United States
Department
of Agriculture

Forest Service

Rocky Mountain
Research Station

Research Paper
RMRS-RP-49

August 2004

Sound Recordings of Road Maintenance Equipment on the Lincoln National Forest, New Mexico

A Report to San Dimas Technology and Development Center, November 2003

David K. Delaney and Teryl G. Grubb

Delaney, D. K.; Grubb, T.G. 2004. Sound recordings of road maintenance equipment on the Lincoln National Forest, New Mexico. Res. Pap. RMRS-RP-49. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 56 p.

Abstract

The purpose of this pilot study was to record, characterize, and quantify road maintenance activity in Mexican spotted owl (Strix occidentalis lucida) habitat to gauge potential sound level exposure for owls during road maintenance activities. We measured sound levels from three different types of road maintenance equipment (rock crusher/loader, dozerlroller, and grader), from seven distances (30, 60, 120, 180,240,320, and 400 m), in two different habitat types (forested and meadow sites) on the Lincoln National Forest, New Mexico, on 22-23 October 2002 to determine how sound varied over distance, habitat type, topography, and stimulus type. Sound levels increased as the distance between road maintenance activity and microphone locations decreased, regardless of stimulus type or habitat type. Concomitantly, the amount of sound energy within the middle frequency range decreased substantially with increasing stimulus distance from microphone locations. The frequency range over which owls can potentially hear road maintenance events decreased with increasing stimulus distance. Sound recordings of road maintenance equipment were louder at tree microphones than at base microphones, regardless of stimulus distance, stimulus type, and site location. The difference in sound levels between tree and base microphones at each distance was consistently louder at meadow sites (tree microphones were located in trees along the edge of the meadow during testing at the meadow site) compared with forested sites, regardless of stimulus type or stimulus distance. Tree microphones registered a greater proportion of sound energy from road maintenance activities in the middle frequency range than at base microphones, regardless of stimulus type, stimulus distance or site location. Sound level and frequency spectra varied by stimulus type. Rock crushing equipment registered the highest sound levels of any of the road maintenance equipment tested, regardless of stimulus distance or habitat type. Rock crushing equipment had the greatest amount of sound energy in the middle frequency range of all the road maintenance equipment tested, followed by the dozer/roller and the grader, regardless of stimulus distance or habitat type. Road maintenance equipment was consistently louder than background ambient forest and meadow sound levels over a range of distances from 30 to 400 m. The extended duration of both rock crusher sound and the multiple passes required of the grader and dozer/roller are additional, potentially negative considerations. Based on our previous sound research with this species, it appears that spotted owls are capable of hearing all the sound sources tested during this pilot study out to distances of at least 400 m.

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Authors

David K. Delaney – Received his undergraduate degree in wildlife management from the University of New Hampshire and a Master's of Science degree in Forestry (with an emphasis in wildlife ecology) from Northern Arizona University. He worked for a number of non-profit organizations on various wildlife projects before starting work as a research biologist for the U.S. Army Construction Engineering Research Laboratory in 1998. Since then he has been studying the potential effects of military training on threatened and endangered species.

Teryl G. Grubb - With a Bachelor of Science in Wildlife Management and a Master of Science in Wildlife Ecology from Colorado State University and University of Washington, respectively, Grubb worked with the Washington State Department of Fish and Wildlife as a non-game biologist before joining the Rocky Mountain Research Station in 1977 as a scientist specializing in raptor research. He has been studying various aspects of bald eagle ecology throughout much of the specie's North American range for nearly 40 years. He was instrumental in early Forest Service efforts in the Southwestern Region to survey nesting peregrine falcons and assess their habitat/management requirements. More recently he has evaluated population, food habits, and nesting habitat of red-tailed hawks as potential competitors with northern goshawks on the Kaibab Plateau, AZ. Since 1995, Grubb and the senior author have been collaborating on pioneering research into the effects of various anthropogenic noise sources on wildlife.

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Executive Summary

The purpose of this pilot study was to record, characterize, and quantify road maintenance activity in spotted owl habitat to gauge potential sound levels that owls might be presented with during road maintenance activities. The results from this pilot project are intended to provide a scientific basis for spotted owl management protocols. We recorded the sound level and frequency spectra for road maintenance equipment on the Lincoln National Forest (LNF) located in south-central New Mexico. We measured the sound levels from three different types of road maintenance equipment (rock crusher/loader, dozerlroller, and grader), from seven distances (30, 60, 120, 180, 240, 320, and 400 meters), in two different habitat types (forested and meadow sites) on the forest, over two successive days during October 2002 to determine how sound varied based on distance, habitat type, topography, and stimulus type.

Sound levels increased as the distance between road maintenance activity and microphone locations decreased, regardless of stimulus type or habitat type. Concomitantly, the amount of sound energy within the middle frequency range decreased substantially with increasing stimulus distance from microphone locations. The frequency range over which owls can potentially hear road maintenance events decreased with increasing stimulus distance. Sound recordings of road maintenance equipment were louder at tree microphones than at base microphones, regardless of stimulus distance, stimulus type, and site location. The difference in sound levels between tree and base microphones at each distance was consistently louder at meadow sites (tree microphones were located in trees along the edge of the meadow during testing at the meadow site) compared with forested sites, regardless of stimulus type or stimulus distance. Tree microphones registered a greater proportion of sound energy from road maintenance activities in the middle frequency range than at base microphones, regardless of stimulus type, stimulus distance, or site location. We observed that sound level and frequency spectra varied by stimulus type. Rock crushing equipment registered the highest sound levels of any of the road maintenance equipment tested, regardless of stimulus distance or habitat type. We found that rock crushing equipment had the greatest amount of sound energy in the middle frequency range of all the road maintenance equipment tested, followed by the dozer/roller and the grader, regardless of stimulus distance or habitat type. Road maintenance equipment was consistently louder than background ambient forest and meadow sound levels over a range of distances from 30 to 400 m.

Based on our previous sound research with spotted owls, it appears that spotted owls are capable of hearing all of the sound sources tested during this pilot study out to distances of at least 400 m. Road maintenance equipment may elicit a greater behavioral response (e.g., increased flush frequency) by spotted owls than comparably distant chainsaw tests (see Delaney et al. 1999 for details on previous chainsaw testing on spotted owls). We do not anticipate that spotted owls will flush in response to road maintenance equipment that is greater than 320 m from an owl's position compared with previous chainsaw testing (according to the level and type of sound sources tested in this study). At distances less than 320 m, all three pieces of road construction equipment either surpassed or were comparable

to sound levels and frequency spectra of chainsaw presentations that elicited flush responses by spotted owls during past research on the Lincoln National Forest. Based on the types of equipment examined and level of testing (i.e., duration, sound level and frequency distribution) during this study, we suggest that the most potentially disruptive stimuli to spotted owls would be rock crushers/loaders at 30 m and the least disruptive activity would be from graders at 400 m. Similarly, owls that nest/roost in deep forest may be disrupted less compared with owls that nest/roost nearer to forest-meadow edges due to the influence that vegetation has on sound propagation. This study provides a hypothetical distance/sound relationship from which we predicted a hypothesized range over which spotted owl flush response could occur.

Given the extended duration of both rock crusher sound and the multiple passes required of the grader and dozer/roller, comparing sound levels of road maintenance equipment with chainsaws to assess potential impact on spotted owls at varying distances, has only limited value and applicability. Such extrapolation should be viewed cautiously. One mitigating approach to reduce overall exposure of owls to the road resurfacing process would be to try running all three pieces of equipment in one simultaneous pass. Otherwise, more traditional approaches of keeping road construction greater than 400 m away or out of MSO PACs entirely during the nesting season may be required. It is important to note that spotted owl behavior was not observed in conjunction with sound testing during this study and therefore we are not able to make any definitive conclusions on how spotted owls would respond to the type of road maintenance equipment tested or based on our level of testing.

We believe this study provides a template for the types of considerations that need to be taken into account during any future sound projects investigating the potential effects of road maintenance equipment on spotted owls. Further research is needed to experimentally test MSO response to road maintenance activity to develop a distance and sound threshold relationship. If possible, all combinations of distances and equipment types should be tested to record owl responses, but based on pilot test sound levels and previous chainsaw research, emphasis should be focused between 180-400 m to develop a potential response threshold. It is also important that researchers investigate the influence that topography and vegetation have on sound propagation.

Given the possible negative impact of extended stimulus duration, we recommend developing future research using a progressive, stepwise approach, i.e., beginning with non-nesting or post-nesting MSOs and proceeding to nesting owls once initial responsiveness, distances, and timing have been determined. The long-term risk to non- or post-nesters is minimal, so initial experimentation with them can be used to focus subsequent, more critical and limited testing on nesting owls. In our helicopter and chain saw research (Delaney et al. 1999), we found the response of non-nesters was very indicative of what to expect from nesting owls.

As the field of bioacoustics develops, natural resource managers and scientists are beginning to understand the importance of studying the potential effects of anthropogenic disturbances on animals. Noise was one issue that was conspicuously absent as a topic of discussion in recovery plans for both the MSO (USDI Fish and Wildlife Service 1995) and the Northern Spotted Owl (USDI Fish and Wildlife Service 1992). It is important that future recovery plans/forest plans, etc., for wildlife species include noise when considering potential human/wildlife conflicts.

Foreword

This study was conducted by the U.S. Army Engineer Research and Development Center's Construction Engineer Research Laboratory (ERDC/CERL) and the USDA Forest Service Rocky Mountain Research Station (RMS) for the USDA Forest Service San Dimas Technology and Development Center. The research scientists on this project were David K. Delaney (CERL) and Teryl G. Grubb (RMS). This study was funded by San Dimas Technology and Development Center. Logistical support was provided by the San Dimas Technology and Development Center, Lincoln National Forest and Coronado National Forest, southwestern Region 3, and USA CERL.

We thank the following people for their help with project logistics and support: Anthony Edwards (San Dimas Development and Technology Center, Contract Officer), Lou Leibbrand (Coronado National Forest), George Garcia and Greg Mendonca (Lincoln National Forest, Supervisor's Office), and Danney Salas (Lincoln National Forest, Sacramento Ranger District). We thank C.T. Hill, Tim Pasqual, Joe Piekenbrock, Jim Stanfill, and Jake Van Winkle for operating road maintenance equipment during sound testing. We also thank Anthony Edwards, Lou Leibbrand, Pat Ward, George Garcia, Greg Mendonca, and Danney Salas for reviewing earlier drafts of this report.

1 Introduction

Background

The U.S. Fish and Wildlife Service (USFWS) listed the Mexican Spotted Owl (MSO; *Strix occidentalis* lucida) as threatened (50 CFR 17.11) effective on 15 April 1993. The Endangered Species Act mandates all federal agencies to conserve threatened and endangered species (TES) and to evaluate the impacts of their activities on listed species (Scott et al. 1994). Increasing importance has been placed on determining the extent that sound stimuli may impact wildlife (Bowles 1995), especially TES (Delaney et al. 1999,2002).

Road management on the Lincoln National Forest is based on the Lincoln National Forest Plan (LNFP) and its amendments (LNFP 2003). The LNFP prioritizes road maintenance activities on forest roads based on risk assessment and road value criteria. Risk assessment of road use within spotted owl habitat is based on the proximity of the road to Protected Activity Centers (PACs). Roads that intersect PACs or are within 0.25 miles from a known owl nest site are considered high-risk roads, while roads that do not intersect PACs and are greater than 0.25 miles from known spotted owl nests are considered low risk to spotted owls (LNFP 2003). The purpose of this pilot study was to record and characterize road maintenance activity in suitable spotted owl habitat to gauge potential sound levels that owls may be presented with during road maintenance activities. Information from this project and any possible future road maintenance sound disturbance studies could be used to determine potential impacts on MSOs, which could influence the timing and location of roadwork on the forest relative to spotted owl PACs. This research was conducted jointly by San Dimas Technology and Development Center, Lincoln National Forest (LNF), Coronado National Forest, Rocky Mountain Research Station (RMS), and the U.S. Army Construction and Engineering Research Laboratory (CERL).

Objective

The primary objective of this pilot study was to record and characterize road maintenance activity in potential spotted owl habitat. Achieving this objective will provide a means to manage for potential effects of road maintenance activity on spotted owls, while also providing a factual basis for mitigation and management protocols and guidelines.

Figure 1. A grader (foreground), loader with rock crusher attachment (middle), and dozer with a grid roller attachment (background) were recorded during sound testing on the Lincoln National Forest, New Mexico on 22-23 October 2002 (see Appendix A).

Scope

Results from this pilot study apply directly to the specific road maintenance equipment tested and to the Lincoln National Forest but may be applicable to other national forests where similar sound levels and stimulus types are present. Road maintenance equipment examined during this study include: a grader, a loader with a rock crusher attachment, and a dozer with a grid roller attachment (Figure 1, Figures A1-3, Appendix A). Spotted owl behavior was not observed during sound trials and therefore we are not able to make any definitive conclusions on how spotted owls would respond to the type of road maintenance equipment tested or based on our level of testing.

2 Literature Review

Sound disturbance studies have often been anecdotal and fail to quantitatively measure either the stimulus or the behavioral response related to the animal's fitness. Predictive models for the relationship between disturbance dosage and quantifiable effects are even more scarce (Awbrey and Bowles 1990; Grubb and King 1991; Grubb and Bowerman 1997). Although many human disturbances have been reported as affecting raptors (Fyfe and Olendorff 1976), very little research has addressed the effects of human activity on owls, especially the threatened spotted owl. Researchers have been aware that human activities might influence spotted owl life history parameters (reproductive fitness, nesting behavior), but have not studied potential impacts directly until recently (Delaney et al. 1999; Swarthout and Steidl 2001; Delaney and Grubb 2003). Delaney et al. (1999) and Delaney and Grubb (2003) are two of the few studies that have experimentally tested spotted owl response to sound stimuli (i.e., military helicopters and chainsaw; motorcycle activity, respectively). The response of raptors to other anthropogenic disturbances, such as construction activity (Holthuijzen 1990), logging truck activity (Grubb et al. 1998), military training (Johnson and Reynolds 2002; Palmer et al. 2003), and recreational activity (Grubb and King 1991) has also been investigated, though more research is needed.

Few researchers have directly compared differences in raptor responsiveness between aerial and ground-based disturbances (Bowles et al. 1990; Grubb and King 1991; Delaney et al. 1999). Studies that have examined the effects of aircraft activity on nesting raptors (e.g., Platt 1977; Windsor 1977; Ellis 1981; Anderson et al. 1989; Delaney et al. 1999) have often noted a slight but non-significant decrease in nesting success and productivity for disturbed versus undisturbed nests. Anderson et al. (1989) noted a slight decline in the nesting success of experimental Red-tailed Hawk (Buteo *jamaicensis*) nests versus control nests after helicopter disturbances (80% experimental versus 86% control). In contrast, ground-based disturbances appear to have a greater effect than aerial disturbances on the nesting success of some raptor species. In their classification tree model of Bald Eagle (Haliaeetus leucocephalus) responses to various anthropogenic disturbances, Grubb and King (1991) determined that Bald Eagles in Arizona showed the highest response frequency and severity of response toward ground-based disturbances, followed by aquatic, and lastly by aerial disturbances. Delaney et al. (1999) reported similar findings for MSO response to military helicopter activity and chainsaws, observing that chainsaws elicited a greater flush response rate than helicopters at comparable distances and sound levels.

A raptor's behavior during the nesting season is an important determinant of its ultimate nesting success or failure (Hohman 1986). Various raptor species have been reported to abandon their nests after being exposed to ground-based and aerial disturbances. White and Thurow (1985) reported that 8 of 24 Ferruginous Hawks (Buteo *regalis*) nests were abandoned after being exposed to various ground-based disturbances, but Anderson et al. (1989) found only 2 of 29 Red-tailed Hawk nests were abandoned after being flushed by helicopter flights. Ellis et al. (1991)

found only 1 of 19 Prairie Falcon (Falco mexicanus) nests were abandoned when exposed to fie-quent low-altitude jet flights during the nesting season. Platt (1977) and Windsor (1977) reported no impact directly related to low-level jet flights over 11 Gyrfalcon (F. *rusticolus*) nests and helicopters over *6* Peregrine Falcon (*F. Peregrinus*) nests, respectively.

Raptors may be more susceptible to disturbance-caused nest abandonment early in the nesting season because parents have less time and energy invested in the nesting process (Knight and Temple 1986). Some raptors appear reluctant to leave the nest later in the nesting season (Anderson et al. 1989; Ellis et al. 1991; Delaney et al. 1999). Steenhof and Kochert (1982) reported that Golden Eagles (Aquila chrysaetos) and Red-tailed Hawks exposed to human intrusions during early incubation had significantly lower nesting success than individuals exposed later in the season (45% success for Golden Eagles and 57% for Red-tailed Hawks within experimental groups versus 71% and 74% success with control groups, respectively). Although reactions of adult raptors at the nest can influence hatching rates and fledgling success (Windsor 1977), flush behavior of adult raptors from the nest is poorly quantified (Fraser et al. 1985; Holthuijzen et al. 1990). In the few studies that have examined raptor responses to specific disturbance types (e.g., aircraft approach distance), flush rates were higher if raptors were naive (i.e., not previously exposed; Platt 1977).

Even fewer examples are available for sound response thresholds. Snyder et al. (1978) reported that Snail Kites (Rostrhamus sociabilis) did not flush even when sound levels were up to 105 decibels, A-weighted (dBA) from commercial jet traffic. This result was qualified by the fact that test raptors were living near airports and may have habituated to the sound. Edwards et al. (1979) found a dose-response relationship for flush responses of several species of gallinaceous birds when approach distances were between 30 and 60 m and sound levels approximated 95 dBA. Delaney et al. (1999) reported that MSOs did not flush during the nesting season when the Sound Exposure Level (SEL) for helicopters was ≤ 102 dBO (owl-weighted; 92 dBA) and the Equivalent Average Sound Level (LEQ) for chainsaws was ≤ 59 dBO (46 dBA). It is important to note that sound from chainsaw and helicopter events were only recorded at the base of nest or roost trees. No recordings were made at nest or roost height and therefore these sound levels are conservative levels compared to what owls were actually receiving, which was almost certainly greater.

3 Technical Approach

Study Area

The study area for this pilot study was located within the Sacramento Ranger District of the Lincoln National Forest, Otero County, in south-central New Mexico (Figure 2). Specifically, sound testing occurred in Deadman Canyon in the west-central portion of the Sacramento Ranger District between 2815-2850 m in elevation. The forest receives a variety of multiple uses from recreational activity (e.g., hiking, motorcycle use), to grazing and logging. Vegetation on the forest is primarily upper montane conifer forest, dominated by Douglas-fir (Pseudotsuga menzesiii) and southwestern white pine (*Pinus* strobiformes) with some ponderosa pine (P. ponderosa; Kaufmann et al. 1998). Elevation across the forest ranges between 1372-2957 m (Skaggs and Raitt 1988).

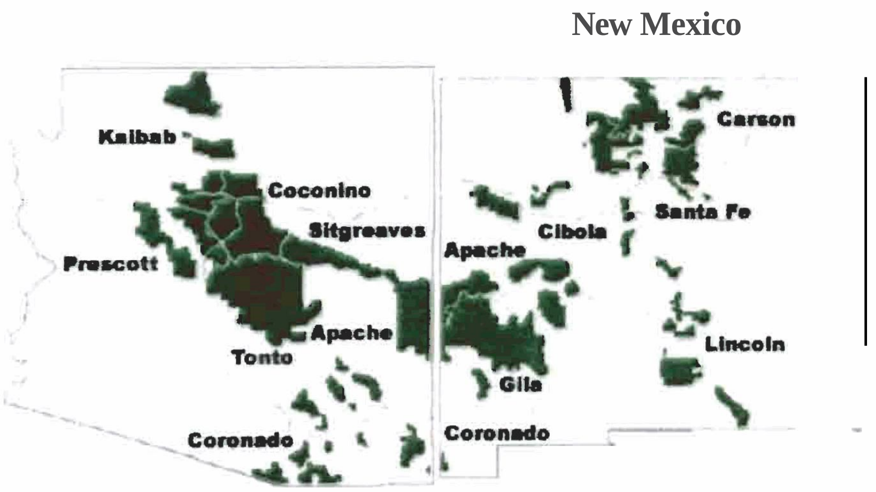

Figure 2. Location of the Lincoln National Forest in south-central New Mexico (USDA Forest Service, Southwestern Region 2003).

Sample Period

We measured sound levels from road maintenance equipment along a maintenance level 3 National Forest System Road at two adjacent study locations on the forest on two successive days during the fall of 2002 (Figure 3). On 22 and 23 October, we recorded road maintenance equipment under realistic conditions to determine how sound varied based on distance, topography, vegetation, and stimulus type. Three different pieces of road maintenance equipment were used during sound testing (Figure A1-A3). A John Deere 770C Motor Grader (engine size: 496 cubic inch; horsepower: 116) was used to grade the road and prepare the road substrate for the rock

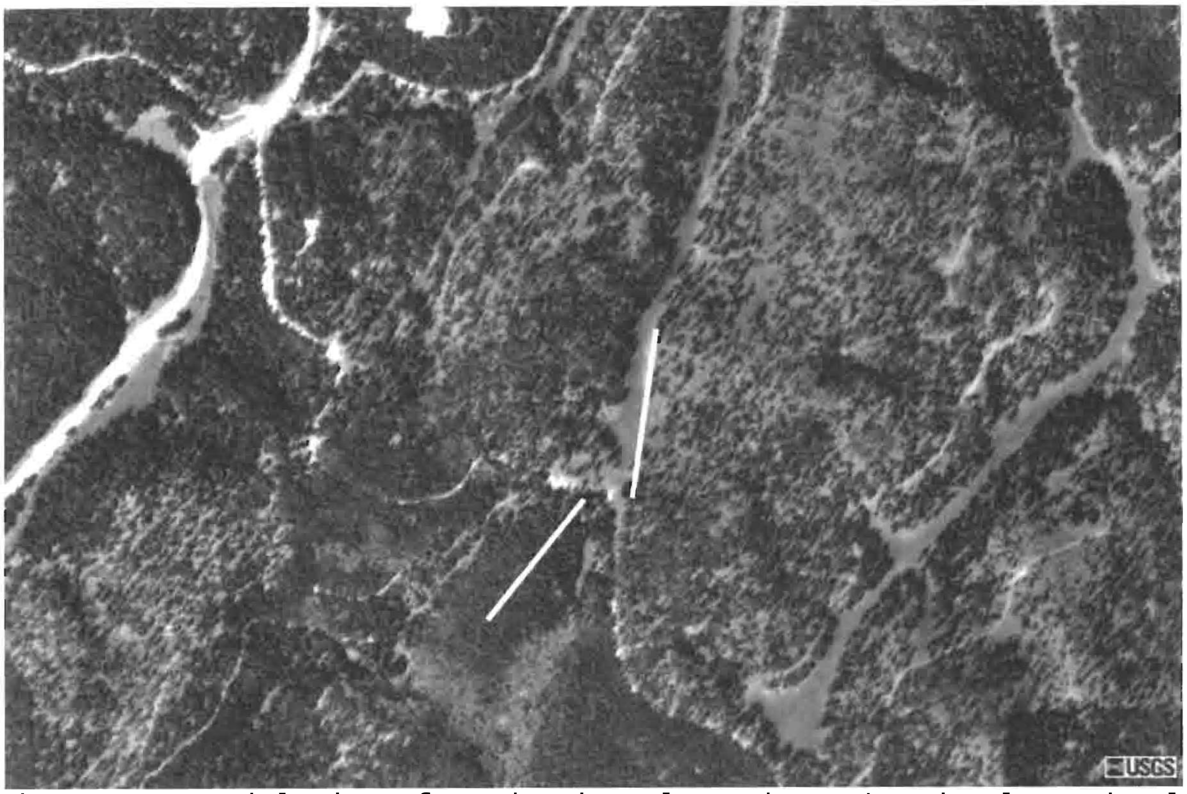

Figure 3. Aerial view of study sites located on the Lincoln National Forest, NM, (USGS 2003). White lines represent approximate study site locations (upper line: meadow site, lower line: forest site).

crusher. A Caterpillar 950F Loader (engine size: 403 cubic inch; horsepower: 170) with a Forester 2000 Rock Crusher attachment (engine size: 636 cubic inch; horsepower: 225) was used to crush road material during the road maintenance process. A John Deere 750B Dozer (engine size: 414 cubic inch; horsepower: 110) with a 15-ton Hyster double barrel grid roller was used to completely pulverize the remaining road material. The grader finished the process by smoothing out the road material. We recorded road maintenance equipment from microphones placed in mid-serial forested habitat on 22 October (elevation range 2816-2852 m; Figure 4) and in a meadow habitat type (2843-2852 m; Figure 5) on 23 October. The forested site had substantially more topographic relief than the meadow site. The forested site increased gradually in elevation from 30 m out to 200 m from the road. Beyond 200 m, the forested site decreased moderately out to the outer test distance of 400 m. The meadow site declined slightly over test distances of 30-400 m. Road maintenance equipment was tested at distances of 30, 60, 120, 180, 240, 320, and 400 m.

Figure 4. Forest habitat site used during road maintenance testing on the Lincoln National Forest, NM, on 22 October 2002.

Figure 5. Meadow habitat site used during road maintenance testing on the Lincoln National Forest, NM, on 23 October 2002. Tree microphones were placed in trees on the edge of the meadow.

Sound Instrumentation and Recording

Sony TCD-D8, Digital Audio Tape (DAT) recorders were used to continuously record all sound events, along with exact time and date. Bruel & Kjaer (B&K) Type 4149, 1.3-cm Condenser Microphones with 7.5-cm wind screens were attached to B&K Model 2639 Preamplifiers. Two microphone configurations were used during sound testing (i.e., base and tree mounts). Microphones were mounted on 1-m tall sticks and placed at the base of each test location, 1 m from the tree trunk. In addition to recording sound levels at the base of the tree, sound levels were also recorded at elevated microphone locations (10 m high) within the same tree. Tree microphones were located in scattered trees along the edge of the meadow during testing at the meadow site. This height was determined to be representative of owl nest/roost tree locations based on prior research on the LNF (Delaney et al. 1999). These microphone locations provided a relative gauge of the sound levels that spotted owls could potentially experience during road maintenance activity and offered a basis of comparison between microphone locations. The power supply and DAT recorder were also placed at the base of the tree in a small container. A 1.0 kHz, 94-dB calibration signal (20 micropascals reference) from a B&K Type 4250 Sound Level Calibrating System was recorded before and after each recorded manipulation. This signal provides an absolute, standardized reference point for sound levels and spectra when data are later reduced using a B&K Type 2144 Frequency Analyzer or Rion NA-27 Sound Level Meter. All sound data were analyzed at ERDC/CERL.

Sound Metrics

Appropriate sound metrics and frequency weighting are essential to adequately quantify sound impact for each type of sound. A sound metric is chosen to measure sound dose in a way that meaningfully correlates with subject response. Frequency weighting is an algorithm of frequency-dependent attenuation that simulates the hearing sensitivity and range of the study subjects. The current project requires specialized metrics and techniques to meaningfully measure the effects of sound on animals. Our paradigm is to measure sound events in terms of unweighted one-third-octave-band levels, apply frequency weighting to the resultant spectra, and calculated appropriate overall metrics. In all cases, the sound signals would be recorded on digital audio tapes and preserved for possible further analysis. A-weighting de-emphasizes the upper (> 5 kHz) and lower (< 0.5 kHz) portions of the frequency spectrum, while emphasizing the middle portion of the frequency spectrum (~ 0.5-5 kHz) where humans have the greatest hearing sensitivity. Flat-weighting (dBF, also termed un-weighted) does not emphasize or de-emphasize any portion of the frequency spectrum, but illustrates how sound energy is actually distributed across the frequency spectrum during a sound event.

An audiogram describes hearing range and sensitivity and provides information on which a frequency weighting algorithm can be based for a specific species. Available information indicates that owl hearing is quite similar among members of a taxonomic order. Within the order Strigiformes, we found audiograms for two species (Great-homed Owl, Bubo virginianus, and Barn Owl, *Tyto* alba) within the same Suborder (Strigi) as spotted owls. These audiograms were used to approximate frequency-weighted sound levels for spotted owls. The owl-weighting curve emphasizes the middle frequency range (1-4 kHz) where test owls had the highest hearing sensitivity (Trainer 1946; Konishi 1973). Most of the sound energy generated by the road equipment is within the lower to middle portions of the frequency spectrum. Figures 6-8 illustrate examples of how sound energy is distributed across the frequency spectra for each of the three sound sources tested. Figure 9 shows a composite average audiogram of seven orders of birds (i.e., "average bird"; Dooling et al. 2000), with an approximate representation of a human audiogram and the "A" weighting curve included for comparison (ANSI 1969). Because both flat- and A-weighting do not accurately reflect the way a spotted owl perceives sound, we used a preliminary estimate for an owl-weighting (dBO) curve (Delaney et al. 1999) based on information in the literature (Trainer 1946; Konishi 1973).

Data Analysis

The current project requires specialized metrics and techniques to meaningfully measure and relate potential sound impacts to animals. We measured sound events in terms of un-weighted one-third-octave-band levels, applied frequency weighting to the resultant spectra, and then calculated the appropriate overall metric. We used two sound metrics in this study: (1) SEL = the sound exposure level, which measures the energy of the sound event taking both intensity and duration into account, and (2) $LEQ_{avg.\ 1\text{-}sec}$ = the 1.0-sec peak equivalent average energy level. Ambient sound was also measured as LEQ (EPA 1982) and compared with sound levels produced by road maintenance activity. We selected one-third-octave band levels at a frequency of 1.6 kHz for the comparison of rock crushing equipment sound levels at varying distances because of increased hearing sensitivity of owls within this range (Trainer 1946; Konishi 1973).

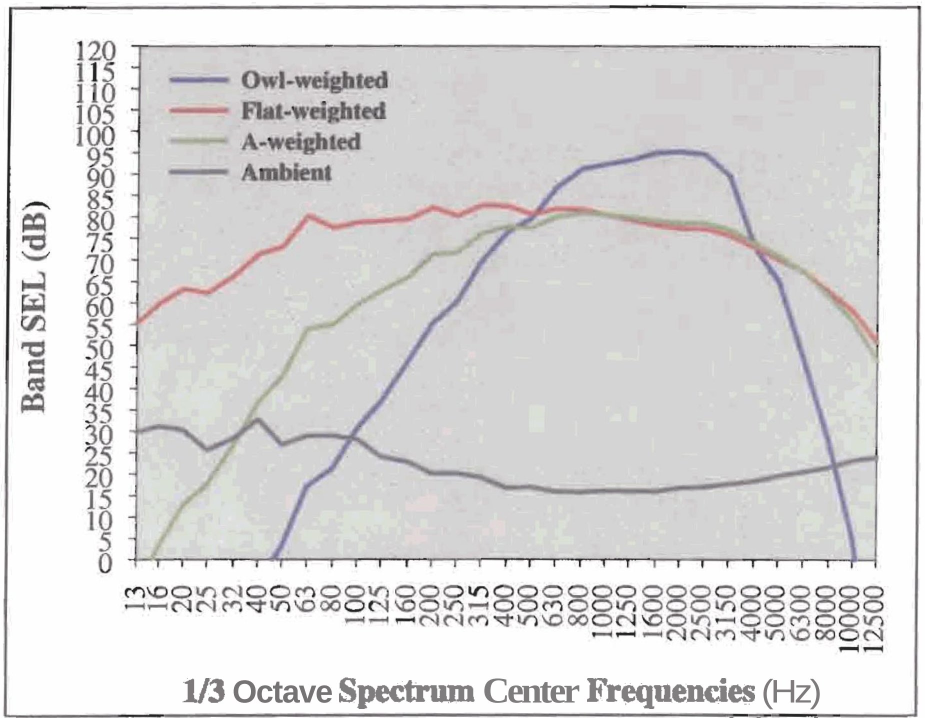

Figure 6. Comparison of owl-, A-, and un-weighted sound levels during a rock crusher pass 60 m from the tree microphone at the forested site on 22 October 2002.

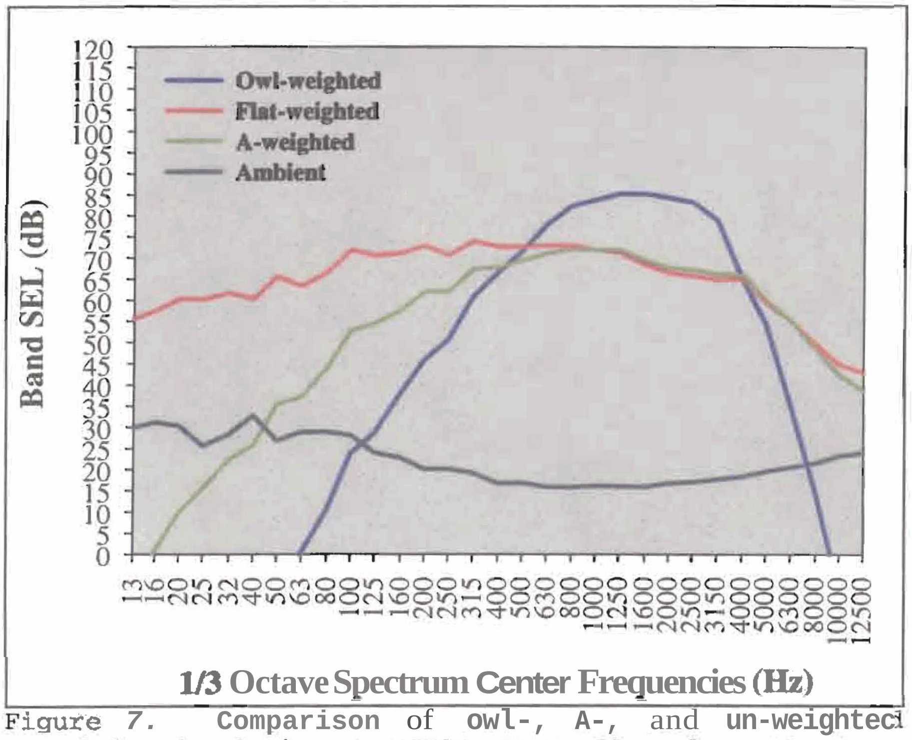

Figure 7. Comparison of owl-, A-, and un-weighted sound levels during a grader pass 60 m from the tree microphone at the forested site on 22 October 2002.

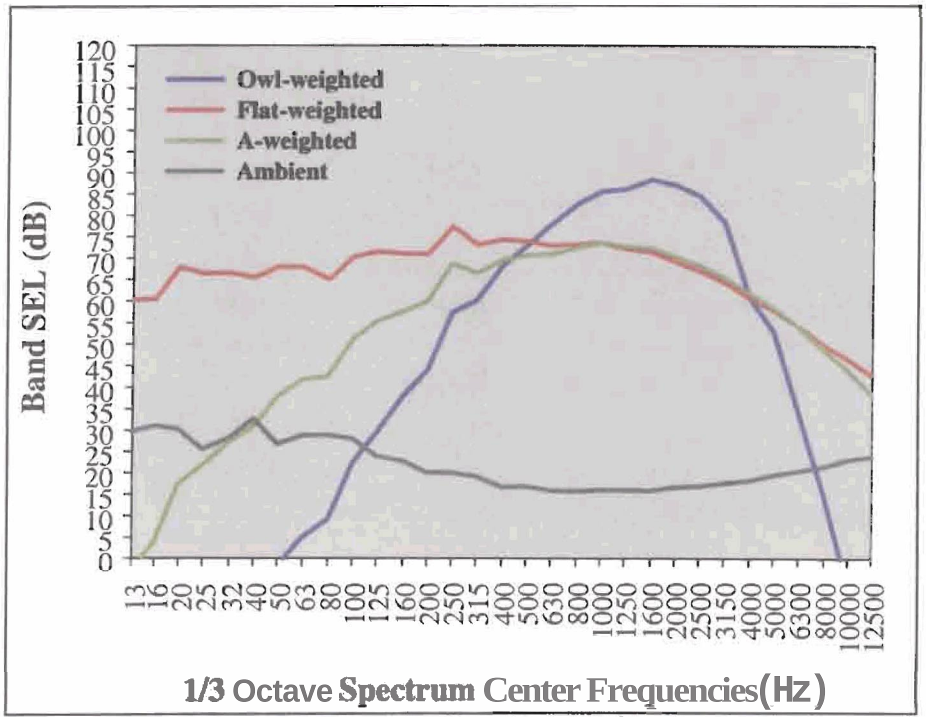

Figure 8. Comparison of owl-, A-, and un-weighted sound levels during a dozer/roller pass 60 m from the tree microphone at the forested site on 22 October 2002.

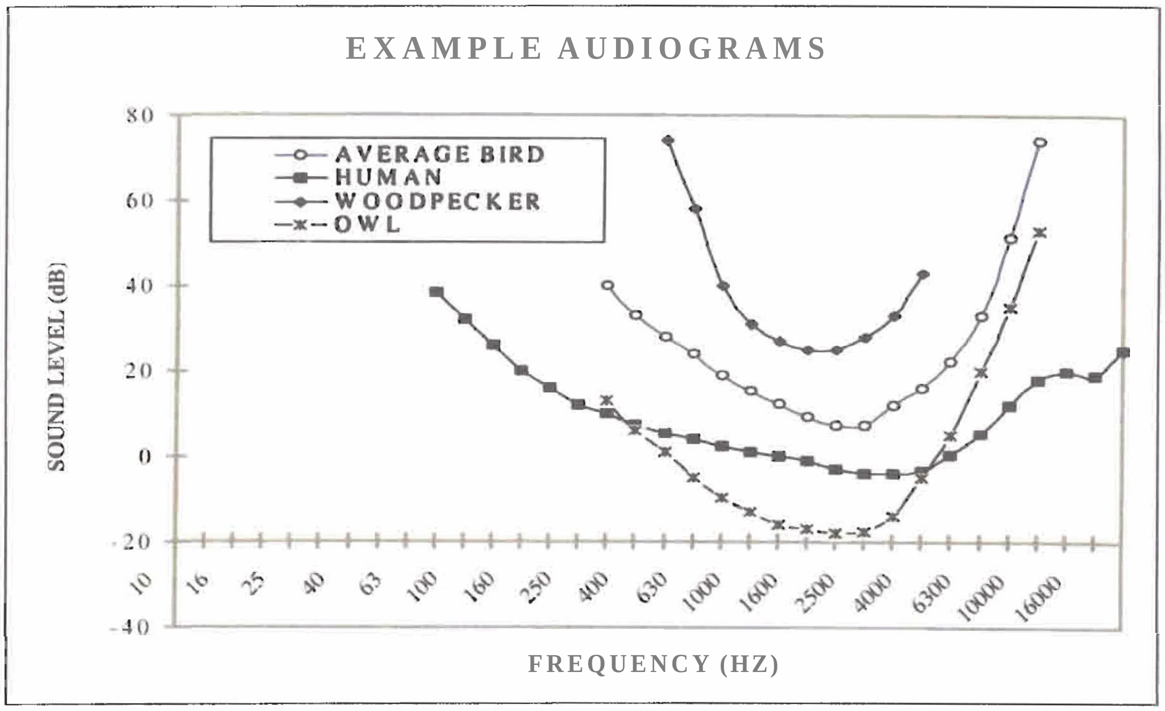

Figure 9. Examples of audiograms and frequency-weighting. Figure developed based on bird audiograms by Dooling et al. (2000), woodpecker audiogram by Lohr et al. (as cited in Delaney et al. 2002), and owl audiograms by Konishi (1973) and Trainer (1946).

4 Results

Detailed results are described below and are also presented in data tables and figures in Appendix B and C, respectively. Tables in Appendix B detail sound levels recorded at various distances for the different types of road maintenance equipment tested. Examples of frequency spectra recorded during sound tests are presented in figures in Appendix C.

Variation in Sound Level and Frequency Spectra

Sound levels from road maintenance equipment increased as the distance between road maintenance activity and microphone locations decreased, regardless of the type of equipment tested or habitat type (Figures 10 and 11). Owl-weighted sound levels from road equipment (forest habitat/tree microphone locations) ranged between 61-69 dBO (51-67 dBA) at 400 m, compared to 96-113 dBO (83-99 dBA) at 30 m (Figure 10; Table B1-B6, Appendix B). Concomitantly, the amount of sound energy within the middle frequency range (between 1-4 kHz) increased sub-

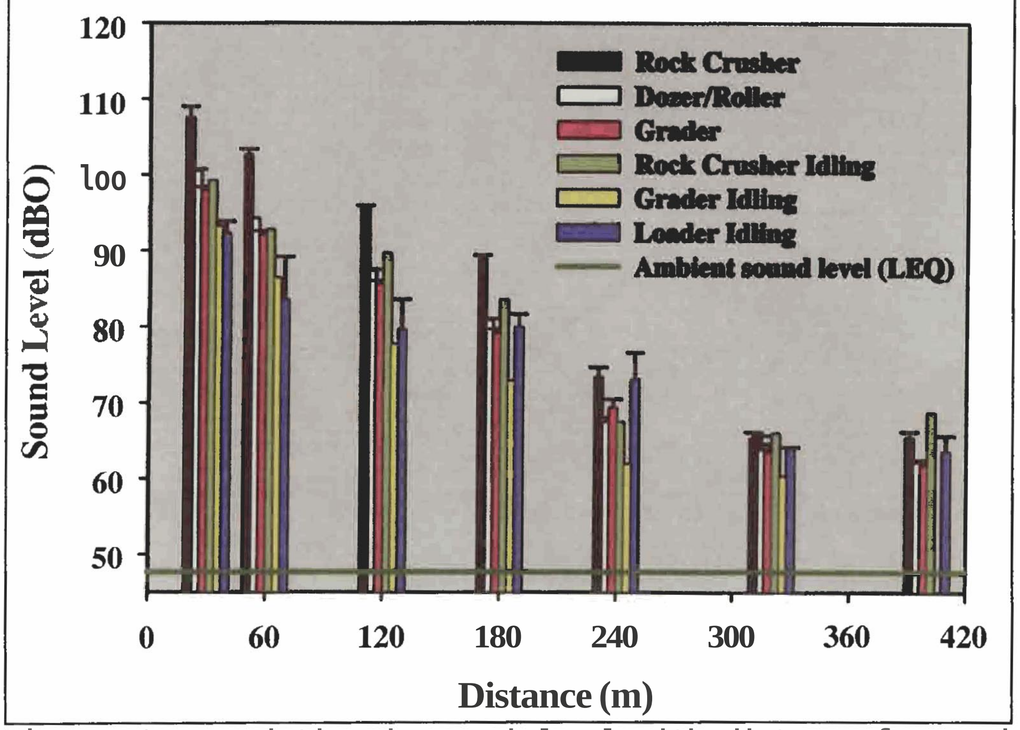

Figure 10. Variation in sound level with distance for road maintenance equipment recorded from tree microphones in a forested site on the Lincoln National Forest on 22 October 2002. Error bars represent one standard error from mean values.

stantially with decreasing stimulus distance from microphone locations (Figures C1-12, Appendix C). Rock crushing equipment registered 53.9 dBO (37.9 dBA) at 400 m in the 1.6 kHz frequency range compared with 102.1 dBO (86.1 dBA) when equipment was 30 m away (Figure C1).

*Forest Versus **Meadow Comparison***

Road maintenance equipment generated consistently higher sound levels and had more sound energy in the middle frequency range at the meadow site compared with similar tests conducted in the forested site, regardless of stimulus type (Figures 10 versus 11; Tables B1-B6 versus Tables B7-B12; Figures C1-C6 versus Figures C7-C12). We found that road equipment was 0.1-21.5 dBO louder during sound recordings at the meadow site compared with the forested site over test distances of 30-400 m (Tables B1, B3, B6 compared with Tables B7, B9, and B11). This pattern was consistent for all stimulus types tested. Rock crushing equipment registered 110.1 dBO (96.6 dBA) at the meadow site at 30 m, compared with 107.5 dBO (94.4 dBA) in the forested site (Table B9 and B3, respectively). At 400 m, rock crushing equipment registered 82.8 dBO (69.3 dBA) at the meadow site compared with 64.4 dBO (56.2 dBA) at the forested site.

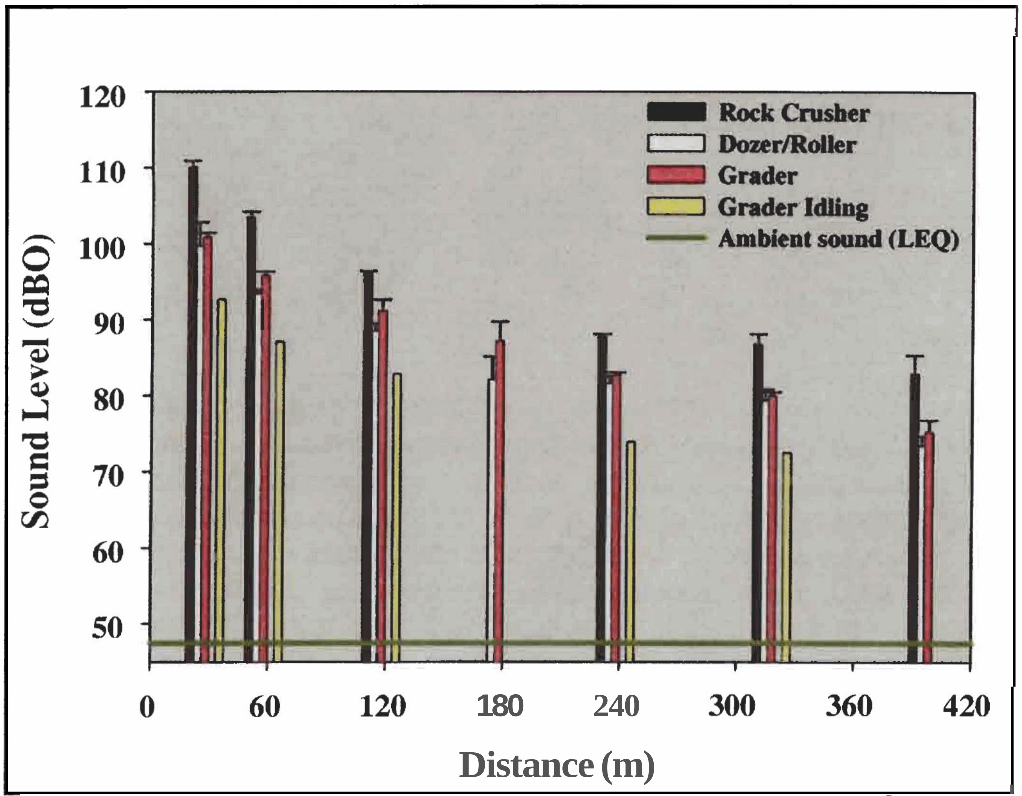

Figure 11. Variation in sound level with distance for road maintenance equipment recorded from a tree microphone along the edge of a meadow site on the Lincoln National Forest on 23 October 2002. Error bars represent one standard error from mean values.

The single largest decrease in sound level between similarly distant tree based microphone locations occurred at the forested site between 180 and 240 m (Figure 10; Tables B1, B3, B6). Road equipment was 9.8-15.4 dBO louder at 180 m than when 240 m away. The drop in sound level between 180 and 240 m was substantially larger than other distance based comparisons (e.g., 6.6 dBO difference between 60 and 120 m tree based microphone recordings, Table B1). We observed a 0.9-8.1 dBO difference between all other tree based microphone site comparisons. A similar comparison could not be made at the meadow site over the same distances due to technical difficulties during sound recording (i.e., Tables B7, B9 and B11). We compared differences in sound level between habitat types over distances of 120-240 m to see if the same trend was evident as between 180-240 m. We found that sound recordings of road equipment passing tree microphones 120 m away were 16.3-22.0 dBO louder than sound recordings at tree microphone recordings 240 m away. We found only a 5.4-8.5 dBO difference at tree microphones when we compared sound recordings from the same vehicles at the meadow site over the same distances (Tables B1, B3, B6 versus Tables B7, B9, B11, respectively).

We observed substantial differences in how sound energy was distributed across test distances of 30-400 m and between test sites. Meadow sites had substantially more sound energy in the middle frequency range than the forested site at comparable distances, regardless of stimulus type (Figures C1, C5, and C9 versus C3, C7, and C11, respectively). Sound energy declined more precipitously with distance at the forested site than at the meadow site. This decline was most evident when we compared distances > 180 m from sound events. Rock crushing equipment registered a 12.6 dBO (53.9-66.5 dBO range) difference in sound energy from 240 to 400 m at the forested site compared with only a 1.0 dBO (78.0-79.0 range) difference at the meadow site over the same distances (Figure C1 versus C3).

Microphone Placement

Tree Versus Base Microphone Comparison

Sound recordings from road maintenance equipment were louder at tree microphones than base microphones, regardless of stimulus distance, stimulus type, or site location (Figures 10 versus 12; Tables B1-B11). For example, a grader at 60 m from a tree microphone in forested habitat registered 92.2 dBO (80.4 dBA) compared with 91.6 dBO (80.2 dBA) from a base microphone (Table B1). At 320 m, the grader registered 63.5 dBO (54.0 dBA) at the tree microphone compared with 62.3 dBO (52.1 dBA) at the base microphone. We observed the same pattern for all sound stimulus types measured. Rock crushing equipment registered 102.6 dBO (89.7 dBA) at 60 m from a tree microphone in forested habitat compared with 101.3 dBO (88.6 dBA) from a base microphone (Table B3). At 320 m, rock crushers registered 65.3 dBO (56.4 dBA) at tree microphones and 64.4 dBO (55.0 dBA) at base microphones.

We found that tree microphones were between 0.2-9.7 dBO louder than base microphones at the forested site (Tables B1-B6) and between 0.2-12.0 dBO louder than sounds recorded from base microphones at the meadow site (Tables B7-B11). Tree microphones registered a greater proportion of sound energy in the middle frequency range than at base microphones, regardless of

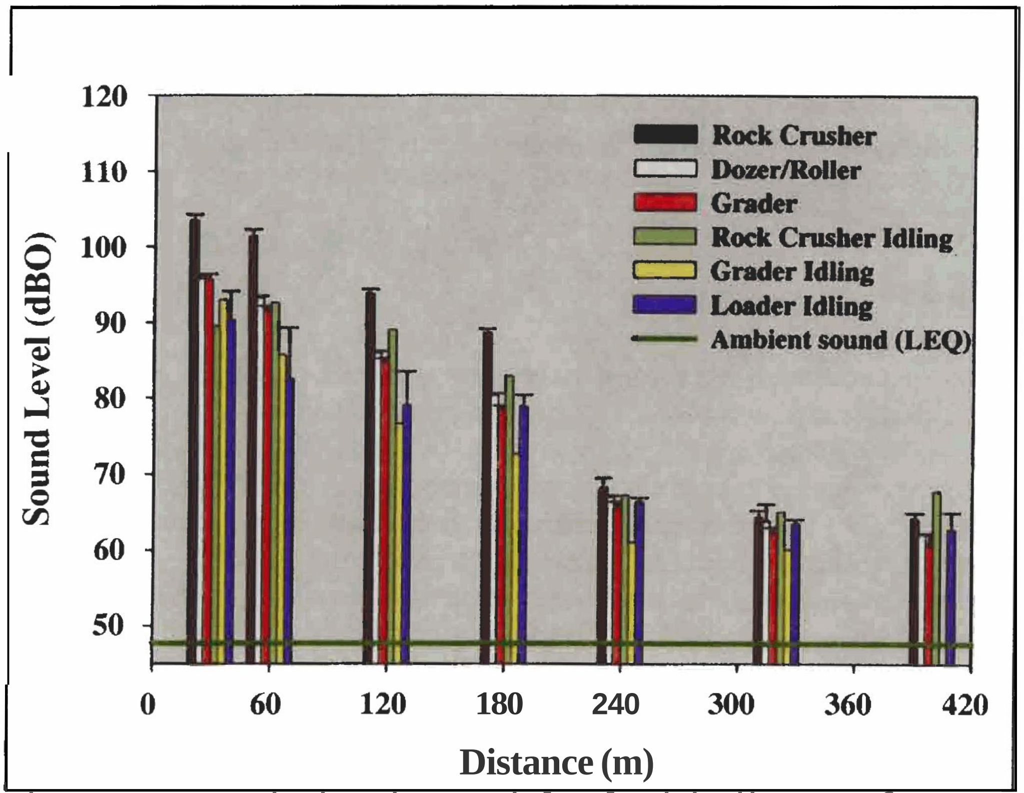

Figure 12. Variation in sound level with distance for road maintenance equipment recorded from a base microphone at a forested site on the Lincoln National Forest on 23 October 2002. Error bars represent one standard error from mean values.

stimulus type, stimulus distance or site location. In examples presented in Figures C1 and C2, sound from rock crushing equipment was approximately 1.0-3.5 dBO greater at tree microphones than base microphones in the 1.6 kHz frequency band over distances of 30-400 m.

Sound Source Comparisons

Road Maintenance Equipment Comparisons

We observed that sound level and frequency spectra varied by stimulus type. Rock crushing equipment registered the highest sound levels (dBO) of any of the road equipment tested, regardless of stimulus distance or habitat type (Figures 10-12). At 30 m, within the forest habitat, rock crushing equipment registered 107.5 dBO (94.4 dBA), followed by the dozer/roller at 100.6 dBO (87.9 dBA), and the grader at 97.9 dBO (85.9 dBA). When road equipment was 400 m away in the forest habitat, rock crushing equipment registered 64.4 dBO (56.2 dBA), compared with 62.2 dBO (54.9 dBA) and 61.1 dBO (54.2 dBA) for dozer/roller and graders, respectively (Tables B1, B3, and B5). We found that rock crushing equipment had the greatest amount of sound energy in the middle frequency range of all the road equipment tested (1-4 kHz), followed by the dozer/

roller and the grader (Figures C1, C5 and C9), regardless of habitat type. We also examined how sound energy was distributed across sound sources when no weighting functions were used (i.e., un-weighted or dBF). We found that the road maintenance equipment we tested had the highest levels of sound energy in the lower portion of the frequency spectrum, that sound energy declined in the middle frequency range, and sound energy dropped off substantially at upper frequencies (Figures 6-8, Flat-weighted).

Road Maintenance Equipment Versus Chainsaws

Road construction equipment was significantly louder and had a greater proportion of its sound energy in the middle frequency range compared with equally distant chainsaw tests. Test results for chainsaws are based on work done in 1995-1996 on the LNF under another project (Delaney et al. 1999). At 60 m, rock-crushing equipment registered a maximum 1-sec LEQ of 78.0 dBO at 1.6kHz compared with 42.7 dBO during a typical chainsaw event that elicited an owl flush response (Figure C13). Dozer/rollers and graders registered a maximum 1-sec LEQ of 72.0 dBO and 68.9 dBO, respectively, compared with chainsaws at that same distance (Figure C14-C15). Sound levels and frequency spectra for chainsaws were only comparable to road maintenance equipment when maintenance equipment was 320 m away (Figures C13-C15). At 320 m, rock-ing crushing equipment registered a maximum 1-sec LEQ of 40.1 dBO at 1.6 kHz compared with 39.4 dBO during chainsaw testing at 60 m (Figure C13). The dozer/roller registered a maximum 1-sec LEQ of 37.2 dBO, while the grader registered 36.4 dBO compared with the same chainsaw test (Figure C14-C15).

Road Maintenance Equipment Versus Ambient Sound Levels

Road equipment was consistently louder than background ambient forest and meadow sound levels over a range of distances from 30-400 m (Figures 10-12; Tables B1-B11; Figures C1-C12). Based on information on owl hearing sensitivity (Figure 6), it appears that spotted owls would be capable of hearing road equipment out to 400 m.

5 Discussion

Spotted owl response to road maintenance activities was not specifically studied during this pilot study and therefore we cannot make any definitive recommendations on the effects of road maintenance activities on Mexican Spotted Owls. Animal response to road maintenance activity depends on a number of complex factors. Such factors and their various interactions need to be taken into account when examining the potential effects that sound generated by road maintenance activities may have on animals. For road equipment, these factors may include: sound level and frequency distribution, stimulus distance and event duration, equipment type and condition, frequency of sound events per unit time, temporal patterns (daily and seasonal) of road maintenance activity, road slope, topography, weather conditions, type and size of road material. For animals, these factors can include: previous experience with a particular sound source, hearing sensitivity, reproductive status, time of day, current behavior or activity during a sound event, and animal location relative to the sound source. Microphone position relative to the sound source, type and quality of recording equipment, and sound metrics measured must also be taken into account for their influence on research results and interpretation.

Variation in Sound Level and Frequency Spectra

It is well documented in wildlife sound disturbance literature that sound level and frequency spectra vary with distance from the sound source (Delaney et al. 1999, Delaney et al. 2002). The important aspect is not just that sound level and frequency spectra vary with distance, but the degree that these variables vary with distance and act in concert together in potentially influencing animal behavior. It is important that both sound level and frequency spectral data be quantified for the basis of developing distance and sound threshold relationships for specific animal/sound source combinations. It is important to note that not all animals will respond the same to similar sound sources and not all individuals will respond the same to different types of sound sources.

Only sound that is audible to the study species should be accounted for in the metric used to quantify sound level. The commonly used "A" frequency weighting (ANSI S1.40-1983) attenuates sound energy according to human hearing range and sensitivity and generally will not be appropriate for animal species. A-weighting de-emphasizes the upper and lower portions of the frequency spectrum, while emphasizing the middle portion of the frequency spectrum where humans have greatest hearing sensitivity. However, it is useful to present "A"-weighted sound levels (i.e., secondarily to animal specific weighting curves or flat-weighted curves) because they occur on sound-level meters, are widely used, and offer a basis of comparison with other studies. Flat-weighting does not emphasize or de-emphasize any portion of the frequency spectrum, but illustrates how sound energy is actually distributed across the frequency spectrum during a sound event. Because both flat- and A-weighting do not accurately reflect the way a spotted owl perceives sound, therefore we used a preliminary estimate for an owl-weighting curve (Delaney et al. 1999) based on information in the literature (Trainer 1946; Konishi 1973). Most sound disturbance research on animals is limited in scope and applicability because sound levels were recorded primarily in terms of A-weighted frequency spectra. It is important that sound effects studies on animals record sound events in terms of un-weighted frequency spectra. Recording sound events as un-weighted spectral data allows for future analysis and interpretation of the data (i.e., application of other algorithms). When data are only recorded according to a specific weighted algorithm (i.e., A-weighted), no other frequency weighting can subsequently be applied to the data.

Forest Versus Meadow Comparison

There are a number of factors that affect sound propagation in outdoor environments. Some of the primary factors include: meteorological effects, air absorption of sound energy, ground interference (i.e., when direct sound energy over ground is impeded by reflected sound waves off the ground surface), ground impedance (i.e., absorption of sound energy by the ground), and sound absorption by vegetation (Aylor 1971; Wiener and Keast 1959; Embleton 1996; Alberts 2001). Sound has been shown to attenuate more quickly in forested habitats versus open habitat types (Aylor 1971). Trend data from this study indicates that habitat type and topography influenced sound level and frequency spectra during testing of road maintenance equipment. Due to the limited number of sites tested, we were not able to separate out which parameter had a greater influence on sound attenuation. Possible mechanisms for higher attenuation rates in forests include scattering of sound from tree trucks and branches and increased complexity (i.e., increased ground absorption from downed logs and branches) of the ground component within the forest compared with an open field environment (Alberts 2001).

An examination of the sound data (Appendix B and C) reveals a range of received sound levels for each sound source at a given distance. One reason is that different types of sound sources have different acoustic source energy. Variation in the frequency and timing of a sound source can change its total emissive power. For a given sound source, the received sound level also depends on differences in propagation conditions, a result of differences in atmospheric wind and temperature structure. It is well known that at distances of several kilometers, received sound level can vary by as much as 50 dB above and below the mean due to changes in meteorological conditions (Piercy et al. 1977; Pater 1981; Embleton 1982; White and Gilbert 1989; Larsson and Isrealsson 1991; White et al. 1993; Li et al. 1994). Differences in received sound level can also be due to orientation of the sound source relative to the receiving animal. Many sound sources exhibit substantial directivity; some as much as 15 dB louder in front of the sound source versus behind (Walther 1972; Schomer et al. 1979; Pater 1981).

Microphone Placement

Tree Versus Base Microphone Comparison

An animal's location relative to a sound source can have a significant effect on the amount of sound (i.e., sound level and event duration) that the animal receives. We used microphone location as a surrogate for owl location during this pilot study. We found that sound from road maintenance equipment varied substantially depending on the location of the receiving microphone. Road equipment recorded at tree microphones was consistently louder than base microphones over similar distances, regardless of stimulus type or habitat type. This has important consequences when we consider nest/roost height relative to road maintenance activities. There are at least two main reasons why sound levels are louder when recorded at tree microphones than base microphones. The first is that base microphones record less sound energy for ground-based sound events than tree microphones due to ground absorption (i.e., impedance). Absorption is the loss or dissipation of sound energy in passing through a material or on striking a surface (Embleton 1982). Softer, rougher surfaces, like the forest floor, will absorb more sound energy than smoother, harder surfaces such as water. Wiener and Keast (1959) reported that sound levels are reduced by up to 10 dB per 100 m at 2 kHz across softer ground surfaces. Secondly, the reflection of sound off the ground can result in a "ground effect". When the sound source and the receiver are both close to the ground, as was the case for road equipment and base microphones, the sound wave reflected from the ground may interfere with the direct sound wave from the sound source to the microphone reducing the sound level at the receiver (Wiener and Keast 1959). Tree microphones were not influenced by ground absorption or "the ground effect" to the degree that ground based microphones and therefore more sound energy was received at tree microphones than base microphones.

Sound Source Comparisons

The sound level and frequency distribution of a stimulus event has important consequences on its propagation across the landscape. Over long distances, lower frequency sound events are attenuated less than higher frequency events (Embleton 1982). Over shorter distances such attenuation may take place, but on a more limited scale. All of the road maintenance equipment tested during this study had fairly high to moderate levels of sound energy within the middle to lower portions of the frequency spectra across all distances tested. We observed some variation in sound level and sound energy distribution between the different sound sources tested. Overall, the loader with the rock crushing attachment registered the highest sound levels and had more sound energy in the middle frequency range of all of the road equipment tested. Rock crusher/loaders registered the highest sound levels of the road maintenance equipment tested, followed by dozer/rollers and then the grader. While these other pieces of equipment pass through an area relatively quickly, the rock crusher was very slow, moving at about 1-mph depending on roadbed composition. The duration of the stimulus becomes a critical issue in this case (see Delaney et al. 1999 for a discussion of the duration of chainsaws versus the brevity of a helicopter flyover). Nearby spotted owls would be exposed to rock crusher sounds for much longer than any type of equipment or vehicles we have tested previously.

Management Implications

Management

Based on our previous sound research with spotted owls, it appears that spotted owls are capable of hearing all of the sound sources tested during this pilot study out to distances of at least 400 m. Road maintenance equipment may elicit a greater behavioral response (e.g., increased flush frequency) by spotted owls than comparably distant chainsaw tests (see Delaney et al. 1999 for details on previous chainsaw testing on spotted owls). We do not anticipate that spotted owls will flush in response to road maintenance equipment that is greater than 320 m from an owl's position compared with previous chainsaw testing (according to the level and type of sound sources tested in this study). At distances less than 320 m, all three pieces of road construction equipment either surpassed or were comparable to sound levels and frequency spectra of chainsaw presentations that elicited flush responses by spotted owls during past research on the Lincoln National Forest. Based on the types of equipment examined and level of testing (i.e., duration, sound level, and frequency distribution) during this pilot study, we found that the most potentially disruptive stimuli to spotted owls would be rock crushers/loaders at 30 m and the least disruptive activity would be from graders at 400 m. Similarly, owls roosting in deep forest may be disrupted less compared with owls roosting nearer to forest-meadow edges due to the influence that vegetation has on sound propagation. This pilot study provides a hypothetical distance/sound relationship from which we predict a hypothesized range over which spotted owls flush response could occur.

Given the extended duration of both rock crusher sound and the multiple passes required of the grader and dozer/roller, comparing sound levels of road maintenance equipment with chainsaws to assess potential impact on spotted owls at varying distances has only limited value and applicability. Such extrapolation should be viewed cautiously. One mitigating approach to reduce overall exposure of owls to the road resurfacing process would be to try running all three pieces of equipment in one simultaneous pass. Otherwise, more traditional approaches of keeping road construction greater than 400 m away or out of MSO PACs entirely during the nesting season may be required. It is important to note that spotted owl behavior was not observed in conjunction with sound testing during this pilot study and therefore we are not able to make any definitive conclusions on how spotted owls would respond to the type of road maintenance equipment tested or based on our level of testing.

Future Research

We believe this pilot study provides a template for the types of considerations that need to be taken into account during any future sound projects investigating the potential effects of road maintenance equipment on spotted owls. Further research is needed to experimentally test MSO response to road maintenance activity to develop a distance and sound threshold relationship. If possible, all combinations of distances and equipment types should be tested to record owl responses, but based on pilot test sound levels and previous chainsaw research, emphasis should be focused between 180-400 m to developa potential response threshold. It is also important that researchers investigate the influence that topography and vegetation have on sound propagation.

Given the possible negative impact of extended stimulus duration, we recommend developing future research using a progressive, stepwise approach, i.e. beginning with non-nesting or post-nesting MSOs and proceeding to nesting owls once initial responsiveness, distances, and timing have been determined. The long-term risk to non- or post-nesters is minimal, so initial experimentation with them can be used to focus subsequent, more critical and limited testing on nesting owls. In our helicopter and chainsaw research (Delaney et al. 1999), we found the response of non-nesters was very indicative of what to expect from nesting owls.

As the field of bioacoustics develops, natural resource managers and scientists are beginning to understand the importance of studying the potential effects of anthropogenic disturbances on animals. Noise was one issue that was conspicuously absent from recovery plans for both the MSO (USDI Fish and Wildlife Service 1995) and the Northern Spotted Owl (USDI Fish and Wildlife Service 1992). It is important that future natural resource management plans/recovery plans for wildlife species consider potential human/wildlife conflicts.

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Appendix A: Road Maintenance Equipment

Figure A 1. Loader with rock crusher attachment **used** during sound testing on the Lincoln National Forest, NM, 22-23 October 2002.

Figure *A* 2. Grader used during sound testing on the Lincoln National Forest, NM, 22-23 October 2002.

Figure A 3. Dozer and grid roller equipment used during sound testing on the Lincoln National Forest, NM, 22-23 October 2002.

Appendix B: Summary Tables

Table B 1. Variation in road maintenance equipment (grader) sound level based on stimulus distance and weighting function during testing on the Lincoln National Forest, NM, in forested habitat on 22 October 2002.

Stimulus Distance (m)	Site Tested	Sound Type	Microphone Location	Sound Levels, SEL (dB) Un-weighted	"Owl" weighted	"A" weighted	Typical Ambient LEQ (dB) "Owl" weighted
30	Forest	Grader	Base	85-91 (87.2)	92-102 (95.7)	79-90 (83.3)	44.0-47.8
	Forest	Grader	Tree	87-91 (89.2)	96-101 (97.9)	83-89 (85.9)	45.5-47.7
60	Forest	Grader	Base	82-87 (84.4)	89-98 (91.6)	77-86 (80.2)	44.0-47.8
	Forest	Grader	Tree	81-86 (83.8)	89-96 (92.2)	77-84 (80.4)	45.5-47.7
120	Forest	Grader	Base	74-79 (76.3)	82-90 (84.8)	70-77 (72.9)	44.0-47.8
	Forest	Grader	Tree	77-81 (78.3)	83-89 (85.6)	72-77 (74.2)	45.5-47.7
180	Forest	Grader	Base	71-80 (74.6)	77-83 (78.4)	65-71 (67.2)	44.0-47.8
	Forest	Grader	Tree	72-78 (74.3)	75-83 (79.2)	66-72 (68.3)	45.5-47.7
240	Forest	Grader	Base	64-74 (69.0)	62-73 (65.6)	52-61 (55.0)	44.0-47.8
	Forest	Grader	Tree	63-75 (68.4)	64-78 (69.3)	55-68 (59.3)	45.5-47.7
320	Forest	Grader	Base	63-72 (67.1)	60-73 (62.3)	50-61 (52.1)	44.0-47.8
	Forest	Grader	Tree	61-81 (65.6)	60-77 (63.5)	50-64 (54.0)	45.5-47.7
400	Forest	Grader	Base	60-69 (65.7)	60-63 (60.7)	50-61 (52.5)	44.0-47.8
	Forest	Grader	Tree	59-68 (64.4)	61-63 (61.8)	51-62 (54.2)	45.5-47.7

Table B 2. Variation in road maintenance equipment (grader idling) sound level based on stimulus distance and weighting function during testing on the Lincoln National Forest, NM, in forested habitat on 22 October 2002. Dashed lines signify that the sound system setup at 400 m was not in place in time to record the idling grader.

Stimulus Distance (m)	Site Tested	Sound Type	Microphone Location	Sound Levels, SEL (dB) Un-weighted	"Owl" weighted	"A" weighted	Typical Ambient LEQ (dB) "Owl" weighted
30	Forest	Grader Idling	Base	88.1	93.0	79.9	44.0-47.8
	Forest	Grader Idling	Tree	88.9	93.2	80.1	45.5-47.7
60	Forest	Grader Idling	Base	87.0	85.7	74.1	44.0-47.8
	Forest	Grader Idling	Tree	80.2	86.4	74.3	45.5-47.7
120	Forest	Grader Idling	Base	81.3	76.6	64.2	44.0-47.8
	Forest	Grader Idling	Tree	78.5	77.7	66.1	45.5-47.7
180	Forest	Grader Idling	Base	78.4	72.6	61.5	44.0-47.8
	Forest	Grader Idling	Tree	74.2	72.9	62.1	45.5-47.7
240	Forest	Grader Idling	Base	71.2	61.0	51.2	44.0-47.8
	Forest	Grader Idling	Tree	68.9	61.9	52.2	45.5-47.7
320	Forest	Grader Idling	Base	67.5	60.1	50.3	44.0-47.8
	Forest	Grader Idling	Tree	67.6	60.3	50.3	45.5-47.7
400	Forest	Grader Idling	Base	---	---	---	
	Forest	Grader Idling	Tree	---	---	---	

Table B 3. Variation in road maintenance equipment (rock crusher) sound level based on stimulus distance and weighting function during testing on the Lincoln National Forest, NM, in forested habitat on 22 October 2002.

Stimulus Distance (m)	Site Tested	Sound Type	Microphone Location	Sound Levels, SEL (dB) Un-weighted	"Owl" weighted	"A" weighted	Typical Ambient LEQ (dB) "Owl" weighted
30	Forest	Rock Crusher	Base	92-99 (95.8)	100-106 (103.5)	87-93 (90.0)	44.0-47.8
	Forest	Rock Crusher	Tree	91-102 (97.4)	101-113 (107.5)	88-99 (94.4)	45.5-47.7
60	Forest	Rock Crusher	Base	93-97 (94.8)	99-105 (101.3)	87-92 (88.6)	44.0-47.8
	Forest	Rock Crusher	Tree	91-94 (92.6)	100-106 (102.6)	88-92 (89.7)	45.5-47.7
120	Forest	Rock Crusher	Base	84-88 (85.7)	92-97 (93.8)	79-83 (80.5)	44.0-47.8
	Forest	Rock Crusher	Tree	85-88 (86.5)	94-98 (95.4)	81-85 (82.8)	45.5-47.7
180	Forest	Rock Crusher	Base	80-85 (84.8)	86-91 (88.6)	74-78 (76.2)	44.0-47.8
	Forest	Rock Crusher	Tree	81-84 (81.9)	87-91 (88.8)	76-79 (77.2)	45.5-47.7
240	Forest	Rock Crusher	Base	67-72 (69.4)	62-71 (68.2)	52-59 (57.1)	44.0-47.8
	Forest	Rock Crusher	Tree	70-78 (72.9)	66-76 (73.4)	57-71 (63.6)	45.5-47.7
320	Forest	Rock Crusher	Base	66-77 (70.3)	62-69 (64.4)	52-65 (55.0)	44.0-47.8
	Forest	Rock Crusher	Tree	63-76 (67.5)	63-70 (65.3)	53-67 (56.4)	45.5-47.7
400	Forest	Rock Crusher	Base	62-75 (67.4)	61-66 (63.2)	51-62 (54.5)	44.0-47.8
	Forest	Rock Crusher	Tree	60-75 (66.0)	63-68 (64.4)	52-67 (56.2)	45.5-47.7

Table B 4. Variation in road maintenance equipment (rock crusher idling) sound level based on stimulus distance and weighting function during testing on the Lincoln National Forest, NM, in forested habitat on 22 October 2002.

Stimulus Distance (m)	Site Tested	Sound Type	Microphone Location	Sound Levels, SEL (dB) Un-weighted	"Owl" weighted	"A" weighted	Typical Ambient LEQ (dB) "Owl" weighted
30	Forest	Rock Crusher Idling	Base	88.8	89.5	75.5	44.0-47.8
	Forest	Rock Crusher Idling	Tree	90.5	99.2	85.3	45.5-47.7
60	Forest	Rock Crusher Idling	Base	91.9	92.6	79.4	44.0-47.8
	Forest	Rock Crusher Idling	Tree	85.9	92.8	79.9	45.5-47.7
120	Forest	Rock Crusher Idling	Base	86.3	89.1	75.4	44.0-47.8
	Forest	Rock Crusher Idling	Tree	83.2	89.6	76.5	45.5-47.7
180	Forest	Rock Crusher Idling	Base	85.2	82.9	70.8	44.0-47.8
	Forest	Rock Crusher Idling	Tree	87.8	83.5	71.1	45.5-47.7
240	Forest	Rock Crusher Idling	Base	72.3	67.2	56.1	44.0-47.8
	Forest	Rock Crusher Idling	Tree	73.0	67.4	56.2	45.5-47.7
320	Forest	Rock Crusher Idling	Base	72.3	65.0	54.1	44.0-47.8
	Forest	Rock Crusher Idling	Tree	68.1	66.0	54.8	45.5-47.7
400	Forest	Rock Crusher Idling	Base	68.6	67.8	56.3	44.0-47.8
	Forest	Rock Crusher Idling	Tree	64.7	68.7	57.2	45.5-47.7

Table B 5. Variation in road maintenance equipment (rock crusher, loader only) sound level based on stimulus distance and weighting function during testing on the Lincoln National Forest, NM, in forest habitat on 22 October 2002.

Stimulus Distance (m)	Site Tested	Sound Type	Microphone Location	Sound Levels, SEL (dB) Un-weighted	"Owl" weighted	"A" weighted	Typical Ambient LEQ (dB) "Owl" weighted
30	Forest	Rock Crusher Loader Only	Base	84-86 (84.7)	87-94 (90.3)	73-82 (77.5)	44.0-47.8
	Forest	Rock Crusher Loader Only	Tree	83-86 (84.6)	91-94 (92.3)	78-82 (80.2)	45.5-47.7
60	Forest	Rock Crusher Loader Only	Base	81-85 (82.7)	76-89 (82.5)	64-78 (71.1)	44.0-47.8
	Forest	Rock Crusher Loader Only	Tree	78-82 (80.2)	78-89 (83.5)	67-77 (71.9)	45.5-47.7
120	Forest	Rock Crusher Loader Only	Base	76-80 (78.3)	75-84 (79.0)	63-71 (66.8)	44.0-47.8
	Forest	Rock Crusher Loader Only	Tree	77-79 (78.0)	76-84 (79.6)	65-72 (68.3)	45.5-47.7
180	Forest	Rock Crusher Loader Only	Base	78-79 (78.4)	77-80 (78.8)	62-66 (66.0)	44.0-47.8
	Forest	Rock Crusher Loader Only	Tree	70-75 (72.2)	78-82 (79.9)	67-68 (67.3)	45.5-47.7
240	Forest	Rock Crusher Loader Only	Base	69-72 (70.3)	66-67 (66.4)	55-56 (55.8)	44.0-47.8
	Forest	Rock Crusher Loader Only	Tree	69-72 (70.4)	69-77 (73.0)	59-62 (60.6)	45.5-47.7
320	Forest	Rock Crusher Loader Only	Base	68-69 (68.7)	63-64 (63.5)	52-53 (52.3)	44.0-47.8
	Forest	Rock Crusher Loader Only	Tree	64-66 (65.3)	63-64 (63.9)	52-53 (52.7)	45.5-47.7
400	Forest	Rock Crusher Loader Only	Base	65-67 (65.9)	61-65 (62.8)	50-54 (51.9)	44.0-47.8
	Forest	Rock Crusher Loader Only	Tree	62-63 (62.9)	62-66 (63.6)	51-55 (52.7)	45.5-47.7

Table B 6. Variation in road maintenance equipment (dozer and roller) sound level based on stimulus distance and weighting function during testing on the Lincoln National Forest, NM, in forested habitat on 22 October 2002.

Stimulus Distance (m)	Site Tested	Sound Type	Microphone Location	Sound Levels, SEL (dB)			Typical Ambient LEQ (dB) "Owl" weighted
				Un-weighted	"Owl" weighted	"A" weighted	
30	Forest	Dozer and Roller	Base	87-88 (87.5)	95-96 (95.8)	82-83 (82.4)	44.0-47.8
	Forest	Dozer and Roller	Tree	91-92 (91.2)	100-101 (100.6)	87-88 (87.9)	45.5-47.7
60	Forest	Dozer and Roller	Base	86-87 (86.3)	93-94 (93.3)	81-82 (81.1)	44.0-47.8
	Forest	Dozer and Roller	Tree	85-86 (85.3)	94-95 (94.3)	81-82 (81.9)	45.5-47.7
120	Forest	Dozer and Roller	Base	77-78 (77.6)	85-87 (86.0)	73-74 (73.1)	44.0-47.8
	Forest	Dozer and Roller	Tree	79-80 (79.6)	87-88 (87.4)	75-76 (75.3)	45.5-47.7
180	Forest	Dozer and Roller	Base	74-75 (74.9)	80-81 (80.4)	68-69 (68.6)	44.0-47.8
	Forest	Dozer and Roller	Tree	75-76 (75.3)	80-81 (81.0)	69-70 (69.8)	45.5-47.7
240	Forest	Dozer and Roller	Base	69-72 (70.3)	66-68 (67.0)	55-56 (55.9)	44.0-47.8
	Forest	Dozer and Roller	Tree	69-71 (69.7)	67-68 (67.5)	57-61 (59.1)	45.5-47.7
320	Forest	Dozer and Roller	Base	65-69 (67.2)	62-65 (63.7)	51-61 (56.1)	44.0-47.8
	Forest	Dozer and Roller	Tree	63-68 (67.9)	62-66 (63.9)	52-61 (56.8)	45.5-47.7
400	Forest	Dozer and Roller	Base	65.1	61.2	54.3	44.0-47.8
	Forest	Dozer and Roller	Tree	65.7	62.2	54.9	45.5-47.7

Table B 7. Variation in road maintenance equipment (grader) sound level based on stimulus distance and weighting function during testing on the Lincoln National Forest, NM, in meadow habitat on 23 October 2002. Diamond symbol signifies the distance where we were not able to find a tree to set up a tree microphone at the 120 m distance. The closest tree was at 110 m from the road equipment. Asterisk signifies distance at which sound could not be recorded due to interference from animal activity in the microphone tree.

Stimulus Distance (m)	Site Tested	Sound Type	Microphone Location	Sound Levels, SEL (dB)			Typical Ambient LEQ (dB) "Owl" weighted
				Un-weighted	"Owl" weighted	"A" weighted	
30	Meadow	Grader	Base	92-96 (94.3)	98-101 (99.1)	85-89 (86.9)	45.1-46.9
	Meadow	Grader	Tree	91-94 (92.5)	100-103 (100.9)	88-90 (88.7)	45.4-47.5
60	Meadow	Grader	Base	84-87 (85.3)	84-89 (86.6)	73-77 (75.1)	45.1-46.9
	Meadow	Grader	Tree	88-90 (88.8)	95-98 (95.8)	83-86 (83.8)	45.4-47.5
110♦	Meadow	Grader	Base	79-84 (81.9)	78-86 (83.0)	65-74 (70.6)	45.1-46.9
	Meadow	Grader	Tree	78-85 (82.6)	85-94 (91.1)	73-81 (78.7)	45.4-47.5
180	Meadow	Grader	Base	*	*	*	
	Meadow	Grader	Tree	*	*	*	
240	Meadow	Grader	Base	80-84 (81.3)	80-82 (79.8)	67-70 (67.5)	45.1-46.9
	Meadow	Grader	Tree	77-79 (77.6)	81-84 (82.6)	70-72 (71.1)	45.4-47.5
320	Meadow	Grader	Base	76-81 (77.3)	75-78 (76.0)	63-66 (63.7)	45.1-46.9
	Meadow	Grader	Tree	78-84 (80.6)	79-82 (80.0)	67-70 (68.1)	45.4-47.5
400	Meadow	Grader	Base	76-81 (78.3)	69-73 (70.5)	57-61 (58.8)	45.1-46.9
	Meadow	Grader	Tree	74-80 (76.9)	70-79 (75.2)	60-68 (64.1)	45.4-47.5

Table B 8. Variation in road maintenance equipment (grader idling) sound level based on stimulus distance and weighting function during testing on the Lincoln National Forest, NM, in meadow habitat on 23 October 2002. Asterisk signifies distance at which sound could not be recorded due to interference from animal activity in the microphone tree. Dashed lines signify that the sound system setup at 400 m was not in place in time to record the idling grader.

Stimulus Distance (m)	Site Tested	Sound Type	Microphone Location	Sound Levels, SEL (dB) Un-weighted	"Owl" weighted	"A" weighted	Typical Ambient LEQ (dB) "Owl" weighted
30	Meadow	Grader Idling	Base	92.5	91.4	77.7	45.1-46.9
	Meadow	Grader Idling	Tree	93.2	92.6	77.9	45.4-47.5
60	Meadow	Grader Idling	Base	86.5	81.2	67.4	45.1-46.9
	Meadow	Grader Idling	Tree	86.6	87.0	73.8	45.4-47.5
120	Meadow	Grader Idling	Base	84.2	77.1	64.0	45.1-46.9
	Meadow	Grader Idling	Tree	80.2	82.8	69.6	45.4-47.5
180	Meadow	Grader Idling	Base	*	*	*	
	Meadow	Grader Idling	Tree	*	*	*	
240	Meadow	Grader Idling	Base	83.5	73.7	61.9	45.1-46.9
	Meadow	Grader Idling	Tree	75.8	73.9	62.5	45.4-47.5
320	Meadow	Grader Idling	Base	80.4	71.9	60.2	45.1-46.9
	Meadow	Grader Idling	Tree	79.0	72.5	60.9	45.4-47.5
400	Meadow	Grader Idling	Base	---	---	---	
	Meadow	Grader Idling	Tree	---	---	---	

Table B 9. Variation in road maintenance equipment (rock crusher) sound level based on stimulus distance and weighting function during testing on the Lincoln National Forest, NM, in meadow habitat on 23 October 2002. Asterisk signifies distance at which sound could not be recorded due to interference from animal activity in the microphone tree.

Stimulus Distance (m)	Site Tested	Sound Type	Microphone Location	Sound Levels, SEL (dB) Un-weighted	"Owl" weighted	"A" weighted	Typical Ambient LEQ (dB) "Owl" weighted
30	Meadow	Rock Crusher	Base	98-99 (98.8)	105-111 (107.9)	92-97 (94.5)	45.1-46.9
	Meadow	Rock Crusher	Tree	98-99 (98.7)	109-111 (110.1)	96-98 (96.6)	45.4-47.5
60	Meadow	Rock Crusher	Base	88-89 (88.7)	90-93 (91.5)	78-80 (78.5)	45.1-46.9
	Meadow	Rock Crusher	Tree	92-93 (92.6)	102-105 (103.5)	88-91 (89.7)	45.4-47.5
120	Meadow	Rock Crusher	Base	86-88 (86.8)	89-91 (89.3)	75-77 (75.9)	45.1-46.9
	Meadow	Rock Crusher	Tree	86-88 (87.0)	96-97 (96.1)	82-83 (82.5)	45.4-47.5
180	Meadow	Rock Crusher	Base	*	*	*	
	Meadow	Rock Crusher	Tree	*	*	*	
240	Meadow	Rock Crusher	Base	79-80 (79.7)	87-88 (87.7)	74-75 (74.6)	45.1-46.9
	Meadow	Rock Crusher	Tree	84-86 (85.2)	86-91 (87.9)	73-77 (74.9)	45.4-47.5
320	Meadow	Rock Crusher	Base	78-80 (79.2)	82-86 (84.0)	68-72 (69.7)	45.1-46.9
	Meadow	Rock Crusher	Tree	80-81 (80.3)	85-89 (86.8)	72-75 (73.4)	45.4-47.5
400	Meadow	Rock Crusher	Base	78-81 (78.8)	73-78 (74.8)	60-64 (61.6)	45.1-46.9
	Meadow	Rock Crusher	Tree	77-79 (77.9)	78-86 (82.8)	65-72 (69.3)	45.4-47.5

Table B 10. Variation in road maintenance equipment (rock crusher/loader only) sound level based on stimulus distance and weighting function during testing on the Lincoln National Forest, NM, in meadow habitat on 23 October 2002. Asterisk signifies distance at which sound could not be recorded due to interference from animal activity in the microphone tree.

Stimulus Distance (m)	Site Tested	Sound Type	Microphone Location	Sound Levels, SEL (dB) Un-weighted	"Owl" weighted	"A" weighted	Typical Ambient LEQ (dB) "Owl" weighted
30	Meadow	Rock Crusher Loader Only	Base	90.9	96.9	84.4	45.1-46.9
	Meadow	Rock Crusher Loader Only	Tree	88.9	97.5	85.3	45.4-47.5
60	Meadow	Rock Crusher Loader Only	Base	80.6	83.7	71.8	45.1-46.9
	Meadow	Rock Crusher Loader Only	Tree	84.8	91.9	79.9	45.4-47.5
120	Meadow	Rock Crusher Loader Only	Base	76.9	80.0	67.8	45.1-46.9
	Meadow	Rock Crusher Loader Only	Tree	79.2	87.4	75.0	45.4-47.5
180	Meadow	Rock Crusher Loader Only	Base	*	*	*	
	Meadow	Rock Crusher Loader Only	Tree	*	*	*	
240	Meadow	Rock Crusher Loader Only	Base	73.9	76.6	64.2	45.1-46.9
	Meadow	Rock Crusher Loader Only	Tree	75.3	78.4	67.5	45.4-47.5
320	Meadow	Rock Crusher Loader Only	Base	73.8	72.7	60.4	45.1-46.9
	Meadow	Rock Crusher Loader Only	Tree	80.3	77.8	66.1	45.4-47.5
400	Meadow	Rock Crusher Loader Only	Base	81.3	67.6	56.6	45.1-46.9
	Meadow	Rock Crusher Loader Only	Tree	71.5	70.6	60.1	45.4-47.5

Table B 11. Variation in road maintenance equipment (dozer/roller) sound level based on stimulus distance and weighting function during testing on the Lincoln National Forest, NM, in meadow habitat on 23 October 2002. Asterisk signifies distance at which sound could not be recorded due to interference from animal activity in the microphone tree.

Stimulus Distance (m)	Site Tested	Sound Type	Microphone Location	Sound Levels, SEL (dB)			Typical Ambient LEQ (dB) "Owl" weighted
				Un-weighted	"Owl" weighted	"A" weighted	
30	Meadow	Dozer and Roller	Base	94-95 (94.4)	100-101 (100.3)	87-89 (88.0)	45.1-46.9
	Meadow	Dozer and Roller	Tree	93-100 (96.4)	100-103 (100.7)	87-90 (88.5)	45.4-47.5
60	Meadow	Dozer and Roller	Base	84-85 (84.8)	85-87 (85.7)	74-75 (74.6)	45.1-46.9
	Meadow	Dozer and Roller	Tree	87-89 (88.1)	93-97 (95.2)	82-85 (83.1)	45.4-47.5
120	Meadow	Dozer and Roller	Base	79-82 (80.0)	81-82 (81.4)	67-70 (68.5)	45.1-46.9
	Meadow	Dozer and Roller	Tree	78-82 (79.9)	87-89 (88.0)	73-77 (75.1)	45.4-47.5
180	Meadow	Dozer and Roller	Base	*	*	*	
	Meadow	Dozer and Roller	Tree	*	*	*	
240	Meadow	Dozer and Roller	Base	79-83 (80.7)	80-82 (80.9)	68-69 (68.3)	45.1-46.9
	Meadow	Dozer and Roller	Tree	76-77 (76.9)	82-83 (82.6)	71-72 (71.2)	45.4-47.5
320	Meadow	Dozer and Roller	Base	75-80 (77.8)	77-78 (77.3)	64-65 (64.5)	45.1-46.9
	Meadow	Dozer and Roller	Tree	75-82 (78.8)	80-81 (80.8)	68-69 (68.8)	45.4-47.5
400	Meadow	Dozer and Roller	Base	71.6	68.1	56.3	45.1-46.9
	Meadow	Dozer and Roller	Tree	70.9	74.7	63.7	45.4-47.5

Appendix C: Source Spectra

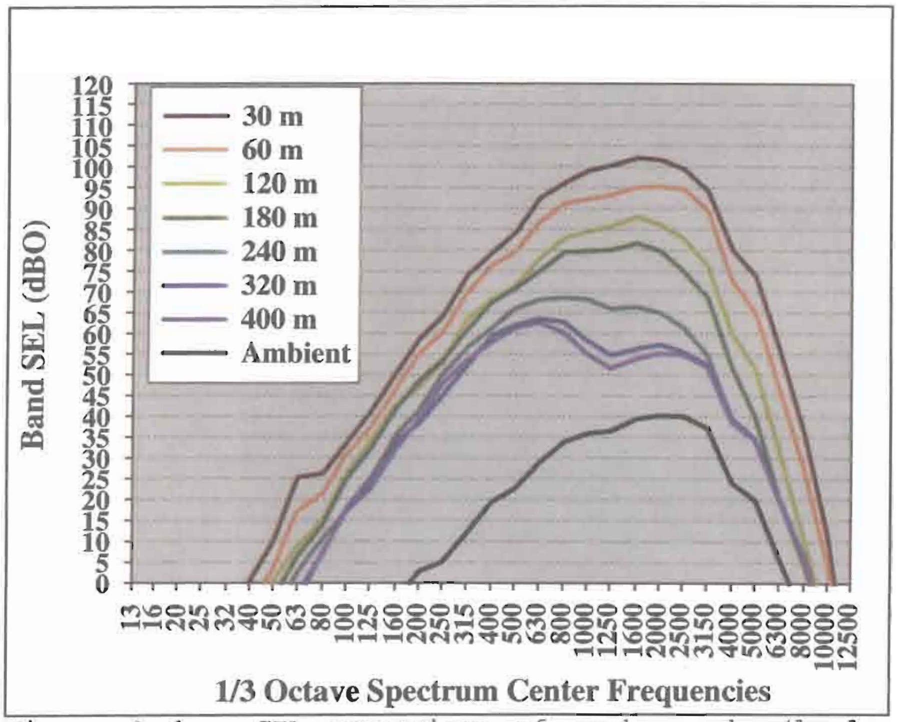

Figure C 1. SEL comparison of rock crusher/loader frequency spectra over distances of 30-400 m at tree microphone (forest site) on the Lincoln National Forest, NM, on 22 October 2002.

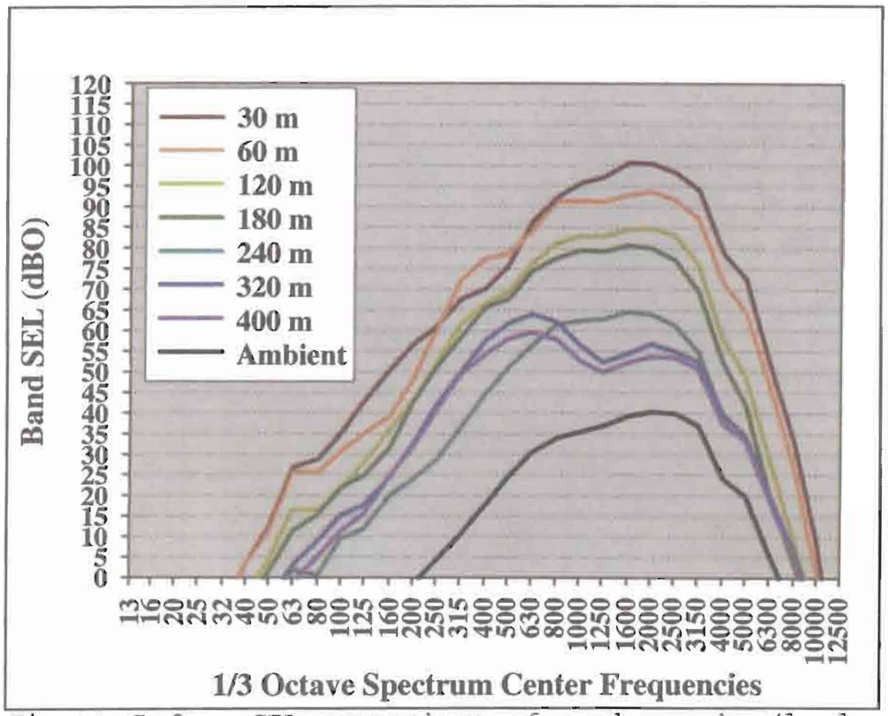

Figure C 2. SEL comparison of rock crusher/loader frequency spectra over distances of 30-400 m at base microphone (forest site) on the Lincoln National Forest, NM, on 22 October 2002.

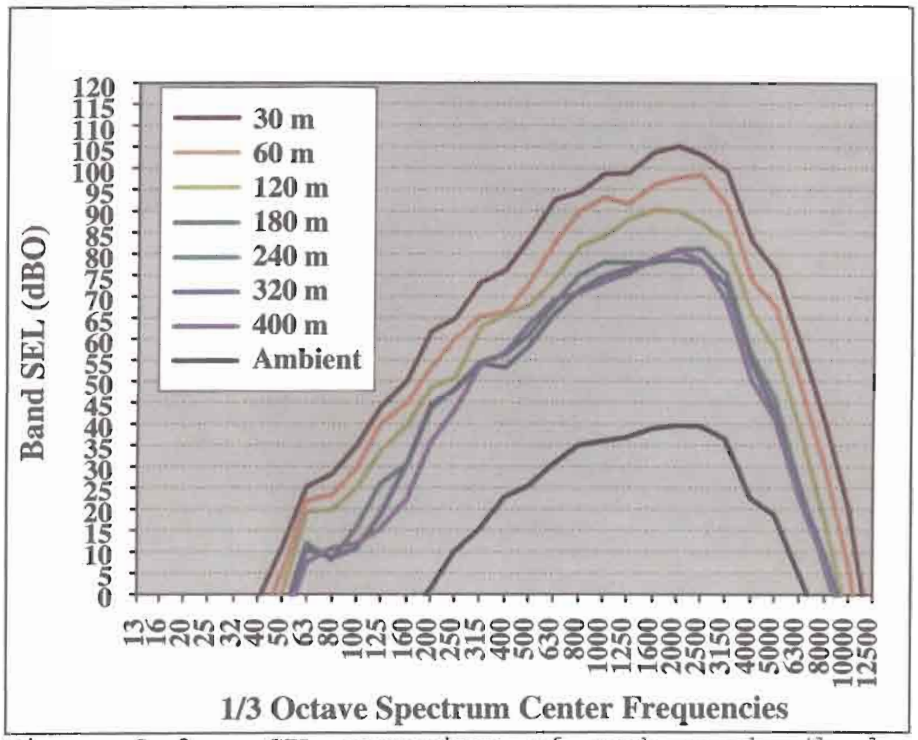

Figure C 3. SEL comparison of rock crusher/loader frequency spectra over distances of 30-400 m (meadow site) at tree microphone on the Lincoln National Forest, on 22 October 2002.

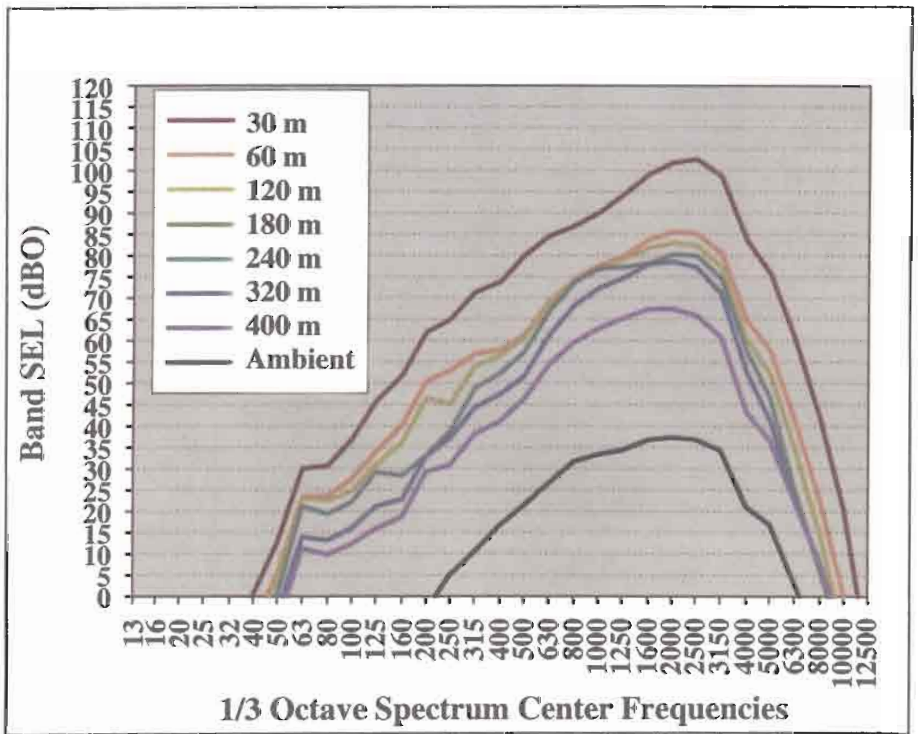

Figure C 4. SEL comparison of rock crusher/loader frequency spectra over distances of 30-400 m (meadow site) at base microphone on the Lincoln National Forest, NM, on 23 October 2002.

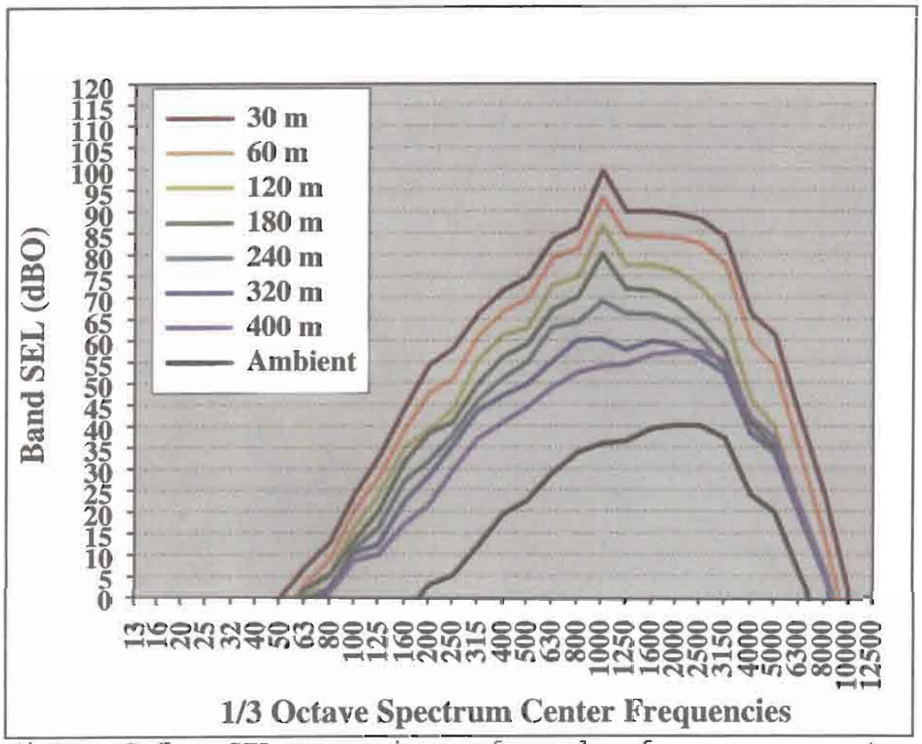

Figure C 5. SEL comparison of grader frequency spectra over distances of 30-400 m at tree microphone (forest site) on the Lincoln National Forest, NM, on 22 October 2002.

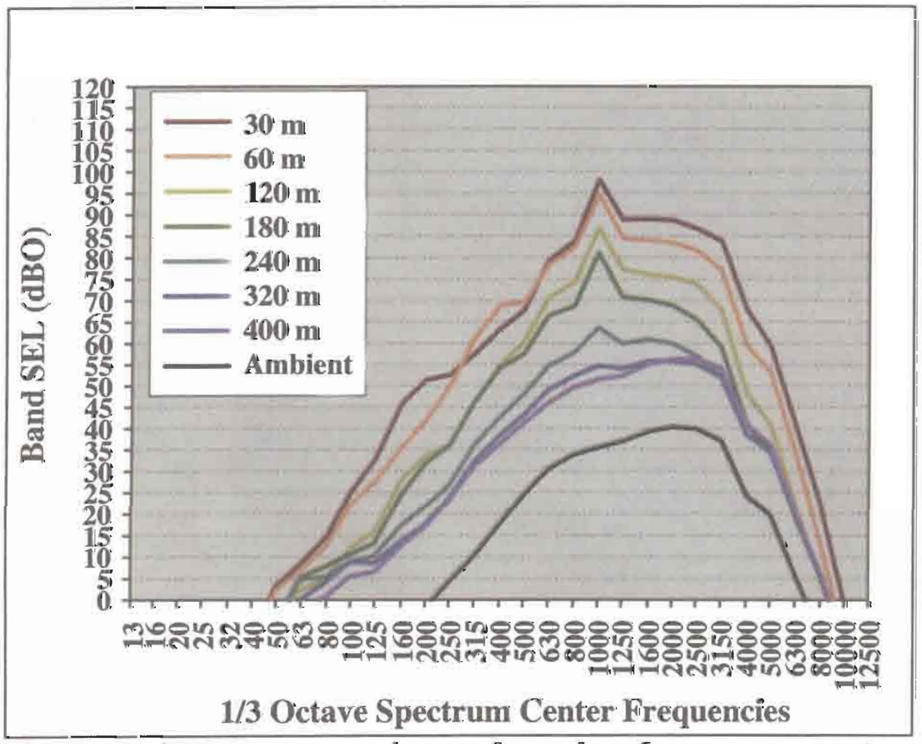

Figure C 6. SEL comparison of grader frequency spectra over distances of 30-400 m at base microphone (forest site) on the Lincoln National Forest, NM, on 22 October 2002.

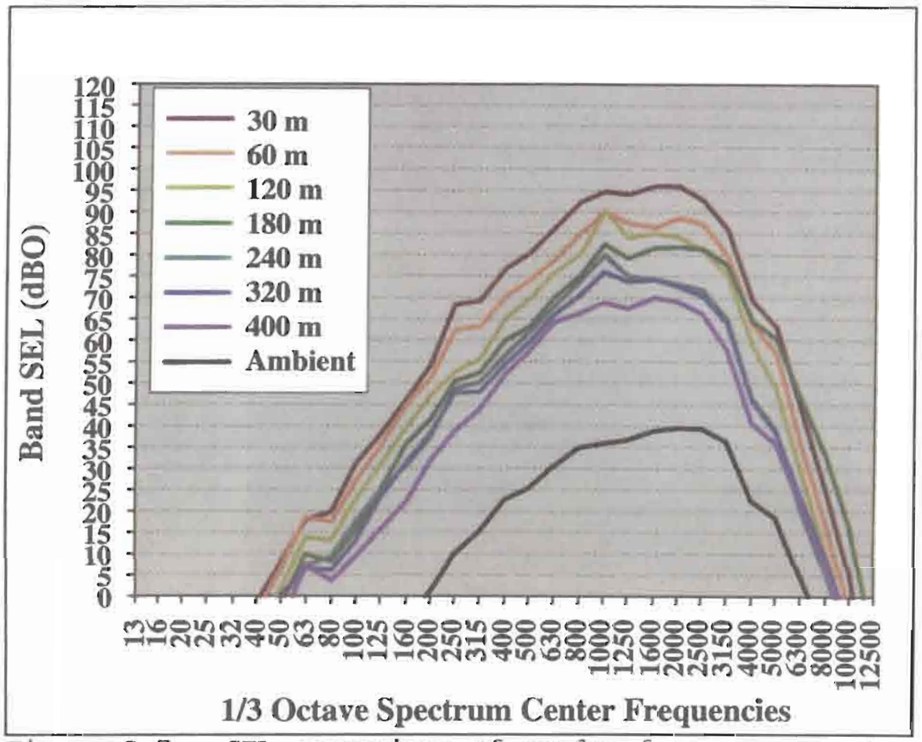

Figure C 7. SEL comparison of grader frequency spectra over distances of 30-400 m at tree microphone (meadow site) on the Lincoln National Forest, NM, on 23 October 2002.

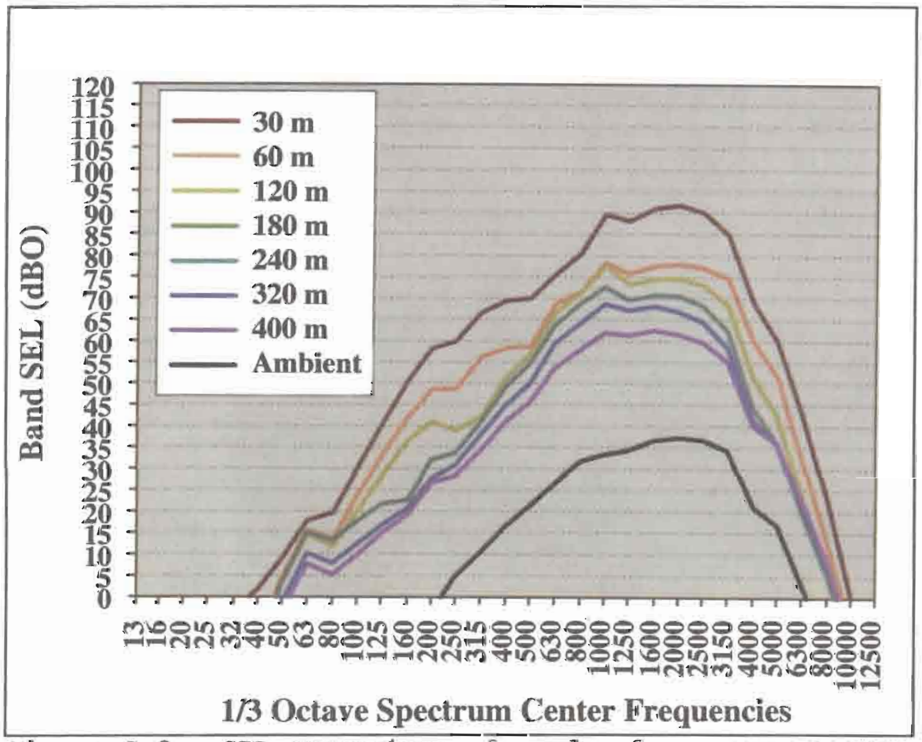

Figure C 8. SEL comparison of grader frequency spectra over distances of 30-400 m at base microphone (meadow site) on the Lincoln National Forest, NM, on 23 October 2002.

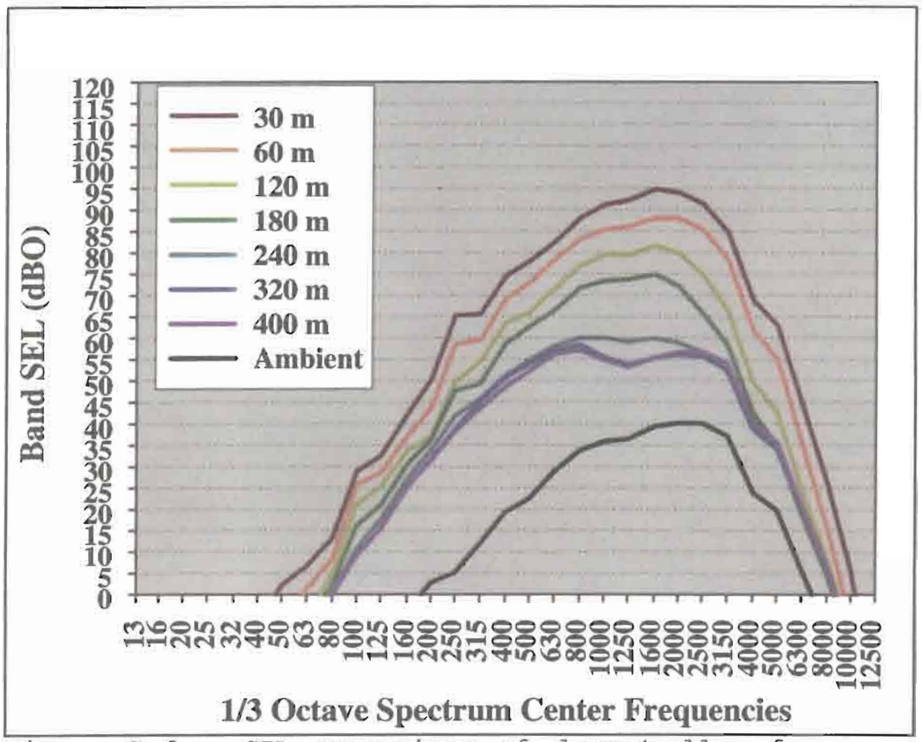

Figure C 9. SEL comparison of dozer/roller frequency spectra over distances of 30-400 m at tree microphone (forest site) on the Lincoln National Forest, NM, on 22 October 2002.

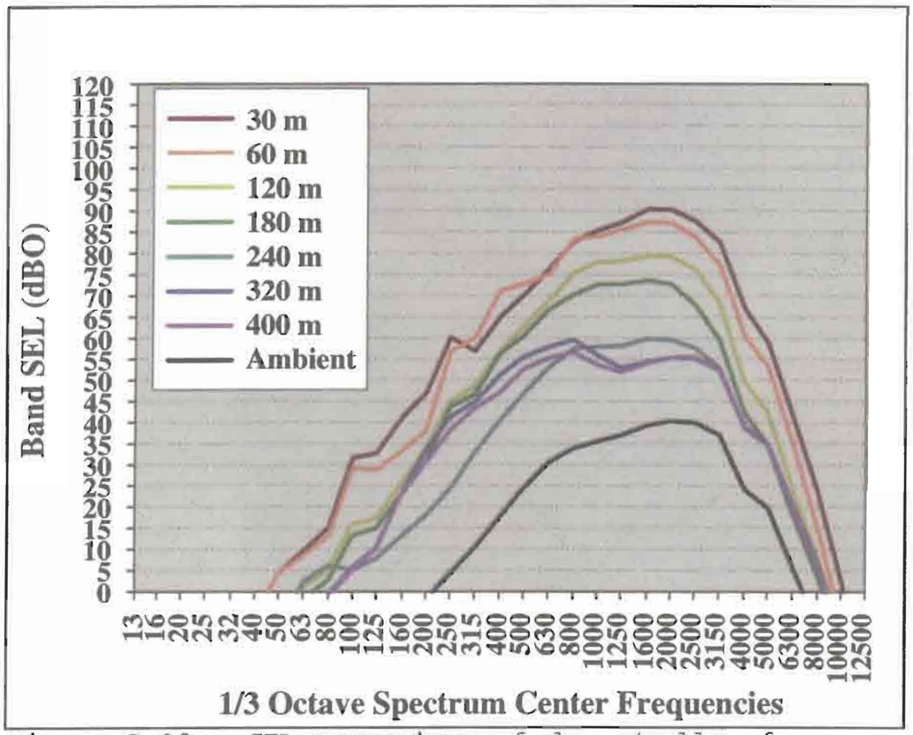

Figure C 10. SEL comparison of dozer/roller frequency spectra over distances of 30-400 m at base microphone (forest site) on the Lincoln National Forest, NM, on 22 October 2002.

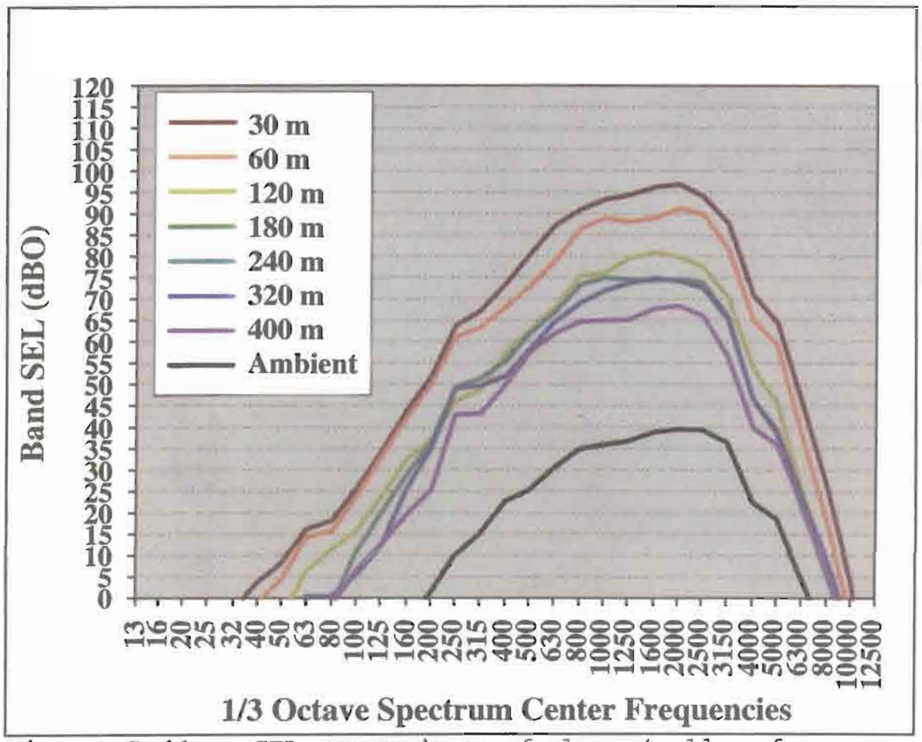

Figure C 11. SEL comparison of dozer/roller frequency spectra over distances of 30-400 m at tree microphone (meadow site) on the Lincoln National Forest, NM, on 23 October 2002.

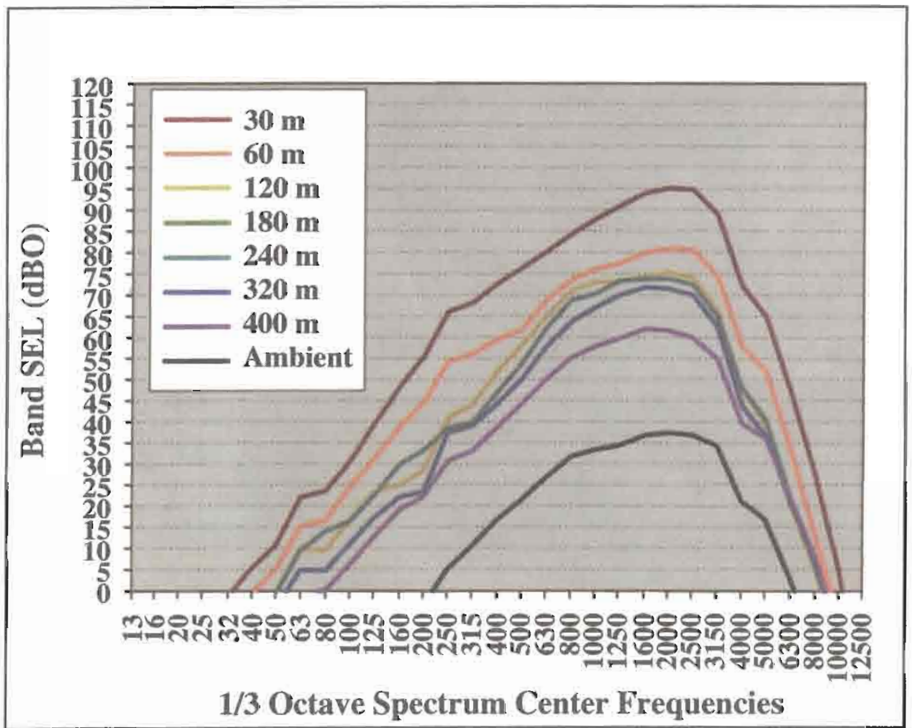

Figure C 12. SEL comparison of dozer/roller frequency spectra over distances of 30-400 m at base microphone (meadow site) on the Lincoln National Forest, NM, on 23 October 2002.

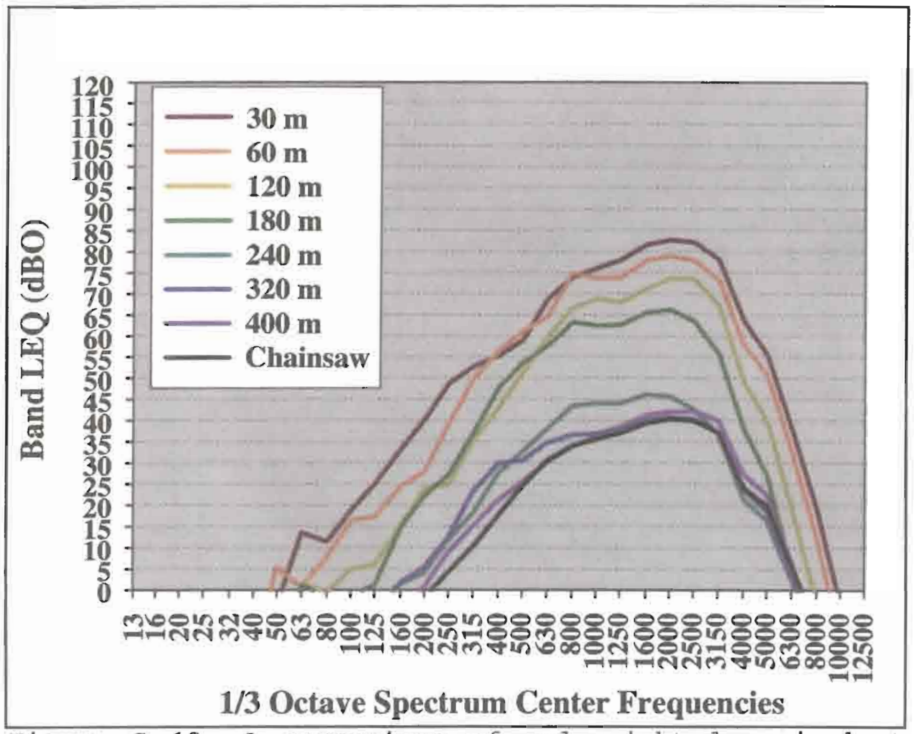

Figure C 13. A comparison of owl-weighted equivalent maximum (rock crusher) and average (chainsaw) sound energy levels (LEQs) for rock crusher activity from 30-400 m and a 60-m chainsaw event.

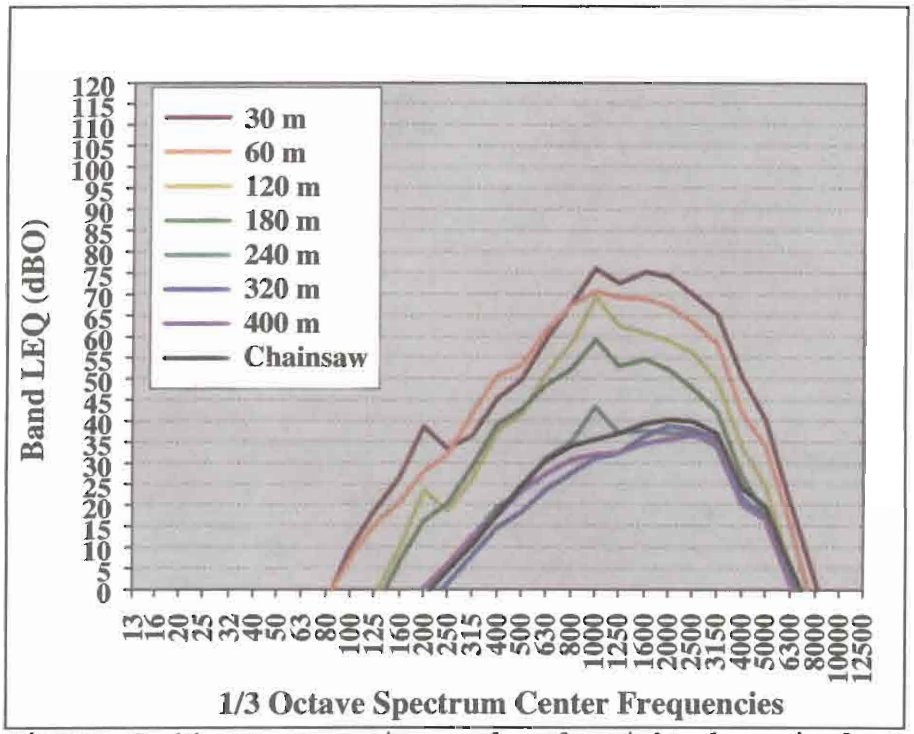

Figure C 14. A comparison of owl-weighted equivalent maximum (grader) and average (chainsaw) sound energy levels (LEQs) for grader activity from 30-400 m and a 60-m chainsaw event.

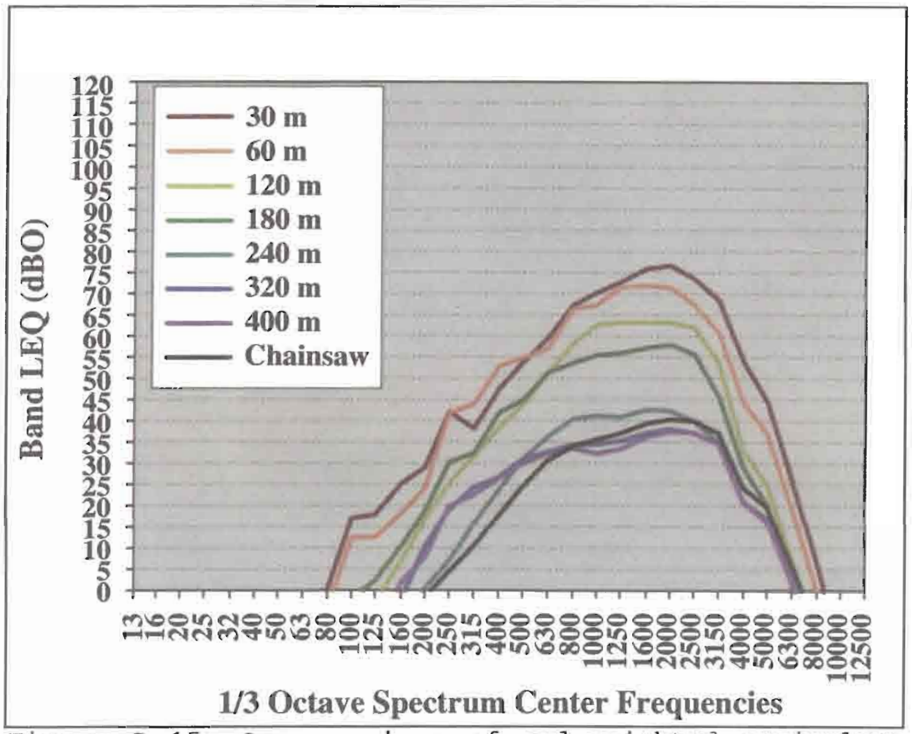

Figure C 15. A comparison of owl-weighted equivalent maximum (dozer/roller) and average (chainsaw) sound energy levels (LEQs) for dozer/roller activity from 30-400 m and a 60-m chainsaw event.

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