The Journal of Wildlife Management 77(8):1618–1625; 2013; DOI: 10.1002/jwmg.607

Management and Conservation

Response of Nesting Northern Goshawks to Logging Truck Noise in Northern Arizona

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ABSTRACT We recorded 94 sound-response events at 3 adult-occupied northern goshawk (*Accipiter gentilis*) nests 78 m, 143 m, and 167 m from the nearest United States Forest Service maintenance level 3, improved gravel road on the Kaibab Plateau in northern Arizona. During 4 test sessions on 7, 8, 10, and 11 June 2010, we recorded 60 experimentally controlled logging trucks; 30 non-experimental, civilian, fixed-winged aircraft; 3 non-experimental, passing cars; and 1 all-terrain vehicle (ATV). Logging truck sound, principally engine and exhaust, was concentrated in the 63 Hz and 80 Hz, 1/3-octave frequency bands. Aircraft sound was concentrated in the 100 Hz and 125 Hz, 1/3-octave frequency bands. Logging truck noise levels varied among nest sites and with distance from roads. At 167 m from the closest road, the logging truck averaged approximately 8 decibels (dB, all decibel levels C-weighted, adjusted, 1 s, equivalent sound level, CLEQ) quieter than aircraft. At 143 m, the logging truck was approximately 3 dB quieter than passing aircraft. Only at 78 m was logging truck noise louder on average than aircraft, by approximately 6 dB. Average aircraft noise levels for each day of testing ranged between 45.6 dB and 67.9 dB and when averaged across the entire study period, varied little among the 3 test sites, 60.1–65.6 dB. On average, our test logging truck (61.9 dB) was no louder than passing aircraft (62.3 dB), which goshawks generally ignored. The logging truck resulted in 27% no response and 73% alert (head turning) response, passing aircraft resulted in 90% no response and only 10% alert response, and the cars and ATV combined resulted in 50% each for no response and alert response. Goshawk alert response rates were inversely proportional to nest distance from the nearest road, decreasing from 91% to 57% alert between 78 m and 167 m. No movements or flushes were associated with either our experimental testing or passive recording of other vehicular noise stimuli. All tested pairs of goshawks successfully fledged young. Because logging truck noise had no effect on northern goshawks nesting along level 3, improved gravel roads on the Kaibab Plateau, restriction of log hauling and other road-based travel activities on similar roads within post-fledging family areas (PFAs) appears unnecessary based on the type and extent of our testing.

KEY WORDS *Accipiter gentilis*, aircraft, forest roads, human disturbance, logging truck, management, noise, northern goshawk, response behavior.

Because timber harvest has traditionally been the primary threat to northern goshawks (*Accipiter gentilis*) throughout their range (Reynolds 1989, Bright-Smith and Mannan 1994, Beier and Drennan 1997), the United States Forest Service, Southwest Region, designated this raptor as a sensitive species in 1982. With a high density of nesting goshawks on the Kaibab Plateau in northern Arizona, early logging pressure further elevated concern for appropriate management measures (Crocker-Bedford 1990, Reynolds et al. 2005). In 1996, the Kaibab National Forest responded to this potential threat and went beyond recently published recommendations (Reynolds et al. 1992) by amending its Forest Plan to afford special protection to goshawk nesting areas and post-fledging family areas (PFAs). As a result of this Forest Service action, log hauling at present is categorically precluded from northern goshawk PFAs on the Kaibab Plateau, to the detriment of efficient logging practices (U.S. Forest Service, Kaibab National Forest, unpublished data).

A pilot study using state-of-the-art sound measuring techniques was conducted on the Kaibab National Forest in the late 1990s, and those limited data remain among the only published 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 response thresholds for distance and noise levels, as well as assess potential impacts from the frequency,

Received: 13 March 2013; Accepted: 3 June 2013
Published: 19 September 2013

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duration, and timing of common hauling practices. Although our research focused primarily on logging truck noise, other vehicles including general aviation aircraft, several passenger cars, and a recreational, all-terrain vehicle (ATV) were also recorded opportunistically during our truck testing.

As a contextual framework for the results that follow, the smallest change in noise level that humans can reliably perceive is approximately 3 decibels (dB). Increases of 5 dB or more are clearly noticeable. In general, a 10-dB increase in noise level results in a subjective doubling in perceived loudness to humans. Under ideal conditions (i.e., no intervening buffering), a line noise source (such as flowing traffic on a busy highway) decreases approximately 3 dB each time distance from the source doubles (U.S. Department of Labor, Occupational Safety & Health Administration [OSHA], 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 United States Forest Service wild or urban lands: Type A for "lands on which serenity and quiet are of extraordinary significance . . .," have a limit of 57 dBA (A-weighted); and Type B for "picnic areas, recreation areas, active sports areas . . .," have a limit of 67 dBA. Similarly, the Federal Department of Housing and Urban Development (HUD) requirements for environmental noise state that 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." The HUD nighttime average exterior noise levels between 2200 hours and 0700 hours must be 10 dBA lower than daytime levels (i.e., $<$55 dBA; HUD Regulations 24 CFR Part 51B). Established requirements for vehicular, environmental, or exterior noise (such as these OSHA, FHWA, and HUD standards) substantiate case-specific management guidelines (Pierson 2009), such as those we develop here for log hauling near nesting northern goshawks on southwestern national forests.

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 above 2,150 m consists of ponderosa pine (*Pinus ponderosa*) and mixed-conifer forest comprised of 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 similar, relatively level terrain within the ponderosa pine type. We chose goshawk nests based on their immediate proximity to log hauling roads to maximize the opportunity to observe any behavioral response associated with the noise from a passing logging truck.

METHODS

Field Observations

We conducted logging truck noise tests at 3 northern goshawk nests on 7, 8, 10, and 11 June 2010. A logging truck made 4 round trips past each nest, spaced at 1-hour intervals each test day between approximately 0630–1130 Mountain Standard Time (MST). These 8 passes in a 4–5-hour period far exceeded 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 48 km back to the mill, unload, and return, yielding no more than 4 passes by any given nest site in a 10-hour 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-hour day. Unfortunately, not all of the 32 logging truck passes past each nest resulted in usable sound-response data points because of varying ambient conditions (see Acoustical Analysis section below).

During days of logging truck noise tests, each of the 3 study nests was kept under surveillance by a trained field observer from 1 hour before testing began until 30 minutes to 1 hour afterwards. Nest observers arriving at the nest prior to the passing logging truck permitted adult goshawks to return to normal undisturbed behavior well before the test began. Observers found protected viewing locations approximately 100 m from each nest and used spotting scopes to monitor behavior. Observers synchronized their watches and time stamps on all 3 noise recording digital recorders (detailed below) prior to deployment. Observers recorded anthropogenic activities and corresponding goshawk behaviors to the nearest second throughout the entire observation period each day. We categorized goshawk responses as none (1), alert (2, looking in direction of stimulus), move (3, agitated changes in position or orientation), and fly (4, flushing, flying off abruptly). Chicks in the study nests were $\leq$15 days old. We chose this timing to ensure adult presence at nests during our testing. Because adult female flushing behavior is more detrimental with younger chicks present (Boal 1994), we would have immediately terminated testing at any nest if an adult had flushed.

Our test vehicle was an unloaded, 1994 Kenworth T800 (Kenworth, Kirkland, WA), 500-horsepower, logging truck (gross vehicle weight [GVW] = 36,287 kg). Empty trucks are noisier than trucks with loads because of hanging chains and the bounce of the rear trailer absent the dampening weight of logs. Our test truck began traveling down a maintenance level 3, improved gravel road (U.S. Forest Service 2005; Table 1) approximately 400 m before the nearest northern goshawk nest, and continued for approximately 12.2 km, passing 3 goshawk nests. The truck turned around approximately 400 m past the last nest, and 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. The driver made 4 round trips (8 passes) each test day.

All aircraft recorded during our noise testing were general aviation, civilian, fixed-wing, light aircraft. Occasionally

Table 1. United States Forest Service (2005; see also Forest Service Handbook 7709.58, 10, 12.3) forest road maintenance levels.

Road maintenance level	Description
1	Closed, intermittent roads, custodial maintenance only to minimize resource damage.
2	Open for use by high-clearance vehicles. Traffic normally minor, usually administrative, permitted, dispersed recreation, or other special use, including log hauling. Typically 1 lane, or "2-track."
3	Open and maintained for prudent travel by passenger cars. Often single lane, and gravel surfaced. Low to moderate traffic volume.
4	Roads have moderate traffic volume and speeds, offer moderate user comfort and convenience. Most double lane and aggregate (or gravel) surfaced. Moderate traffic volume and speeds.
5	Roads with high degree of comfort and convenience. Normally double-lane and paved. Greatest traffic volume and speeds.

low-level, military training jets pass near the Kaibab Plateau, but none were recorded during our testing. Commercial jetliners and their contrails are a common sight above the Plateau, but such aircraft were too high to produce any measurable noise levels. 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 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 is approximately 300 m above ground level (AGL) across the Kaibab Plateau, which lies immediately adjacent to and just north of the Park. Passenger cars and ATVs had very limited occurrence during our truck testing, and specific descriptions were unknown. These vehicles were either recorded by observers in notes, or identified during playback assessment of noise events.

Acoustical Analysis

We recorded sound levels at goshawk locations continuously throughout each test period, which enabled post-test laboratory measurement and analysis of each sound event. We simultaneously recorded goshawk behavioral responsiveness during each sound event, 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, 2011). 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 procedures eliminated such unknown stimulus variation that can result from using only a representative or average value for noise stimulus events, significantly improving the validity of our data and subsequent conclusions.

We recorded sound directly below the observed nesting goshawks at the base of each nest tree, approximately 1 m above ground and approximately 1 m from the tree. Our sound measurement equipment had sufficiently constant sensitivity over the frequency range of interest to avoid significant artificial accentuation or attenuation of sound energy at any of the tested frequencies. We recorded sound with Brüel & Kjær (B&K; Nærum, Denmark) Type 4149, 1.3-cm microphones, 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 (Sony Corporation, Tokyo, Japan). We recorded a 94-dB, 1-kHz steady tone signal generated by a B&K Type 4250 sound level calibrator before and after each test session at each test site.

We reduced data from the audio recordings to digitized tabular data values 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 (Rion Co, Ltd., Tokyo, Japan). We used the recorded pre-test calibration signal to adjust the Rion NA-27 calibration before reducing the data from any session. We used the post-test signal to check for system drift during the session. Drift never exceeded a small fraction of 1 dB, which is excellent system stability. We transferred resulting data files to computer memory for analysis. To gain subjective perspective for better sound event identification, evaluation, and analysis, we listened to a playback of every noise stimulus event, and also sampled ambient sound, during data reduction.

Data reduction yielded 1/3-octave band spectra and overall (wide-band) levels, in terms of unweighted 1-s equivalent (time average) sound level (1-s LEQ), for each successive 1-s time period during the entire time when the stimulus sound was significantly louder than ambient sound level. We applied C- and A-weighting filters to the spectra to obtain weighted spectra. Truck acoustical energy emission was concentrated in the 1/3-octave bands centered at 63 Hz and 80 Hz, whereas aircraft sound was concentrated in the 1/3-octave bands centered at 100 Hz and 125 Hz. Turbulence associated with wind blowing over a microphone generated spurious low frequency noise in the recordings, concentrated at frequencies typically below 10 Hz but sometimes extending to higher frequencies. We validated spectra for each noise stimulus event to ensure apparent vehicle noise level peaks were not due to wind.

We then plotted weighted 1-s LEQ data, 63-Hz 1/3-octave band and broad-band levels for successive 1-s time periods. By this method, we determined, and ultimately reported, the maximum 1-s CLEQ and maximum 1-s ALEQ value for each stimulus event. The standard C-weighting filter attenuates by −0.5 dB at 80 Hz (characteristic of the logging trucks), −3 dB at 31.5 Hz, −10 dB at 10 Hz, and almost none at 125 Hz (aircraft noise). These attenuations caused no significant degradation of the truck or aircraft noise but did help to screen out spurious wind noise.

When 2 sounds occur simultaneously, each contributes to the total sound level. If the lower sound level is more than 10 dB lower than the louder sound, it makes no significant contribution to the total sound level. Spectra for which the sound of interest, for example truck noise, was more than 10 dB louder than ambient sound levels, including wind, accurately measure the event. We adjusted event sound levels that were 5–10 dB higher than ambient sound level to a lower value (adjusted CLEQ values; Table 2) that more accurately represented actual sound level of a truck or aircraft without the contamination of wind noise (see Pater et al. 2009 for methodology). Stimulus noise levels <5 dB above ambient levels could not be reliably adjusted. About 15% of all recorded stimulus events had 1-s CLEQ sound levels so near ambient that they could not be meaningfully adjusted; we discarded these to preserve data quality and validity. Of the remaining 94 events, approximately 50% of aircraft and approximately 25% of truck events had maximum 1-s CLEQ sound levels <10 dB above ambient.

We used adjusted 1-s CLEQ as our primary comparative metric. We also report A-weighted 1-s LEQ values (1-s ALEQ; Table 2). Both A-weighting and C-weighting attenuate low-frequency spurious wind noise that can mask truck and airplane noise. C-weighting attenuates low frequency sound to a lesser extent than A-weighting, so less severely attenuates the truck and aircraft sound event levels. A-weighting has the advantage of being a more familiar metric that arguably better correlates with human and perhaps avian hearing response at the sound levels of this study, but it significantly attenuates the event level of both trucks (approx. 80 Hz) and aircraft (approx. 125 Hz), to the point that many of our sound stimulus events fall too near ambient level to be valid data points. Since both weighting schemes lead to the same conclusions, for the sake of clarity and improved statistical significance we discuss in detail only the C-weighted results (see Table 2 for both metrics). The stimulus event sound levels were generally quite low; none of our measured ALEQ truck noise levels, and only 1 aircraft measured level, rose to the FHWA Type A criteria average levels for even 1 s. Both C-weighted and A-weighted results offer conservative estimates of the sound level perceived by northern goshawks. Birds in general, including goshawks, are thought to have less sensitive hearing at low frequencies than humans (Dooling et al. 2000, Yamazaki et al. 2004; Fig. 1).

Statistical Analysis

We initially calculated frequencies and means for stimulus sound levels (dB) with Microsoft Excel spreadsheet software (Microsoft Office Professional Plus 2010, Microsoft Corporation, Redmond, WA). We used PROC GLIMMIX in SAS/STAT analytical software (Version 9.2, 2012, SAS Institute, Inc., Cary, NC) to run a 2-treatment fixed-effects analysis of variance (ANOVA) including interactions to assess variation in average sound levels by source (stimulus type) and site (distance). Significant main effects tests were followed by post hoc comparisons using a Tukey–Kramer adjustment to limit family-wise Type I error rate to $\alpha = 0.05$. We evaluated differences among response rates (dependent

Table 2. Daily averages of sound level metrics (decibels [dB]; C-weighted [CLEQ] and A-weighted equivalent sound level averages [ALEQ][a]) of logging truck and aircraft noise recorded near 3 adult-occupied, northern goshawk (*Accipiter gentilis*; NOGO) nests on the North Kaibab Ranger District, Kaibab National Forest, Arizona, 2010, with associated goshawk response[b].

Nest	Date (Jun)	Source distance (m)	Source type	NOGO responses 1	NOGO responses 2	NOGO responses ≥3	Max. 1-s CLEQ (dB)	Background CLEQ (dB)	Valid event count	Adjusted CLEQ (dB)	Max. 1-sec ALEQ (dB)	Background ALEQ (dB)	Valid event count	Adjusted ALEQ (dB)
1	8, 10, 11	78	Truck	2	21	0	66.4	52.4	23	66.1	51.3	45.0	20	49.8
		≥300	Aircraft	11	0	0	60.9	49.7	11	60.1	50.1	41.7	10	49.0
2	7, 8	143	Truck	8	15	0	62.3	50.3	23	61.8	47.9	42.6	15	46.7
		≥300	Aircraft	8	2	0	65.7	48.3	10	65.6	51.6	43.1	10	50.8
		143	Car ATV	2	2	0	56.4	46.5	4	55.7	46.5	38.3	3	45.7
3	8, 10, 11	167	Truck	6	8	0	55.9	47.3	14	55.1	40.0	35.7	12	38.1
		≥300	Aircraft	8	1	0	64.1	47.6	9	63.7	51.9	40.2	9	51.4

[a] Event sound metric levels were generally less different from ambient (background) levels for A-weighted than C-weighted metrics. Thus, for some stimulus events, A-weighted levels were invalid (event level <3 dB higher than ambient), whereas C-weighted levels remained valid. As a result, the number of valid maximum 1-s ALEQ events is smaller than the number of valid maximum 1-s CLEQ events.
[b] Northern goshawk responses: 1 = none, 2 = alert, 3 = move, 4 = fly.

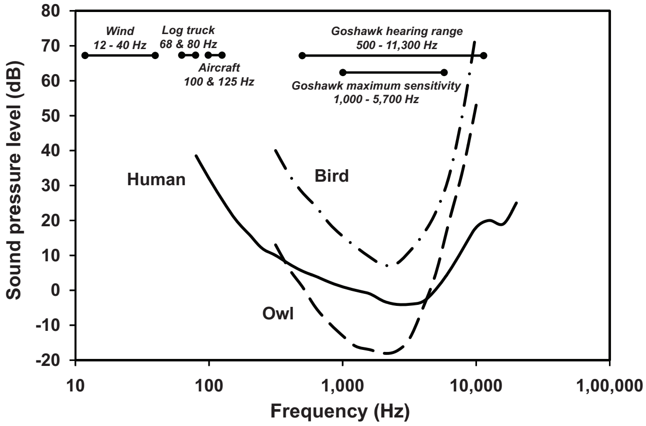

Figure 1. Audiograms for 1) a composite average developed for 7 orders of birds (Dooling 1980, Dooling et al. 2000), 2) a composite average for owls (*Strigiformes*; Trainer 1946, Konishi 1973), and 3) a human threshold audiogram (International Organization of Standardization 2003), illustrating differences 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 (*Accipiter gentilis*) hearing range and range of maximum hearing sensitivity (Yamazaki et al. 2004).

variable) within or between stimuli using CROSSTABS procedures (chi-square) within PASW Statistics 18 (2009, SPSS, Inc., Chicago, IL). Adult goshawks were unmarked so repeated measures on the same subject could not be incorporated into the model. Interpretation of response comparisons from this case study is inherently limited by the small number of individual respondents sampled. Significance level for all analyses was $P < 0.05$.

RESULTS

We recorded 94 sound-response events at 3 adult-occupied northern goshawk nests 78 m (nest 1), 143 m (nest 2), and 167 m (nest 3) from the nearest log hauling road during 4 test sessions in June 2010: 60 experimentally controlled logging trucks; 30 non-experimental, general aviation, fixed-wing aircraft; 3 non-experimental, passing cars, and 1 ATV (Table 2). Twenty-three trucks and 11 aircraft passed nest 1; 23 trucks, 10 aircraft, and 4 cars or ATVs passed nest 2; and 14 trucks and 9 aircraft passed nest 3. Not all truck passes resulted in usable sound-response data points because of varying ambient conditions.

Logging truck sound was concentrated in the 63 Hz and 80 Hz 1/3-octave frequency bands, principally engine and exhaust sound. Some higher frequency sound was typically present because of banging of log chain or other metal parts. Airplane sound was concentrated in the 100 Hz and 125 Hz 1/3-octave frequency bands. At 167 m from closest road, the logging truck averaged approximately 8 dB quieter than aircraft. At 143 m, the logging truck was approximately 3 dB quieter than passing aircraft. At 78 m, logging truck noise was louder on average than aircraft, by approximately 6 dB. At nest 2 (143 m), which was the only test location with all 3 types of stimuli, limited car and ATV sound levels ($n = 4$) averaged 55.7 dB (adjusted CLEQ) and were quieter than either the logging truck or passing aircraft (Table 2).

Results from ANOVA indicated a significant interaction between source (stimulus type) and site (distance) thereby precluding marginal tests of main effects (Table 3). Therefore, we ran post hoc comparisons between site and source combinations (Table 4). Mean aircraft noise levels across all sites for each day of testing ranged between 45.6 dB and 67.9 dB, and study average levels (60.1–65.6 dB) did not vary among the 3 test sites (Tables 2 and 4; Fig. 2), yielding an overall combined aircraft average noise level for 30 recorded response events of 63.2 dB adjusted 1-s CLEQ. Aircraft levels could be combined into an overall average because stimulus distance variation among nest sites was negligible when flight altitudes of general aviation aircraft were taken into account, whereas logging truck noise levels varied with distance from roads (and thus among nest sites; Tables 2 and 4; Fig. 2). If inherent variation of truck noise with distance is temporarily overlooked for the sake of a simplified, but instructive comparison, our test logging truck (61.9 dB adjusted CLEQ) was no louder on average than passing aircraft (62.3 dB adjusted CLEQ).

Northern goshawk response rates varied among noise source types ($\chi^2_2 = 82.365$, $P < 0.005$). 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. We did not observe movements or flushes (level 3 or 4 responses) during either our experimental logging truck testing or passive recording of the other noise stimuli. Goshawk alert response rates to the logging truck were inversely proportional to nest distance from the nearest road, decreasing from 91% to 57% alert between nest 1 (78 m) and 3 (167 m; $\chi^2_2 = 29.861$, $P < 0.005$). Goshawks generally did not respond (80–100% no response) to passing aircraft and were typically less responsive to aircraft than to the logging truck, although in most cases aircraft were louder than the logging truck (Table 2; Fig. 2). This may indicate some degree of acclimatization to aircraft noise, although response rates to aircraft did vary among test sites ($\chi^2_2 = 21.657$, $P < 0.005$).

Table 3. Results of a fixed-effects analysis of variance (ANOVA) including interactions to assess variation in average sound levels by source (stimulus type) and site (distance) for logging truck and aircraft noise recorded near 3 adult-occupied, northern goshawk (*Accipiter gentilis*) nests on the North Kaibab Ranger District, Kaibab National Forest, Arizona, 2010.

Effect	Numerator df	Denominator df	*F*-Value	Probability > *F*
Source	1	84	4.09	0.0462
Site	2	84	5.68	0.0049
Source × site	2	84	16.13	<0.0001

Table 4. Results of post hoc comparisons between site (distance; 1 = 78 m, 2 = 143 m, and 3 = 167 m) pairs and within source (stimulus types), using a Tukey–Kramer adjustment to limit family-wise Type I error rate to $\alpha = 0.05$, for logging truck and aircraft noise recorded near 3 adult-occupied, northern goshawk (*Accipiter gentilis*) nests on the North Kaibab Ranger District, Kaibab National Forest, Arizona, 2010.

Source	Sites	df	*t*-Value	Probability > |*t*|
Aircraft	1 vs. 2	84	−0.83	0.9604
	1 vs. 3	84	1.69	0.5396
	2 vs. 3	84	2.62	0.1040
Truck	1 vs. 2	84	−4.19	0.0009
	1 vs. 3	84	−6.83	<0.0001
	2 vs. 3	84	−3.03	0.0374

DISCUSSION

We found no discernible responses based on the extent of our testing during this study (i.e., 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, head turning or looking in the direction of stimuli, whether actively or passively). Chicks in our study nests were all ≤15 days old, ensuring adult presence during our testing, but also arguably reducing the likelihood of an adult flush while brooding. However, the absence of any agitation suggests flight was never an issue. No startle effects were associated with our recorded logging truck and aircraft stimuli, because sound levels for both rose gradually to a maximum and then gradually faded during the stimulus event. All tested pairs of goshawks successfully fledged young.

Both logging truck and aircraft noise is predominantly very low frequency and therefore at the lower extreme of northern goshawk hearing sensitivity (Fig. 1), which may help explain the absence of any significant or detrimental behavioral response, as similarly recorded for military helicopters in New Mexico with Mexican spotted owls (*Strix occidentalis lucida*; Delaney et al. 1999) and in Utah with golden eagles (*Aquila chrysaetos*; Grubb et al. 2010). Neither stimulus was visible to our Arizona goshawks because of intervening forest canopy, but they may still be more acclimated to aircraft noise when compared to less common and sporadic logging 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 helicopters (Delaney et al. 1999). Similarly Grubb and King (1991) found ground-based human activities elicited greater response from nesting bald eagles (*Haliaeetus leucocephalus*) than aircraft.

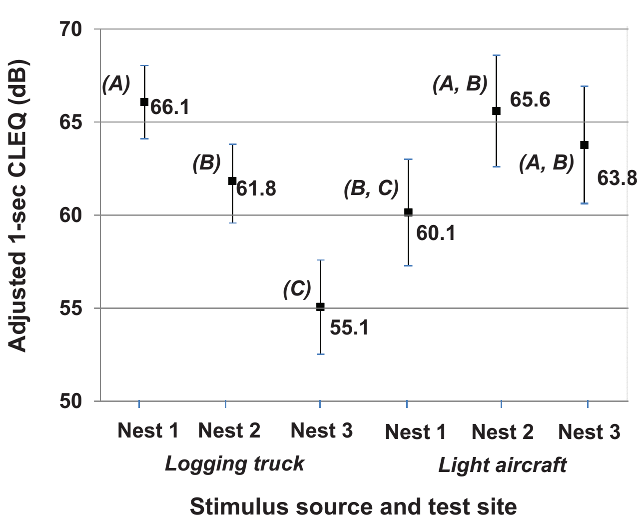

Figure 2. Logging truck and light, civilian aircraft mean noise levels (with 95% CI, C-weighted, adjusted, 1 s, equivalent sound level [CLEQ] in decibels [dB]) measured near 3 adult-occupied, northern goshawk (*Accipiter gentilis*) nests, 78 m, 143 m, and 167 m from the nearest Forest Service maintenance level 3 road (nests 1–3, respectively) on the North Kaibab Ranger District, Kaibab National Forest, Arizona, 2010. Means with the same letters are not different ($P > 0.05$).

The only meaningful comparison of aircraft and logging truck noise levels (Fig. 2) with associated response rates 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 logging truck noise levels between nest 1 (78 m) and 3 (167 m) suggests, at least to human hearing, the noise level at the nearer nest was approximately twice as loud as that at the farther one. Very few goshawk nests are found near level 3 roads (U.S. Forest Service 2005) on the Kaibab Plateau. In 2010, only 3 were within 100 m, 14 between 101 m and 200 m, 21 between 201 m and 300 m, 3 between 400 m and 600 m, and 6 between 1,100 m and 9,800 m. Thus at most nest sites, civilian aircraft flying overhead are likely louder than any passing logging trucks on those roads. 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 these improved roads. Our nearest study nest site (1, chosen for that reason) was closer to a level 3 road than any other known nest sites on the Kaibab Plateau. Since nest 1 was the only study site at which trucks were louder on average than aircraft, aircraft sound levels should be predictably louder than logging truck sound levels at almost all Kaibab Plateau northern goshawk nest sites.

However, this observation is based upon nest proximity to and hauling along level 3 improved, gravel forest roads on the Kaibab Plateau, whereas nearly a third (30%) of Kaibab goshawk nests used since 1991 lie within 75 m of unused, unimproved level 1 and 2 roads (R. T. Reynolds, U.S. Forest Service, unpublished data; Table 1). If log hauling were to occur on these historical roads much closer to nesting goshawks, noise levels would be louder, and the resultant frequency and severity of response would also very likely increase, resulting in potentially serious detrimental impacts. Morrison et al. (2011) found frequently occupied northern goshawk territories in the Lake Tahoe Basin, California and Nevada, had about half the extent of all roads and trails within 800 m as infrequently occupied territories. Even so, despite the abundance of roads on the Kaibab Plateau, its remoteness results in much less traffic than around the Tahoe Basin. Our impression (and that of others [R. T. Reynolds, personal communication]) is that over the years, northern goshawks on the Kaibab Plateau have acclimated to current levels of traffic, regardless of type, on level 3 or higher, forest gravel roads.

Archibald et al. (1987) recorded noise levels (dB, C-weighted) of logging trucks hauling on a road in British Columbia, Canada, at 25-m intervals along 18, 200-m transects laid out perpendicular to the road. Three of those intervals (75 m, 150 m, and 175 m) approximated our 78 m, 143 m, and 167 m test distances, and corroborate our recorded noise levels, as well as validate our experimental use of an empty truck (Fig. 3). Recorded noise levels between the 2 studies are remarkably close. Even at the farthest pair of distances, the difference is only approximately 3 dB, which for humans is at the lower limit of difference perceptibility, and is most likely because of differing propagation conditions at the time of measurement between the Arizona and British Columbia study areas. Archibald et al. (1987) developed 2, hauling activity bands on either side of the road (50-m wide >80 dBC, and 300-m wide 80–60 dBC) to quantify 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 had no negative impact on our targeted, nesting northern goshawks. Since goshawks on the Kaibab Plateau typically do not nest any closer to level 3 hauling roads, no special management restrictions or zones appear to be necessary where those roads pass through PFAs.

Because our results were derived from a small, non-replicated sample, we strongly recommend additional testing across a larger sample population to further substantiate the apparent lack of goshawk response. We were constrained by budget, limited occurrence of active goshawk nests near suitable hauling roads, and the logistical considerations for cost-effective, efficient testing. Replicate and control sites were not available. However, previous research found no evidence that northern goshawks on the Kaibab Plateau avoid roads when selecting nest sites, nor that more sensitive pairs nest farther from roads, given the wide distribution of nests and their frequent proximity to roads (R. T. Reynolds, personal communication). Although we only considered behavioral response measures, goshawks may exhibit less obvious but potentially detrimental, physiological responses to anthropogenic disturbances. The possibility of longer-term effects beyond immediate behavior response should be considered, as well as testing during other times within the breeding season. Also, logging trucks different from the specific type, weight, and configuration of the 1 tested may elicit different behavioral responses from those we identified. Different patterns in log hauling activity, changes in proximity of goshawk nests to existing roads, or even different forest and terrain types could all result in different levels of response.

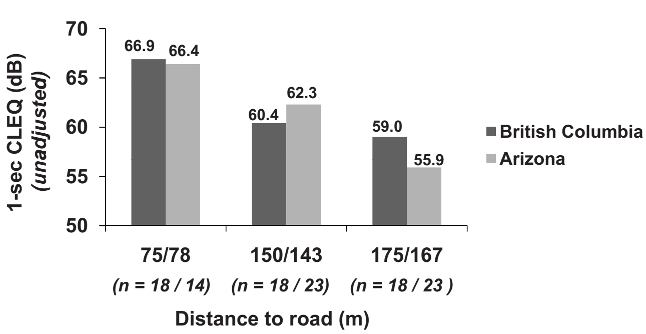

Figure 3. Comparison of logging truck noise levels (C-weighted, unadjusted, 1 s, equivalent sound level [CLEQ] in decibels [dB]) for an empty truck recorded near 3 northern goshawk (*Accipiter gentilis*) nests on the Kaibab National Forest, Arizona, 2010, and round-trip log hauling (loaded and empty) measured by 18 transects at comparable distances from a logging road in British Columbia, Canada, 1984–1985 (Archibald et al. 1987). On the *x*-axis, numbers to the left of the slash are British Columbia data and numbers to the right of the slash are Arizona data.

MANAGEMENT IMPLICATIONS

We found no evidence based on our level of testing that logging truck noise negatively affects nesting northern goshawks on the Kaibab Plateau. Observed goshawk response was limited to at most looking in the direction of the hauling road. Categorical restriction of all hauling and other activities within a PFA may not be necessary to protect nesting northern goshawks in northern Arizona. Seasonal restrictions also appear unnecessary for road-based travel, whether by logging trucks or other vehicles, within PFAs on level 3 or higher roads. General aviation aircraft were louder than our test logging truck at most nest sites but 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. We do not suggest that goshawks cannot be disturbed by anthropogenic activities in proximity to their active nests, but at the levels and for the types of stimuli we tested, we did not observe any substantial behavioral response. However, our sample was limited and further research is definitely warranted.

ACKNOWLEDGMENTS

The authors would like to thank NKRD field technicians R. Dastrup, C. Hagemann, and K. Miles for their dedication and long hours in the field recording logging truck and other noise levels, while diligently observing northern goshawk response behaviors. D. Saunders and P. Callaway, NKRD foresters, provided valuable advice and insight into log hauling operations. The cooperation of L. Reidhead, logging truck owner operator, is also greatly appreciated. R. Reynolds, Rocky Mountain Research Station scientist, and his field crews provided much helpful information on northern goshawk nesting activities, nest locations, and adult behaviors. C. 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. We thank R. Reynolds and J. Cooper for reviewing an earlier draft manuscript, and S. Baggett for statistical advice. We also appreciate the helpful comments of 2 anonymous reviewers. Primary funding for field data collection and analyses was provided by the Kaibab National Forest. We thank S. Brown, Kaibab National Forest Contracting, for facilitating that financial support. The U.S. Forest Service, Rocky Mountain Research Station, and U.S. Army, Engineer Research and Development Center, Construction Engineering Research Laboratory provided technical and logistical support. Use of trade names does not imply endorsement by any of the participating agencies to the exclusion of other potentially suitable products or services.

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Associate Editor: Paul Beier.