific)
- inadequate attention to the role of ambient noise
- failure to separate the visual and auditory components of reported disturbances
- the applicability of experimental research to a natural setting

Response to noise disturbance cannot be generalized across species or among genuses. (Larkin et al. 1996). There might even be response differences among individuals or groups of individuals of the same species. An animal's response to noise can depend on a variety of factors, including:

- noise level
- frequency distribution
- duration
- number of events
- variation over time
- rate of onset
- noise type, e.g., white noise versus harmonic or pure tones
- existence and level of ambient (background) noise
- time of year
- time of day. Little work has been done on the effect of noise at night, but many animals might rely on auditory cues more at night than during the day (Larkin et al. 1996, A. Barrass, pers. comm., November 2003).
- animal activity and location
- age and sex class
- past experience (Larkin et al. 1996; Voipio et al. 1998; Pater 2001; OSB 2003)

The potential effects of noise on wildlife are numerous, and include:

- acute or chronic physiological damage to the auditory system
- increased energy expenditure
- physical injury incurred during panicked responses
- interference with normal activities, such as feeding
- impaired communication among individuals and groups

The impacts of these effects might include habitat loss through avoidance, reduced reproductive success and mortality. Noise thresholds are unknown, evidence for habituation is limited, long-term effects are generally unknown, and how observed behavioural and physiological response might be manifested ecologically and demographically are poorly understood and seldom addressed (Brown 2001; OSB 2003).

Although it is important to consider whether an animal is responding to noise or to some other aspect of a disturbing activity (Pater 2001), in most studies on wild animals it is not clear whether observed reactions are in response to the sound or some other component of the disturbance, such as visual elements. This doubt applies to most data on reactions to aircraft and some data on reactions to ships and other human activities (Richardson et al. 1995). This distinction might be of particular relevance when designing mitigative measures (Richardson et al. 1995) because, for mitigation to be effective, it must aim at minimizing the cause of the disturbance. Noise playback experiments are one method for testing reactions to noise in the absence of other cues (Richardson et al. 1995). However, Pater (2001) suggests that simulated noise sources are limited in their ability to explain animal responses to the actual disturbance events because of differences in spectral content, and visual and temporal aspects, such as suddenness of onset. Table 1-1 presents the level of knowledge currently available on the noise effects.

1.3.1 Understanding the Effects of Noise on Wildlife

An animal's sensitivity to sound varies with frequency and its response to a sound depends largely on the presence and levels of sound in the frequency band (range of frequencies) to which it is most sensitive (Richardson et al. 1995; Larkin et al. 1996). Frequency weighting discriminates, i.e., filters, against sounds, which, while easily measured by instruments, are not heard by the study subjects (Pater 2001). The A-weighted sound level (dBA) is widely used as the unit of sound level in studies of noise effects (Bommer and Bruce 1996; Mancini et al. 1988) and in impact assessments (Stewart 1999). This weighting system puts the greatest emphasis on sounds between 1 kHz and 6 kHz, to which humans are most sensitive (Mancini et al. 1988; Richardson et al. 1995).

Sound levels vary with distance from a sound source because of such factors as:

- volume
- the source level
- the frequency spectrum of the source
- atmospheric conditions, e.g., wind, humidity and temperature
- features that act as sound barriers, e.g., stands of trees

- ground cover
- terrain
- water depth
- wind
- weather
- inverse-square spreading loss

Inverse-square spreading loss is the geometrical decrease of sound pressure level (SPL) by 6 dB with every doubling of distance from a point source. (Richardson et al. 1995; Bommer and Bruce 1996; Larkin et al. 1996; Mancini et al. 1988; Pater 2001).

Table 1-1: Knowledge of Effects of Noise on Wildlife

Valued Component	Direct Effects of Noise	Indirect Effects of Noise	Information on Hearing Characteristics	State of Knowledge: Effects of Noise
Barren-ground caribou	Good	Good	Indirect	Good
Woodland caribou	Fair	Good	Indirect	Fair
Muskox	Limited	Fair	Indirect	Fair
Moose	Limited	Good	Indirect	Fair
Grizzly bear	Limited	Good	Indirect	Fair
Polar bear	Limited	Fair	Indirect	Fair
Wolverine	None	Fair	Indirect	Poor
Lynx	None	Fair	Indirect	Poor
Beaver	None	Limited	Indirect	Poor
Marten	None	Fair	Indirect	Poor
Marine mammals	Good	Good	Direct	Very Good
Amphibians	Limited	Limited	Indirect	Limited
Shorebirds and waterfowl	Fair	Good	None	Fair
Songbirds	Limited	Good	Indirect	Fair
Raptors	None	Fair	Indirect	Poor

Although distance is often used as a surrogate for noise levels in many wildlife studies, e.g., altitude of aircraft overflights, distance measurements are specific to a particular noise stimulus situation, whereas noise levels in decibels are more universally applicable (Pater 2001). Ideally, the sound levels associated with a noise event should be recorded as the animal receives it, e.g., same location, same height above ground. Any response variables, such as vocalizations, movements and physiological changes, should also be recorded in real time (Pater 2001; OSB 2003). For example, the animal noise monitor (ANM) collar, used by Maier et al.

1998 in their study of barren-ground caribou, has noise level and event monitoring capability, such as a heart rate monitor.

Sound levels vary with the source, magnitude and duration, with varying reactions to noise disturbance. For example, the highest aircraft noise levels occur during takeoff as engines reach maximum power levels. During landings, aircraft noise levels are reduced as engine power decreases. Passing fixed-wing aircraft (single-engine) emit a noise level of 66 to 76 dBA while flying at an altitude of 300 m. Twin-engine planes transporting operations and maintenance personnel to the CD-3 site at an altitude of 300 m would result in a noise level of 69 to 81 dBA. Helicopters typically have noise emissions of between 68 to 78 dBA, while flying at an altitude of 400 m. During takeoffs and landings, jet aircraft have much higher noise emissions. However, these higher noise levels occur for a shorter period of time than for helicopter operations.

Ambient (background) noise greatly affects the distance at which animal vocalizations, human-made noises and other sound signals can be detected (Richardson et al. 1995). Even within the range of detectability, variations in ambient noise levels greatly affect the prominence (signal to noise ratio) of sound signals (Richardson et al. 1995). Many sources contribute to natural ambient noise. Ambient noise in the terrestrial environment (Ehret and Gerhardt 1980) includes:

- the calls and songs of birds, insects and frogs
- running water
- waterfalls
- wind
- wind-blown plants

Ambient noise in the ocean includes natural elements, such as wind, waves, surf, ice, precipitation, animal vocalizations and sounds, earthquakes, and volcanoes, but is also typically described as including human-made sounds, such as those from distant shipping (traffic noise) and fishing boats (Richardson et al. 1995). Ambient noise levels can vary greatly. For example, Blix and Lentfer (1992) found that ambient noise levels recorded in the Arctic winter were greatly affected by wind. Background noise was 0 to 15 dB during a windless period, but reached 50 dB under windy conditions (Blix and Lentfer 1992). In another example, ambient noise levels at the Lancaster Sound ice edge ranged from 93 to 104 dB (re: 1 μ Pa in the 20 to 1,000 Hz band) at a depth of 20 m, but averaged 9 dB lower at a depth of 3 m (Finley et al. 1990). The underwater reference pressure is 1 micropascal (μ Pa), and the airborne reference pressure is 20 μ Pa (Richardson et al. 1995). The reference unit should be cited in studies but seldom is (Richardson et al. 1995).

Natural sounds can be as loud as noisy industrial facilities, but these tend to be intermittent events, such as thunder and high winds, in most areas, and even fairly steady sounds like waterfalls affect only limited areas (Bommer and Bruce 1996). Presumably, most animals have evolved to deal with these conditions. Whales and

dolphins, in particular, have evolved ears that function well within the context of natural ambient noise (OSB 2003).

Ambient levels, hearing thresholds and levels potentially causing hearing loss of underwater sounds are about 60 dB higher than the equivalent decibel levels of airborne sound (Bommer and Bruce 1996). Sound propagation in deep water is affected by depth variations in water properties (Richardson et al. 1995). In shallow water, it is affected by interactions with the surface and bottom (Richardson et al. 1995). The ocean environment associated with the production area would be considered shallow water (less than 200 m) regarding sound propagation (Richardson et al. 1995). Refraction of sound in shallow water can result in either reduced or enhanced sound transmission (Richardson et al. 1995).

The air to water transmission of sound is a complicated process, further confounded by the presence of ice that affects the characteristics of airborne sounds received by marine mammals below the surface (Richardson et al. 1995). For example, an approaching aircraft can be heard in the air well before it is audible underwater (Richardson et al. 1995). Airborne sounds can also affect marine mammals when they are at the surface or hauled out (Richardson et al. 1995). Sounds produced on islands are greatly attenuated at the air–water and bottom–water interfaces (Richardson et al. 1995). Some pinniped species are considered to be effectively double-eared, in that they hear moderately well in two domains, air and water, but are not particularly acute in either (OSB 2003).

1.3.2 Hearing Characteristics

Sound pressure level (SPL) is used to describe sounds and is often used in hearing literature. They can be expressed in bels or, more commonly, decibels (dB). Hearing is not well studied in wild animals, and even among domestic animals, knowledge of specific audiograms is scant (Manci et al. 1988). An audiogram is a graph of auditory threshold, i.e., the minimum sound level at which a sound can be perceived, versus frequency (Richardson et al. 1995). Therefore, whether the auditory systems of different animal species respond to noises like the human ear, or which frequencies of sound are responded to by VCs, is not well known (Stewart 1999). Consequently, the A-weighting system (dBA), because it was designed for humans, is not considered appropriate for other animals (Bommer and Bruce 1996; Richardson et al. 1995; Voipio et al. 1998; Pater 2001). The only weighting filter that has been developed specifically for wildlife is a filter that was developed for harbour seals (Foster 2001). However, the specific frequencies of sound responded to by other animal species have not been examined. In this report, sound measurements are reported as they were measured in the original reports (dB, dBA or dBC). However, in light of the virtual absence of species-specific weighting filters, sound levels for wildlife are most accurately expressed using either unweighted (i.e., dB; ‘flat’) or C-weighted (dBC) SPLs (Fletcher and Busnel 1978; Richardson et al. 1995; Larkin et al. 1996; Stewart 1999; Barrass, pers. comm., November 2003). The ‘dBC’ begins to cut off low frequencies only below about 50 Hz (Larkin et al. 1996). Reported sound levels should include reference to the weighting system applied (Larkin et al. 1996).

1.3.3 Effects of Noise on Wildlife

Signal detection theory predicts that noise should reduce (mask) both the detection and discrimination of signals. However, little is known about these effects in animal communication (Wollerman and Haven Wiley 2002), even though masking might be one of the most significant effects of a general increase in background noise on most vertebrates (OSB 2003). Amphibians, whales and birds are obvious candidates for such effects, but vocal communication is part of the behaviour of many other species. For example, during caribou calving season, vocalizations seem to keep cows and calves together (de Vos 1960). Calf bawls, in the absence of wind, could be heard at a distance of 800 m (de Vos 1960).

Human-made noise has the potential of interfering with animal communication signals, sounds animals might listen to for orientation and for predator and prey detection (Erbe et al. 1999). The biological implications of signal masking will depend greatly on the function of the signal and its context (OSB 2003). For example, reproduction in many frog species is initiated when sexually mature males use vocalizations to advertise their sex, receptiveness, location and species identity (Odendaal et al. 1986). Noisy environments can interfere with this communication process, and create problems with respect to detection, discrimination and localization of appropriate signals (Wollerman 1999). In a healthy population, there might be little effect, but in a severely depleted population, interference with mating via acoustic cues could be serious (OSB 2003).

Most experimental evidence indicates that exposure to intense noise can lead to a wide variety of functional and structural changes in laboratory and domestic animals (Peterson 1980). Effects implicated as the result of intense noise exposure include alterations in gastrointestinal, immunological, reproductive, nervous and cardiovascular systems (Geber and Anderson 1967; Ames 1978; Peterson 1980; Nayfield and Besch 1981). Changes in hormone balance, blood parameters and adrenal structure have also been reported (Peterson 1980; Nayfield and Besch 1981). Physiological responses to noise disturbance in wild animals have received limited attention to date, with heart rate being the most commonly measured parameter (e.g., Moen et al. 1982; Reynolds et al. 1986; Andersen et al. 1996; Weisenberger et al. 1996; Krausman et al. 1998). Physiological reactions, such as increased heart rate, might occur even if no overt behavioural response is evident (Moen et al. 1982; Richardson et al. 1995).

Interspecific differences exist among lab animals in susceptibility to noise-induced hearing loss (Peterson 1980). Exposure to uniform stimulus patterns might lead more readily to hearing loss, whereas exposure to irregular patterns might be more likely to cause disorders because of repeated activation of the neuro-endocrine system (Peterson 1980). Recent evidence suggests that whales and dolphins are more resistant than many terrestrial mammals to temporary threshold shifts (hearing loss) (OSB 2003).

Responses to noise disturbance might have energetic impacts on wildlife. For example, Stockwell et al. (1991) found that the winter foraging efficiency of

desert bighorn sheep (*Ovis canadensis nelsoni*) in Grand Canyon National Park was reduced by 43% as a result of disturbance from helicopter overflights. The cost of human disturbance (mountain climbers) to grizzly bears feeding on moths in Glacier National Park was determined to be 12 kCal per minute (White et al. 1999). Bradshaw et al. (1998) estimated that disturbed woodland caribou expend 3.9 to 5.8 MJ per single disturbance event, i.e., loud noise, in the winter.

Indirect evidence suggests that habitat loss is a potential impact of noise disturbance. For example, the distances of woodland caribou from such disturbances as roads, seismic lines and well sites were so large that 22 to 48% of their preferred habitats were avoided in their northern Alberta study area (Dyer et al. 2001). Archibald et al. (1987) estimated that 23% of a female grizzly bear's annual home range was avoided for 14 hours a day because of disturbance from logging truck traffic. Similarly, McLellan and Shackleton (1988) found that road avoidance represented a loss of 8.7% of the available habitat in their entire study area.

The significance of the short-term effects of noise disturbance on the long-term health of individuals and populations is rarely known (Harrington and Veitch 1992; Richardson et al. 1995). However, most brief interruptions of normal behaviour might have little effect on energetics and reproductive success (Richardson et al. 1995). Also, noises resulting in one-time acute responses are less likely to have population-level effects than are sounds to which animals are exposed repeatedly over extended periods of time (OSB 2003). Demographic responses do not necessarily follow, even from significant behavioural responses (McLellan and Shackleton 1988). For example, den abandonment following human disturbance will not always lead to harmful effects if alternative denning areas are available within a bear's home range (Linnell et al. 2000).

Habituation might occur if a stimulus occurs repeatedly without negative consequence, if the benefits, such as access to food (OSB 2003) outweigh the costs of reacting, or if the cost of the animal's reaction itself, such as caribou running in deep snow in late winter (Maier et al. 1998) outweighs the negative effects of the stimulus. Although snowmobiles and chainsaws sound similar, deer learn to associate chainsaws with new forage supplies (from tree felling), whereas fast-moving snowmobiles might be perceived as predators (Moen et al. 1982). Acoustic harassment devices (AHDs) have produced some of the best evidence of habituation in marine mammals (Richardson et al. 1995, OSB 2003), which will show habituation to many signals that initially cause an overt reaction. However, the effectiveness of the AHDs declined over time, and with increased mass of the individuals, such as polar bear, California sea lion, harbour seal and sea otter (Richardson et al. 1995).

1.4 Summary of Results

Information from this report was used as one of the assumptions in determining the Zones of Influence (ZOI) used in the *Wildlife Models Potential Effects and Wildlife Habitat Suitability Modelling: Birds*. The ZOIs used for the wildlife modelling can be considered conservative in that they include consideration of

noise as well as knowledge regarding visual and olfactory disturbance effects on wildlife.

Table 1-2 summarizes the species-specific information on noise effects presented in the body of this report.

Table 1-2: Summary of Results

Wildlife Species	Potential Effects of Noise	Seasons of Concern	Application of Noise Effect Information in ZOI Assumptions of Mackenzie Gas Project EIS
Barren-ground caribou	Good knowledge. React to aircraft overflights, and generator noise. The behavioural responses of caribou to project-related activities can vary with season, the type of stimuli, and the sex and age class, group size, and previous experience of the animals involved.	Spring (calving and post-calving seasons)	Aircraft: 300 m diagonal distance response of up to 14% of caribou. ZOIs used for airstrips 2,000m and for helicopter routes 250 m. Industrial activity: largest measured distance responding to noise was 800 m. ZOIs used were graded in response from 500 to 1,000 m.
Woodland caribou	Fair knowledge. Assume similarities to barren-ground caribou. React to aircraft overflights.	Spring (calving and post-calving seasons)	Response to seismic noise was measured at 331 m. ZOIs used were graded in response from 250 to 500 m.
Moose	Fair knowledge.	Spring, winter	Greatest distance measured presumed from human-caused noise at 400 m. ZOIs used were graded in response from 200 to 1,000 m.
Grizzly bear	Fair knowledge. React to aircraft overflights, sudden loud noises. Denning may be disrupted.	Winter (denning)	Seismic disturbance of denning bears was measured at 2.4 km. ZOIs for primary industry site were graded in response from 1,000 to 2,000 m. Other noise sources that disturbed bears were measured at up to 600 m. ZOIs used were graded in response from 500 to 1,000 m.
Polar bear	Fair knowledge. Denning may be disrupted.	Winter (denning)	Similar to grizzly bear, noise effects less conclusive.
Marten	Poor knowledge. Assume startle response to sudden loud noises. Assume habitat avoidance as the result of loud continuous noises.		Noise effects for these species are inconclusive, but ZOIs were based on reported industry experience of up to 200 m.
Lynx	Poor knowledge. Assume startle response to sudden loud noises. Assume habitat avoidance as the result of loud continuous noises.		

Table 1-2: Summary of Results (cont'd)

Wildlife Species	Potential Effects of Noise	Seasons of Concern	Application of Noise Effect Information in ZOI Assumptions of Mackenzie Gas Project EIS
Beaver	Poor knowledge. Assume startle response to sudden loud noises. Assume habitat avoidance as the result of loud continuous noises.	Winter	There were no habitat models and hence no ZOIs for these species but buffer zones are recommended for various project activities in mitigation measures.
Beluga whale	Very good knowledge. Masking effects from loud continuous noises, startle response from sudden loud noises.	Year-round	
Amphibians	Limited knowledge. Assume masking effects from loud continuous noises and startle response from sudden loud noises. Effects presumed to be more significant during mating season (spring).	Spring	
Shorebirds and waterfowl	Fair knowledge, assume startle response from sudden loud noises, and sensitivity during nesting.	Spring/summer	Measured disturbance presumed from noise measured at 1,000 m for white-fronted geese. ZOIs used were graded in response from 250 to 2,000 m. ZOIs for shorebirds assumed at 300 m.
Songbirds	Fair knowledge, assume masking effects from loud, continuous noises. Startle response from sudden loud noises, and sensitivity during nesting.	Spring/summer	Distance effects of noise are inconclusive, but ZOIs assumed 50 m distance.
Raptors	Poor knowledge, assume startle response from sudden loud noises, and sensitivity during nesting.	Spring	Distance effects of noise itself are inconclusive. No models for nesting raptors were developed, but buffer distance from nests is recommended at 500 m.

2 Caribou and Moose

2.1 Barren-Ground Caribou

2.1.1 Direct Effects of Noise

There is more direct evidence for the effects of noise on barren-ground caribou (see Table 2-1) than for any of the other terrestrial mammal VCs. Most studies have focused on aircraft overflights, and results indicate that aircraft overflights (both fixed-wing and rotary) elicit a range of responses. However, as discussed in Section 1, it is not clear what elements of overflights cause these responses. Although McCourt et al. (1974) made numerous observations of caribou reacting to auditory stimuli alone – individuals often reacted before visual contact was made with aircraft flying low over forested areas – a visual effect cannot be ruled out.

McCourt et al. (1974) provide the most quantitative study of the effect of steady state noise on barren-ground caribou, as noted by Jakimchuk (1980) and still true today. The simulated sound of a gas compressor elicited an increased incidence of alert postures in caribou passing within about 300 m of the simulator, and there was some apparent avoidance of this zone, but no strong reactions were observed. Limited data was collected, but in most cases, noise levels of the simulator had dropped to ambient levels at 800 m from the simulator. Noise levels dropped off more rapidly behind and lateral to the simulator (McCourt et al. 1974). The simulator was in full view during the trials for an unknown distance, and although the general reaction of control caribou indicated that the visual was not disturbing, there were exceptions (see Table 2-1). Visual or olfactory stimuli associated with a gas compressor station have not been tested. McCourt et al. (1974) suggest that the lack of a significant reaction to the simulator noise might be because caribou do not normally associate loud noise with a threat.

Numerous studies have reported that females with calves, and calves themselves, are more sensitive to disturbance, including noise disturbance (overflights), than other herd members (de Vos 1960, Calef et al. 1976, Miller and Gunn 1981, Whitten and Cameron 1983, Smith and Cameron 1983, Nellemann and Cameron 1998, Maier et al. 1998). Miller and Gunn (1981) speculate that calves were more excited than adults during helicopter overflights, and that this level of excitement led to a general readiness to be active that was released as play when the adults did not overtly respond to the same disturbance. Seasonal variations in response levels have also been noted. For example, Calef et al. (1976) reported greater responses to overflights during the calving season, and during cold weather in early winter, relative to observations made during the spring and fall migrations.

There is limited direct evidence, but it does appear that caribou can habituate to some levels of industrial activity, including noise (Valkenburg and Davis 1985). Caribou herds consistently overflowed, but not chased or hunted by aircraft, were found to react less to this sensory disturbance over time (Davis et al 1985, Valkenburg & Davis 1983). However, there are also indications of sensitization to disturbance. For example, the differences in response to aircraft overflights

observed by Valkenburg and Davis (1985) were attributed to herd experience related to hunting, and their speculated differences regarding their perception of aircraft as a threat.

The conclusion of most authors is that the impacts of acute (short-term, high-level) and chronic (long-term, low-level) noise on barren-ground caribou results in variable types of disturbance responses occurring over variable time frames (Webster 1997). For example, after acute exposure to low level (less than 150 m) helicopter or fixed-wing aircraft, unhabituated caribou demonstrated panic responses (Calef et al. 1976, Valkenburg and Davis 1983), and even after chronic noise exposure, caribou were found to significantly alter their daily activity cycles and movements as a result of overflights (Maier et al. 2005).

2.1.2 Indirect Effects of Noise

Barren-ground caribou are known to avoid roads and areas of industrial activity (Urquhart 1973, Smith and Cameron 1983, Curatolo and Murphy 1986, Cameron et al. 1992, Cameron et al. 1995, Nellemann and Cameron 1998), particularly where these developments are quite concentrated. However, some authors consider caribou to be reasonably tolerant of human activities (Bergerud et al. 1984, Davis et al. 1985), especially during periods of insect harassment (Cronin et al. 1998, Murphy and Lawhead 2000).

Although caribou appear to avoid active roads, it is not clear whether it is noise or visual stimuli that cause the disturbance. Dau and Cameron (1986) and Cameron et al. (1992) reported that caribou were displaced up to 2 km from a road with moderate to heavy traffic for a two to three-week period around calving time. However, road avoidance in the Kuparuk Development Area occurred despite low levels of vehicular traffic (Cameron et al. 1992). Approaching vehicles might cause individuals to run (Horesji 1981; Murphy and Curatolo 1987). Horesji (1981) found that sound did not appear to be a factor in alerting caribou to the approach of a vehicle. This finding is in contrast to observations by Urquhart (1973), in which caribou ran off at the sound of a vehicle, and by Russell (1977) in which a small group of caribou responded (by altering their movement pattern) to the exhaust 'snort' of a nodwell at a distance of 1.2 km. In the same study area as for Urquhart, caribou were also seen to passively watch vehicles as they passed within 800 m. Curatolo and Murphy (1986) suggest that caribou on the oilfield respond to two types of stimuli – structures that might resemble concealing habitat, such as a pipeline, and moving vehicles that might resemble predators.

Observations by Hanson (1981) suggested that diesel generators and vehicle traffic at Prudhoe Bay did not greatly affect barren-ground caribou. Individuals appeared undisturbed by steady noise from the generator exhaust located about 60 m away (Hanson 1981).

Two caribou observed within 1.2 km of a series of seismic detonations looked up for about one second after one of the 11 detonations, but for the remainder of the time they were feeding or bedded (Russell 1977). Similarly, no overt response was detected when barren-ground caribou were exposed to a mine blast at more

than 500 m, which was audible to observers (Grindal 1998). Reindeer on Richards Island were observed to run 30 to 50 m and then resume feeding, following a dynamite blast at a distance of 4 km in the winter (Slaney 1974).

Anecdotal information suggests that the audible noise (hum) of power lines, which varies considerably with weather conditions (Lee and Griffith 1978), disturbs reindeer and contributes to difficulties in herding in Scandinavia (Klein 1971). Also, it is believed that reindeer quickly learn to associate the sound of power saws with the availability of arboreal lichens, and, as a result, reindeer congregate in cutting areas in Scandinavia (Klein 1971).

Studies of the effects of noise on muskoxen have focused on helicopter overflights and landings, and results indicate that these activities elicit a range of responses (see Table 2-2). However, as discussed in Section 1, it is not clear what elements (noise or visual) of overflights cause these responses.

McLaren and Green (1985) found that the distance at which the first muskoxen reacted to a snowmobile was strongly negatively correlated with wind speed during the calving season. This, and the fact that on calm days muskoxen were alerted to the snowmobile at distances of over 1 km, even when it was not moving towards them, suggests that they responded to the sound of the machine, in addition to its sight and smell. Muskoxen were also seen to react to the start-up of the snowmobile engine when it was 950 to 1,000 m away, and to the acceleration of the vehicle (McLaren and Green 1985).

Other indirect evidence for the effects of noise on caribou may be inferred from related ungulate species, such as muskoxen. For example, on Melville Island, muskoxen were found to respond to the sound of a helicopter that was more than 1 km away and not visible (McLaren 1981). The herd remained alert and in a compact formation for about one minute after the helicopter's departure, and then resumed grazing (McLaren 1981).

Muskoxen on Banks Island reacted to the initial 'snort' of exhaust made by nodwells as they started moving or when they were working hard, e.g., turning or drilling. The sound of the exhaust from nodwells carries for a greater distance than any other noise created by seismic activity. It was audible to humans up to 4.8 km away (Russell 1977). One herd apparently galloped off when such a sound was generated 800 m away, and another herd got up from resting and grouped in response to a machine snort about 400 m away (Russell 1977). In some cases, however, animals showed no reaction to this noise (Russell 1977).

On a calm day, Gray (1972) observed a Bathurst Island herd, feeding 1.6 m from camp, that reacted to the sound of sawing plywood by running several kilometres. However, seismic blasts at a distance of about 6.5 km from another herd resulted in no noticeable response (Gray 1972). In Russell's study area, a herd less than 3.2 km from a seismic detonation had no apparent reaction, but the local topography possibly prevented them from hearing it (Russell 1977).

Some muskoxen herds on Bathurst Island were easily induced into stampeding by the buzzing or circling of helicopters and fixed-wing aircraft (Gray 1972). Herds

will often stand in a tight group when an aircraft is overhead, but in many cases, will run as the aircraft approaches (Gray 1972). At such times, the herd might split up, and individuals might stumble or flounder and fall behind with possible subsequent harmful effects on weaker members of the herd (Gray 1972). McLaren (1981) found that Melville Island animals showed no visible reaction to aircraft that flew by or flew overhead at altitudes greater than 200 m (McLaren 1981). Female muskoxen have been found to be more wary of snowmobiles than males or young (McLaren and Green 1985).

The response to the noise of seismic exploration appears to differ from herd to herd, perhaps because of each herd's previous experience. Some muskoxen seem unaffected by seismic activities as close as 300 m, while others appear disturbed by activity 10 times more distant (Winters and Shideler 1990 cited in NRC 2003). Overall, evidence for muskoxen habituation to motorized activities, such as snowmobiles and helicopters, is inconclusive (McLaren and Green 1985), and responses appear to vary among herds (Miller and Gunn 1980, Miller and Gunn 1984, McLaren and Green 1985).

2.1.3 Hearing Characteristics

Reactions were observed for barren-ground caribou to sounds ranging from 46 to 127 dBA (Maier et al. 1998). However, hearing characteristics have not been ascertained specifically for barren-ground caribou, but there is some information on a member of the same species – the reindeer ecotype. Flydal et al. (2001) found that two yearling male reindeer detected sounds at intensities of 60 dB or less from 70 Hz to 38 kHz. The frequency range of best sensitivity was relatively flat, from 1 kHz to 16 kHz, with a best sensitivity of 3 dB at 8 kHz (Flydal et al. 2001). The hearing ability of reindeer has been found to be similar to white-tailed deer (*Odocoileus virginianus*) and domestic ungulates, such as sheep (Risenhoover et al. 2005).

2.2 Woodland Caribou

2.2.1 Direct Effects of Noise

Woodland caribou studies have focused on jet overflights, and results indicate that these elicit a range of responses (see Table 2-3). However, as discussed in Section 1, it is often not clear what elements (noise or visual) of overflights cause these responses. Harrington and Veitch (1990) suggest that caribou responded earlier when they could see a jet approaching. Beyond 150 m, the sound of the jet was less than 90 dB. However, on windy days, caribou in the trees usually had little or no advance warning of overpass, which enhanced the startle effect (Harrington and Veitch 1990).

Table 2-1: Summary of Direct Evidence for the Effects of Noise on Barren-Ground Caribou

Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference
Simulation of turbine gas compressor ¹	Unknown; multiple times over study period.	'Met specifications', decreased to ambient levels within less than 800 m in front of compressor	None ²	Seven groups during test conditions (including a single group of 5000) (total = 18); no individual observations	Chute Pass (Rat River crossing), Richardson Mtns (Porcupine herd)	Spring migration: Apr 8-May 2, 1972	McCourt et al. 1974
Simulation of turbine gas compressor	Unknown; multiple times over study period.	Single day (in front of simulator): 90-92 dB at 90 m; 76-82 dB at 180 m; 45-47 dB at 650 m	Test groups exhibited higher frequency of alert postures during 'initial reaction'; fewer test groups (2%) came within 135 m of the simulator than control groups (27.4%); behaviour did not vary significantly between test and control individuals	106 groups during test conditions (total = 179); 366 individuals observed during test conditions (total = 637)	Old Crow Range (Porcupine River crossing near Old Crow) (Porcupine herd)	Spring migration: May 17-31, 1972	McCourt et al. 1974
Simulation of turbine gas compressor	Unknown; multiple times over study period.	Single day (in front of simulator): 88-92 dB at 90 m; 78-90 dB at 180 m; 60-71 dB at 640 m; Single day: ambient ranged from 50-64 dB	Proportion of individuals observed < 200 m from simulator was significantly lower and exhibited a significantly greater frequency of changes in activity during the test period	No group observations; 449 individuals observed during test conditions (total = 604) ³	Jago River, Brooks Range, Alaskan North Slope (Porcupine herd)	Calving: Jun 9-19, 1972	McCourt et al. 1974
Simulation of turbine gas compressor	3 hours (14:30-17:30)	Not recorded; high and variable wind conditions; beyond 275 m the ambient noise level likely masked the sound of the simulator.	General pattern of movement unaffected. However, groups passing within 275 m of simulator showed deflection and alert posture, those passing within 90 m advanced at an increased pace. Note that visual disturbance cannot be ruled out in this case. ⁴	15,000 individuals passed during test period (total > 20,000), evaluated as a herd; no individual observations	Bell River, headwaters, northern Richardson Mtns (Porcupine herd)	Summer: Jul 24, 1972	McCourt et al. 1974

Table 2-1: Summary of Direct Evidence for the Effects of Noise on Barren-Ground Caribou (cont'd)

Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference
Simulation of turbine gas compressor	Unknown; multiple times over study period.	Single day (in front of simulator): 78-85 dB at 90 m; 61-63 dB at 180 m; 53 dB at 800 m; Single day: ambient 53 dB	Evidence suggests that groups were deterred from approaching simulator closer than 800 m during test period; this result may be a statistical artifact because of small sample size.	12 groups observed during test period (total = 17). ⁵ No individual observations.	Schaeffer Mt., overlooking Old Crow Flats (Porcupine herd)	Fall migration: Sep 22-26, 1972	McCourt et al. 1974
Aircraft overflights (fixed wing and rotary)	Not specified	< 90 to > 300 diagonal metres	Flying at < 90 diagonal metres elicited a strong response from 13-56% of groups observed (depending on season), at 90-182 diagonal metres there was a strong response from 1-14% of groups observed; most 'reactive' season was post-calving, least 'reactive' season was summer (movement).	4134 observations, 238 groups	Yukon and NE Alaska (Porcupine herd)	All seasons, 1972-1973	McCourt and Horstman 1974
Aircraft overflights (fixed wing and rotary)	Not specified	Altitude: < 30 m to >150 m	Pronounced increase in panic and strong escape responses when aircraft flew lower than 60 m; 30-65% of groups still exhibited some type of escape response for altitudes up to 150 m.	736 groups	Yukon, NE Alaska, and northwestern NWT (Porcupine herd)	Spring, fall, early winter, 1972-73	Calef et al. 1976
Helicopter overflights and landings	Not specified	Overflights: altitude < 400 m	Overflights: 64% responded overtly; 12.1% still responding after completion of overflight. Landings: 28.7% responded at extreme level.	671 overflights, 3939 'response samples'; 116 landings, 736 'response samples'	Prince of Wales and Russell islands	Summer, 1976-1977	Miller and Gunn 1979

Table 2-1: Summary of Direct Evidence for the Effects of Noise on Barren-Ground Caribou (cont'd)

Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference
Helicopter (to simulate cargo slinging)	Not specified	Altitude: 200 - 400 m	Play was more frequent during the harassed phase, less frequent during the undisturbed phase, and occurred slightly less than expected during the recovery phase. Calves that played during harassment did not exhibit any form of alarm or escape behaviour.	93 play bouts observed on 20 occasions (12 occasions were during harassment).	Prince of Wales Island (northeastern).	June-August, 1977	Miller and Gunn 1981
Helicopter landings (with overflight)	Not specified	Passed over caribou at altitude of 300 m and landed 300 - 2200 m away.	Caribou in 13 of 16 groups moved at 1 - 3 km away from landings. No significant differences, but a greater proportion of cows and calves walked, trotted, or galloped during post-disturbance than pre-disturbance periods, responses of calves were more marked than those of adults.	16 groups, 16 landings	Beverly herd calving grounds, Nunavut	Calving and post-calving seasons (June), 1982	Gunn et al. 1983
Light fixed-wing aircraft overflights	Not specified	Not specified but altitude was 'low enough in most cases to identify visual collars'	Western Arctic caribou herd were found to react less to aircraft overflights over time	Western Arctic herd n=153 passes.	Delta herd from the Central Alaska Range; Western Arctic herd from northwestern Alaska.	Winter, 1979-1983	Valkenburg and Davis 1985
Jet overflights	Not specified ⁶	Altitude 25 - 50 m ⁷	Strong startle response but otherwise short-lived reaction. Ran or walked for < 5 s and moved 10 - 15 m; those directly under an overflight ran 3 times farther on average than those 50 m or more away.	13 overflights	Labrador and northern Quebec (George River herd)	May (2 days), 1988	Harrington and Veitch 1990

Table 2-1: Summary of Direct Evidence for the Effects of Noise on Barren-Ground Caribou (cont'd)

Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference
Jet overflights	Unknown	Overflight was considered to be within 1 km of 'target'; avoidance was considered to be at least 9.2 km	An animal's exposure to overflights was not related to its subsequent use or abandonment of its core areas.	11 collared individuals	Labrador and northern Quebec (George River herd)	1986-1988	Harrington and Veitch 1990
Jet overflights	Not specified	Maximum L_{EQ} was 98.7 dBA	78% showed no overt response to the overflights.	107 overflights (811 reactions recorded)	Central Alaska Range (Delta herd)	April	Murphy et al. 1991
Jet overflights	Not specified	Mean = 98 dBA; range 46-127 dBA	Mild response in late winter; intermediate response in insect season; strongest response during post-calving season; females with calves were most sensitive	159 overflights	Central Alaska Range (Delta herd)	Post-calving; insect; late winter	Maier et al. 1998

Note:

1. Sound output of all speakers combined was 107.5 dB at 4.5 m from source.
2. Simulator noise levels at the point at which caribou crossed valley did not exceed ambient noise levels. However, humans could apparently distinguish the noise of the simulator from that of the wind because of its different frequency. The authors suggest that 'there is no reason to assume that caribou do not have a similar ability', but there is, in fact, no evidence to this effect.
3. Predominantly cows and calves.
4. At this site, individuals were observed to 'retreat' when they came into visual contact with the simulator (and observers) during the control period.
5. Some groups were observed during both the test and control periods.
6. Typically, noise level increased rapidly as jet approached – from ambient to maximum in 1 s, and then dropped immediately after jet passed, returning to ambient in 10 s.
7. Mean altitude 47 m. Mean noise level for direct overflight at 30 m was 115 dB(C).

Table 2-2: Summary of Indirect Evidence for Noise Effects on Muskoxen (Ungulates Other than Caribou)

Species	Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference
Muskoxen	Helicopter overflights and landings	Not specified	Altitude: < 400 m	Overflights: 43.6% responded overtly, 21% were still responding after completion of overflight. Landings: 12.3% responded at extreme level.	315 overflights, 4011 'response samples'; 69 landings, 1192 'response samples'	Prince of Wales and Russell islands	Summer 1976-77	Miller and Gunn 1979
Muskoxen	Helicopter overflights (simulated cargo slinging)		Altitudes ranged from 180 m to 400 m agl.	Consistent variation in level of response among the three herds, but indication that some degree of habituation had occurred; no evidence that helicopter disturbances caused any injuries, herd splintering, or range abandonment.	3 herds	Prince of Wales Island		Miller and Gunn 1980
Muskoxen	Helicopter overflights	'Several minutes'	Variable: overflights were < 100 kph and 100 - 400 m in altitude	74.7% of individuals came together in herd defense formations	111 'occasions'; ¹ 1,815 individual behavioural observations from 13 herds	Northeastern Prince of Wales Island	Summer: Jun-Aug, 1976-1977	Miller and Gunn 1984
Muskoxen	Helicopter overflights		Altitudes of 240 - 400 m	Nursing bouts observed: 63% under undisturbed conditions, 25% during post overflight periods, and 12% during overflights; younger calves nursed longer and more often than older calves, and made more nursing bouts during overflights; calves move closer to cows during overflights, and then take the opportunity to nurse.	15 muskox calves. Observations were made during 71 undisturbed periods, 29 overflight phases, and 34 recovery periods.	Prince of Wales Island	Summer	Miller et al. 1988

Note:

- Overflights of herd were either a single pass or a series of five or more passes. It is unclear from text whether this number includes all passes or only each instance of helicopter harassment regardless of number of passes.

Woodland caribou ran longer and farther in response to helicopter overflights than to jet overflights (Harrington and Veitch 1990). Bradshaw (1994) found that disturbed caribou travelled on average 2.11 km farther than control animals during and immediately following a single disturbance event for about 15 minutes. Bradshaw et al. (1997) suggest that increased movement of caribou disturbed by simulated seismic testing might result in higher energy expenditure during winter. They also suggest that disturbed caribou might switch habitat type to those types with better cover.

Modelling the cumulative influence of disturbances demonstrates an effect on individual energy loss during winter at certain exploration intensities (Bradshaw et al. 1998). Because a single encounter with disturbance, i.e., loud noise, is unlikely to cause harmful energy consumption, the significance of exposure to disturbance should be proportional to the number of times an animal encounters disturbance events (Gilliam and Lent 1982, Bradshaw et al. 1998). Harrington and Veitch (1992) speculate that the impacts of predation and disturbance from low-level jet activity might be preventing the recovery of the Red Wine Mountain population, despite many years of protection from hunting.

2.2.2 Indirect Effects of Noise

Simpson (1987) found that sound stimulus had a greater disturbance impact on woodland caribou than visual stimulus. Avoidance of roads, seismic lines and oil and gas well sites in northeastern Alberta was positively correlated with the level of human activity. It was highest during late winter and calving seasons, and lowest during summer, possibly because of lower traffic levels during that season (Dyer et al. 2001).

Woodland caribou tend to avoid roads, seismic lines and pipeline rights-of-way (Jalkotzy et al. 1997, James and Stuart-Smith 2000, Dyer et al. 2002). However, considerable individual variation has been documented (James and Stuart-Smith 2000). Roads with moderate vehicle traffic acted as semipermeable barriers to woodland caribou movements (Dyer et al. 2002). The greatest barrier effects were evident during late winter, when caribou crossed roads six times less frequently than simulated (GIS) road networks (Dyer et al. 2002).

Before 1996, 45% of the range of the Labrador Red Wine Mountains woodland caribou herd was exposed to overflights (Jung and Jones 2001). In 1996, the entire range was exposed to subsonic low-level overflights (Jung and Jones 2001). This greater exposure to low-level jet overflights negatively affected late summer site fidelity. However, expansion of the overflight zone had no effect on home range size, movement rates, distance travelled, path tortuosity or year-round site fidelity (Jung and Jones 2001). Jung and Jones (2001) note that their study addresses only indirect impacts and suggest that the direct impacts of disturbance need to be examined.

Table 2-3: Summary of Direct Evidence for the Effect of Noise on Woodland Caribou

Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference
Simulation of seismic exploration (blasting phase) ¹	Cannon fired every 1-2 min for one hr	90-110 dB (2 m from cannon mouth); distance from cannon to animal averaged 331 m.	Disturbed caribou moved significantly faster and crossed habitat boundaries (i.e., habitat patch changes) significantly more often than control caribou.	Five caribou in 1993; 20 caribou in 1994	Northeastern Alberta	Mar 1993, Jan-Mar, 1994	Bradshaw et al. 1997
Jet overflights	Not specified ²	Altitude 30-300+ m. Mean altitude 47 m; mean noise level for direct overflight at 30 m was 115 dB(C).	Strong startle response but otherwise short-lived reaction. Ran an average of 7 seconds and moved 12-16 m in response to direct overflight. No difference according to group composition.	Five targets, five controls	Labrador and northern Quebec	Apr-May (4 days), 1987-88	Harrington and Veitch 1990
Jet overflights	Unknown	Overflight was considered to be within 1 km of 'target'; avoidance was considered to be at least 9.2 km.	Level of exposure did not significantly affect daily activity level, daily distance travelled or habitat use patterns. No range abandonment was observed. See Harrington and Veitch (1992) regarding calf survival.	18 test individuals, four control individuals monitored by satellite telemetry; overflights/day mean of 4.5	Labrador and northern Quebec	1986-1988	Harrington and Veitch 1990
Jet overflights	Unknown	Overflight was considered to be within 1 km of 'target'; avoidance was considered to be at least 9.2 km.	Calf survival was negatively correlated with exposure to overflights during calving, early post-calving and during insect harassment in the summer.	Calves of 15 radio-collared females	Labrador and northern Quebec	1986-1988	Harrington and Veitch 1992
<p>Note:</p> <ol style="list-style-type: none"> 1. Sound created with a propane cannon. 2. Typically, noise level increased rapidly as jet approached – from ambient to maximum in 1 second, and then dropped immediately after jet passed, returning to ambient in 10 seconds. 							

Some disturbance response information available for barren-ground caribou might be applicable to woodland caribou (see Section 2.1). However, the smaller herd size and more cover habitat available to the woodland caribou might mean that they are less reactive to some disturbances, such as overflights, than barren-ground caribou (Eccles et al. 1991).

2.2.3 Hearing Characteristics

Harrington and Veitch (1990) suggest that woodland caribou can detect sounds greater than 90 dB. As described for barren-ground caribou (see Section 2.1), reindeer detected sounds at intensities of 60 dB or less from 70 Hz to 38 kHz, and the frequency range of best sensitivity was relatively flat, from 1 kHz to 16 kHz, with a best sensitivity of 3 dB at 8 kHz (Flydal et al. 2001).

2.3 Moose

2.3.1 Direct Effects of Noise

There is limited direct evidence for the effects of noise on moose. McCourt et al. (1974) recorded the response of moose in the Richardson Mountains to fixed-wing aircraft overflights on 46 occasions during 1972. Moose reacted visibly to aircraft overflights 55% of the time when the overflight was at less than 60 m of altitude, and 37.5% of the time when overflights were at altitudes between 60 and 180 m. Moose were not seen to react to any overflights above 180 m of altitude. Moose are considered much less sensitive to noise impacts than caribou (Klein 1973).

2.3.2 Indirect Effects of Noise

Moose are known to avoid roads, pipelines and seismic lines (Horesji 1979, Rolley and Keith 1980, Morgantini 1984, Rudd and Irwin 1985, Singer and Beattie 1986, Jalkotzy et al. 1997). In central Alberta, moose were located farther from roads than expected, from November to January, and they avoided well-travelled roads about one-third more often than less-travelled roads (Rolley and Keith 1980). Horesji (1979) also reported that moose were less likely to be found within 1 km of seismic lines while seismic operations were underway.

Military disturbance in central Norway had some effect on moose movement in early fall. The disturbance included humans on foot, all-terrain vehicles, tanks, self-propelled cannons, helicopters and jet fighters. Home range size for moose increased during active manoeuvres, but no collared individuals abandoned the area (Andersen et al. 1996). Andersen et al. (1996) caution that the same level of disturbance in the winter or during calving could have more detrimental effects.

Andersen et al. (1996) found that sources of disturbance that could be identified as human, such as skiers, elicited flight responses at greater distances and elevated heart rates for longer periods than disturbances that were recognized as mechanical, such as snowscooters. The noise of a jet flying at an altitude of 150 m did not trigger any flight response or increase in heart rate in a moose, while people on foot or skis flushed moose at 200 to 400 m (Andersen et al. 1996).

Andersen et al. (1996) attribute this difference to past experience, as most moose hunting in Norway has been by hunters on foot rather than from motorized vehicles. Of the mechanical stimuli examined, including a tracked all-terrain vehicle, a snowscooter, a four-wheel motorcycle, a helicopter, a military jet and cannon fire, helicopter overflights produced a substantial increase in heart rate, in conjunction with a flight response (Andersen et al. 1996).

A few studies have been specifically attempted to examine the direct effects of noise on other cervids. For example, Kuck et al. (1985) found that elk calves in southeast Idaho that were exposed to recorded mine noises (about 100 dB(A) at a range of 3 m) consistently moved farther, made greater elevation changes and used larger areas than undisturbed calves. Although effects of mine noise were greater in response to human disturbance than the simulated mine noises, two cow and calf pairs left the study area in apparent response to the simulated noises (Kuck et al. 1985). There were no differences in calf survival rates between disturbed and undisturbed animals (Kuck et al. 1985). There was no data to suggest that elk became habituated to mine noises during the study (Kuck et al. 1985). In another example, Weisenberger et al. (1996) found that the heart rates of captive desert mule deer (*Odocoileus hemionus crooki*) increased during simulated low-level jet overflights, returning to pre-disturbance levels in 60 to 180 seconds. Behaviour also changed during disturbance, but returned to pre-disturbance patterns in less than 252 seconds. The maximum sound level of the simulations ranged from 92.5 to 112.2 dB. Individuals responded more (greater heart rate) to the higher sound levels.

2.3.3 Hearing Characteristics

No information was found on hearing in moose. Audiograms determined for another cervid, the white-tailed deer, indicated that their range of greatest hearing sensitivity was between 1 and 8 kHz, with a marked peak centered at 4 kHz (Risenhoover et al. n.d.).

3 Bear

3.1 Grizzly Bear

3.1.1 Direct Effects of Noise

There is little direct evidence for the effects of noise on grizzly bears (see Table 3-1). However, information available for polar bears might be applicable (see Section 3.2). Grizzly bears in British Columbia (BC) were found to have 78 to 80% avoidance of logging areas with noise levels ranging from 60 to 106 dB(C) (Archibald et al. 1987). Denning grizzly bears were found to increase their heart rates from 12 to 26 beats/min to 64 beats/min when disturbed by seismic activities (Reynolds et al. 1986).

3.1.2 Indirect Effects of Noise

The focus of most grizzly bear disturbance research has been related to seismic activities and aircraft overflights. Many findings indicate that grizzly bears are highly responsive to aircraft overflights (e.g., Shank 1979, Kucera 1974, McCourt et al. 1974, Quimby 1974, Harding and Nagy 1980, Reynolds et al. 1986, IGBC 1987). Grizzly bears are also known to avoid areas or to alter their behaviour, e.g., increase nocturnal activity, in response to the presence of roads, seismic blasting and other industrial activities (Harding and Nagy 1980, Archibald et al. 1987, McLellan and Shackleton 1988, Mace et al. 1996, Mueller 2001, Gibeau et al. 2002, Wielgus et al. 2002). For example, barren-ground grizzly bears showed active avoidance responses and disrupted foraging activity up to 4 km from industrial developments (Harding and Nagy 1980). On Richards Island, oil and gas development activities resulted in a loss of habitat for grizzly bears, because they avoided drilling and staging camps (by at least 1 km), and abandoned denning areas because of disturbances around those sites (Harding and Nagy 1978). It is often difficult to distinguish between disturbance effects from air traffic and construction activity. For example, following intensive drilling and constant helicopter work within 100 m of a bedded female, seven minutes of seismic activity prompted her to leave the drainage area (McLellan and Shackleton 1989b).

However, responses appear to be strongly dependent on the bears' previous experience with overflights, e.g., aerial capture history. For example, grizzly bears captured using ground-based techniques did not react to overflights (McLellan and Shackleton 1989a, 1989b). In study areas where many bears are not radio-collared, the most reactive individuals might be more noticeable during overflights (McLellan and Shackleton 1989a). Again, as discussed in Section 1, it is not clear which elements of overflights cause these responses, i.e., sound and sight. The generally moderate response of collared bears to industrial activity and helicopter overflights in southeastern BC might be a function of habituation (McLellan and Shackleton 1989b).

McLellan and Shackleton (1998) found that avoidance of roads was independent of traffic volume in southeastern BC, suggesting that even a few vehicles can

displace bears. Mueller (2001) found that bears were significantly closer to high-use roads and at lower elevations during human inactive periods (6 p.m. to 7 a.m.) than during human active periods (7 a.m. to 6 p.m.). Other factors, aside from traffic noise, might cause bears to avoid roads. For example, every grizzly bear mortality in Banff and Yoho National Parks from 1971 to 1998 occurred within 500 m of a high-use motorized road and within 200 m of a non-motorized trail (Benn and Herrero 2002). Grizzly bears might also be distributed differently in relation to roads, depending on sex and age class (Mueller 2001, Wielgus et al. 2002), although this might be unrelated to noise, e.g., avoidance of adult males. (McLellan and Shackleton 1988). Females with young might be particularly susceptible to disturbance (IGBC 1987, Linnell et al. 2000, Gibeau et al. 2002).

Helicopter overflights might be a significant problem during den entrance (fall) and exit (spring) periods, when bears are in relatively exposed habitats (Quimby 1974). Bears that occur in open tundra habitats in the north might be more sensitive to disturbances than bears occupying forested habitats (McLellan 1990, McLoughlin and Messier 2001, cited in McLoughlin 2001).

Aversive conditioning is commonly used to prevent grizzly bears from becoming habituated in areas of high human use (Miller 1983, Benn and Herrero 2002). Also, as a result of their tendency to habituate to noise disturbance, acoustic deterrent devices have limited efficacy on grizzly bears, unless used in conjunction with visual or consequential cues, and responses can be short-lived (Miller 1983, Augustyn 2001). It is well known that bears can become habituated to human developments if there are energetic benefits, such as camp garbage dumps, and that this occurs despite associated noise and other potentially disturbing activities (Follmann and Hechtel 1990). For example, a subadult male black bear spent several nights under a trailer 20 m from an active drilling platform (the noise level was 99 dB 2 m from the platform), likely because of the small garbage dump located 50 m from the platform (Tietje and Ruff 1983).

Disturbance from human activities can result in den abandonment (Quimby 1974 [helicopter], Harding and Nagy 1980 [seismic vehicle, gravel mining operations], Swenson et al. 1997 [non-motorized human activity]). Den abandonment might then lead to increased cub mortality (Swenson et al. 1997, Linnell et al. 2000), with its subsequent ramifications for overall population viability. Linnell et al. (2000) found that grizzly bears generally select den sites 1 to 2 km from human activity, such as roads and industrial activity. Activity closer than 1 km, and especially within 200 m of a den, caused variable responses, including abandonment (Linnell et al. 2000). Response to denning disturbance might be influenced by many factors, including habituation and age and sex class.

No systematic data is available on how denning bears react to disturbance using controlled acoustic stimuli (Linnell et al. 2000). Reynolds et al. (1986) reported movement and increased heart rates for denned grizzly bears in the vicinity of seismic activities. However, they also observed that similar movements and heart rate patterns sometimes occurred in the absence of human activities, and they concluded that effects on bears were probably minimal (Reynolds et al. 1986).

Table 3-1: Summary of Evidence for Noise Effects on Grizzly Bears

Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference
Fixed-wing aircraft overflights	Not specified	Various altitude over animal (from less than 60 m to more than 300 m)	No trend related to altitude was apparent. Proportion of mild reactions ranged from 60 to 81% (highest proportion at 60.3 m to 180 m); proportion of strong reactions ranged from 7-20% (highest proportion at more than 180 m).	71 observations	Richardson Mtns	Spring, summer, fall: Mar-Oct, 1972	McCourt et al. 1974
Off-road logging trucks	Average number of trucks per day ranged from 10-14, average time between trucks ranged from 30-35 minutes	Noise levels within the 600 m wide Zone of Hauling Activity (ZHA) ranged from 60 to >80 dB{C}, additional measures: 95-106 dB(C) beside truck, 59-67 dB(C) at 100 m	78% reduction in ZHA locations during years with active logging; within those years – 80% reduction in ZHA locations during hauling versus no hauling periods.	2 radio-collared females	Kimsquit R., mid-coast B.C.	Apr-Oct, 1982-1985	Archibald et al. 1987
Seismic crew activities ¹	Not specified	0.8 to 2.4 km from den	Denning grizzly bears were found to increase their heart rates from 12-26 beats/min to 64 beats/min when disturbed by seismic activities.		Northwestern Alaska	Winter, 1980-81	Reynolds et al. 1986
Human activities ²	Not specified	< 76 m to 500+ m	Of the five stimuli, the strongest reactions were to people on foot; bears responded more strongly to fixed-wing aircraft at <150 m than to those farther away ³ , regardless of cover; bears reacted more strongly to ground-based activities (e.g., people on foot or moving vehicles), when in the open.	165 interactions, 29 radio-collared bears	North Fork of Flathead R (southeastern BC and adjacent Montana)	1979-1986	McLellan and Shackleton 1989a
Seismic crew activities ⁴		Zone 1: 500 m on either side of a seismic line. Zone 2: 501-2000 m on either side of a seismic line.	Two of eleven bears showed changes in behaviour.	Looked at seismic lines crossing a high quality habitat (berry patch) – active	North Fork of Flathead R (southeastern BC and adjacent Montana)	Summer	McLellan and Shackleton 1989b

Note:

1. Includes vehicle activity (e.g., snow machines), track-mounted drills and seismic detonations.
2. Includes people on foot (next to or away from a parked vehicle), moving vehicles, heavy industrial equipment, fixed-wing aircraft, and helicopters.
3. No significant difference for helicopters.
4. Includes helicopters, drilling, setting charges, stringing and collecting sensing cable, and blasting.

The results of a study on the noise levels in polar bears' artificial dens by Blix and Lentfer (1992) would apply to grizzly bears denning in the region (see Section 3.2).

3.1.3 Hearing Characteristics

There is no information available on the hearing of grizzly bears. However, rudimentary data obtained for polar bears might be applicable (see Section 3.2). All four carnivore species for which audiograms are available, i.e. least weasel, northern quoll, harbour seal, and domestic cat, lie within the 1 to 16 kHz for their range of best sensitivity (Heffner and Heffner 1985). However, none of these species are North American ursids, i.e., American black bear (*Ursus americanus*), grizzly bear (*Ursus arctos*) and polar bear (*Ursus maritimus*).

3.2 Polar Bear

3.2.1 Direct Effects of Noise

There is only limited direct evidence for the effects of noise on polar bears (see Table 3-2). Two particularly relevant studies focused on denned females, and found that they appeared to be relatively tolerant of noise disturbance (Blix and Lentfer 1992, Amstrup 1993). Two possible den abandonments related to human activities were recorded. However, 22 bears not exposed to human disturbances also abandoned their dens (Amstrup 1993).

Blix and Lentfer (1992) concluded that the dry and wind-beaten arctic snow muffles both sound and vibrations extremely well, and it seems unlikely that polar bears in their dens would be disturbed by the type of industrial activities measured at Prudhoe Bay, providing those activities do not take place within 100 m of the den. However, they did not address the formation of ice and the increasing density of snow that occurs when a den is occupied all winter, and which would reduce the insulation quality of the snow (Amstrup 1993). Blix and Lentfer (1992) observed that only seismic testing less than 100 m from a den and a helicopter taking off 3 m away produced noises inside dens that were notably (10 to 15 dB) above background levels. They also established that a polar bear in its den would normally and quite naturally experience considerable variation in noise levels, caused to a large extent by the wind (Blix and Lentfer 1992).

Polar bears were deterred by continuous and pulsed tones in the 1 to 2 kHz range. The perception was that the aversive response was more pronounced with the use of the pulsed mode (Compuheat 1986). The test bears might have previously visited the test site, and were likely aware of human presence during the trial (Compuheat 1986).

3.2.2 Indirect Effects of Noise

The extent to which industrial development may affect the habitat of the polar bear is not well known (Stirling and Taylor 1999), and interactions of denned polar bears and industrial activities have seldom been reported (Amstrup 1993, Linnell et al. 2000).

Polar bears are not as sensitive to disturbance as once thought (Amstrup 2000). Linnell et al. (2000) suggest that this might be because of the acoustic insulation of a snow den, compared with the excavated dens of other bear species. However, increasing human activity associated with oil and gas exploration and development could adversely affect denning (Lentfer and Hensel 1980, Stirling and Taylor 1999, Linnell et al. 2000).

Females with cubs have abandoned their dens as a result of seismic exploration activity in the vicinity (Moore and Quimby 1975). Pregnant females or females with young might die if they are disturbed and abandon a den in mid-winter. However, when disturbed in the early part of the denning season, they were more likely to be displaced by disturbance when compared to later in the denning season (Linnell et al. 2000). Earlier in the denning season, before the birth of cubs, there might be less risk associated with abandoning their den (Amstrup 1993). As was true for the grizzly bear, polar bears generally select den sites 1 to 2 km from human activity, and activities closer than 1 km and especially within 250 m of a den caused variable responses, including abandonment (Linnell et al. 2000).

Polar bears often run from aircraft overflights at low altitudes (less than 200 m) and short diagonal distances (less than 400 m), but they appear to have no or very limited reactions to shipping activity, including ice-breaking (Richardson et al. 1995).

3.2.3 Hearing Characteristics

Compuheat (1986) found that most polar bears were sensitive to 0.1 to 9 kHz, with most individuals reacting most strongly to the 1-4 kHz range. No bears reacted to ultrasonic stimuli, and there was also no apparent reaction to frequencies immediately below the ultrasonic band (10 to 20 kHz) (Compuheat 1986).

Table 3-2: Summary of Evidence for Noise Effects on Polar Bears

Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference
Broadcast tone	15 seconds	1-2 kHz, continuous mode, pulse mode	All bears exhibited strong aversive reaction	19 tests	Cape Churchill, MB	Winter, Nov 8-9, 1984	Compuheat 1986
Vibroiseis model vibrator vehicle ¹	5 seconds, every 20 seconds	Above ground 3 m from disturbance was 85-90 dB in intervals between vibrations, with a maximum value of 103 dB during vibrations.	Noise measured in the den was 24-42 dB at 530 m, 40-50 dB at 100 m, 58-70 db at 65 m, 78 dB at 18 m	Two artificial dens	Prudhoe Bay, Alaska	Winter	Blix and Lentfer 1992
Drilling tower – drilling rig.	Not applicable	36-42 dB	30 m away during active drilling and changing of shaft 36-42 dB	2 artificial dens	Prudhoe Bay, Alaska	Winter	Blix and Lentfer 1992
Helicopter take-off	Not applicable	Above ground at 3 m from helicopter was 114-116 dB.	Noise measured in the den was 77 dB Den covered by less than 1 m of snow only 3 m away.	2 artificial dens	Prudhoe Bay, Alaska	Winter	Blix and Lentfer 1992
Large vehicle traffic	Not applicable	Large vehicles (80 tons loaded) 30-40 km/h.	Noise measured in the den was 0-15 dB at 700 m, 10-20 dB at 530 m, 15-20 dB at 100 m, and 26-30 dB at 65 m.	2 artificial dens	Prudhoe Bay, Alaska	Winter	Blix and Lentfer 1992
Aircraft overflights	Not specified	Greater than usual levels of aircraft disturbance	Motions detectable among collared bears within dens did not appear elevated during telemetry flights. Responses of four denned bears during this study were mixed.	Recorded 40 cases of potential disruptions of denning by research aircraft.	Beaufort Sea	1981 to 1991	Amstrup 1993
Aircraft overflights, snow vehicles	Repetitive	Low level flights less than 550 m	10 of 12 denned bears tolerated exposure to exceptional levels of activity		Beaufort Sea	1981 to 1991	Amstrup 1993
<p>Note:</p> <p>1. In this case, the steel plate hammers the ground at a frequency of 20 to 30 Hz for 5 seconds, every 20 seconds (with vehicle advancing 15 m each time) (Blix and Lentfer 1992).</p>							

4 Lynx, Marten and Beaver

4.1 Lynx

4.1.1 Direct Effects of Noise

No direct evidence related to the effects of noise on lynx was available.

4.1.2 Indirect Effects of Noise

There is some evidence that roads might influence lynx distribution and movements (Palme et al. 1999; Clayton 2000), but there is also evidence that lynx will cross highways (Mowat et al. 2000). Lynx occasionally hunt or travel along seismic lines (Riewe 1980), and have been reported to follow road edges and forest trails for considerable distances (Parker 1981). In northern Canada and Alaska, anecdotal evidence suggests that lynx will tolerate moderate levels of snowmobile traffic within their home ranges (Mowat et al. 2000). In western Alberta, lynx frequently crossed a pipeline right-of-way before construction began, but almost completely avoided the area during the construction period (Morgantini 1984).

4.1.3 Hearing Characteristics

No information was found on hearing in lynx. The known range of best sensitivity for carnivores is 1 to 16 kHz, with the domestic cat's hearing the highest (Heffner and Heffner 1985). The domestic cat's overall hearing range is shifted higher than the least weasel's hearing range (see Section 4.2.3 and Heffner and Heffner 1985).

4.2 Marten

4.2.1 Direct Effects of Noise

No direct evidence related to the effects of noise on marten is available.

4.2.2 Indirect Effects of Noise

Marten are known to be sensitive to human disturbances, such as clearcut logging (Stevenson and Major 1982; Hargis et al. 1999; Potvin et al. 1999; Forsey and Baggs 2001), but they might be able to adapt to less intense disturbances, such as selective logging (Koehler et al. 1975; Soutière 1979). Marten response to linear developments varies, but there is some evidence that crossings are generally avoided or attempted unsuccessfully (Eccles and Duncan 1986; Jalkotzy et al. 1997; Robitaille and Aubry 1999).

Another mustelid, wolverine, appears to avoid areas of human activity, although wolverines have been observed feeding in garbage dumps, and are known to occur in logged areas and in habitats where seismic lines are common (Banci 1994). Major access routes can act as dispersal barriers to wolverines (Kyle and Strobeck 2001), but individuals are also known to cross highways and reservoirs (Krebs and Lewis 1999). Wolverines might be particularly sensitive to human

disturbance when they have young. Females have been known to move their kits to avoid human contact (Pulliainen 1968; Banci 1984).

Wolverines observed near Lac de Gras, in the central Northwest Territories, tended to maintain a large separation distance (usually greater than 500 m) from human activity, but this result was not significant (AXYS 1998). Individual responses to aircraft overflights included no response, running away, and hiding (AXYS 1998). In one incident, wolverines were reluctant to leave a caribou carcass even when a helicopter approached (AXYS 1998).

Farmed mink (*Mustela vison*) are known to respond to sounds, such as sonic booms, but with apparently no detrimental effects on reproduction (reviewed by Cottreau 1978). Most mink returned to pre-boom activities within two minutes and appeared to habituate to the booms after exposure to three booms over an hour (Travis et al. 1974 cited in Mancini et al. 1988).

4.2.3 Hearing Characteristics

No information was found on hearing in marten. However, the hearing range of another mustelid, the least weasel (*Mustela nivalis*), was found, for intensities of 60 dB, to extend from 51 Hz to 60.5 kHz, with a region of best hearing extending from 1 kHz to 16 kHz (Heffner and Heffner 1985). The least weasel has similar hearing to other carnivores, such as domestic dog, domestic cat and raccoon (*Procyon lotor*), for which data are available (Heffner and Heffner 1985).

4.3 Beaver

4.3.1 Direct Effects of Noise

No direct evidence related to the effects of noise on beaver is available. The beaver might be affected by noise propagated both through the air and through water.

4.3.2 Indirect Effects of Noise

There has been little study of the impacts of industrial activities on beavers, other than that related to logging and water impoundment. Westworth (1980) found that, for the muskrat (*Ondatra zibethicus*), a species with similar habits, seismic activity resulted in short-term reductions in muskrat activity levels, but apparently did not affect daily activity patterns, the number of daily movements, or the use of houses. Reynolds (1974) observed that another rodent, the Arctic ground squirrel (*Spermophilus parryii*), did not appear to be disturbed by the simulated sounds of a diesel generator.

4.3.3 Hearing Characteristics

No information was found on hearing in beavers. However, the 20 rodent species for which there are audiograms have a median upper limit of 52 kHz (Heffner et al. 2001). Behavioural audiograms were prepared for five rodent species – groundhog (*Marmota monax*), eastern chipmunk (*Tamias striatus*), Darwin's leaf-eared mouse (*Phyllotis darwini*), golden hamster (*Mesocricetus auratus*), and

Egyptian spiny mouse (*Acomys cahirinus*). The audiograms fell into two groups with respect to low frequency hearing, those with extended low frequency hearing (below 100 Hz), which included chipmunks, groundhogs and hamsters, and those with restricted low frequency hearing (not below 1 Hz, which included the mice (Heffner et al. 2001). The beaver might be expected to fall within the first group on the basis of body size.

5 Marine Mammals and Amphibians

5.1 Marine Mammals

5.1.1 Direct Effects of Noise

There is better direct evidence for the effects of noise on marine mammals (see Table 5-1) than for any of the other wildlife VCs.

Patenaude et al. (2002) found that bowhead and beluga whales' reactions to sounds and disturbances created by helicopters and fixed-winged aircraft included short surfacings, immediate turns and dives, vigorous swimming, breaching, and changes in behavioural state. Most reactions were exhibited when helicopters were at altitudes of 150 m or less, and at lateral distances of 250 m or less, and when fixed-winged aircraft were at 182 m altitude or less, and at 250 m lateral distance or less (Patenaude et al. 2002).

Beluga whales exposed to 30 minutes of 134 to 153 dB (re: 1 μ Pa) playbacks of simulated oil platform noise showed no short-term behavioural response and no changes in standard blood chemistry parameters or in catecholamines (OSB 2003). Awbrey and Stewart (1983) found that wild belugas in their natural habitat respond more negatively to sudden changes in sound level than to sustained sound levels (see Table 5-1). In Bristol Bay, Alaska, different frequencies and durations of sounds were used to deter belugas from entering Kvichak River (and eating smolts), including a 2,500 Hz continuous tone and 2,500 Hz randomly pulsed tones (Fish and Vania 1971). The belugas continued up the river during the continuous tone playback but turned back on two occasions when pulsed tones were transmitted (Fish and Vania 1971). Beluga whales have adaptive biosonar and have been observed shifting to higher frequencies and intensities after being moved to a site with greater ambient noise (Au et al. 1985).

In Cook Inlet in June 1995, whales were in shallow water (2–7 m) and a seismic exploration ship was in relatively deep (20–27 m) water about 37 km from the whale group. Fifteen beluga whales demonstrated no response to the signals. The limited ability for low frequency sound to travel in shallow water may partly explain the lack of disturbance response (Moore et al. 2000). In 1999, belugas were observed near docks during transits from a dredge site, but none were reported close to the dredge site (McConnell 2000). It appears that belugas can respond to vessels that follow consistent routes (Burns and Seaman 1986).

5.1.2 Indirect Effects of Noise

Escape responses of ringed seals (*Phoca hispida*) to fixed-wing twin-engine aircraft and to helicopters in northwestern Greenland were evaluated (see Table 5-1) (Born et al. 1999). The probability of escaping was found to be influenced by the time of day, relative wind direction and wind chill. The study indicated that appropriate buffer zones for ringed seals are 1,500 m for small helicopters and 500 m for small fixed-winged aircraft (Born et al. 1999).

Belugas are probably less sensitive to aircraft noise than to vessel noise, but their response may be highly variable as a function of previous experience, activity and characteristics of the noise (Moore et al. 2000).

Incidental observations of beluga whale reactions to boat traffic related to ecotourism activities indicated that belugas avoided boats by prolonging intervals between surfacings, increasing their swimming speed, grouping together, and spending a longer time than usual in a dive (Blane and Jaakson 1994). These types of avoidance behaviour increased with the number of boats present (Blane and Jaakson 1994). Belugas respond negatively to the sound of outboard motors, possibly because they have learned to associate the sound with harassment (Slaney 1975). On one occasion, belugas were seen within 22.9 m of a moving gravel barge, and appeared to be undisturbed (Slaney 1975). Whale movements in different years were similar, suggesting that noise from construction and traffic around artificial islands did not affect the animals, nor did construction noise affect the beluga hunt at Kendall Island (Slaney 1975).

Aerial observations of beluga whale reactions to a barge that was being towed through Niakunak Bay on July 11 and 12, 1976, indicated that whales up to 2,400 m from the barge rapidly swam away, and few whales remained within 800 m of it (Fraker 1977). The distribution of belugas was scattered within a 4,800-m-wide corridor around the barge, and remained so for at least three hours after the barge had passed (Fraker 1977). By recording the noise produced by a tugboat that towed a barge across the bay, Richardson et al. (1995) suggested that the whales could probably perceive the noise it produced at a distance of 3,300 m.

Observations made around Tuft Point in the south Beaufort Sea suggested that beluga whales were not affected by the noise produced by a stationary dredge that was operational, but they did respond once a tug began pushing a barge towards the whales (Richardson et al. 1995).

During clean-up operations from July 31 to August 4, 1976, at Netserk South, an artificial island in the Mackenzie River estuary, belugas stayed farther away from the island when the water became rough, or when noise was made on the island from burning fires (Richardson et al. 1995).

Richardson et al. (1995) related the probable auditory sensitivity of belugas with attenuation rates of sounds produced from two borrow sites in Kugmallit Bay, and suggested that the whales could probably hear average operational sounds at a range of 2,900 m, and that some occasional transient sounds might be perceived at a distance of 4,000 m.

There is an association between high-energy mid-frequency military sonar activities and mass strandings of beaked whales, such as Cuvier's beaked whale, *Ziphius cavirostris* (OSB 2003). Jepson et al. (2003) describe gas bubble lesions in stranded cetaceans (primarily Cuvier's beaked whales) that are consistent with either rapid decompression resulting from a change in normal dive profile, such as rapid descent, or the physical effect of sonar (Jepson et al. 2003).

Table 5.1: Summary of Evidence for the Effect of Noise on Marine Mammals

Species	Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference
Ringed seal	Partenavia PN68 Observer Fixed-wing twin-engine aircraft		150 m altitude	6% of the seals ($N_{\text{tot}} = 5,040$) escaped as a reaction to the fixed-wing aircraft	5,040 seals	Eastern Greenland	June 1984	Born et al. 1999
	Bell 206 III helicopter		150 m altitude	49% of seals ($N_{\text{tot}} = 227$ cases) escaped as a response to the stimuli. Small helicopters should not approach closer than about 1,500 m.	227 seals	Northwestern Greenland	May 1992	Born et al. 1999
Beluga whale	Projected 2,500 Hz tone	Continuous and randomly pulsed	2,500 Hz	Whales continued up river during continuous tone playback, but turned back on two occasions when pulsed tones were transmitted.				Fish and Vania 1971
Beluga whale	Recording of noise from a drilling platform projected underwater	Not available	163 dB, re: 1 μPa source level	Whales less than 1.5 km from source usually reacted to onset of noise by swimming away. In two cases, groups at least 3.5 km away when noise began approached – one group to within 300 m and another to within 15 m of the projector.	Not available	Southwest Alaska	Not available	Awbrey and Stewart 1983
Beluga whale	High ambient noise		Loud site had ambient noise, typically 12 to 17 dB greater than the quiet site.	Whale apparently adapted to higher ambient noise by emitting echolocation signals at frequencies where the ambient noise was relatively low ¹ . It is also possible that the whale used higher intensity signals to overcome the higher ambient noise and that the higher frequencies were simply byproducts.	One captive whale	Loud site (Kaneohe Bay, HI); Quiet site (San Diego Bay, CA)		Au et al. 1985
Beluga whale	Ship traffic		Received noise levels ranged from 94 to 105 dB in the 20 to 1,000 Hz band for	Presumed alarm vocalizations indicated awareness of an approaching ship over 80 km away, and strong avoidance reactions exhibited to ships approaching at distances of 35 to 50 km. A 'flee' response involved large herds undertaking long dives close to or		Lancaster Sound and Admiralty Inlet	Spring, 1982-1984	Finley et al. 1990

Table 5.1: Summary of Evidence for the Effect of Noise on Marine Mammals (cont'd)

Species	Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference
Beluga whale (cont'd)	Ship traffic (cont'd)		ships at distances of 35 to 50 km.	beneath the ice edge. In addition, pod integrity broke down and diving appeared asynchronous. Belugas were displaced along ice edges by as much as 80 km, depending on the proximity of ice edges to coastal areas. Typically, they moved rapidly along ice edges, away from approaching ships.				
Beluga whale	Icebreaker bubbler		194 dB re: 1 μ Pa at 1 m (bandwidth 22 kHz)	Heavily masked the noise of the beluga call.	One captive whale			Erbe 2000
Beluga whale	Icebreaker propeller (Ramming)		203 dB re: 1 μ Pa at 1 m (bandwidth 22 kHz)	Moderately masked the noise of the beluga call	One captive whale			Erbe 2000
Beluga whale	Icebreaker ice cracking		147 dB re: 1 μ Pa at 1 m (bandwidth 22 kHz)	Lightly masked the noise of the beluga call.	One captive whale			Erbe 2000
Beluga whale	Canadian Coast Guard icebreaker Bubbler system	Not applicable	Median source level: 192 dB re: 1 μ Pa at 1 m (100 Hz to 20 kHz frequency range)	Temporary hearing damage could be expected to occur if belugas remained within 1 to 4 km of the icebreaker for 20 minutes or more. Modelling was conducted for deep-water and near-shore environments, and it suggested that sounds produced by the vessel were audible to belugas over a range of 35 to 78 km, and that masking of beluga communication signals would occur within a range of 14 to 71 km.	A model was used to estimate zones of impact on beluga whales.	Beaufort Sea		Erbe and Farmer 2000
Beluga whale	Propeller cavitations		Median source level: 205 dB re: 1 μ Pa at 1 m (100 Hz to 22 kHz frequency range)					

Table 5.1: Summary of Evidence for the Effect of Noise on Marine Mammals (cont'd)

Species	Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference
Beluga whale	Helicopter activity	Variable	Altitude 0 to 460 m	Reactions were observed in 38% of occasions. Reactions were more frequent at altitudes of less than 150 m. Reactions were more frequent at lateral distances of 250 m or less.	40 occasions	Western Beaufort Sea	Spring, 1989–1991, and 1994	Patenaude et al. 2002
Beluga whale	Fixed-wing overflights							
<p>Note:</p> <ol style="list-style-type: none"> 1. Au et al. (1985) suggest that there is a small possibility that differences in methodology at the two sites might have affected their results. 2. 1) Overflights, 2) within two minutes of landings or take-offs, and 3) stationary on ice with engine running (more than two minutes after landing). 								

Little work has been done on long-term responses to noise (OSB 2003). Morton and Symonds (2002) document the long-term displacement of killer whales (*Orca orcinus*) by acoustic harassment devices (AHDs) on the west coast of Vancouver Island. A 10 kHz signal at 194 dB (re: μPa at 1 m) is estimated to reach ambient noise levels at 50 km from the source (Morton and Symonds 2002). The frequency of occurrence of killer whales decreased significantly during the six years that AHDs operated in the area (Morton and Symonds 2002).

5.1.3 Hearing Characteristics

Some of the most extensive information on individual variation in hearing has been obtained for belugas (Richardson et al. 1995). The beluga's hearing range extends at least as low as 40 to 75 Hz, although its sensitivity seems quite poor in this range (Richardson et al. 1995). Their hearing range extends up to between 80 and 150 kHz in at least some individuals (Richardson et al. 1995). Beluga hearing was found to be most sensitive at frequencies between 20 and 75 kHz (Finley et al. 1990).

The beluga's detection performance in masking noise was superior to that of the dolphin (Turl et al. 1987). The beluga might be better able to process signals embedded in noise than the dolphin (Turl et al. 1987). Its superior performance might represent an adaptation to an ice-covered environment, where noise levels might be high (Turl et al. 1987). To some degree, the acoustic systems of belugas must be adapted to deal with relatively high levels of ambient noise in a pack ice environment (see Section 1 and Finley et al. 1990).

5.2 Amphibians

5.2.1 Direct Effects of Noise

The only direct evidence related to the effects of noise on any of the amphibian VCs is reported in Nash et al. (1970). They found that leopard frogs exposed to loud noise (a 120 dB signal horn, 8 cm from the frog for one second) before being manually restrained remained immobile almost eight times longer than did the control group. The data provides evidence in support of the hypothesis that the response (immobility) to manual restraint is fear-induced paralysis, and that the loud sound increased the level of fear before the manual restraint (Nash et al. 1970).

5.2.2 Indirect Effects of Noise

Sensory disturbance can impair amphibian movement and, consequently, response to predators and threats. Continuous sensory disturbance impairs call detection and has been found to impair recruitment in amphibians (Gerhardt and Klump 1988; Wollerman 1998; Wollerman and Wiley 2002; Barrass 1986). Some amphibians use auditory stimuli, such as thunderstorms, as a cue to emerge from hibernation, but sensory disturbance can cause early emergence from burrows, a potentially harmful impact in the absence of sufficient water (Brattstrom and Bondello 1983).

Continuous background noise has been shown to impair call detection in some species of frogs (Gerhardt and Klump 1988 [green tree-frog, *Hyla cinerea*]; Wollerman 1999 [*Hyla ebraccata*]; Wollerman and Haven Wiley 2002 [*H. ebraccata*]). In high levels of background sound, females avoided the subtleties of discriminating among calls of conspecific males, and instead, chose calls with properties consistent with the population mode (Wollerman and Haven Wiley 2002). This alteration in a female's tactics for mate choice has potential genetic implications for the population (Wollerman and Haven Wiley 2002).

Most studies have looked at the impact of chorus noise on frog communication. Typically, these studies were conducted in a laboratory setting. Only one study was available that examined the impact of human-made noise on amphibians in the natural environment. Barrass (1986) examined the effects of highway traffic noise on two anuran species, Woodhouse's toad (*Bufo woodhousei*) and the green tree-frog, in Texas. The L_{max} was 61 to 64 dB(C) at 60 m and 52 to 57 dB(C) at 300 m at one highway site. At the second highway site, it was 67 to 78 dB(C) at 60 m and 64 to 68 dB(C) at 300 m. The study found that such noise significantly affected female phonotaxis, resulted in the variation of male mating calls on a microgeographic scale, and affected the spacing and degree of aggregation of the calling males. However, Barrass (1986) did not demonstrate whether these changes had any effect on reproductive success.

Spadefoot toads appear to use auditory stimuli, such as thunderstorms, as a cue to emerge from hibernation. Recorded motorcycle sounds of 95 dBA elicited emergence from their burrows, a potentially harmful impact in the absence of sufficient water (Brattstrom and Bondello 1983).

The location of a Canadian toad overwintering site (with more than 500 toads) in a road cut adjacent to a highway in the Northwest Territories (Kuyt (1991) is an indirect indication that this species may have some tolerance to traffic noise. However, studies that have examined the effects of roads on amphibian movements do not consider noise when discussing cases of apparent avoidance (deMaynadier and Hunter 2000).

5.2.3 Hearing Characteristics

Hearing ranges for amphibians are from about 100 to 1,600 Hz, although bullfrogs (*Rana catesbeiana*) can hear sounds below 10 Hz (Bommer and Bruce 1996). Gerhardt (1975) examined the sound pressure levels and radiation patterns of the mating calls of 21 species of North American frogs and toads, and found that, in most species, the peak levels at 50 cm in front of the male exceeded 100 dB. In multi-species assemblages of synchronously breeding anurans, background noise levels are often very high (Schwartz and Wells 1983).

6 Birds

6.1 Shorebirds and Waterfowl

6.1.1 Direct Effects of Noise

Two comprehensive studies of the effects of noise on waterfowl in the Arctic (see Table 6-1) were conducted at:

- the Alpine Project area, in the Colville River Delta, Alaska (Johnson et al. 2003)
- Point McIntyre, in Prudhoe Bay, Alaska (Anderson et al. 1992)

Noise levels were modelled ranging from 25 to 95 dBA, and maximum noise levels were recorded at 109 dBA in the Alpine Project area (Johnson et al. 2003). Disturbance during heavy construction resulted in displacing 0 to 67% of nesting greater whitefronted geese within 500 m of the airstrip (Johnson et al. 2003). The proportion of greater white-fronted goose nests in the loudest noise contour, closest to an airstrip, declined from 20% in the pre-construction phase to 3% in the operations phase (Johnson et al. 2003). Nesting greater white-fronted geese also took more and longer recesses from incubation as the number of airplanes increased, and at nest sites closer to the airstrip (Gunn and Livingston 1974; Johnson et al. 2003).

Airplanes and pedestrians elicited the highest rates of response from incubating geese and the lowest from vehicles (Gunn and Livingston 1974). However, airplane disturbances did not appear to affect nest outcomes (Johnson et al. 2003). Greater white-fronted geese shifted nests out of areas within 1 km of the airstrip during a period of heavy construction activity (Johnson et al. 2003).

Because brood-rearing birds can move away from disturbances, disturbance may cause further displacement of brood-rearing flocks. However, an analysis of 15 years of tundra swan nest and brood distributions in the Kuparuk oilfield indicate that there was no significant relationship between the intensity of disturbance and nest or brood densities within 1 km of roads (Anderson and Stickney 2004).

6.1.2 Indirect Effects of Noise

In the Mackenzie Valley, waterfowl populations were found to be less disturbed by float planes than by an eagle hunting (Gunn and Livingston 1974). King eider flocks were found to occur further from disturbance during the nesting season in the Prudhoe Bay Region, Alaska (Anderson et al. 1992). Anderson et al. (1992) reported that during the nesting period, spectacled eiders near the GHX-1 facility in the Prudhoe Bay area appeared to adjust their use of the area to locations farther from the facility in response to noise and movements from vehicular traffic, machinery and air traffic. Common eiders were not found to be disturbed by aircraft (Gunn and Livingston 1974).

Table 6-1: Summary of Evidence for the Effect of Noise on Shorebirds and Waterfowl

Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference
GHX-1 central compressor plant	1990–1992	Mean noise levels range 42 to 68 dBA Increase of 2.9 dBA over baseline conditions	Canada goose shifted pre-nesting distribution further from disturbance. Tundra swans, during brood-rearing, occurred further from disturbance. Spectacled eider nesting occurred further from disturbance. Red-throated loons, during brood-rearing, occurred further from disturbance.	About 30 waterbird and 30 loon surveys/year	Prudhoe Bay, Alaska	1989–1991	Anderson et al. 1992
Helicopters, airplanes construction, drilling, vehicles, maintenance	1998–2001	25 to 65 dBA, maximum noise level 109 dBA	Greater white-fronted geese shifted nesting distribution more than 1,000 m from disturbance. Greater white-fronted geese nests declined throughout construction.	1996–2001: Nest searches for 8 to 10 days/year 1998–2001: 12 breeding-bird plots	Colville River Delta, AK	1996–2001	Johnson et al. 2003

Noise and visual stimuli associated with helicopter and fixed-wing air traffic were observed to disturb spectacled eiders near the airstrip (Anderson et al. 1992). Responses of incubating waterfowl to aircraft include alert and concealment postures, interruption of foraging behaviour, flight, and decreases in nest attendance (Johnson et al. 2003). Such disturbances might displace birds from nesting, brood-rearing and feeding habitats, and negatively affect energy budgets.

Of the various aerial disturbance types, helicopters were the least predictable because they did not have a restricted flight pattern (Johnson et al. 2003). Although some studies have suggested that helicopters might be more disturbing to wildlife than low-flying fixed-wing aircraft, both elicit disturbance reactions (Gollop et al. 1974b; Johnson et al. 2003). Incubating greater white-fronted geese and tundra swans reacted more often to fixed-wing aircraft than to helicopters, possibly because monitored nests were closer to the airstrip than to the helipad (Johnson et al. 2003). The potential for noise associated with aircraft to have negative impacts on birds is probably greatest during the nesting period, when movements of incubating birds are restricted.

One study measured the heart rate of black ducks for four days and subjected them to simulated aircraft noise for 48 episodes per day, with peak volume of 110 dB. Acute response occurred on the first day but diminished rapidly after that. This indicated the ability of black ducks to habituate to the auditory component of low-altitude aircraft overflight (Harms *et al.* 1997).

6.1.3 Hearing Characteristics

No information was found on the hearing of shorebirds or waterfowl.

6.2 Songbirds

6.2.1 Direct Effects of Noise

There is some direct evidence of the effects of noise on songbirds. However, it appears to be extremely species or guild-specific.

Manci et al. (1988) reports reproductive losses for small territorial passerines after exposure to low-altitude overflights. Passerine nests were not displaced from the area around an airstrip at the Alpine Development Project (Johnson et al. 2003). Lapland longspurs nested in higher densities near an active airstrip at Alpine than they did away from the airstrip, although the trend was not significant. Other passerines nested in densities too low to evaluate (Johnson et al. 2003). Rheindt (2003) showed a significant relationship between dominant singing frequency and decline in abundance towards a noisy roadway.

Songbirds are resilient and adaptable. Those that can adjust their call frequency are not as significantly affected by noise levels. Species with high-pitched songs with frequencies well above that of industrial noise are less susceptible to noise pollution. Slabbekoorn and Peet (2003) documented birds at noisy locations consistently singing with a higher minimum frequency, thereby preventing their songs from being masked by predominantly low-frequency urban noise, and

recorded mean amplitude levels per territory ranging from 42 to 63 dB. Peris and Pescador (2004) cited greater tolerance to noise in some Ploceidae, Fringillidae and Emberizidae species because of morphological features in the middle ear of these birds.

6.2.2 Indirect Effects of Noise

Reijnen and Foppen (1994) and Reijnen et al. (1995) reported reduced woodland bird density near roads, and attributed this finding to higher noise levels near roads, which disturbed communication patterns between birds, distorted male breeding songs, and hampered the effectiveness of alarm calls.

High-pitched or high-intensity environmental noise has the potential to mask songs and other vocalizations, such as nestling begging calls, distress calls and alarm calls, used by passerines and related birds. Many vociferous species, like songbirds, might exhibit potential fitness consequences, or might altogether abandon noisy environments simply because such 'acoustic masking' effects prevent them from readily communicating with each other (Boudreau 1968, Madhusudan and Warren 2004).

6.2.3 Hearing Characteristics

No information was found on hearing in songbirds. However, there is a small amount of quantitative data relating to songbirds and acceptable noise levels or thresholds for impact assessment. Peris and Pescador (2004) evaluated the effects of traffic noise on passerine populations and found that most (55%) did not show differences in breeding densities, even in high traffic densities with noise levels of 69 +/- 5 dB. Other studies have also shown that noise levels and military training activities did not affect red-cockaded woodpecker densities, nesting success or productivity (Delaney et al. 2001) when experimental noise stimuli were more than 150 m away. However, this study concentrated on the distance of the noise stimuli, rather than the noise level itself.

6.3 Raptors

6.3.1 Direct Effects of Noise

Most studies on the effects of disturbance on diurnal raptors, such as hawks, falcons and eagles, have concentrated on behavioural responses to aircraft and related noise at nest sites (see Table 6-2). Many of these and similar studies have not quantified noise levels as part of the study, and many have not differentiated between the effect of the noise itself and other aspects of the disturbance.

6.3.2 Indirect Effects of Noise

Ellis et al. (1991) estimated peregrine falcon responses to low-level jet aircraft and sonic booms. They reported that frequent and nearby jet aircraft passes noticeably alarmed the birds, and sometimes caused a flight response, but never caused nest abandonment or reproductive failure. Holthuijzen et al. (1990) studied the effects of blasting on behaviour and productivity of nesting prairie falcons,

and found that, although falcons behaviourally reacted to blasting in most of the events, all incubating and brooding falcons that were flushed from their nests returned within four minutes. Based on this data, Holthuijzen et al. (1990) suggest that occupied prairie falcon nests can withstand peak noise levels up to 140 dB.

Fleischner and Weisberg (1986) have shown that bald eagles are susceptible to being startled by loud noise during the breeding season. Bald eagles typically respond to the proximity of disturbance, such as from pedestrian traffic or aircraft within 100 m, because of the increased visibility of the perceived threat, rather than the noise level (Ellis et al. 1991). Bald eagles' reactions to commercial jet flight were twice as likely to occur within eagle-jet distances of 800 m (Fleischner and Weisberg, 1986). Fraser et al. (1985) found that 10% of nesting bald eagles interrupted their incubation or brooding activities during overflights.

Trimper et al. (1998) evaluated the effects of jet aircraft noise on the behaviour of nesting osprey, and found that osprey behaviour did not differ significantly between pre- and post-overflight periods despite maximum noise levels exceeding 100 dB. Grubb et al. (1998) recorded logging truck noise within 500 m of nesting northern goshawks (*Accipiter gentilis*), and reported no discernable behavioural response to the noise, which peaked at 53.4 dBA.

As with many other types of disturbance, the intensity of response by raptors to noise depends largely on the familiarity of the noise. For example, White and Thurow (1985) reported that ferruginous hawks and other similar species will tolerate considerable noise (about 80 dB) close to their nests if they are familiar with it, especially if humans are not visible or otherwise obviously associated with the noise.

There is little data on the effects of noise on owl behaviour or reproductive success. Tempel and Gutierrez (2003) tested the physiological responses of California spotted owls (*Strix occidentalis occidentalis*) to low-intensity chainsaw noise with a maximum sound pressure level of 50 to 60 dB, and found no stress response in these owls. Similarly, Delaney et al. (1999) reported that Mexican spotted owls (*Strix occidentalis lucida*) did not flush when total sound energy levels were less than 92 dBA, and that owls returned to their predisturbance behaviour within 10 to 15 minutes after the noise stimuli.

Overall, increased noise disturbance can reduce the ability of individual owls to detect prey, cause flight responses in both breeding and non-breeding individuals, reduce nest attentiveness of breeding females, and affect the rate of prey delivery to the female by breeding males.

6.3.3 Hearing Characteristics

No information has been found on hearing in raptors. However, owls have extremely sensitive hearing with audible frequency ranges ranking among the best high-frequency (0.4 to 9 kHz) hearing known in birds (Knudsen 1981). For example, long-eared owls, known to be present in the project area, depend on the sounds of prey, such as the squeaks and rustle of rodents under snow or leaves, calls from nestlings, fledglings, and other adult owls, and nuptial alarm calls

(Ilichev et al. 1971). To perceive and locate these sounds, which vary from 0.5 to 11.0 kHz, the owl's hearing has to be selective to distinguish them from natural background noise.

Table 6-2: Summary of Direct Evidence for the Effect of Noise on Raptors

Species	Source of Noise	Duration of Noise	Magnitude of Noise	Observed Impact	Sample Size	Study Area	Study Period	Reference																																							
Raptors (Peregrine falcon)	Low-level jet aircraft	Frequent	85 – 117 dBA	Passes noticeably alarmed the birds, and sometimes caused a flight response, but never caused nest abandonment or reproductive failure.	30 nests and two captive birds	Arizona	1980–1981	Ellis et al. (1991)																																							
	Sonic booms	Frequent	114-141 dBA						Prairie falcon	Blasting		140 dB	Incubating and brooding falcons were flushed from their nests but returned within four minutes.				Holthuijzen et al. (1990)	Osprey	Jet aircraft		> 100 dB	Behaviour did not differ significantly between pre- and post-overflight periods.				Trimper et al. (1998)	Northern Goshawk	Logging truck noise		53.4 dBA within 500 m	No behavioural response was detected.				Grubb et al. (1998)	Bald eagle	Commercial jet		Eagle to jet distance of 800 m	Behavioural response was detected.				Fleischner and Weisberg (1986)		Overflight	
Prairie falcon	Blasting		140 dB	Incubating and brooding falcons were flushed from their nests but returned within four minutes.				Holthuijzen et al. (1990)																																							
Osprey	Jet aircraft		> 100 dB	Behaviour did not differ significantly between pre- and post-overflight periods.				Trimper et al. (1998)																																							
Northern Goshawk	Logging truck noise		53.4 dBA within 500 m	No behavioural response was detected.				Grubb et al. (1998)																																							
Bald eagle	Commercial jet		Eagle to jet distance of 800 m	Behavioural response was detected.				Fleischner and Weisberg (1986)																																							
	Overflight			10% of nesting bald eagles interrupted their incubation or brooding activities during overflights.				Ellis et al. 1991																																							

7 References

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7.3 Personal Communications

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