RESPONSE OF NESTING NORTHERN GOSHAWKS TO LOGGING TRUCK NOISE KAIBAB NATIONAL FOREST, ARIZONA

Teryl G. Grubb
U.S. Forest Service
Rocky Mountain Research Station
Flagstaff, Arizona

Angela E. Gatto
U.S. Forest Service
North Kaibab Ranger District
Kaibab National Forest
Fredonia, Arizona

Larry L. Pater
Noise Consultant
Champaign, Illinois

David K. Delaney
U.S. Army
Research and Development Center
Construction Engineering Research Laboratory
Champaign, Illinois

8 May 2012

RESPONSE OF NESTING NORTHERN GOSHAWKS TO LOGGING TRUCK NOISE
KAIBAB NATIONAL FOREST, ARIZONA

Teryl G. Grubb
U.S. Forest Service
Rocky Mountain Research Station
Flagstaff, Arizona

Angela E. Gatto
U.S. Forest Service
North Kaibab Ranger District
Kaibab National Forest
Fredonia, Arizona

Larry L. Pater
Noise Consultant
Champaign, Illinois

David K. Delaney
U.S. Army
Engineer Research and Development Center
Construction Engineering Research Laboratory
Champaign, Illinois

Final Report
to
Southwest Region (R-3)
U.S. Forest Service

8 May 2012

EXECUTIVE SUMMARY

At present log hauling is categorically precluded from northern goshawk (*Accipter gentilis*) post-fledging family areas (PFAs) on the Kaibab Plateau to the detriment of efficient U. S. Forest Service contract logging. The goal of the current research was to test sufficiently with a logging truck hauling near actively nesting goshawks to establish critical thresholds for distance and noise levels, as well as assess current levels of frequency/duration/timing, i.e., concentration of exposure. Collaboration with U.S. Forest Service Rocky Mountain Research Station (RMRS) and U.S. Army Engineer Research and Development Center/Construction Engineering Research Laboratory (ERDC/CERL) brought wildlife and acoustical expertise, as well as sophisticated, professional grade, recording equipment to the project. Although the project focused on logging truck noise, general aviation civilian aircraft, and a few recreational off-highway (OHVs) and other vehicles were also monitored opportunistically. Our study area was located on the Kaibab Plateau, on the North Rim of the Grand Canyon, in northwestern Arizona within the North Kaibab Ranger District (NKRD), Kaibab National Forest.

During days of logging truck noise tests, each of 3 adult-occupied northern goshawk nests was kept under surveillance by a trained field observer from 1 h before testing began until ~30 min to 1 h afterwards. The test logging truck made 4 round trips past each nest, with 1 h rest between each, on each test day, between approximately 0630-1130 Mountain Standard Time (MST). These 8 passes in a 4-5 h period far exceeded current, normal hauling practices on the NKRD. Our test vehicle was an unloaded, 1994 Kenworth T800, 500 horsepower, logging truck (gross vehicle weight (GVW) 80,000 lb. (36,287 kg)). All aircraft recorded during our noise testing were civilian, fixed-wing, light aircraft. The aircraft noise events we recorded were unscheduled events that were not under experimental control. The distance to aircraft was in all cases unknown, except for the fact that any aircraft should have been flying at an altitude no less than 300 m (1,000 ft) above ground level per Federal Aviation Regulation.

We recorded 94 sound/response events at 3 occupied northern goshawk nests, at 3 different distances from the nearest road (167, 143, and 78 m) during 4 test sessions (07, 08, 10, and 11 Jun 2010): 60 experimentally controlled logging trucks; 30 non-experimental, passive civilian light aircraft; 3 non-experimental, passive cars; and 1 non-experimental, passive all- terrain vehicle (ATV). Logging truck sound was concentrated in the 63 and 80 Hz 1/3-octave frequency bands, principally engine and exhaust sound. Some higher frequency sound was typically present, from banging of log chain or other metal parts. Airplane sound was concentrated in the 100 and 125 Hz 1/3-octave frequency bands. Aircraft average noise levels at the 3 nest sites varied insignificantly between approximately 60-66 dB (maximum 1-sec adjusted CLEQ). At nest 5C (167 m from closest road) the logging truck averaged

about 8 dB quieter than the aircraft (t-test, $P < 0.001$). At nest 71D (143 m) the logging truck was about 3 dB quieter than passing aircraft (t-test, $P = 0.026$). Only at nest 108D (78 m) was logging truck noise louder on average than aircraft, by about 6 dB (t-test, $P < 0.001$). Average aircraft noise levels for each day of testing ranged between 45.6-67.9 dB, and varied little among the 3 test sites, 60.1-65.6 dB ($F = 2.008$, $P = 0.154$, df = 29); whereas logging truck noise levels varied significantly among nest sites and with distance from roads ($F = 36.753$, $P < 0.001$, df = 59). On average, our test logging truck (61.9 dB adjusted CLEQ) was no louder than passing aircraft (62.3 dB adjusted CLEQ; *t*-test, $P = 0.191$), which goshawks generally ignored.

The logging truck resulted in 27% no response and 73% alert response (n = 60); passing aircraft resulted in 90% no response and only 10% alert response (n = 30); and 3 cars and 1 ATV, combined, resulted in 50% each for no response and alert response ($\chi^2 = 82.365$, $P < 0.005$). Goshawk alert response rates were inversely proportional to nest distance from the nearest road ($\chi^2 = 29.861$, $P < 0.005$), increasing from 57% to 91% alert between site 5C (167 m from road) and 108D (78 m from road). There were no movements or flushes associated with either our experimental testing or passive recording of the other noise stimuli. The stimulus event sound level, for both logging trucks and aircraft, rose gradually to a maximum and then gradually faded over a period of a few minutes. There was no startle effect from our recorded stimuli. All tested pairs of goshawks successfully fledged young. Our recorded logging truck noise levels (43.5-50.5 dBA) fell well below conservative Federal Highway Administration and Federal Department of Housing and Urban Development exterior noise standards for wild or urban areas. An experimental study of noise from loaded and unloaded logging trucks hauling on a road in British Columbia, Canada, corroborated our recorded noise levels, as well as validated our experimental use of an empty truck for testing.

We found no evidence of any negative effects of logging truck noise on nesting northern goshawks on the Kaibab Plateau. Observed goshawk response was limited to at most looking in the direction of the hauling road. This study shows that any broad restriction of hauling and other activities within a PFA is unnecessary. It also shows that no restrictions are needed for road-based travel, whether by logging trucks or other vehicles, within PFAs or nest areas. However, our anecdotal evidence strongly indicates pedestrian activities should continue to be restricted within a ¼ mi (400 m) radius of an active goshawk nest.

ACKNOWLEDGEMENTS

The authors would like to thank NKRD field technicians Ryan Dastrup, Cassandra Hagemann, and Korin Miles for their dedication and long hours in the field recording logging truck and other noise levels, and diligently observing northern goshawk response behaviors. Deb Saunders and Paul Callaway, NKRD foresters, provided valuable advice and insight into log hauling operations. The cooperation of Larry Reidhead, logging truck owner/operator, is also greatly appreciated. Richard Reynolds, RMRS scientist, and his field crews provided much helpful information on northern goshawk nesting activities, nest locations, and adult behaviors. Carrie King, formerly with NKRD and now with Arizona Department of Game and Fish, is gratefully acknowledged for her pioneering research into logging truck noise levels and effects on northern goshawk behavior in 2001-2002, a project that precipitated the current research effort. Primary funding for field data collection and analyses was provided by the Kaibab National Forest. We thank Susan Brown, Kaibab National Forest Contracting, for facilitating that financial support. U.S. Forest Service, Rocky Mountain Research Station, and U.S. Army, Engineer Research and Development Center, Construction Engineering Research Laboratory provided both additional technical and logistical support.

Contents

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The northern goshawk (*Accipiter gentilis*) is a pandemic species found across North America and Eurasia. The Kaibab Plateau on the Kaibab National Forest in northern Arizona supports one of the most concentrated populations of goshawks known in North America, averaging 43 active breeding areas per year until a 2001 drought reduced the subsequent number of nesting pairs (Reich et al. 2004, Reynolds et al. 2004). Goshawks occupy nearly every forest and woodland habitat type that occurs within this forest raptor's geographic range (Reynolds et al. 1982, Younk and Bechard 1994, Siders and Kennedy 1996, Squires and Ruggiero 1996). Goshawks are territorial and will actively defend their nest area, not only against their own species but other raptors as well (Speiser and Bosakowski 1991). Attila the Hun wore an image of a northern goshawk on his helmet to scare his enemies. This reflects the goshawk's habit of also commonly attacking people and other animals that approach their nests too closely (Squires and Reynolds 1997).

Goshawks were designated as a sensitive species by the Regional Forester of the Southwest Region, U.S. Forest Service, in 1982. Timber harvest has traditionally been the primary threat to goshawks throughout their range (Reynolds 1989, Bright-Smith and Mannan 1994, Beier and Drennan 1997). With their unusually high density on the Kaibab Plateau, early logging pressure was feared a threat and raised the issue of appropriate management measures (Crocker-Bedford 1990). The Kaibab National Forest responded to this risk in 1996 when the Forest amended the Kaibab National Forest Plan. This amendment incorporated the "Management Recommendations for the Northern Goshawk in the Southwestern United States" (Reynolds et al. 1992), and afforded special protection to goshawk nesting areas and post-fledging family areas (PFAs).

As a result, at present log hauling is categorically precluded from northern goshawk PFAs on the Kaibab Plateau to the detriment of efficient U.S. Forest Service contract logging. A pilot study using state-of-the-art sound measuring techniques was conducted on the Kaibab National Forest in the late 90s, and those limited data remain among the only published data available for assessing potential impacts and establishing appropriate management practices for log hauling on southwestern national forests (Grubb et al. 1998). The goal of the current research was to test sufficiently with a logging truck hauling near actively nesting goshawks to establish critical thresholds for distance and noise levels, as well as assess current levels of frequency/duration/timing, i.e., concentration of exposure. Collaboration with U.S. Forest Service Rocky Mountain Research Station (RMRS) and U.S. Army Engineer Research and Development Center/Construction Engineering Research Laboratory (ERDC/CERL), brought wildlife and acoustical expertise, as well as sophisticated, professional grade, recording equipment to the project. Although the project focused on logging truck noise, other vehicles including general aviation aircraft, recreational off-highway vehicles (OHVs), and several cars were also monitored opportunistically. Project results should have broad applicability throughout the Forest Service.

OBJECTIVES

To determine the efficacy of log hauling restrictions, as implemented by the 1996 Forest Plan Amendment in northern goshawk PFAs on the Kaibab Plateau, North Kaibab Ranger District, Kaibab National Forest, this study was designed to address the following objectives:

1. To measure sound levels of a logging truck driving near nesting northern goshawks.
2. To observe and record northern goshawk behavioral response associated with the passing logging truck, and with any other opportunistically occurring, anthropogenic noise stimuli.
3. To develop management implications of the scientific results obtained in Objectives 1 and 2.

ANNOTATED BIBLIOGRAPHY

Several bibliographies summarize the literature relative to effects of noise on wildlife. Radle (2007, wfae.proscenia.net/library/articles/radle_effect_noise_wildlife.pdf) provides a summary of the objectives of many key studies and reports relative to noise effects on wildlife from the 1970's through the 1990's. An extensive annotated bibliography is included in the Federal Highway Administration's 2004 report, "Synthesis of Noise Effects on Wildlife Populations" (Publication No. FHWA-HEP-06-016). Most recently the Natural Sounds Program within the National Park Service has established an annotated bibliography (Turina and Barber 2011) on the Natural Sounds Program website: www.nature.nps.gov/naturalsounds/pdf_docs/wildlifebiblio_Aug2011.pdf. However, although many studies have identified noise as a disturbance factor for wildlife, very few actually measured sound levels and quantified the corresponding effects of noise disturbance. Below are a few selected references that have quantified noise impacts to raptors and other wildlife:

Delaney, D.K., L.L. Pater, L.D. Carlile, E.W. Spadgenske, T.A. Beatty, and R.H. Melton. 2011. Response of red-cockaded woodpeckers to military training operations. Wildlife Monographs 177:1-38.

During extensive monitoring, measuring, and experimentation with a variety of military stimuli, authors noted red-cockaded woodpeckers (*Picoides borealis*) did not flush from nests when helicopter noise levels were <102 dB, unweighted, and noise levels from passing military and civilian vehicles were <75 dB, unweighted.

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

Reported that Mexican spotted owls (*Strix occidentalis lucida*) did not flush during the nesting season when the Sound Exposure Level (SEL) for helicopters was <92 dBA and the Equivalent Average Sound Level (LEQ) for chainsaws was <46 dBA.

Grubb, T.G., L.L. Pater and D.K. Delaney. 1998. Logging truck noise near nesting northern goshawks. Research Note RMRS-RN-3. U.S. Forest Service, Rocky Mountain Research Station, Flagstaff, Arizona.

The authors reported on the effect of logging trucks on a breeding female and juvenile goshawk (*Accipter gentilis*). There was no discernible effect on either bird. Measured noise levels were quite low, with a maximum noise of ~50 dB (ALEQ) centered at ~80 Hz.

P**almer, A.G., D.L. Nordmeyer, D.D. Roby. 2003. Effects of jet aircraft overflights on parental care of peregrine falcons. Wildlife Society Bulletin. 31: 499-509**

Recorded overflight events >85 dB above nesting peregrine falcons (*Falco peregrinus*). Authors concluded that results provided very little support for the hypothesis that low-altitude jet aircraft overflights affect parental behavior of peregrine falcons.

Trimper, P. G., N. M. Standen, L. M. Lye, D. Lemon, T.E. Chubbs and G. W. Humphries. 1998. Effects of low-level jet aircraft noise on the behavior of nesting osprey. Journal of Applied Ecology. 35:122-130.

Study was based on 240 h of observation with 139 jet overflights. Despite noise levels exceeding 100 dB, osprey (*Pandion haliaeetus*) behavior did not change significantly. However, osprey were attentive to and occasionally flushed from nests when float planes, other osprey, or raptors entered territories, and when observers were entering or exiting blinds.

STUDY AREA

Our study area was located on the Kaibab Plateau, on the North Rim of the Grand Canyon, in northwestern Arizona within the North Kaibab Ranger District (NKRD), Kaibab National Forest. The plateau encompasses 2,980 km^2 above 1,830 m elevation. Vegetation on the plateau consists of ponderosa pine (*Pinus ponderosa*) and mixed-conifer forest (ponderosa pine, Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), blue spruce (*Picea pungens*), and quaking aspen (*Populus tremuloides*; Rasmussen 1941, White and Vankat 1993). Northern goshawk nests monitored during this project were all in the ponderosa pine type. Goshawk nests were chosen based on their immediate proximity to log hauling roads, in order to maximize the opportunity to observe any behavioral response associated with the noise from a passing logging truck (Figure 1).

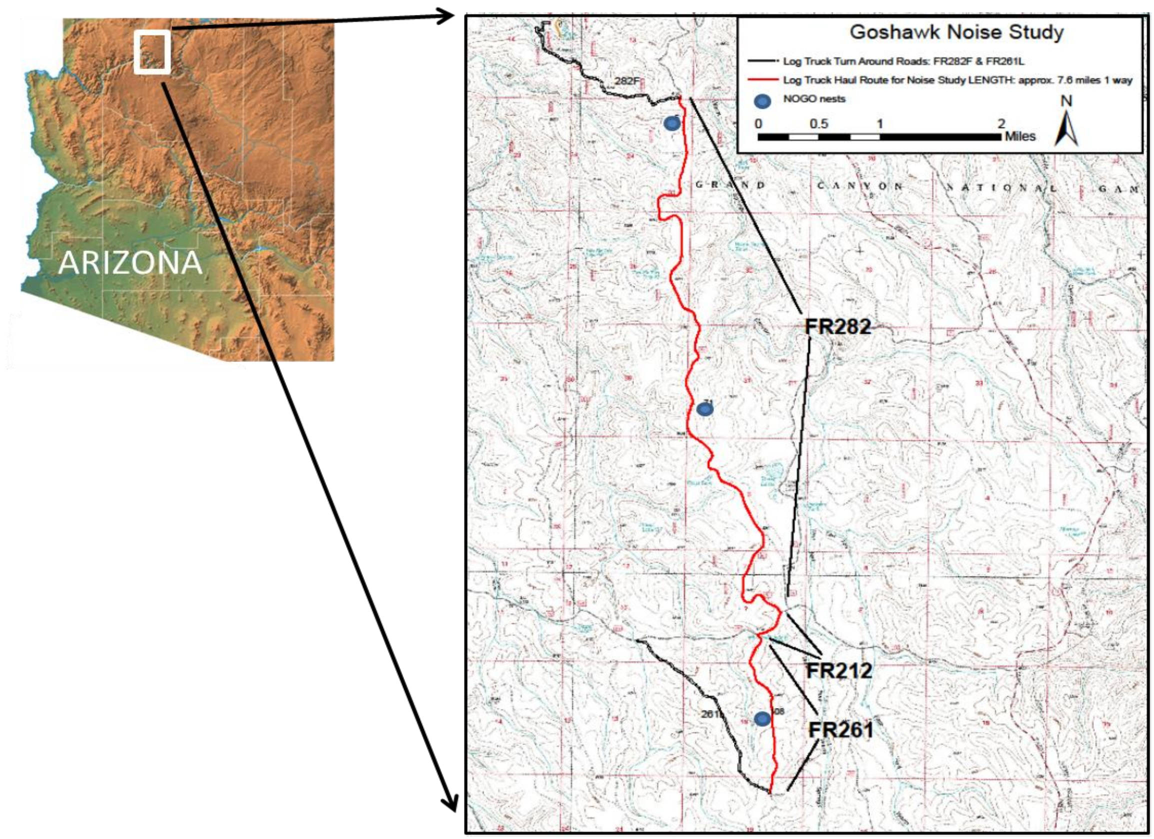

Figure 1. Study area map showing location of northern goshawk nests 5C, 71D, and 108D, 167, 143, and 78 m, respectively, from Forest Roads 282 and 261, on the North Kaibab Ranger District, Kaibab National Forest, Arizona, 2010.

METHODS

Field Observations

Timing

We conducted logging truck noise tests at 3 northern goshawk nests on 4 days in June 2010, the 7th, 8th, 10th, and 11th. Four round trips past each nest, spaced at 1-h intervals, were made by the logging truck each test day, between approximately 0630-1130 Mountain Standard Time (MST). These 8 passes in a 4-5 h period far exceeded current, normal hauling practices on the NKRD, where 2 scenarios currently exist. First, the nearest mill has 1-2 trucks that can be loaded, travel a minimum of 30 mi (48 km) back to the mill, unload, and return, yielding no more than 4 passes by any given nest site in a 10-h day. More distant mills can load up to 2 trucks per day with only 1 round trip each back to the mill, again yielding no more than 4 passes by any given nest site in a 10-h day.

Personnel

During days of logging truck noise tests, each of the 3 study nests was kept under surveillance by a trained field observer from 1 h before testing began until ~30 min to 1 h afterwards. Human activity near a goshawk nest typically causes a reaction from attending adults, but the nest observers arriving at the nest 1 h prior to the passing of the logging truck permitted adult goshawks to return to normal undisturbed behavior well before the test began. Nest observers found viewing locations approximately 100 m from each nest and then used spotting scopes to observe behavior. Observers' watches and all 3 noise recording digital recorders (detailed below) were synchronized prior to observer deployment. Meticulous notes were kept throughout the entire observation period each day, with all anthropogenic activities and corresponding goshawk behaviors recorded to the nearest sec. Chicks in the study nests were ≤15 da old, which insured adult presence at the nests. Because adult female flushing behavior is more detrimental with younger chicks present (Boal 1994), testing at any nest would have been terminated immediately if an adult female flush had been caused by the test stimulus.

Logging Truck Test Vehicle

Our test vehicle was an unloaded, 1994 Kenworth T800, 500 horsepower, logging truck (gross vehicle weight (GVW) 80,000 lb (36,287 kg)). Various field personnel in the timber industry observed that empty trucks were noisier than trucks with loads, due to hanging chains and the bounce of the rear trailer absent the dampening weight of logs (pers. comm. AEG). Our test truck began traveling down a Level 3, gravel road approximately 400 m (1/4 mi) before the nearest northern goshawk nest, and continued on the road for approximately 12.2 km (7.6 mi), passing 3 goshawk nests (Figure 1). The truck turned around ~400 m (1/4 mi) past the last nest, then made the return trip with no other break than the time required to turn around. At the end of each round trip, the driver shut the engine off and waited 1 h before beginning the next test. Four round trips (8 passes) were made each day.

Other Vehicles

Aircraft – All aircraft recorded during our noise testing were civilian, fixed-wing, light aircraft. Occasionally low-level, military training jets pass near the Kaibab Plateau (pers. observation AEG) but none were recorded during our testing. Commercial jetliners and their contrails are a common sight above the Kaibab Plateau but such aircraft were much too high to be heard or have any noise effects. The aircraft noise events we recorded were unscheduled events that were not under experimental control. The distance to aircraft was in all cases unknown, except for the fact that any aircraft should have been flying at an altitude no less than 3,048 m (10,000 ft) above mean sea level (MSL), as required by Special Federal Aviation Regulation No. 50–2, "Special Flight Rules in the Vicinity of the Grand Canyon National Park, Arizona." This minimum flight altitude translates to ~300 m (1000 ft) above ground level (AGL) across the Kaibab Plateau which lies immediately adjacent to and just north of Grand Canyon National Park.

Car and ATV – Cars and all-terrain vehicles (ATVs) had very limited occurrence and specific descriptions were unknown. They were either recorded in notes by observers or identified by LLP during playback assessment of noise events. (See Discussion section and Table 2 for comparative, representative noise levels for cars, trucks, ATVs, motorcycles, and several types of aircraft.)

Acoustical Analysis

Data Collection and Reduction

We measured sound levels at goshawk locations continuously throughout each test period, which enabled measurement of each and every sound event. We simultaneously recorded goshawk behavioral responsiveness, thus obtaining ordered pairs of stimulus and response measurements. Sound level changes of only a few decibels can result in significant changes in animal responses (Grubb et al. 1998, Delaney et al. 1999, Delaney et al. 2011). As a general rule of thumb, humans perceive a twofold increase in loudness for every 10-decibel (dB) increase in measured sound. Received sound level can vary widely, by as much as 50 dB, and over very short time intervals, as a result of slight variations in atmospheric temperature and wind (Pater et. al. 2009). Our recording procedures eliminated such unknown stimulus variation that would have resulted from using only a representative or average value for noise stimulus events.

We measured sound stimulus events directly below the observed nesting goshawks at the base of each nest tree, ~1 m above ground and ~1 m from the tree. Our high quality, professional grade, sound measurement equipment had sufficiently constant sensitivity over the frequency range of interest to avoid artificial accentuation or attenuation of sound energy at any of the tested frequencies. Sound stimuli were recorded with Bruel & Kjaer (B&K) Type 4149, 1.3-cm microphones, powered by Type 2639 preamplifiers, and Type 2804 power supplies. The resulting electrical signal was recorded on Sony Walkman, Model TCD-D8, digital audio tape (DAT) recorders. The system was calibrated, before and after each data session at each nest site, with a 94-dB, 1-kHz steady tone signal generated by a B&K Type 4250 sound level calibrator.

Data reduction from the audio tapes to digitized tabular data values was accomplished by playing the field-recorded tapes on the Sony DAT recorders into a Rion Model NA-27 sound level meter and 1/3 octave band analyzer, with the microphone replaced by a BNC connector. The recorded pre-calibration signal was used to adjust the Rion NA-27 calibration before reducing the data from any session. The post-calibration signal was used to check for system drift during the session. (Drift never exceeded a small fraction of 1 dB, which is excellent system stability.) Resulting data files were transferred to computer memory for analysis. To gain subjective perspective during identification, evaluation, and analysis, LLP listened to a playback of every noise stimulus event, and also sampled ambient sound, during data reduction.

Sound Measurements

Average Sound Level (LEQ) – Animal (as well as human) responses to sound may depend on sound level, rate of onset, duration, number of events, spectral distribution of sound energy, presence of pure tones, and relative level of background noise. The sound stimuli of primary interest in the current study are due to logging trucks, but we also measured and observed response to airplanes and several other wheeled vehicles that chanced to pass by. These sound stimuli become louder and then fade over a period of many seconds. An appropriate measurement procedure is to measure the average sound level during successive seconds (1-sec LEQ). The most significant aspect of this measurement is the maximum 1-sec LEQ value during a sound event (Figure 2). Total duration of the sound signal that is above a specified level (usually 10 dB below the maximum value) is also of interest. We also calculated an estimated, adjusted CLEQ, to use in most of our subsequent analyses, because this approach removes much of the audio contamination (wind noise in our case) from the overall event metric or LEQ.

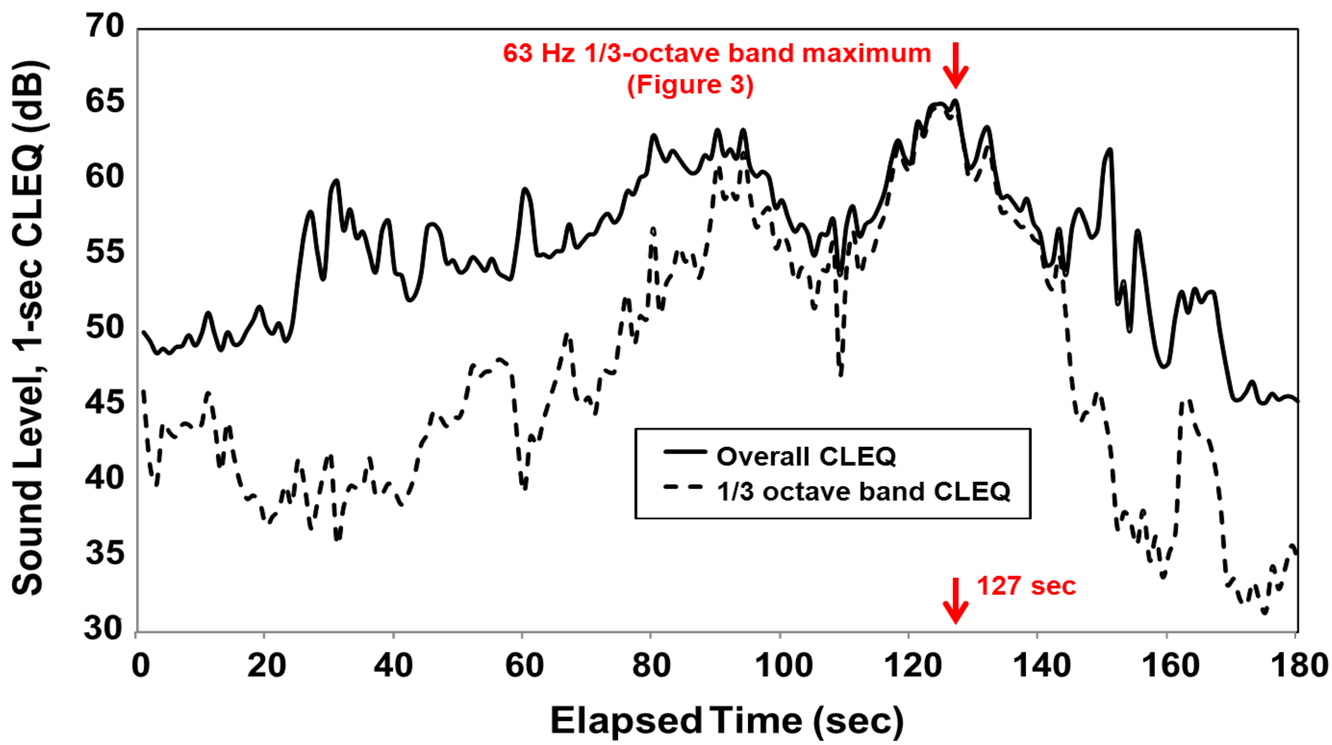

Figure 2. Logging truck and ambient sound level versus elapsed time, 1-sec C-weighted LEQ metric, overall level and 63 Hz center frequency 1/3 octave band level, nest 108D, 8 June 2010, 1017 MST. The logging truck (63 Hz band) sound is initially a small portion of the overall sound, then increases as the truck nears closest approach at about 127 sec, then fades as distance to the truck increases.

Spectrum – The noise sources in the present study produced sound energy distributed over a range of frequencies. Characterizing such a noise stimulus adequately requires not only the value of an appropriate overall sound level metric (such as 1-sec LEQ), but also a spectrum that shows how the magnitude of that sound metric varies with frequency (pitch). We measured spectra using 1/3-octave, constant-percentage width, frequency bands (Figure 3), which are denoted by the center frequency of each band. These frequency bands cover an increasingly wider range of frequencies as frequency increases (ANSI S1.6 2001), which is appropriate for animal auditory systems because of their generally logarithmic response. We used spectral analysis to identify and differentiate separate maximum average sound levels (LEQ) resulting from ambient wind noise (particularly 12-40 Hz), logging trucks (63 and 80 Hz), and aircraft (100 and 125 Hz).

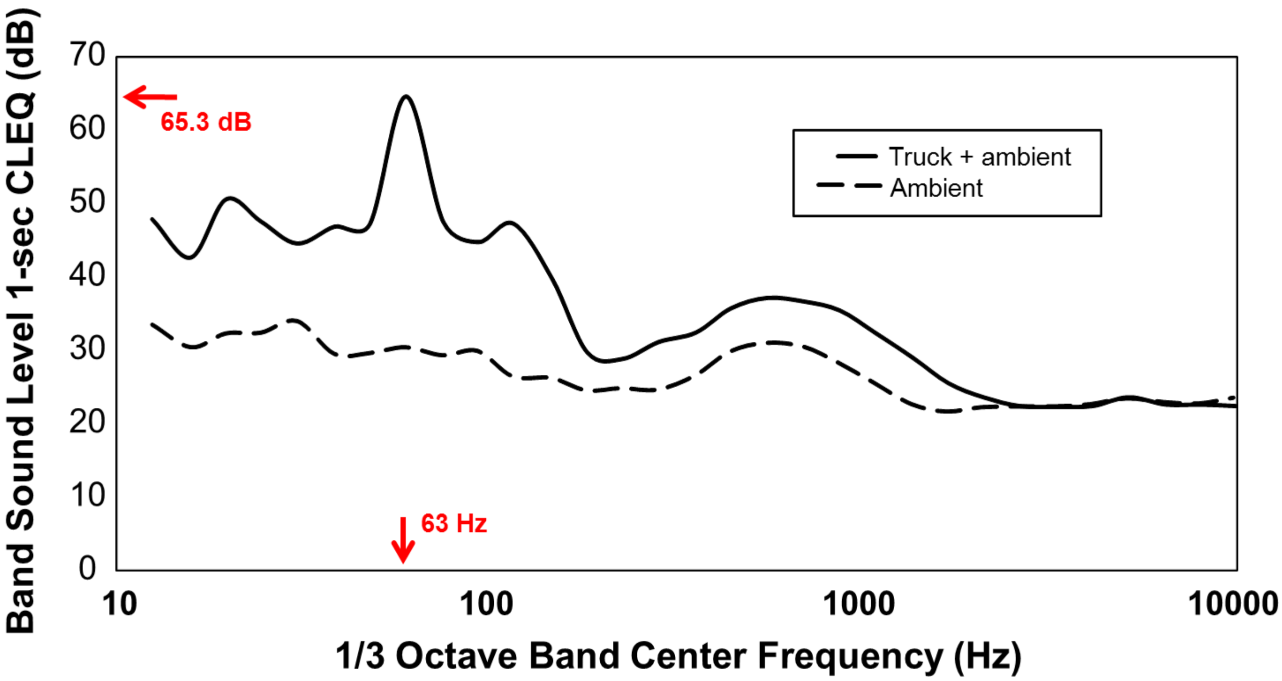

Figure 3. Logging truck and ambient sound spectrum, 1/3 octave band 1-sec C-weighted LEQ, nest 108D, 8 June 2010, at 1017 MST, at the time that the 63 Hz band level, logging truck noise is maximum (Figure 2). The ambient spectrum, due primarily to wind, was measured at 0713 MST when wind speed was lower.

Audiogram – An audiogram describes a human's or animal's hearing range and sensitivity. An audiogram of the species being studied is useful to guide interpretation of noise-response data (see Delaney et al. 1999, Pater et al. 2009, and Grubb et al. 2010 for examples). Audiograms tend to be U-shaped because hearing becomes less sensitive (i.e., requiring higher sound levels to be heard) at the extremes of the hearing frequency range. Human hearing range is roughly from 20 to 20,000 Hz. Birds typically do not hear higher and lower frequency sound as well as humans (Figure 4), illustrating that animal perception of sounds cannot generally be accurately inferred based on human perception alone. Comparing the spectrum of a sound with the audiogram of an animal can aid in response interpretation. For example, an animal is unlikely to respond to a sound that occurs at frequencies outside of its hearing range (Delaney et al. 1999), Grubb et al. 2010).

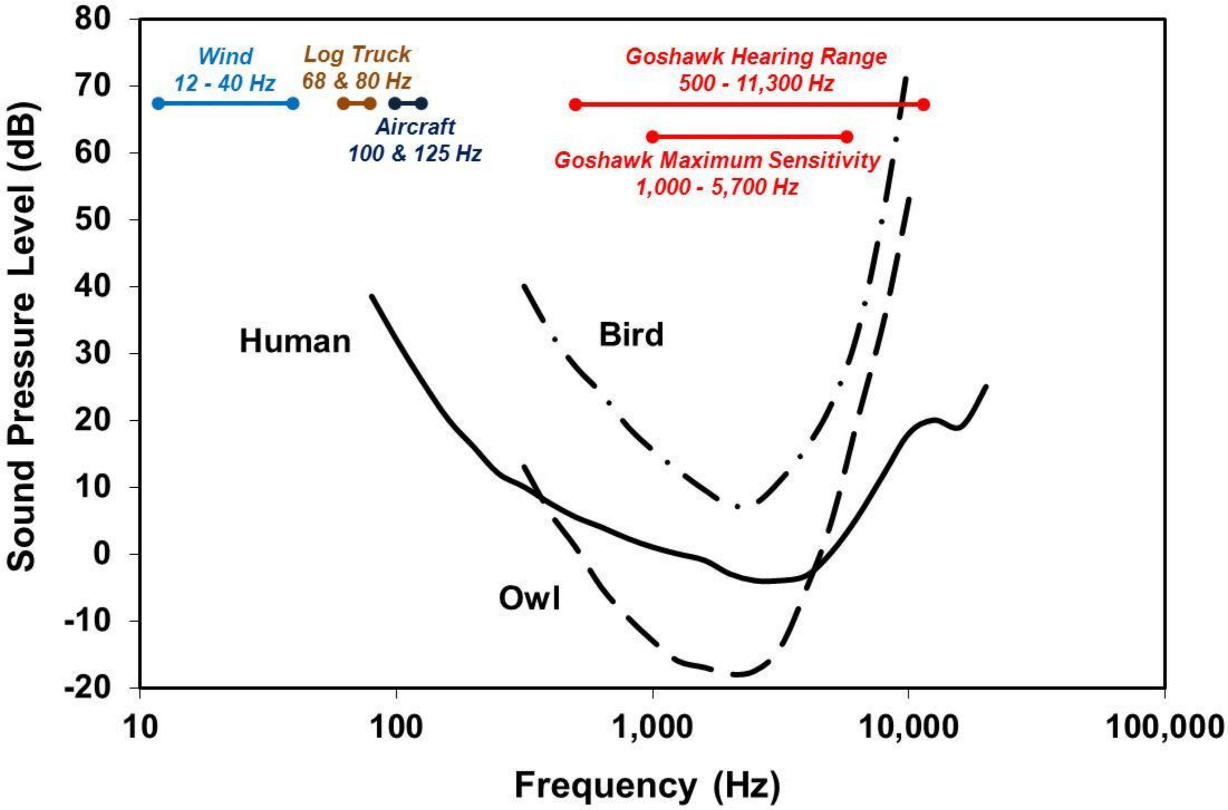

Figure 4. Audiograms for 1) a composite average developed for 7 orders of birds (Dooling 1980, Dooling et al. 2000), 2) a composite average for owls (*Strigiformes*, Trainer 1946, Konishe 1973), and 3) a human threshold audiogram (International Organization of Standardization (ISO) 226 2003), illustrating differences in hearing range and sensitivity among species. (dB = decibels; Hz = hertz; modified from Pater et al. 2009). Also indicated are frequency ranges and peaks for wind, logging truck, general aviation aircraft; as well as northern goshawk hearing range and range of maximum hearing sensitivity (Yamazaki et al. 2004).

Frequency Weighting – Frequency weighting (ANSI S1.4 2001) is a filtering algorithm of frequency-dependent attenuation. A frequency weighting scheme that simulates the hearing sensitivity and range of a study species can be applied to a sound event to more meaningfully correlate stimulus sound with species' response. An example is the ubiquitous "A" weighting that filters sound energy according to human hearing range and sensitivity at moderate sound levels (ANSI S1.4 2001). Weighting systems developed for humans are not strictly appropriate for animal species that have significantly different audiograms (Bowles and Pater 2000). If a weighting filter is available, species-specific weighting can be implemented by measuring the sound stimulus in terms of a metric such as 1/3 octave band 1-sec LEQ (determined by sound level meters, or post-processing of recordings such as in this study), applying attenuation values to the frequency band metrics, and then calculating overall broad-band weighted values. In the absence of a species-specific audiogram for northern goshawks as well as to provide a more familiar metric frame of reference, we have included maximum 1-sec ALEQ (A-weighted, unadjusted) decibel levels in our results (see Table 1).

In the current study, we used frequency weighting to deal with the turbulence associated with wind flowing over microphones and causing low frequency contamination of the stimuli sound recordings. The standard "C" frequency weighting filter strongly attenuates such low frequency signals without significantly attenuating vehicle noise signals in the 80-125 Hz 1/3-octave bands. Data reduction yielded values for C-weighted 1-sec LEQ, both 1/3-octave band levels and overall levels, for successive seconds during the entire event for which the stimulus event was <10 dB of the maximum 1-sec C-weighted LEQ. We also calculated values for A-weighted 1-sec LEQ by determining the difference between the A and C filters on the C-weighted spectral data. The C filter attenuated by -0.5 dB at 80 Hz (characteristic of the logging trucks), -3 dB at 31.5 Hz, and -10 dB at 10 Hz. These attenuations caused no significant degradation of the truck or aircraft noise, but did help to screen out spurious wind noise. Noise levels that were between 5-10 dB higher than ambient sound level were adjusted to a lower value (Adjusted CLEQ) that more accurately represented the actual sound level of a truck or aircraft. We used Adjusted CLEQ as our final, comparative metric. Stimulus noise levels <5 dB above ambient levels were unreliable and not included in analyses.

Ambient Sound – Ambient, or background, sound due to insects or rustling vegetation for example, is defined as all sound other than the sound of interest. Event level measurements may be compromised by background sound, particularly wind as during the series of experiments reported here. Wind noise is concentrated at low and very low frequencies, and is the result of air flowing over the microphone. The associated turbulence causes pressure fluctuations at the microphone diaphragm which are of course recorded as sound. Air flow over a microphone can introduce spurious, very-low-frequency noise into a measurement. Use of open-cell foam wind screens and low-cut filters minimizes this problem. A noise event measurement will not accurately measure the event level unless the event sound is at least 10 dB louder than the ambient sound. Both the overall ambient level and its level within the primary bands of event acoustic energy are required to evaluate this criterion during data analysis. Figure 3 illustrates the ambient component associated with 1 logging truck, maximum noise level recorded during this study. Any report of noise event measurements should always include a description and measurement of ambient sound before and after noise events. Event measurements can sometimes be corrected for ambient sound contribution to the measurement when the event level is between 3-10 dB above ambient. A qualitative description of the event and ambient noise helps to define the noise environment. Careful examination of the time-varying, overall sound level measurements and sound spectra (Figures 2-3) was often required to accurately identify the truck noise level on windy days.

Other Sound Measurement Considerations

Species-Specific Frequency Weighting -- We considered using a northern goshawk (or related species) audiogram to develop a frequency weighting (attenuation) curve that could be used to get a sense of how this particular species might perceive truck and airplane noise. However, available hearing data for birds generally does not extend below about 500 Hz (in part due to technical limitations associated with measuring avian hearing acuity), and the frequency range of primary interest for trucks and airplanes is in the range of 50 to 125 Hz. Extrapolating hearing data to such low frequencies cannot be done with acceptable reliability. In the absence of sufficient guidance to develop a weighing filter for this particular species, using the A-weighting filter for a species that is likely to have a narrower hearing sensitivity spectrum will at least approximate the attenuation of high and low frequency sound, which is why we included maximum 1-sec ALEQ (A-weighted, unadjusted) dB levels in our results.

Microphone Placement – Ideally, the noise stimulus should be measured at the exact location occupied by the animal. Practical considerations often dictate that recording microphones be placed at locations that minimize disturbing the animals, such as directly below adult-occupied nests in this study. This must be carefully done to ensure that microphone placement yields sound measurements that represent as nearly as practical the sound stimulus to which the animal is exposed. For example, a microphone located at the base of a tree may not accurately characterize the sound at a nest high up in the tree. One useful technique is to establish a correction, based on sound measurements at both the animal location and the data microphone location, made when the animal is not present, that can be used to extrapolate the sound measurements from the data microphone location to the animal location during response observations. Although recordings from ground and tree microphones required for such an extrapolation were collected on NKRD by Carrie King (unpubl. data) in 2001 and 2002, the cost to benefit ratio in terms of time and money to reduce those tapes was beyond the scope of this current study. We also deemed further analysis unnecessary because a) we observed no response during our study, regardless of whether sound levels were louder in the tree, b) most managers are typically unable to place microphones for future assessments anywhere other than on the ground, and c) distance remains the primary management consideration over sound level, whether measured on the ground or in the tree.

Dose-Response – One way to express the observed responses of an animal to noise is by means of a “dose-response model,” an equation or graph that describes how the probability of a specific response measure varies with noise stimulus level. Response probability is expected to be negligible at very low stimulus levels and approach 100% at high stimulus levels. In the present study, no significant responses or impacts were observed. We thus established a lower limit for the response threshold, in terms of noise level and noise source distance for our primary stimulus, logging trucks. Using distance, rather than noise level, as the independent variable for response provides less information regarding subjects’ response to noise, and may entail larger variance in noise stimulus data because the noise level almost always varies substantially due to changing sound propagation conditions. However, distance is a straight forward metric to utilize for management purposes.

Terminology

Goshawk Response – Northern goshawk response behaviors were defined as follows: None, 0 = no visible response; Alert, 1 = look toward sound source; React, 2 = move, sit lower, stand up, twitch wings, call; and Flush, 3 = fly off the nest, after Grubb et al. (2010) and consistent with Pater et al. (2009) recommendations.

Forest Service Road Maintenance Levels – These are defined as the level of service provided by, and maintenance required for, a specific road, consistent with road management objectives and maintenance criteria. (Forest Service Handbook (FSH) 7709.58, 12.3). Roads associated with our test nest sites were Level 3. Levels 4 and 5 which are not included here primarily describe paved roadways.

Maintenance Level 1. Assigned to intermittent service roads during the time they are closed to vehicular traffic. The closure period must exceed 1 year. Basic custodial maintenance is performed to keep damage to adjacent resource to an acceptable level and to perpetuate the road to facilitate future management activities. Emphasis is normally given to maintaining drainage facilities and runoff patterns. Planned road deterioration may occur at this level. Appropriate traffic management strategies are "prohibit" and "eliminate". Roads receiving level 1 maintenance may be of any type, class or construction standard, and may be managed at any other maintenance level during the time they are open for traffic. However, while being maintained at level 1, they are closed to vehicular traffic, but may be open and suitable for non-motorized uses (FSH 7709.58, 12.3).

Maintenance Level 2. Assigned to roads open for use by high clearance vehicles. Passenger car traffic is not a consideration. Traffic is normally minor, usually consisting of one or a combination of administrative, permitted, dispersed recreation, or other specialized uses. Log hauling may occur at this level. Appropriate traffic management strategies are either to (1) discourage or prohibit passenger cars or (2) accept or discourage high clearance vehicles (FSH 7709.58, 12.3).

Maintenance Level 3. Assigned to roads open and maintained for travel by a prudent driver in a standard passenger car. User comfort and convenience are not considered priorities. Roads in this maintenance level are typically low speed, single lane with turnouts and spot surfacing. Some roads may be fully surfaced with either native or processed material. Appropriate traffic management strategies are either "encourage" or "accept." "Discourage" or "prohibit" strategies may be employed for certain classes of vehicles or users (FSH 7709.58, 12.3).

Noise-Related Terms – Although described in detail when introduced above, the following terms are redefined again here to facilitate easy reference.

Ambient. Ambient, or background, sound due to insects or rustling vegetation for example, is defined as all sound other than the sound of interest.

Audiogram. An audiogram describes a human's or animal's hearing range and sensitivity. An audiogram of the species being studied is useful to guide interpretation of noise-response data.

Average Sound Level (LEQ). For more or less constant sounds, such as traffic noise and most ambient noise, a measure of averaged sound level is most appropriate, using the metric equivalent average sound level (LEQ) over a specified time period, such as 1 sec. (By comparison, sound exposure level (SEL) not used during this study, is generally accepted as the best metric for brief noise events, especially those <1 sec in duration, like blasts or gunshots.)

Decibel. Sound levels are measured on a logarithmic decibel (dB) scale, which corresponds fairly well to the human hearing response (dB = 10 Log_{10} sound intensity/threshold sound intensity). Common interpretation and usage is that decibel levels are a measure of loudness.

Frequency Weighting. This is an algorithm of frequency-dependent attenuation, a filter, often used to simulate the hearing sensitivity and range of a study species. The ubiquitous "A" weighting filters sound energy according to human hearing range and sensitivity at moderate sound levels. "C" weighting de-emphasizes lower frequencies, which helped reduce impacts of wind noise prevalent in our measurements. Unweighting or "flat" weighting means no weighting or filtering at all.

Noise. Noise is a subjective term used to denote unwanted, typically annoying or disturbing, sound.

Reduction. The process of converting raw, field-acquired, digital recordings of noise events into analytically usable, frequency and sound level data. Ideally date/time linked with target species behavioral observations to develop dose-response thresholds.

Sound. Most commonly understood as a phenomenon of pressure waves emanating from a sound source and propagating through the atmosphere. Measured in decibels (dB). Sound pressure levels vary substantially with distance from source and also diminish as a result of intervening obstacles and barriers, air absorption, wind, and other factors.

Spectrum. A spectrum shows how the magnitude of a sound metric (dB level) varies with frequency (pitch), which is usually measured in hertz (Hz, cycles per sec). In our analysis, we measured spectra using 1/3-octave, constant-percentage width, frequency bands. These bands cover an increasingly wider range of frequencies as frequency increases, which is appropriate for animal auditory systems and their logarithmic response.

Statistical Analyses

Frequencies, means, and Student's *t*-tests for stimulus sound levels (dB) were calculated with Microsoft Excel spreadsheet software (Microsoft Office Professional Plus 2010, Microsoft Corporation). Multiple comparisons of average sound levels across sites or stimulus types, and among response rates within or between stimuli were calculated using One-Way Analysis of Variance (ANOVA) and Crosstabs (chi-square, χ^2) procedures within PASW Statistics 18 (SPSS, Inc., 2009). Graphs and bar charts were built in Excel and in most cases refined for presentation with Microsoft PowerPoint (Microsoft Office Professional Plus 2010, Microsoft Corporation).

RESULTS

Acoustical Findings

We recorded 94 sound/response events at 3 adult occupied northern goshawk nests, at 3 different distances from the nearest road (167, 143, and 78 m) during 4 test sessions (07, 08, 10, and 11 Jun 2010): 60 experimentally controlled logging trucks; 30 non-experimental, passive civilian light aircraft; 3 non-experimental, passive cars; and 1 non-experimental, passive ATV (Table 1). There were 14 logging truck and 9 aircraft events recorded at nest 5C; 23 trucks, 10 aircraft, and 4 cars/ATVs at nest 71D; and 23 trucks and 11 aircraft at nest 108D (Figure 1).

Logging truck sound was concentrated in the 63 and 80 Hz 1/3-octave frequency bands, principally engine and exhaust sound. Some higher frequency sound which could be clearly heard on the DAT recordings, was typically present, due to banging of log chain or other metal parts. Airplane sound was concentrated in the 100 and 125 Hz 1/3-octave frequency bands. Aircraft mean noise levels at the 3 nest sites ranged between approximately 60-66 dB, maximum 1-sec adjusted CLEQ (Figure 5).

At nest 5C (167 m from closest road) the logging truck averaged about 8 dB quieter than the aircraft (*t*-test, $P < 0.001$). At nest 71D (143 m) the logging truck was about 3 dB quieter than passing aircraft (*t*-test, $P = 0.026$). Only at nest 108D (78 m) was logging truck noise louder on average than aircraft, by about 6 dB (*t*-test, $P < 0.001$).

Mean aircraft noise levels for each day of testing ranged between 45.6-67.9 dB, and varied little among the 3 test sites, 60.1-65.6 dB (F = 2.008, $P = 0.154$, df = 29; Table 1; Figure 5), yielding an overall combined aircraft average noise level for 30 recorded response events of 63.2 dB adjusted CLEQ. These aircraft levels could be combined into an overall average because stimulus distance variation among nest sites was negligible when flight altitudes of general aviation, civilian aircraft were taken into account, whereas logging truck noise levels varied significantly among nest sites and with distance from roads (F = 36.753, $P < 0.001$, df = 59; Table 1; Figure 5). If this inherent variation of truck noise with distance is temporarily overlooked for the sake of a generalized comparison, our test logging truck (61.9 dB adjusted CLEQ) was no louder on average than passing aircraft (62.3 dB adjusted CLEQ; *t*-test, $P = 0.191$), which goshawks generally ignored (see below, Figures 6 and 8).

At site 71D, which was the only test location with all 3 types of stimuli, car and ATV data were limited (n = 4). However, sound levels (averaging 55.7 dB adjusted CLEQ) were much less than either the logging truck (*t*-test, $P = 0.028$) or passing aircraft (*t*-test, $P = 0.005$; Table 1; Figure 5).

Goshawk Response

Our test logging truck resulted in 27% no response and 73% alert response (n = 60); passing aircraft resulted in 90% no response and only 10% alert response (n = 30); and 3 cars and 1 ATV, combined, resulted in 50% each for no response and alert response ($\chi^2 = 82.365$, P < 0.005; Figure 6). There were no movements or flushes associated with either our experimental testing or passive recording of the other noise stimuli. All tested pairs of goshawks successfully fledged young. Goshawk alert response rates were inversely proportional to nest distance from the nearest road ($\chi^2 = 29.861$, P < 0.005; Figure 7), increasing from 57% to 91% alert between site 5C (167 m from road) and 108D (78 m from road). Goshawks generally did not respond (89-100% no response) to passing aircraft (Figure 8) and were typically less responsive to aircraft than to the logging truck ($\chi^2 = 81.742$, P < 0.005), although in most cases aircraft were louder than the logging truck (Table 1, Figure 5). As would be expected, response rates to aircraft did not vary among test sites ($\chi^2 = 21.657$, P < 0.005). However, adult goshawks at each of the 3 tested nest sites responded quite differently to the logging truck and passing aircraft ($\chi^2 = 22.178$, P < 0.005; Figure 9).

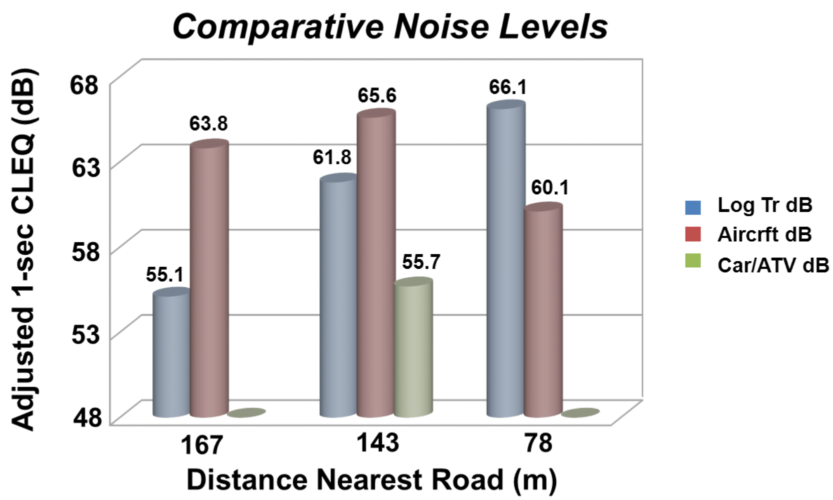

Figure 5. Comparative logging truck, aircraft, and car/ATV noise levels (adjusted maximum 1-sec CLEQ dB) measured near 3 adult occupied northern goshawk nests, 167, 143, and 78 m from nearest road on the North Kaibab Ranger District, Kaibab National Forest, Arizona, 2010.

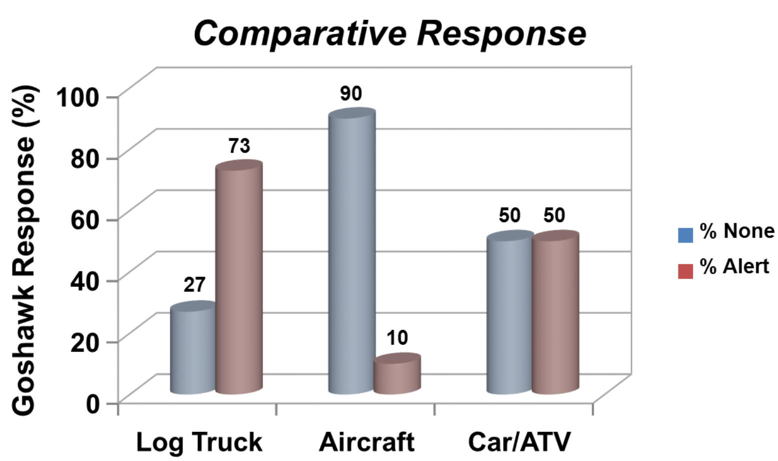

Figure 6. Comparative responsiveness of northern goshawks to logging truck, aircraft, and car/ATV noise levels recorded near 3 adult occupied nests on the North Kaibab Ranger District, Kaibab National Forest, Arizona, 2010.

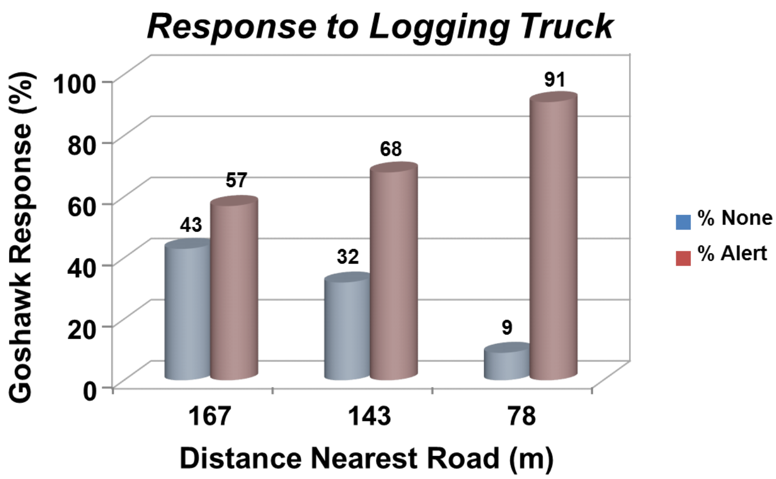

Figure 7. Comparative responsiveness of northern goshawks to logging truck noise levels recorded near 3 adult occupied nests at 167, 143, and 78 m from the nearest road on the North Kaibab Ranger District, Kaibab National Forest, Arizona, 2010.

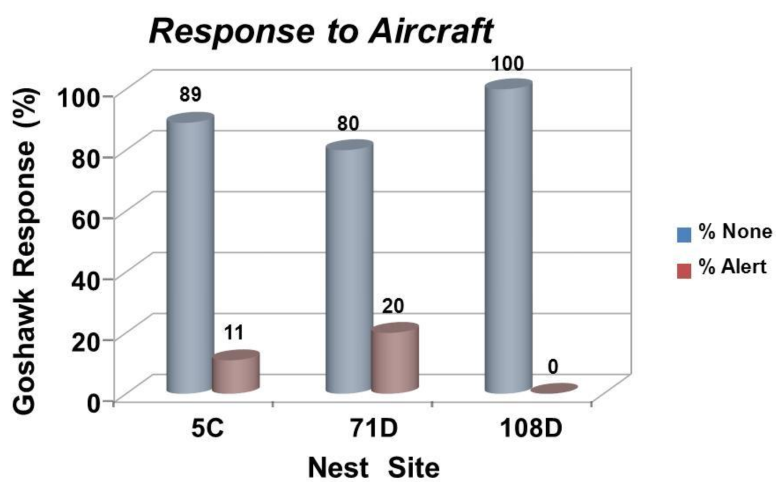

Figure 8. Comparative responsiveness of northern goshawks to passive, civilian aircraft noise levels recorded near 3 adult occupied nests at 167, 143, and 78 m from the nearest road on the North Kaibab Ranger District, Kaibab National Forest, Arizona, 2010.

Typically, observed goshawks, whether they were on or off the nest, spent much time just looking around, and sometimes shifting their gaze towards or responding to, branch snaps, passing squirrels (*Sciurus aberti kaibensis*, *Tamiasciurus hudsonicus*), deer (*Odocoileus heminonus*), ravens (*Corvus corax*), another raptor, or the observers. Sometimes it was clear when a goshawk looked toward a sound, whereas other times it seemed they just happened to be looking around when the noise event occurred. These instances were all classed as alert (1) response, as a conservative procedure. Often goshawks showed no response at all to a sound source. In general, if goshawks were feeding young or preening or interacting with a mate, they ignored noise events. When sitting quietly, they either ignored the event or looked in the direction of the source, as they did with various other natural events. Field observers noted that goshawks were more relaxed and less responsive to noise events after recently eating prey. Sometimes during our experimental testing, the observed goshawk was occupied with some activity such as preening or feeding young and made no acknowledgement of the sound source. These were classed as no response (0). As mentioned, there were no instances of movement (2) or flush (3) response classifications. However, goshawk movements were observed as they shifted position or stood up and sat back down on the nest as part of normal behavior. Because the stimulus event sound level for both logging trucks and aircraft rose gradually to a maximum and then gradually faded over a period of a few minutes, there was no startle effect from our recorded stimuli.

Anecdotal Observations

On 26 June 2009, preliminary to this study, observations were recorded during timber-related activities (grading, loading and hauling) at nest 22C near Forest Service Level 3 roads 752/753. During a 5-h observation period, an adult northern goshawk at the nest with 1 young was aware of these activities, as evidenced by direction of head movements; but the bird did not move or flush from the nest. However, at one point a second adult circled above and made 2 alarm calls directed at a ground crew working just off the roadway. Similarly, the collective experience of NKRD and RMRS field crews also reveals that biologists' arrival at a nest site does not typically elicit an alarm call from attending adults until the nest is actually approached. Field crews are required to wear personal protective equipment (hard hats and goggles) to prevent injury from an aggressive adult goshawk defending its territory. The behaviors of the adults at 22C mentioned above were congruent with what would be expected based on 20 years of goshawk field observations on the NKRD. Activities on the road alone did not elicit a response, however any personnel appearing to approach a nest definitely did.

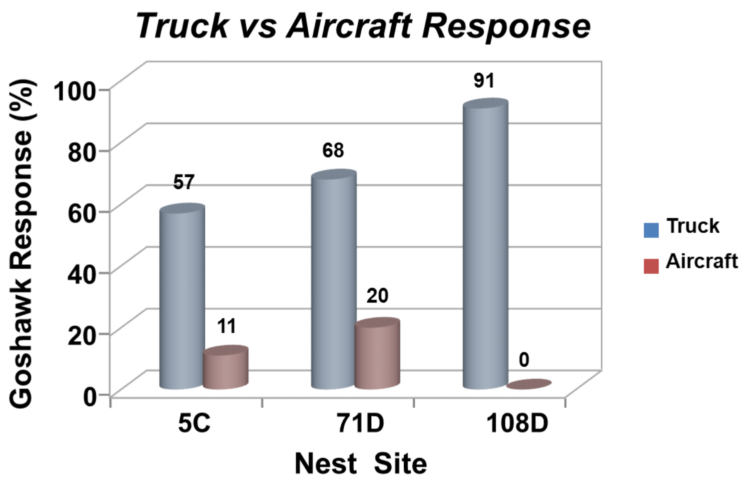

Figure 9. Comparative responsiveness of northern goshawks to logging truck and passing civilian aircraft noise levels recorded near 3 adult occupied nests on the North Kaibab Ranger District, Kaibab National Forest, Arizona, 2010.

Table 1. Mean decibel (dB) levels of logging truck and aircraft noise recorded at 3 nesting northern goshawk (*Accipter gentilis*, NOGO) nests on the North Kaibab Ranger District, Kaibab National Forest, 2010, with associated northern goshawk response (0 = none, 1 = alert, 2 = move, 3 = fly).

Test Site	**Source Distance (m)**	**Date**	**Event Type**	**(#)**	**NOGO Response 0**	**1**	**≥2**	**Max 1-sec CLEQ (dB)**	**Backgrd CLEQ (dB)**	**Δ Event - Backgrd CLEQ (dB)**	***Adjusted* Max 1-sec CLEQ (dB)**	**Max 1-sec ALEQ (dB)**
5C	167	08 Jun 10	Truck	(5)	2	3	0	56.1	43.5	12.7	55.8	42.6
	>150		Airplane	(6)	5	1	0	63.4	45.5	17.9	63.2	50.2
		10 Jun 10	Truck	(3)	1	2	0	55.5	50.0	05.5	53.9	47.8
			Airplane	(2)	2	0	0	66.8	52.0	14.8	65.9	56.6
		11 Jun 10	Truck	(6)	3	3	0	56.0	48.6	07.4	55.0	42.0
			Airplane	(1)	1	0	0	63.1	51.5	11.6	63.1	52.8
		Site 5C	***Truck***	***(14)***	***6***	***8***	***0***	***55.9***	***47.1***	***08.9***	***55.1***	***43.5***
		Summary	***Airplane***	***(9)***	***8***	***1***	***0***	***64.1***	***47.6***	***16.5***	***63.8***	***51.9***
71D	143	07 Jun 10	Truck	(8)	2	6	0	61.3	50.7	11.8	60.6	48.0
	>150		Airplane	(2)	1	1	0	68.1	52.6	15.5	67.9	55.1
			ATV	(1)	1	0	0	58.6	45.8	12.8	58.4	44.8
		08 Jun 10	Truck	(6)	3	3	0	63.6	48.1	15.4	63.4	47.4
			Airplane	(5)	5	0	0	63.7	45.2	18.5	63.6	50.0
		10 Jun 10	Truck	(3)	1	2	0	63.0	53.7	09.3	62.0	49.0
			Airplane	(2)	1	1	0	66.2	52.0	14.2	65.4	52.5
		11 Jun 10	Truck	(6)	2	4	0	62.2	50.8	11.3	61.8	48.6
			Airplane	(1)	1	0	0	60.0	48.0	12.0	59.7	45.6
			Car	(3)	1	3	0	55.6	46.7	08.9	54.9	45.3

Test Site	Source Distance (m)	Date	Event Type (#)		NOGO Response 0 1 ≥2	Max 1-sec CLEQ (dB)	Backgrd CLEQ (dB)	Δ Event - Backgrd CLEQ (dB)	*Adjusted* Max 1-sec CLEQ (dB)	Max 1-sec ALEQ (dB)
		Site 71D Summary	***Truck***	***(23)***	***8 15 0***	***62.3***	***50.4***	***12.3***	***61.8***	***48.1***
			Airplane	***(10)***	***8 2 0***	***65.7***	***48.3***	***17.4***	***65.6***	***51.6***
			Car	***(4)***	***2 2 0***	***56.4***	***46.5***	***09.9***	***55.7***	***45.2***
108D	78	08 Jun 10	Truck	(8)	1 7 0	66.7	48.9	17.8	66.6	48.0
	>150		Airplane	(5)	5 1 0	59.3	45.2	14.1	58.8	46.9
		10 Jun 10	Truck	(7)	1 6 0	66.8	54.0	12.8	66.5	53.1
			Airplane	(1)	1 0 0	64.7	59.0	05.7	63.3	59.4
		11 Jun 10	Truck	(8)	0 8 0	65.6	53.8	11.9	65.2	50.8
			Airplane	(5)	5 0 0	61.7	52.4	09.3	60.8	50.1
		Site 108D Summary	***Truck***	***(23)***	***2 21 0***	***66.4***	***52.1***	***14.2***	***66.1***	***50.5***
			Airplane	***(11)***	***11 0 0***	***60.9***	***49.7***	***11.1***	***60.1***	***49.5***

DISCUSSION

Goshawk Response

At the outset, it is important to clarify that even though we have presented northern goshawk response rates in the foregoing results, and will discuss them further in this section, *we observed no discernible, potentially detrimental responses during this study*, i.e. there were no agitated movements (response level 3) nor flushes (response level 4). All of our results and further discussion are based on distinguishing between the nuances of no observed response (level 1) and alert response (level 2, or looking in the direction of stimuli, whether active or passive in nature).

Goshawk response to our logging truck was inversely proportional to distance from the road and directly related to noise level (Table 1, Figures 5 and 7). Both logging truck and aircraft noise is predominantly very low frequency and therefore at the lower extreme of goshawk hearing sensitivity (Figure 4; see below), which helps explain the absence of any significant or detrimental response, as similarly recorded for military helicopters in New Mexico with Mexican spotted owls (*Strix occidentalis*, Delaney et al. 1999) and in Utah with golden eagles (*Aquila chrysaetos*, Grubb et al. 2009). Neither stimulus was visible to our Arizona goshawks due to intervening forest canopy, but they may still be more acclimated to aircraft noise when compared to less common and sporadic log truck noise. The higher frequency aspects of truck noise, associated with banging chains and other metal parts, may also attract attention. Goshawks may be more likely to look in the direction of passing logging trucks simply because they are a ground-based activity that may often be associated with more disturbing secondary activities, such as loggers with chainsaws, tree felling, log yarding and loading. Chainsaws were more disturbing at closer distances to Mexican spotted owls than much louder HH-60 Pave Hawk helicopters (Delaney et al. 1999). Similarly Grubb and King (1991) found ground-based human activities to elicit greater response from nesting bald eagles (*Haliaeetus leucocephalus*) than aircraft.

The only meaningful comparison of aircraft and logging truck noise levels (Figure 5) with associated response rates (Figure 9) must be made on a site-specific basis because of the powerful effect distance to road had on logging truck metrics. The approximately 11 dB difference in noise levels at site 5C (167 m) and 108D (78 m) suggests, at least to human hearing, the noise level at the nearer site was double that at the farther one. Very few goshawk nests are found near roads on the Kaibab Plateau, so at most nest sites, civilian aircraft flying overhead are likely louder than any passing logging trucks. Further, noise levels from logging trucks at almost all goshawk nests can be expected to be less than noise levels measured during this experimental research because of the greater distances of most nests from roads. Thus any associated logging truck noise is even less likely to elicit any goshawk response.

Noise Context

To set a general context for interpreting our results, as previously mentioned, a 10-dB increase in noise level results in a doubling in perceived loudness to humans. The smallest change in noise level that humans can reliably perceive is ~3 dB. Increases of 5 dB or more are clearly noticeable. Under ideal conditions (i.e., no intervening buffering), a line noise source (such as flowing traffic on a busy highway) decreases at a rate of ~3 dB each time distance from the source doubles (U.S. Dept. of Labor 1983, 29 CFR 1910.95). The Federal Highway Administration (FHWA) has identified roadway noise abatement criteria for 5 land use categories, 2 of which potentially apply to U.S. Forest Service wild or urban lands: Type A for "lands on which serenity and quiet are of extraordinary significance…," 57 dBA (A-weighted); and Type B for "picnic areas, recreation areas, active sports areas…," 67 dBA. The sound levels in these criteria are long-term average sound levels. Our logging truck noise levels (43.5-50.5 dBA, Table 1) fall well below even the more conservative FHWA standard. Similarly, the Federal Department of Housing and Urban Development (HUD) noise requirements for environmental noise state an average daytime exterior noise level of 65 dBA or less is "acceptable", whereas daytime exterior noise levels of 75 dBA or greater are "normally unacceptable." HUD nighttime exterior noise levels, between 2200-0700 must be 10 dBA lower than daytime levels, i.e. <55 dBA (HUD Regulations 24 CFR Part 51B). Again our logging truck noise levels fall below even this most conservative HUD exterior noise standard for urban developments. In addition, our reported noise levels are maximum 1-sec levels that only briefly approach the long-term-average criteria levels of these standards.

The Noise Control Act (1972) established Environmental Protection Agency (EPA) noise emission standards for off-road motorcycles depending on engine displacement and year of manufacture (80-86 dBA; 40 CFR 205.152, revised 1998). Standardized testing procedures for measurement of exhaust sound levels of stationary motorcycles were established by the Society of Automotive Engineers (SAE, Surface Vehicle Standard J1287, reaffirmed 1998). However, primary responsibility for control of noise has for years rested with state and local governments, resulting in a range sometimes within, as well as among states of 92-99 dBA for maximum OHV noise emissions. Recently, many states have adopted a 96 dBA standard (e.g., AZ, CA, ME, OR, WI) for off road motorcycles as well as ATVs. Most sources now indicate OHVs (motorcycles and ATVs) range between 90-100 dB (Table 2). Table 2 also provides reported generic sound levels for a variety of other related vehicles. The fact that car and ATVs recorded during our study were so much lower than these levels is probably a function of distance

Table 2. Relative sound pressure levels expressed in decibels (dB) for common vehicular sources, collected from a variety of literature and online references (including Beranek 1988, EPA 1972, U.S. Dept. of Labor 1983), resulting in an approximate range of variation in relative 'loudness' for each vehicle group. *Italicized entries* are data collected by the authors during previous studies.

Source	**Decibels (dB) (Sound Pressure Level)**
Virtual silence – normal conditions	10
Rustling leaves	20
Whispering	30
Normal conversation @ 3-6 ft (1-2 m)	44-65
Passenger vehicles – 55 mph @ 50 ft	72-74
Cars	80-85
Motorcycles/Snowmobiles	88-100
ATVs	90-100
OHV motorcycles – Mendocino NF, 2000-2001[1,2]	*90 (max)*
Enduro race – Mendocino NF, 2000[1]	*96 (max)*
SUVs, 4x4s – 55 mph @ 50 ft	80-82
Semi-trucks, log haulers – 55 mph @ 50 ft	84-86
Truck traffic	90
Diesel truck	100
Road Maintenance Equipment – Lincoln NF, 2002[3]	*102 (max)*
Jet takeoff @ 650 m (2130 ft)	100
Large aircraft overhead @ 150 m (500 ft)	110
Jet plane @ 30 m (100 ft)	130
Jet engine	140
Pave hawk helicopter – Lincoln NF, 1996[4]	*100 (max)*
Apache helicopter – Wasatch-Cache NF, 2006-2007[5]	*110 (max)*

[1] *Delaney and Grubb (2001).*

[2] *Delaney and Grubb (2002).*

[3] *Delaney and Grubb (2003).*

[4] *Delaney et al. (1999).*

[5] *Grubb et al. (2007, 2010).*

from the roadway and screening vegetation. Limited variation among test sites for response to aircraft is not a function of distance but more likely is explained by goshawk pair differences, site differences that might affect exposure duration, different types of aircraft or some other subtle variability. Regardless of such inherent variation, having established requirements for vehicular, environmental, or exterior noise (such as SAE, FHWA, HUD standards) greatly facilitates developing case-specific management guidelines (Pierson 2009).

The NHWA 2004 synthesis of noise effects on wildlife (op. cit.) describes the hearing range for birds in general as between 100 and 10,000 Hz, with a typical best sensitivity level between 0-10 dB, owls being the exception with sensitivity to nearly -20 dB. Mammals on the other hand range between ~10 and 15,000 Hz, with sensitivity to -20 dB. Our recorded logging truck (63 and 80 Hz) and aircraft (100 and 125 Hz) sound levels occurred at rather low frequencies within the hearing range of humans and raptors. At such low frequencies, human hearing response is less acute than at higher frequencies. Based on available bird audiograms (Figure 4), raptor hearing seems to be even less sensitive at these low frequencies.

Logging Truck Noise Levels

Archibald et al. (1987) recorded noise levels (dBC, C-weighted) of logging trucks hauling on a road in British Columbia, Canada, along 18 transects at 25-m (0-200 m) intervals perpendicular to the road. Three of those intervals (75, 150, 175 m) approximated our 78, 143 and 167 m test distances, and corroborate our recorded noise levels, as well as validate our experimental use of an empty truck (Figure 10). It is unclear whether this Canadian study combined loaded and unloaded passes, or only passes of loaded haulers were recorded. All that was noted were 14-27 daily loads. Regardless, recorded noise levels between the 2 studies are remarkably close. Even at the farthest pair of distances, the difference is only ~3 dBC, which for humans is at the lower limit of perceptibility, and is most likely due to differing propagation conditions at the time of measurement, as well as differing vegetation and terrain buffering features between the Arizona and British Columbia study areas. Archibald et al. (op. cit.) developed 2, zone of hauling activity (zha) bands on either side of the road (50-m wide >80 dBC nearest, and 300-m wide 80 to 60 dBC secondary) to document grizzly bear (*Ursus arctos*) avoidance within these bands during log hauling. Our results indicated <67 dBC at just under 80 m from the hauling road with no negative impact on our targeted, nesting northern goshawks. Since goshawks on the Kaibab Plateau typically do not nest any closer to hauling roads, it would appear no special management restrictions or zones are necessary.

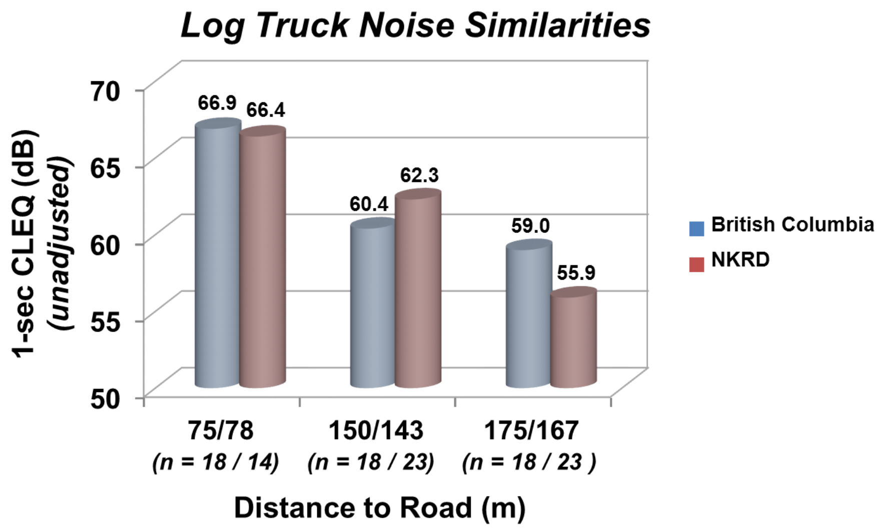

Figure 10. Comparison of logging truck noise levels (1-sec CLEQ dB, unadjusted) for an empty truck recorded near 3 northern goshawk nests on the Kaibab National Forest, Arizona, 2010, and round-trip log hauling (loaded and empty) measured by 18 transects at comparable distances from a logging road in British Columbia, 1984-1985 (Archibald et al. 1987).

Truck noise levels at nest 108D, which was located closest to the road at 78 m, were comparatively easy to analyze and interpret, largely because the truck sound signal level was usually substantially higher than the background sound, typically by about 18 dB. Truck noise data for nests 71D (143 m from the road) and nest 5C (167 m from the road) were more difficult to analyze because the signal to noise ratio was smaller, sometimes <10 dB that is generally considered to be adequate signal to noise ratio. About 15% of all recorded stimulus events had sound levels so near ambient that they could not be meaningfully adjusted and had to be discarded. Of the remaining 94 events, ~50% of aircraft and ~25% of truck events had maximum 1-sec CLEQ sound levels <10dB above ambient. These had to be adjusted to remove the contribution of ambient sound to the measured event level.

During data reduction and analysis, every event was listened to, along with samples of background sound. Truck noise and airplane noise are different in character, as verified by their measured spectra. Subjective impressions during listening to taped sound, as well as sound level measurements, indicated that both truck noise and airplane noise were not loud enough, nor of a character, to likely be disturbing to northern goshawks. This impression was confirmed by observed goshawk responses, or lack thereof, when presented with our test stimuli. Aircraft noise levels, which are not subject to control, were louder than logging truck noise at the two more distant sites where logging truck noise was lessened by distance, and only 30% (6 dB) quieter at the nearest site. The overall conclusion of this study is that logging truck sound levels experienced by nesting northern goshawks at distances similar to those in this study (>78 m) do not constitute a significant disturbance.

MANAGEMENT IMPLICATIONS

We found no evidence of any negative effects of logging truck noise on nesting northern goshawks on the Kaibab Plateau. Observed goshawk response was limited to at most looking in the direction of the hauling road.

However, as a result of the 1996 the Forest Plan amendment, seasonal hauling restrictions through active northern goshawk PFAs were implemented. Based on the preliminary results from Grubb et al. (1998), NKRD also implemented a seasonal restriction (1 March – 30 September), including a ¼ mile (400 m) radius buffer around active northern goshawk nests, to mitigate effects of noise and other anthropogenic disturbances.

This study shows that the broad restriction of hauling and other activities within a PFA is unnecessary. It also shows that no restrictions are needed for road-based travel, whether by logging trucks or other vehicles, within PFAs or nest areas. However, our anecdotal evidence strongly indicates pedestrian activities should continue to be restricted within a ¼ mi (400 m) radius of active goshawk nests.

General aviation aircraft were louder than our test logging truck at most nest sites, but they elicited even less behavioral response from nesting goshawks, which generally ignored passing aircraft. Given the Special Flight Rules in effect for Grand Canyon National Park that also encompass much of the adjacent Kaibab Plateau, no additional flight restrictions appear necessary for NKRD.

LITERATURE CITED

ANSI S1.4. 2001. American national standard specification for sound level meters. American National Standards Institute, Washington, D.C.

ANSI S1.6. 2001. American national standard preferred frequencies, frequency levels, and band numbers for acoustical measurements. American National Standards Institute, Washington, D.C.

Archibald, W.R., R. Ellis, and A.N. Hamilton. 1987. Responses of grizzly bears to logging truck traffic in the Kimsquit River Valley, British Columbia. Int. Conf. Bear Res. and Manage. 7:252-257.

Beier, P., and J. E. Drennan. 1997. Forest structure and prey abundance in foraging areas of northern goshawks. Ecological Applications 7:564–571.

Beranek L.L., ed. 1988. Noise and vibration control (revised edition). Institute of Noise Control Engineering, Washington, D.C. 672 p.

Boal, C. 1994. A photographic and behavioral guide to aging nestling northern goshawks. Studies in Avian Biology No. 16:32-40.

Bowles, A.E., and L.L. Pater. 2000. Developing noise-dosage weighting functions for animals. Journal of Acoustical Society of America 107:2784.

Bright-Smith, D. J., and R. W. Mannan. 1994. Habitat use by breeding male northern goshawks in northern Arizona. Studies in Avian Biology 16:58-65.

Crocker-Bedford, D. C. 1990. Goshawk reproduction and forest management. Wildlife Society Bulletin 18: 262-269.

Delaney, D.K., and T.G. Grubb. 2001. Effects of off-highway vehicle noise on northern spotted owls: sound data results. Report to Mendocino National Forest, Contract No. 43-91Z9-0-0055. U.S. Forest Service, Rocky Mountain Research Station, Flagstaff, Arizona.

Delaney, D.K., and T.G. Grubb. 2002. Effects of off-highway vehicles on northern spotted owls: 2002 results. Report to Mendocino National Forest, Contract No. 43-91Z9-0-0055. U.S. Forest Service, Rocky Mountain Research Station, Flagstaff, Arizona, and U.S. Army Construction Engineering Research Laboratory, Champaign, Illinois.

Delaney, D.K., and T.G. Grubb. 2003. Sound recordings of road maintenance equipment on the Lincoln National Forest, New Mexico. A report to San Dimas Technology and Development Center, November 2003. Research Paper, RMRS-RP-49. U.S. Forest Service, Rocky Mountain Research Station, Flagstaff, Arizona.

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

Delaney, D.K., L.L. Pater, L.D. Carlile, E.W. Spadgenske, T.A. Beatty, and R.H. Melton. 2011. Response of red-cockaded woodpeckers to military training operations. Wildlife Monographs 177:1-38.

Dooling, R.J. 1980. Behavior and psychophysics of hearing in birds. Pages 261-288 *in* A. Popper and R. Fay, editors. Comparative studies of hearing in vertebrates. Springer-Verlag, New York, New York.

Dooling, R.J., B. Lohr, and M.L. Dent. 2000. Hearing in birds and reptiles. Pages 308-359 *in* J.R. Dooling, R.R. Fay, and A.N. Popper, editors. Comparative hearing: birds and reptiles. Springer-Verlag, New York, New York.

Grubb, T.G., L.L. Pater, and D.K. Delaney. 1998. Logging truck noise near nesting northern goshawks. Research Note RMRS-RN-3. U.S. Forest Service, Rocky Mountain Research Station, Flagstaff, Arizona.

Grubb, T.G., D.K. Delaney, and W.W. Bowerman. 2007. Investigating potential effects of heli-skiing on golden eagles in the Wasatch Mountains, Utah. Final Report to Wasatch-Cache National Forest, Agreement No. 05-JV-11221607-237. U.S. Forest Service, Rocky Mountain Research Station, Flagstaff, Arizona.

Grubb, T.G., D.K. Delaney, W.W. Bowerman, and M.R. Wierda. 2010. Golden eagle indifference to heli-skiing and military helicopters in northern Utah. Journal of Wildlife Management 74: 1275-1285.

ISO 226. 2003. Acoustics – normal equal-loudness-level contours. International Organization of Standardization, Geneva, Switzerland.

Konishi, M. 1973. How the owl tracks its prey. American Scientist 61:414-424.

Pater, L.L., T.G. Grubb, and D.K. Delaney. 2009. Recommendations for improved assessment of noise impacts on wildlife. Journal of Wildlife Management 75:788-795.

Pierson, R. 2009. Acceptability of OHM and ATV noise – case studies of environmental noise produced by OHM and ATV riding areas. SAE International Journal of Passenger Cars – Mechanical Systems 2:1574-1583.

Rasmussen, D.I. 1941. Biotic Communities of the Kaibab Plateau, Arizona. Ecological Monographs 11: 229-276.

Reich, R.M., S.M. Joy, and R.T. Reynolds. 2004. Predicting the location of northern goshawk nests: modeling the spatial dependency between nest locations and forest structure. Ecological Modeling 176: 109-133.

Reynolds, R.T. 1989. Accipiters. Pp. 92-101 *in* Proceedings of the Western Raptor Management Symposium and Workshop, National Wildlife Federation Science and Technical Series No. 12.

Reynolds, R.T., E.C. Meslow, and H.M. Wight. 1982. Nesting habitat of coexisting Accipiter in Oregon. Journal of Wildlife Management 46: 124-138.

Reynolds, R.T., S.M. Joy, and D.G. Leslie. 1994. Nest productivity, fidelity, and spacing of northern goshawk in Arizona. Studies in Avian Biology 16:106-113.

Reynolds, R.T., R.T. Graham, M.H. Reiser, R.L. Bassett, P.L. Kennedy, D.A. Boyce Jr., G. Goodwin, R. Smith, and E.L. Fisher. 1992. General Technical Report RM-217; Management Recommendations for the Northern Goshawk in the Southwestern United States. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO. 90p.

Siders, M.S., and P.L. Kennedy. 1996. Forest structural characteristics of Accipiter nesting habitat: is there an allometric relationship? Condor 98:123-132.

Speiser, R. and T. Bosakowski. 1991. Nesting phenology, site fidelity, and defense behavior of northern goshawk in New York and New Jersey. Journal of Raptor Research. 25(4):132-135.

Squires, J. R., and R.T. Reynolds. 1997. Northern Goshawk (*Accipiter gentilis*). *In* The Birds of North America, No. 298 (A. Poole and F. Gill, eds.). Academy of Natural Sciences, Philadelphia, PA, and American Ornithologists' Union, Washington, D.C.

Squires, J.R., and L.F. Ruggiero. 1996. Nest-site preference of northern goshawk in southcentral Wyoming. Journal of Wildlife Management 60: 170-177.

Trainer, J.E. 1946. The auditory acuity of certain birds. Dissertation, Cornell University, Ithaca, New York.

U.S. Dept. of Labor. 1983. Occupational Safety and Health Administration (OSHA) Noise Exposure: Hearing Conservation Amendment, Final Rule. Federal Register 48:9738-9784.

White, M.A. and J.L. Vankat. 1993. Middle and high elevation coniferous forest communities of the North Rim region of Grand Canyon National Park, Arizona, USA. Vegetatio 109: 161-174.

Yamazaki, Y., H. Yamada, M. Murofushi, H. Momose, and K. Okanoya. 2004. Estimation of hearing range in raptors using unconditioned responses. Ornithological Science 3:85-92.

Younk, J. V., and M. J. Bechard. 1994. Breeding ecology of the northern goshawk in high elevation aspen forest of northern Nevada. Studies in Avian Biology 16: 119-121.