A STUDY OF THE EFFECTS OF GAS WELL COMPRESSOR NOISE ON BREEDING BIRD POPULATIONS OF THE RATTLESNAKE CANYON HABITAT MANAGEMENT AREA, SAN JUAN COUNTY, NEW MEXICO

prepared by

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NOTATION

°F	degree(s) Fahrenheit
ANSI	American National Standard Institute
Argonne	Argonne National Laboratory
ASC	acoustic source center
BLM	U.S. Bureau of Land Management
dB	decibel(s)
dBA	decibel(s), A-weighted
dBC	decibel(s), C-weighted
DOE	U.S. Department of Energy
FFO	Farmington Field Office of the Bureau of Land Management
ft	foot (feet)
ha	hectare(s)
hp	horsepower
Hz	hertz
in.	inch(es)
km	kilometer(s)
m	meter(s)
mi	mile(s)
mm	millimeter(s)
mph	mile(s) per hour
µPa	micropascal(s)
pW	picowatt(s)
RH	relative humidity
SPL	sound pressure level

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SUMMARY

Our study examined the effect of gas well compressor noise on breeding bird populations of the Rattlesnake Canyon Habitat Management Area in San Juan County, New Mexico. The U.S. Bureau of Land Management administers approximately 18,000 actively producing gas wells within the San Juan Basin on about 1.5 million acres of land. Large gas-fired compressors are used on many wells to increase the efficiency of gas extraction and to pressurize gas pipelines to transport the extracted gas. Noise produced by these compressors has prompted concern both for its effect on human communities and for its potential to affect wildlife populations in adjacent habitats.

We quantified noise output from a set of representative compressors in the study area and surveyed bird populations during the breeding season (June 2000) in adjacent pinyon-juniper habitat (treatment sites) along 400-m linear transects. Along these transects, noise levels were predicted to range from about 40 dBA at 400 m from the compressor to about 70 dBA and higher on the cleared well pad itself. Birds were also surveyed at control sites (gas wells without compressors) where noise levels adjacent to the well were about 28 to 45 dBA. Vegetation surveys confirmed that control and treatment sites had similar vegetation characteristics, although, by chance, control sites had taller vegetation closer to the well than did treatment sites.

Forty-six bird species were observed during the study (37 species on control sites, 42 on treatment sites). The eight most abundant species were (in decreasing order of abundance) Bewick's wren, spotted towhee, juniper titmouse, ash-throated flycatcher, bushtit, house finch, chipping sparrow, and western scrub jay. In general, the number of birds observed per species and the total number of birds (regardless of species) observed tended to be higher on control sites than treatment sites, but this difference was significant only for the spotted towhee (1.75 vs 1.28 birds per 50 m). On treatment sites, the number of birds per species per 50 m of transect did not increase with increasing distance from compressors, but instead decreased with distance and was consistent with the pattern observed on control sites. This relationship of numbers to distance was attributed to the edge effect (i.e., the number of birds is greatest at transition zones between habitats).

Distances along transects on treatment sites corresponded to different levels of noise exposure and were categorized as high noise ($\geq$ 50 dBA, 0 to 150 m) and moderate noise

(40 to 50 dBA, 151 to 400 m). The strongest noise effect on birds was observed in the high noise zone. In this zone, the number of spotted towhees was significantly lower (42% fewer), and the numbers of house finches and juniper titmice were significantly higher (71% and 167% more, respectively) than in the same distance interval on control transects. These differences apparently reflect species-specific differences in habitat requirements and tolerance to noise; both the house finch and juniper titmouse may have gained competitive advantage over less tolerant species in the high noise zone. In moderate noise zones, the overall number of birds per species was significantly lower (19% fewer birds) than on control sites; the number of house finches and juniper titmice were comparable to their numbers on control sites; and the number of spotted towhees was significantly lower relative to controls (24% fewer), but less so than in the high noise zone. These results indicate that the effect of noise varies among bird species, is greatest in areas exposed to 50 dBA or higher, but is measurable in areas exposed to relatively moderate levels of noise (40 to 50 dBA). The effects of compressor noise on bird populations could be reduced by using noise abatement measures to reduce the noise level at the edge of pinyon-juniper habitat to 50 dBA or less.

1 INTRODUCTION

The San Juan Basin is one of the most heavily developed gas-producing regions in the conterminous United States. The basin is located in northwestern New Mexico and southwestern Colorado. The U.S. Bureau of Land Management (BLM) Farmington Field Office (FFO) administers approximately 18,000 actively producing gas wells on 1.5 million acres within the San Juan Basin. Proposals for new wells are likely to increase in the future.

The increasing age of production from the San Juan Basin gas fields and the operators' need to recover as much natural gas as is technically and economically feasible have led to the installation of large compressors at individual well locations and along gas pipelines. These compressors are needed to effectively extract gas from the subsurface and transport it in pipelines. The compressors installed in the field are made by various manufacturers and vary in size, depending upon the requirements at each specific location.

The FFO is concerned that use of these compressors may result in adverse impacts to wildlife species that inhabit or migrate through the San Juan Basin area. The FFO has developed an interim policy with respect to mitigation of noise impacts on BLM-administered lands. This policy, however, is based primarily on human standards for noise tolerance and does not address potential impacts or mitigation requirements for wildlife species.

The U.S. Department of Energy (DOE), Office of Fossil Energy, agreed to fund Argonne National Laboratory (Argonne) to conduct an assessment of the potential impacts to wildlife from compressor-related noise on behalf of the FFO. This study, conducted from May through July 2000, addressed the potential effect of compressor noise on breeding birds in gas-production areas administered by the FFO, specifically in the Rattlesnake Canyon Habitat Management Area northeast of Farmington, New Mexico. The study was designed to quantify and characterize noise output from these compressors and to determine if compressor noise affected bird populations in adjacent habitat during the breeding season. The specific objectives of the study included:

- Determine sound pressure levels at each of the one-third octave bands for representative compressors in the Rattlesnake Canyon Habitat Management Area;
- Predict, through modeling, sound pressure levels (noise) at increasing distances from the compressors;
- Determine if compressor noise affects the relative abundance of breeding birds in the vicinity of compressors;
- Determine if compressor noise affects the species composition of breeding bird communities in the vicinity of compressors; and
- Determine if any observed effects of compressors on bird populations diminished at increasing distances from compressors.

2 PREVIOUS RESEARCH

The effects of noise on wildlife in general and birds in particular have been the subject of considerable research. Much of this research has focused on the effects of noise generated by military activities, particularly helicopter and other aircraft noise (including sonic booms), explosive noise on bombing ranges, and intermittent vehicle noise on training ranges. Other studies have focused on the effects of continuous noise such as that produced by traffic and coronal discharge along electric transmission lines.

Much of the wildlife-related noise-effects research to date has focused on birds. Birds are excellent subjects for studies of noise effects, especially during the breeding season. The breeding season represents a critical period in the life cycle of birds, and noise may adversely affect territory selection, territorial defense, dispersal, foraging success, fledging success, and song learning (Reijnen and Foppen 1995a; Foppen and Reijnen 1995; Marler et al. 1973; Larkin 1996). Essentially, these adverse noise effects reduce the quality of affected habitats. The hypothesized influence of noise on habitat quality could result in avoidance of noisier habitats and reduced population density in those habitats relative to that in quieter habitats.

Hearing sensitivity in birds is thought to be relatively similar to that in humans (Dooling 1982; Manci et al. 1988; Larkin 1996). Studies of a variety of bird species indicate a region of maximum sensitivity between 1,000 and 5,000 Hz, with a rapid decrease in sensitivity at higher frequencies. Exceptions to this general rule are pigeons and doves (Family Columbidae), which are apparently able to hear low-frequency sounds (1 to 10 Hz), and oilbirds (*Steatornis caripensis*), which use ultrasound (greater than 20,000 Hz) for echolocation.

Manci et al. (1988) and Larkin (1996) provided comprehensive literature reviews on the effects of military operational noise on wildlife and related topics. The effects documented in studies on different species and in different regions have been quite variable. Perhaps the most dramatic effect observed in response to noise was the catastrophic reproductive failure of the large sooty tern (*Sterna fuscata*) population of the Dry Tortugas in southern Florida. Normal annual production in this colony was 20,000 to 25,000 chicks, but in 1969 only 242 chicks were produced. This failure was attributed to near-daily sonic booms over the nesting colony, which caused the adults to flush from the nests during incubation (Manci et al. 1988). Brown noddies (*Anous stolidus*), another species of tern that shares the Dry Tortugas nesting ground with the sooty tern, showed no reduction in hatching success. Additional studies have since indicated that the effects of periodic loud noises can range from relatively mild alarm (Lynch and Speake 1978) to flushing and abandonment of nests (Manci et al. 1988; Larkin 1996) and these effects are highly dependent on a variety of factors, including species, life stage, season, ecological niche, population density, and physical characteristics of the noise (Busnel 1978). Eventual habituation to these sounds by individuals of most species appears to be fairly typical (Manci et al. 1988; Larkin 1996).

Several studies have examined the effects of continuous noise on bird populations. Most of that research examined the effect of traffic noise, but studies have also been conducted on the effects of noise associated with coronal discharge along electric transmission lines. The effects of noise from gas compressors were examined in two studies that addressed the impacts of pipeline development in the Arctic. The results of those studies are discussed in the following paragraphs.

Reijnen and associates studied the effects of highways on forest and grassland birds in the Netherlands (Reijnen and Foppen 1995a, 1995b; Foppen and Reijnen 1995; Reijnen et al. 1995, 1996, 1997). In forest habitat, 26 of 43 bird species showed evidence of reduced density adjacent to roads with the distance at which effects were detectable ranging from 40 to 2,800 m, depending on the species and the traffic volume along the road (Reijnen et al. 1995). In grassland habitat, a long-distance effect of roads was detected in 7 of 12 bird species, and the distance at which effects could be detected varied from 20 to 3,530 m (Reijnen et al. 1996). An adverse effect on total number of birds of all species was also observed. On the basis of these relationships, Reijnen et al. (1996) determined a threshold effect level of 47 dBA for all species combined and 42 dBA for the most sensitive species, the black-tailed godwit (*Limosa limosa*).

These observed reductions in population density along highways were attributed to a reduction in habitat quality produced by elevated noise along the highways. This conclusion was based on closer examination of the data. A distance effect was not observed along roads that had limited traffic (eliminating the possibility that the effect was due to habitat conditions along the road), but was observed in areas with visual screening, eliminating the possibility that the effect was due to visual disturbance from the moving cars (Reijnen et al. 1995). Air pollution levels were not considered to be of sufficient magnitude to produce the observed effect (Reijnen et al. 1997).

Van der Zande et al. (1980) also reported a long-distance effect (200 to 2,000 m) of highways on the density of two species of birds in Netherlands grasslands (northern lapwing, *Vanellus vanellus*, and the black-tailed godwit), but identified noise as only one of several factors that could have produced the effect. Ferris (1979) observed a change in bird species representation at increasing distance from a highway in the United States but attributed this distance effect to the changes in habitat ("edge effect"), not noise. Clark and Karr (1979) observed a decrease in the number of horned larks (*Eremophila alpestris*) along a highway in Illinois and attributed this to a habitat effect.

The effects on birds of noise from the coronal discharge of electric transmission lines have been examined in several studies. Lee and Griffith (1978) found that bird population densities were reduced up to 25% in survey plots near transmission lines in Oregon (where noise levels were approximately 50 dBA) relative to those in control plots away from the line. Although care was taken during surveys to reduce bias, the observed differences could have been attributed at least in part to differences in habitat between study plots and a reduced ability to detect birds in the noisier plots near the line (Lee and Griffith 1978).

A study of the effect of wind turbines on grassland birds was conducted in southwestern Minnesota (Leddy et al. 1999). Control areas and areas that were 180 m away from the turbines had higher bird population densities than areas that were within 80 m of the turbines. The authors could not determine the cause of the effect, but thought that noise, the presence of an access road, and physical movement of the turbines could have produced the effect.

While the studies discussed above provide important context to our study of breeding birds in the Rattlesnake Canyon Habitat Management Area, certain aspects of gas-compressor noise output and operations make the situation unique and could influence the impact of these compressors on bird populations. A limited study of the effects of gas-compressor noise on bird populations was conducted in the Canadian arctic in the early 1970s as part of an environmental impact analysis of proposed oil and gas development (LGL Limited 1974). That study used noise generators to simulate noise output from gas compressors that would be used along proposed pipelines and examined the effects on breeding Lapland longspurs (*Calcarius lapponicus*). Two noise simulators were placed together in the field in May 1972 and were run continuously during the breeding season (through July). Noise levels produced on the survey area were 60-83 dBC. No significant effects of noise on clutch size or the density of breeding birds were observed, but the study was hampered by a lack of replication and the fact that the noise simulators were placed after the birds had established territories.

Several possible proximate mechanisms for noise effects on bird populations have been hypothesized. Noise could interfere with the vocal communication of birds, particularly singing males, and thus make it more difficult for males in noisy environments to defend territories and attract and maintain mates (Busnel 1978; Reijnen and Foppen 1995a; Reijnen et al. 1995). Alternatively, if noise produced stress in exposed birds, avoidance of noisy environments would result in lower densities in those environments. Reijnen and co-workers (Reijnen et al. 1995, 1997; Reijnen and Foppen 1995a) presented support for a stress-mediated effect of noise, and physiological studies have demonstrated that stress-related hormone levels increase in domestic hens exposed to continuous loud noise (Manci et al. 1988).

As suggested earlier, the interpretation of the results of noise studies is often complicated by the presence of confounding factors that co-occur with the noise and that could explain all or part of the observed effects. For example, aircraft noise is usually accompanied by the visual stimulus of the moving aircraft. Traffic noise occurs along roadways with accompanying visual stimuli of moving vehicles, associated habitat changes, and air pollution. Most studies have attempted to discern which of these factors were operating to affect subject populations. Carefully designed studies are needed to minimize or eliminate the effects of confounding factors.

3 STUDY AREA

The Rattlesnake Canyon Habitat Management Area contains approximately 43,862 ha (108,384 acres) of public land that is administered by the BLM (Hansen 1997). The area is northeast of Farmington, New Mexico, in San Juan County. Primary uses of the habitat management area are natural gas development, livestock grazing, and hunting. In 1997, there were 759 active gas wells, 446 km (277 mi) of secondary road, and 483 km (300 mi) of natural gas pipelines within the boundaries of the habitat management area (Hansen 1997). These wells and associated infrastructure are widely and relatively evenly dispersed across the landscape according to the underlying geologic formations and associated gas reserves (Figure 1). Livestock grazing on the area occurs year-round.

The Rattlesnake Canyon Habitat Management Area is located in the Colorado Plateau Physiographic Region (Hansen 1997). It is characterized by mesas intersected by deep canyons. Woodland habitat predominates in the area (about 93% of total area); this habitat is mostly pinyon-juniper (*Pinus edulis, Juniperus osteosperma*) woodland, but ponderosa pine (*Pinus ponderosa*) woodland is found in deep canyons and on east- and north-facing slopes. A variety of shrubs occur in the subcanopy of wooded areas and in woodland openings; shrubs of the habitat management area include big sagebrush (*Artemisia tridentata*), bitterbrush (*Purshia tridentata*), mountain mahogany (*Cercocarpus montanus*), broom snakeweed (*Gutierrezia sarothae*), and Gambel oak (*Quercus gambelii*). Grasses and forbs are scattered throughout wooded and open areas.

4 METHODS

Replicate study sites were chosen within the Rattlesnake Canyon Habitat Management Area. All study sites were natural gas wells with a cleared, level gravel or dirt pad approximately 0.5 to 1 ha (1 to 2 acres) in size surrounded by pinyon-juniper woodland. Treatment sites had active, noise-generating compressors associated with the well (Figure 2). Control sites did not have an active compressor, but superficially were similar to treatment sites in other characteristics (Figure 3). Although compressors are sometimes moved from well to well as needed for gas production and sometimes are turned off for short periods of time (several hours) for maintenance, compressors at all treatment sites had been in place and active for at least one month before initiation of the study and remained active for the entire period of the study. Thus, compressors were running during the period birds arrived from their wintering grounds and established territories on the study area.

Sixteen treatment sites and eight control sites were chosen for survey (Table 1). Survey locations were chosen on the basis of similarity of topographic and vegetation characteristics to enable a determination of the effects of compressor noise without other confounding effects. All sites were away from primary roads and areas of high human activity. Topography was controlled for by picking survey locations that had similar topographic characteristics and relatively unobstructed exposure to the compressor noise (e.g., no topographic features such as a hill or canyon between compressor and transect that would attenuate noise levels). Topographic maps and aerial photographs were used to select study areas. All chosen study sites had adjacent pinyon-juniper woodland, which reduced the potentially confounding effects of vegetation differences (Figure 4). Although all surveys were conducted in pinyon-juniper woodland, any differences in vegetation characteristics (e.g., percent cover, vegetation height) could affect bird population characteristics and confound the detection of noise effects. Vegetation surveys were conducted at each of the study sites to characterize vegetation and to determine if any differences in vegetation characteristics existed between control and treatment sites (see Section 4.3).

Figure 1. Aerial View of a Portion of the Rattlesnake Canyon Habitat Management Area Showing Distribution of Well Pads, Roads, and Pinyon-Juniper Woodland. (Well pads are light tan rectangles; pinyon-juniper woodland is grayish green.)

Figure 2. Examples of Compressors Used on Gas Wells in Rattlesnake Canyon Habitat Management Area. (Top photo is compressor on site T05; bottom photo is compressor on site T13.)

Figure 3. Examples of Control Study Sites (gas well sites without compressors) in Rattlesnake Canyon Habitat Management Area. (Top photo is site C04; bottom photo is site C02.)

Table 1. Sites Surveyed in Rattlesnake Canyon Habitat Management Area, San Juan County, New Mexico.

Site Number[a]	Well ID	Company	Compressor Engine Make/Model	Township-Range-Section	Survey Transect Azimuth
C01	51	Burlington	Not applicable	32-9-29	54
C02	42MV	Phillips	Not applicable	31-8-10	149
C03	3A	Burlington	Not applicable	31-8-8	50
C04	1A	Burlington	Not applicable	31-8-8	156
C05	6C	Koch	Not applicable	32-9-25	70
C06	111	Burlington	Not applicable	31-9-8	25
C07	16A	Burlington	Not applicable	31-9-8	227
C08	2	Amoco	Not applicable	32-9-30	166
T01	Fed28#1	Phillips	Waukesha F18GL	32-9-28	191
T02	228	Phillips	Ajax DPC 2802LE	31-8-16	240
T03	221	Phillips	Ajax DPC 2802LE	31-8-9	200
T04	240	Phillips	Ajax DPC 2802LE	31-8-3	187
T05	238	Phillips	Waukesha F18GL	31-8-23	19
T06	236	Phillips	Ajax DPC 2802LE	31-8-22	157
T07	206	Phillips	CAT 3306NA	31-8-24	265
T08	202	Phillips	CAT 3306NA	31-8-26	106
T09	203	Phillips	Ajax DPC 2802LE	31-8-35	224
T10	333	Burlington	CAT 398TA	31-8-8	217
T11	330	Burlington	CAT 3512TA	31-8-5	160
T12	711	Burlington	Waukesha H24GL	31-9-01	213
T13	2C	Koch	Waukesha/Ariel JGK	32-8-31	248
T14	254	Burlington	Ajax DPC600	31-9-6	218
T15	1R	Burlington	Ajax DPC60	32-9-29	261
T16	342	Burlington	Ajax DPC 600	31-8-19	25

[a] Sites C01 to C08 were control sites (i.e., well sites without a compressor); sites T01 to T16 were treatment sites (i.e., well sites with an active noise-generating compressor).

Figure 4. Typical Pinyon-Juniper Woodland in Rattlesnake Canyon Habitat Management Area. (Photo is from survey transect on site T05.)

4.1 Noise Characterization

Noise measurements were made at 15 treatment and seven control study sites on the Rattlesnake Canyon Habitat Management Area from 30 May to 2 June 2000. Noise measurements could not be made at all of the study sites — the compressor at site T11 was turned off temporarily at the time the noise measurements were to be made and construction work was underway at the site chosen as control site C01. A different site was subsequently chosen for survey as site C01, but noise measurements were not made there.

4.1.1 Noise Measurement Activities

Noise measurements were made at treatment sites and control sites with the acoustic survey instrumentation shown in Figure 5 and described in Section 4.1.2. At each measurement location, three sets of sound pressure level[1] (SPL) measurements were taken at each of the 27 one-third octave bands centered from 25 Hz to 10,000 Hz for a stated integration time of about 4 seconds. Also, overall unweighted SPL and A-weighted SPL data were collected.

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[1] Sound pressure level (SPL) is a measure of the pressure fluctuations in the air (acoustical disturbance) produced at a point away from the sound source by the acoustic power radiated by the source.

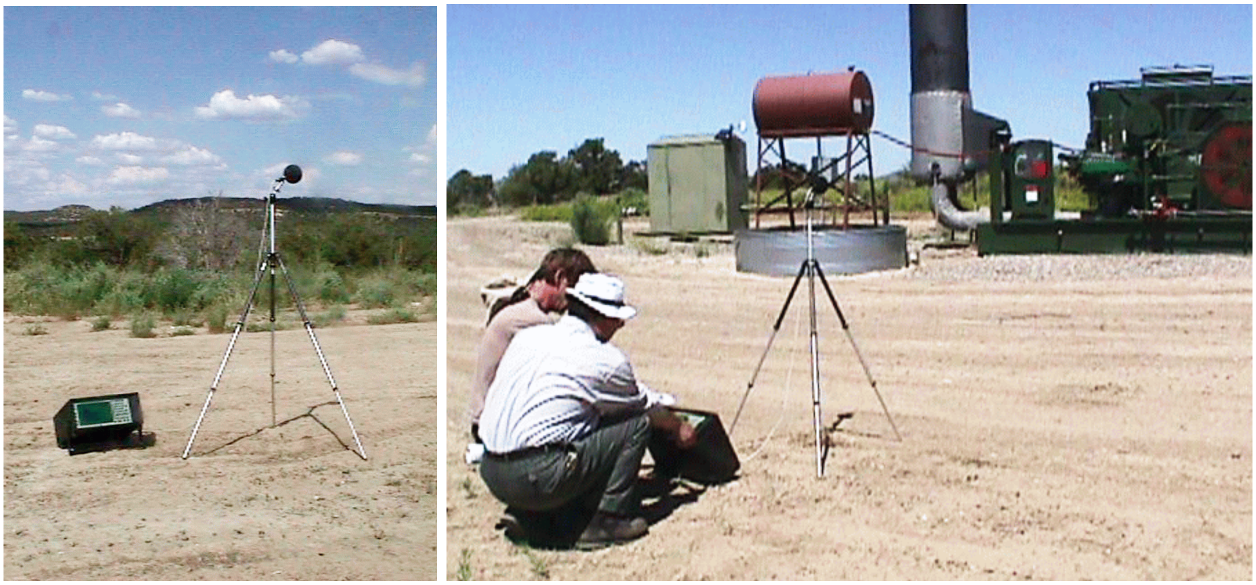

Figure 5. Apparatus Used To Collect Noise Measurements.

Calibration of the SPL system was verified each morning during the measurement period. At each study site, a hand-held anemometer was used to measure wind speed and direction; temperature and relative humidity were measured with a digital thermometer-hygrometer; and barometric pressure was measured with a barometric pressure gauge.

At each treatment site, SPL measurements were taken at eight locations representing two distances from the compressor (inner and outer) and four orthogonal directions. Outer distances were selected to be twice the inner distance from the compressor. This second measurement was taken to provide a rough check on propagation conditions since, in a uniform "free-field" with no variable terrain features, a doubling of sound propagation distance produces 6 dB of change in SPL due to spherical spreading of the wavefront.

The eight measurement locations at each site were established in reference to the acoustic source center (ASC) of the compressor and associated equipment. The distance from the ASC to each measurement location was at least six times the greatest horizontal dimension of the site's noise source system (including reflecting surfaces). The intent of this criterion was to ensure that measurements were made in the acoustic far-field of the noise source.

Inner and outer measurement distances for most study sites were 30.5 m (100 ft) and 61.0 m (200 ft) relative to the ASC of each site. However, at some sites, shorter measurement distances from the ASC were necessary because of topographic and vegetation constraints. In every case, a 1:2 ratio was maintained between the two radial distances. The location of each measurement location was determined with a tape-measure stretched from the ASC location to the measurement location.

Noise at both the inner and outer distances was measured simultaneously with two complete microphones plus real-time analyzer systems (Figure 5). The spectrum SPLs at the inner measurement locations were used to calculate sound power levels[2] at the source and predict SPLs outward from the noise source (see Section 4.1.3).

At the control sites, residual environmental (ambient background) masking noise was measured. These sites were remote from any operating gas compressors or other noise sources, such as other operating equipment, facilities, roads, or residences. Noise measurements were made at only one location near the center of control sites.

4.1.2 Acoustic Survey Instrumentation

Sound pressure levels were measured with a Bruel & Kjaer (B&K) 2144 portable real-time analyzer connected sequentially to a B&K Type 2669 pre-amplifier and a B&K 12.7-mm (diaphragm diameter) Type 4189 electrostatic (condenser) microphone that sensed SPL. The microphone, with a B&K Type UA0237 windscreen, was mounted on a tripod (Figure 5).

The microphones were calibrated with a B&K Type 4231 Acoustical Calibrator, at 93.8 dB unweighted (ref. 20 µPa) level with a 1,000-Hz signal. The 12.7-mm microphone system cited above is specified by B&K as having unweighted one-third octave-band equivalent self-noise levels of 0.7, -1.1, -2.0, -1.5, 0.1, 2.5, 4.7, and 5.2 dB, respectively, at the center frequencies of 63, 125, 250, 500, 1000, 2000, 4000, and 8,000 Hz. These levels are more than 10 dB below the documented National Park Service wilderness average daytime residual levels.

This instrumentation provided ± 1 dB unweighted measurement accuracy in accordance with Type-1 precision of the American National Standards Institute (ANSI) Standard S1.4 (ANSI 1997). SPL data were taken at each one-third octave band and digitally filtered in accordance with ANSI Standard S1.11 (ANSI 1998), to Order 3, Type 1-D standards. All SPL data were stored on 3.5-in. floppy diskettes with the B&K Type 2144 analyzer.

4.1.3 Noise Modeling

SPLs were predicted at 50-m intervals up to 400 m from the ASC of each treatment site along the transect established for the bird survey (see Section 4.2). To accomplish this, measured SPL data were used to estimate the sound power level at the ASC of each treatment site, and these estimates were then used to predict SPLs at various distances along the bird transect. This same approach was used to normalize measured SPL data to 30.5 m from the source to allow comparison among compressors.

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[2] Sound power level is the total acoustic energy radiated per unit time by a sound source.

Estimations of sound power level and predictions of SPL were made by using the classical engineering equation to estimate outdoor sound propagation (Beranek 1988). Beranek's sound propagation equation relates the sound power level at the ASC to SPLs at receptor locations considering the geometric divergence of sound energy in space, directivity of sound power at its source, and sound attenuation due to such factors as barriers, absorption by air molecules, ground cover effects, atmospheric discontinuities (e.g., air turbulence), and precipitation. Detailed description of Beranek's equation and assumptions made in using the equation for computing sound power levels and predicting SPLs for this study are provided in Appendix A.

4.2 Bird Survey Methods

Data on abundance, distribution, and species composition of bird communities were collected along line transects at each study site. The particular objective of the surveys was to determine if there were differences in bird communities between treatment and control sites (site type effect) or if there were differences in bird communities related to distance from the compressor and therefore relative noise level (distance effect). The survey approach used was similar to that originally proposed by Emlen (1971) but was modified to fit the particular needs of this study. Mikol (1980) presented guidelines for applying the Emlen technique and other line transect protocols to collect data on nongame bird populations.

One line transect was established for survey at each study location. Transects were 400 m long and radiated away from the compressor on treatment sites and from the well head on control sites. Because transects originated at the compressor or well head, a portion of each transect was located on the cleared area surrounding the site (the well pad). Each transect was marked with wire flags at 25-m intervals. Painted rebar was driven into the ground at the point where the transect entered pinyon-juniper habitat and at the end of the transect (400 m from origin). Rebar provided a relatively permanent marker for the transect. Transect number and distance from the origin were marked in permanent ink on each flag. The flags were removed at the conclusion of the study.

All transects were placed within pinyon-juniper habitat and in areas where topography did not preclude normal walking (e.g., level to rolling ground or small hills, but no cliffs or canyons). Within these constraints, orientation of the transect was determined at random (using a random numbers table to determine the uncorrected compass direction or azimuth); all orientations were not possible given habitat and topographic limitations that were a factor at most study locations. Some randomly chosen lines were eliminated if they extended beyond pinyon-juniper habitat or could not be traversed because of topography.

Bird surveys were conducted between 6 and 27 June 2000 from about 0500 to 1000 Mountain Standard Time to include the breeding period and the time of day when birds were most active. Sites to be surveyed on any given morning were determined in advance to include a mix of control and treatment sites. Each transect was sampled on three separate mornings during the month-long survey period, and the results were combined for analysis (the sum of counts for each species was used as the dependent variable in the analyses). This replication was used to reduce the amount of variability due to sampling error. Each transect survey was conducted by a single observer. Four observers collected all bird information, but no observer collected information along a transect more than once. Thus, each of the three survey replicates was conducted by a different observer to reduce any effects of differences among observers.

Before the survey was conducted at treatment sites, the compressor was turned off and remained off for the duration of the survey. Turning compressors off before surveying was necessary because many birds are detected at least initially by hearing rather than sight; turning compressors off ensured that the probability of detecting birds was equal on control and treatment sites. We assumed that turning the compressors off for the survey period did not have an effect on the number or types of birds observed during the survey. We feel that this assumption is reasonable given the fact that surveys were conducted during the breeding season when territoriality prevents long-distance movement of most individuals. Each survey began within 10 minutes of turning the compressor off. Surveys were begun at either the beginning of the transect (0 m) or the end of the transect (400 m), and the origin of the survey was selected randomly (flip of a coin). This procedure ensured that any observed changes in bird communities along the transect were related to distance from the compressor (treatment sites) or well head (control sites) rather than time since the survey began.

In conducting a survey, the observer walked slowly along the transect line at a pace timed such that each 100 m of the transect took 20 minutes to survey. This pace ensured equal coverage of each distance interval and resulted in each 400-m transect's taking 80 minutes to survey.

All birds seen or heard along the transect were recorded by the observer on a standard data sheet (Appendix C). Care was taken to avoid counting the same bird twice. Information collected for each individual bird detected included:

- Species name following the nomenclature of the American Ornithologists' Union 7th edition of the *Checklist of North American Birds* (American Ornithologists' Union 1998). If the species could not be identified, it was recorded as unidentified.

- Distance of the bird along the transect (distance from the compressor or well head to the point of intersection between an imaginary perpendicular line from the bird to the transect). This distance was recorded as the 25-m distance interval as marked on adjacent flags.

- Distance of the bird from the transect (length of the imaginary perpendicular line from the bird to the transect) estimated in the following distance intervals: 0-5, 6-10, 11-15, 16-20, 21-25, 26-30, 31-50, >50 m. This was the horizontal (ground) distance; distance of the bird above the ground was not determined.

The location of each bird was sketched on a schematic map of the transect that showed distance intervals along transect and distance bands from transect (Appendix C).

4.3 Vegetation Survey Methods

Surveys were conducted to determine vegetation characteristics of the study sites. Although sites were selected on the basis of apparent similarities of vegetation, any differences between control and treatment sites could influence habitat quality and the composition of bird communities. Any such differences could confound interpretation of results of the bird surveys and determination of noise effects.

A line-intercept approach (Hays et al. 1981) was used to measure vegetation cover in each of the 24 study areas. The 400-m line transects used to collect bird data (see Section 4.2) were used as the baseline for the vegetation survey. A series of 20-m line transects were placed perpendicular to and centered on the 400-m bird transect. Vegetation survey transects were placed at the origin of the bird transect and at the 50, 100, 150, 200, 250, 300, 350, and 400-m flags along the transect. This process resulted in a total of nine plant transects per bird transect, with a total of 180 m of vegetation transect length for each 400-m bird transect.

To begin a vegetation survey, a metric tape measure was placed perpendicular to the 400-m bird transect with the 10-m mark of the tape at the crossing point, and the tape anchored at each end to prevent movement. The intercept length (i.e., that portion of a plant or group of plants that intersected the vertical plane projected above a line transect) of trees, shrubs, grasses, and forbs was measured along the transect (Figure 6). Only trees and shrubs were identified to species; herbaceous species were categorized as grasses or forbs. A 3-m vertical rod was used to determine the intercept points for plants whose canopy was above head height. Areas along the transect with no plant cover in any strata were recorded as bare.

Vegetation data were recorded on a standard data sheet (Appendix C). Intercept length was recorded for each individual plant (if isolated from others), group of plants (if contiguous with others of the same species), or area of bare ground (i.e., an area where no vegetation crossed the vertical plane of the transect). If an individual plant had a significant gap in its canopy (see *b* and *c* on Figure 6), each portion of the plant was recorded as a separate observation. Intercept lengths of individual plants or groups of plants were measured to the nearest 0.1 m as read from the transect tape. Height of individual plants or groups was recorded as one of four categories: 0-0.5 m, 0.6-1 m, 1.1-2 m, 2.1-5 m, and > 5 m.

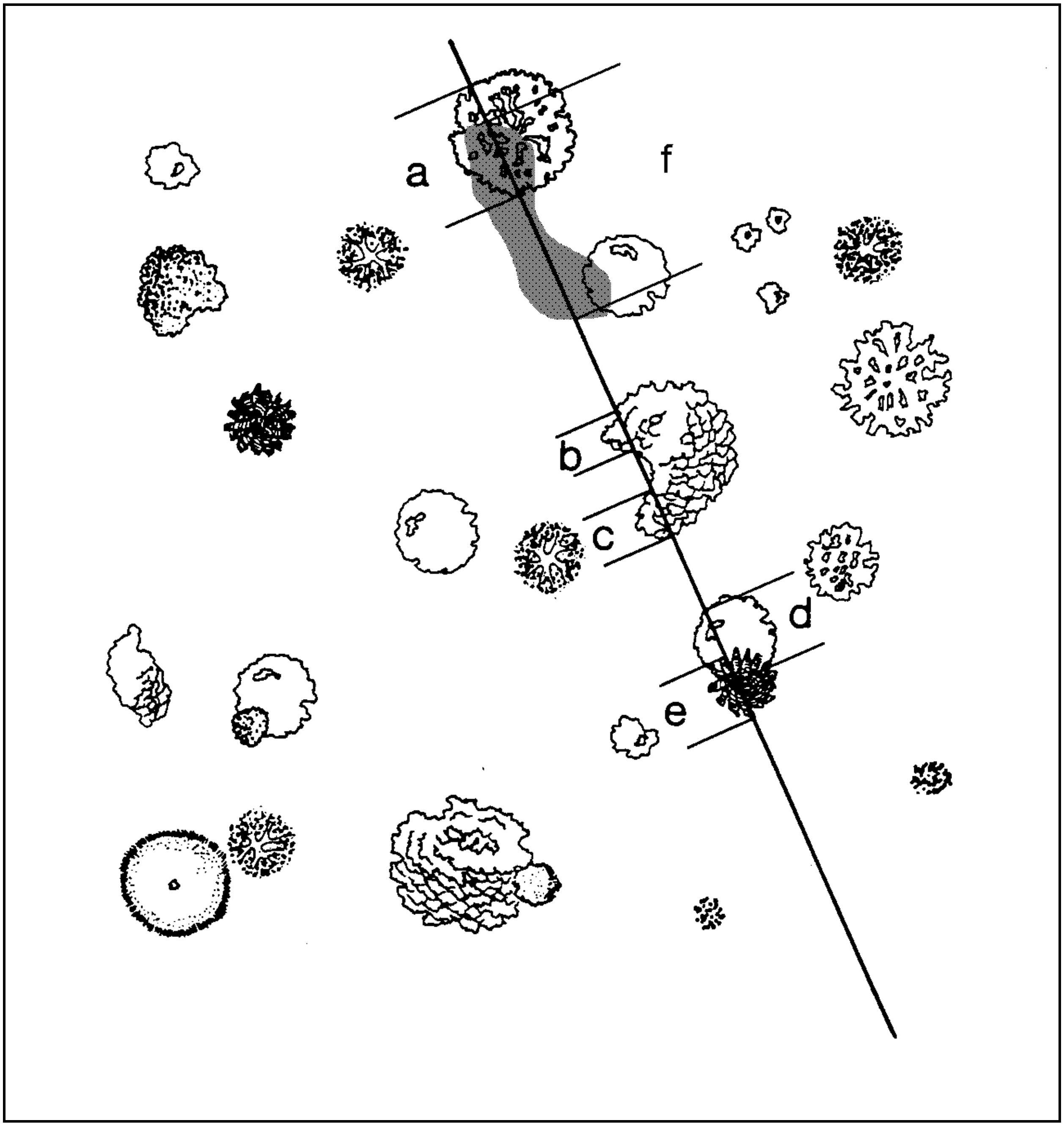

Figure 6. View from above Hypothetical Vegetation Survey Line Transect Showing Intercept Lengths *a* through *f*. [Note that (1) minor gaps in canopy were included in the measurement of intercept length (as in *a*), but larger gaps were not (between *b* and *c*); (2) intercept length was recorded for individual plants of different species even when overlap occurred (*d* and *e*); and (3) intercept length for contiguous patches of vegetation (grasses, forbs, and sometimes shrubs and trees) was measured when it was not practical to measure individual plants (*f*). Source: Modified from Hays et al. (1981).]

5 RESULTS

5.1 Noise Characterization Results

A variety of noise sources was located at gas wells in the study area. The major sources of noise at wells with compressors were the exhaust stack and air-cooling fan of the compressor unit. Other noise sources included such equipment as oil/gas separators, dehydrators, lubricating oil pumps, well-head valves, flywheel-support systems, and the surfaces of both the engine (driving) and compression sections of the overall machine. A simple depiction of the locations of machines and equipment at each of the treatment sites is included in Figures B-1 through B-15 in Appendix B. Compressor units were of two types — piston-type and screw-type.

The exhaust stack emitted the lowest frequency noise at or below 100 Hz. The cooling-fan blades, impulses produced by fuel-valve action and cylinder ignitions within the engine casing, and, in some cases, unbalanced (worn) flywheel bearing-support systems and water-tank pumps produced small peaks of acoustic power in the frequency range from 100 to 1,000 Hz. Oil pumps, oil/gas separators, dehydrators, and gas flow-through well-head control valves in some cases produced intermittent noise above 1,000 Hz. In general, screw-type compressors were characterized by clusters of tones in the region of 1,000 to 6,000 Hz.

5.1.1 Field Measurement Data

Sound pressure levels measured at the center locations of seven control sites and the median values of measured SPLs normalized to 30.5 m from the source at 15 treatment sites are presented in Table 2. Measured SPL spectral data for the control sites are presented in Figure 7. SPL spectral data for the treatment sites are provided in Appendix B (Figures B-1 to B-15) along with a summary table for the measured data (Table B-1). At treatment sites, free-field conditions were validated by noting an approximately 6 dBA difference between inner distance (30.5 m) and outer distance (61.0 m) measurements.

The measured SPLs at the seven control sites ranged from about 28 to 45 dBA (Table 2). Two control sites that had measured SPLs greater than 40 dBA (sites C05 and C07) had no compressor in operation, but pipelines and other equipment at the site and vicinity produced some noise as evidenced by the elevated spectral distributions and distinct peaks at several frequency bands (Figure 7). On the basis of these measurements and observations, the residual ambient noise level in the study area is estimated at about 28 dBA.

The compressors surveyed had site power ratings[3] that ranged from 45 to 660 horsepower (hp). This range in horsepower applies to most compressors currently in operation in the study area. The median values of measured ambient SPLs normalized to 30.5 m from

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[3] Site power rating is the horsepower rating at the actual site elevation.

Table 2. Measured A-weighted Sound Pressure Levels at Control Sites and Median Sound Pressure Levels at Treatment Sites[a].

Site[b]	Site Power Rating (hp)	Compressor Type	Sound Pressure Level (dBA)
C01	Not applicable	Not applicable	–[c]
C02	Not applicable	Not applicable	36.3
C03	Not applicable	Not applicable	35.2
C04	Not applicable	Not applicable	27.9
C05	Not applicable	Not applicable	45.3
C06	Not applicable	Not applicable	28.2
C07	Not applicable	Not applicable	43.0
C08	Not applicable	Not applicable	27.6
T01	320	Piston	66.8
T02	305	Piston	68.3
T03	305	Piston	69.8
T04	305	Piston	68.0
T05	320	Screw	67.3
T06	305	Piston	67.6
T07	95	Screw	66.2
T08	95	Screw	66.7
T09	305	Piston	66.5
T10	531	Piston	68.9
T11	660	Piston	–[c]
T12	450	Piston	67.2
T13	651	Piston	67.3
T14	461	Piston	68.6
T15	45	Piston	56.2
T16	461	Piston	68.9

[a] Median sound pressure levels from four directional measurements at each treatment site normalized to 30.5 m from the source.

[b] Sites C01 to C08 were control sites (i.e., well sites without a compressor). Sites T01 to T16 were treatment sites (i.e., well sites with an active noise-generating compressor).

[c] No measurements were made because construction was underway at the site originally chosen for C01, and the compressor at T11 was turned off for maintenance at the time of the noise survey. A new site was chosen for C01 after noise measurements had been completed.

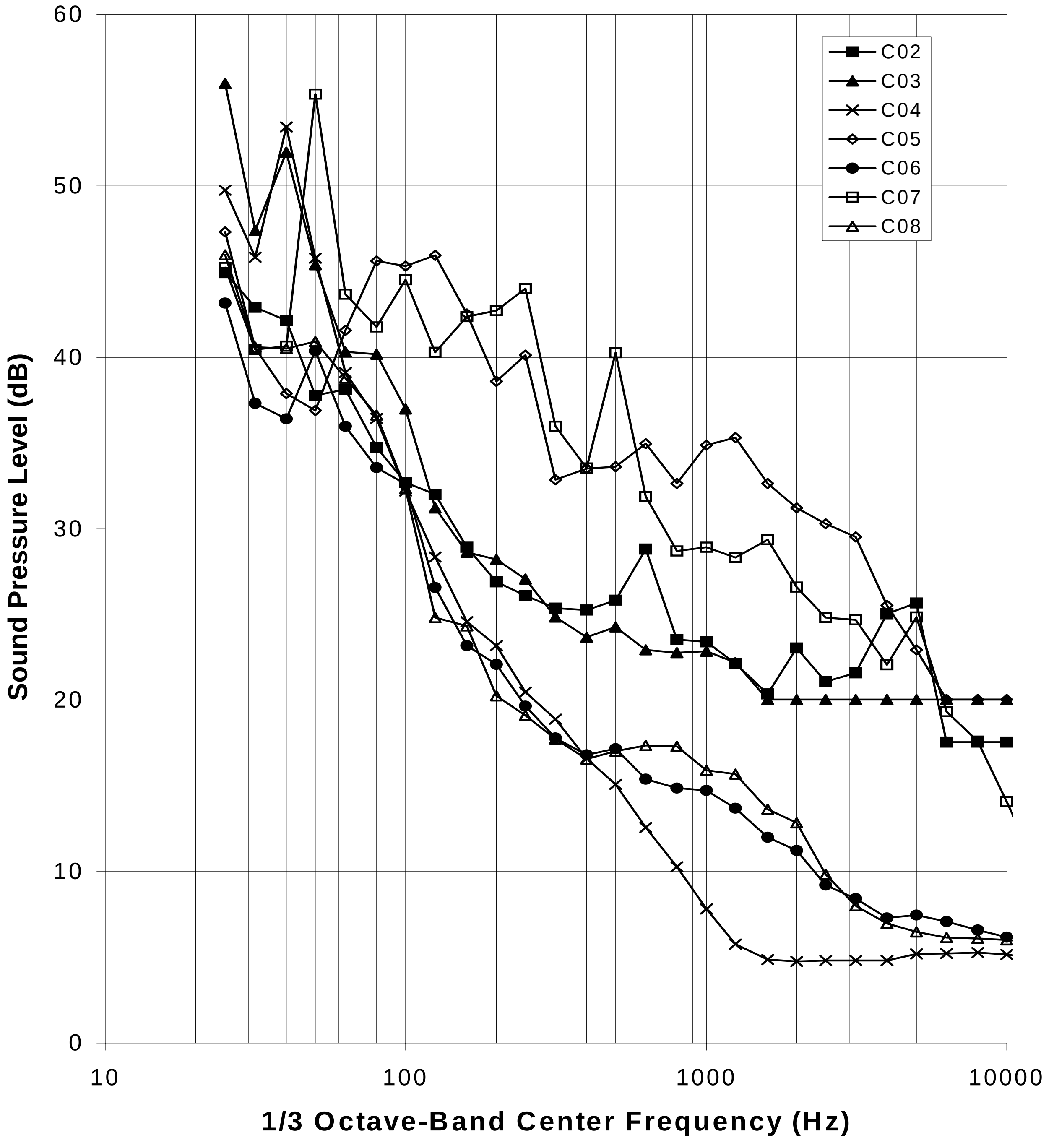


Figure 7. Measured Sound Pressure Levels at Seven Control Sites on the Rattlesnake Canyon Habitat Management Area.

compressors ranged from about 56 to 70 dBA (Table 2). If the lowest horsepower compressor (site T15; 45-hp rating) is excluded, SPL values are clustered within a narrow range of 66 to 70 dBA.

5.1.2 Estimated Source Sound Power Levels

The estimated sound power levels of the 15 compressors are plotted in Figure 8 as a function of site power rating. A regression analysis between the sound power level and logarithm of compressor site power rating was performed Although piston-type and screw-type compressors showed distinctly different source power spectral distributions (Figures 9 and 10), sound power level data for both type compressors were included in the regression analysis because their A-weighted sound power levels (in bels) were not much different. Correlation between sound power level and logarithm of compressor site horsepower rating was reasonably good (r = 0.81). The regression equation, presented in Figure 8, may be used to estimate sound power levels of natural-gas compressors operating under environmental settings similar to that of the Rattlesnake Canyon Habitat Management Area.

5.1.3 Predicted Sound Pressure Levels

Sound pressure levels predicted at 50-m intervals up to 400 m from the ASCs of 15 treatment sites along the bird survey transects are listed in Table 3 and plotted in Figure 11 in relationship to distance from the source. Of the SPL spectral distribution data measured in four orthogonal directions at each treatment site, the one measured in the direction closest to the azimuth of the bird survey transect was used to make these predictions to minimize the error that would be introduced by directional variation in the source sound power level.

The range of SPLs (in dBA) predicted at 50, 100, 200, and 400 m along the 15 treatment site transects are 47.3 to 64.9, 40.0 to 57.7, 32.8 to 50.3, and 25.0 to 42.2, respectively. The range of predicted attenuation (in dBA) that would result from a doubling of distance from 50 to 100 m, 100 to 200 m, and 200 to 400 m are 7.0 to 7.5, 7.0 to 7.8, and 7.6 to 8.8, respectively. These attenuation values are higher than the 6 dBA attenuation predicted from geometric divergence alone. This difference from the theoretical attenuation rate increased as the absolute distances between the two prediction points increased; thus, the amount of attenuation is greater between 200 and 400 m than between 50 and 100 m.

5.2 Bird Survey Results

Birds were seen and heard regularly on all of the study sites and throughout the survey period. Bird activity was conspicuous in the vicinity of gas wells and operating compressors. Several active house finch nests were observed on structures on the well pads, including well equipment adjacent to operating compressors where noise levels were approximately 80 dBA or higher. Several species used well structures for perches. A variety of bird species could be heard

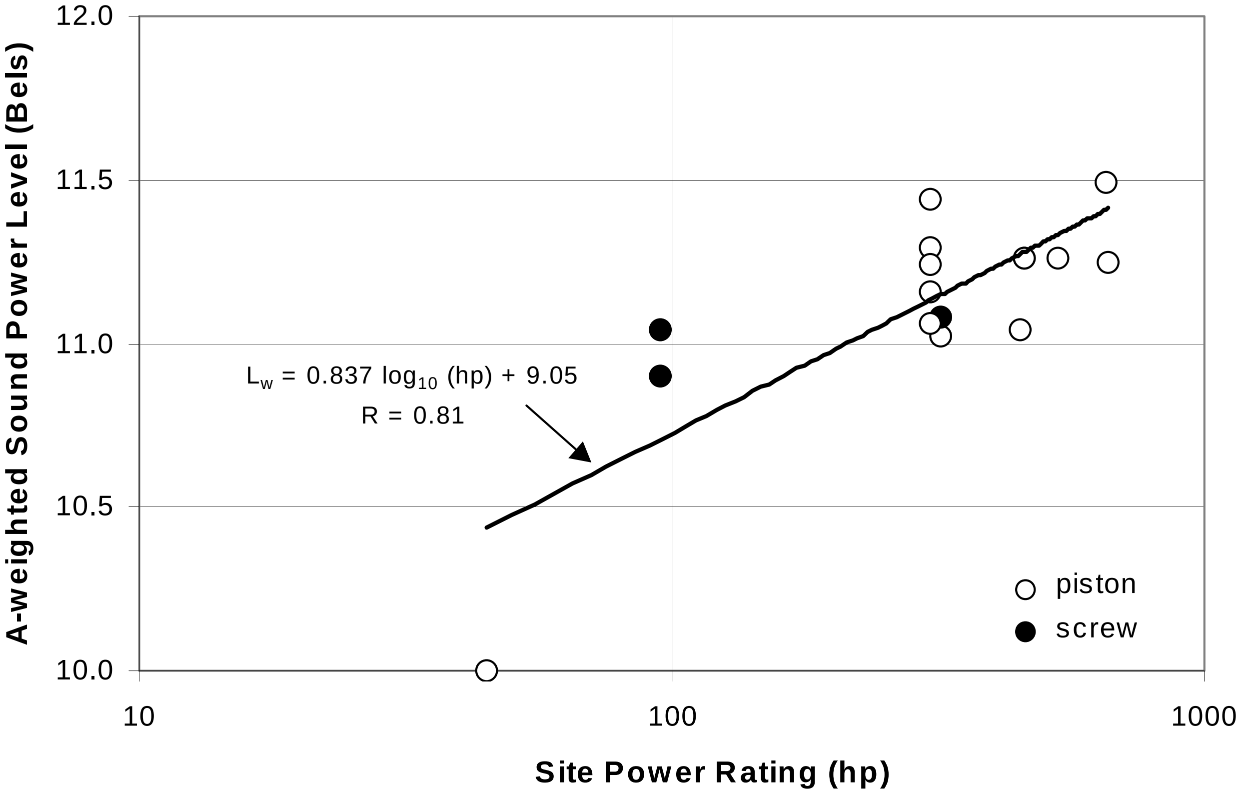


Figure 8. The Relationship between A-weighted Sound Power Level and Site Power Rating of Study Compressors.

singing in adjacent habitat while compressors were operating and immediately after compressors were turned off for surveys. There was no indication that bird use of treatment sites changed in any way after compressors were turned off.

Forty-six species of birds were observed during the course of the study (Table 4); 37 species were observed on control sites and 42 were observed on treatment sites (Table 5). The eight most abundant species observed included (in decreasing order of abundance): Bewick's wren, spotted towhee, juniper titmouse, ash-throated flycatcher, bushtit, house finch, chipping sparrow, and western scrub jay. In general, the number of individual birds observed for each species (Table 5 and Figure 12) and the total number of birds (individuals of all species combined; Table 5) tended to be higher on control sites than treatment sites.

The following two sections present the results of analyses conducted to determine the effects of site type and distance from the well on the eight most abundant species (Section 5.2.1) and the total number of birds, regardless of species (Section 5.2.2). Distance effects were examined by analyzing the number of birds (1) in each 50-m interval of the line transect and (2) in a high noise

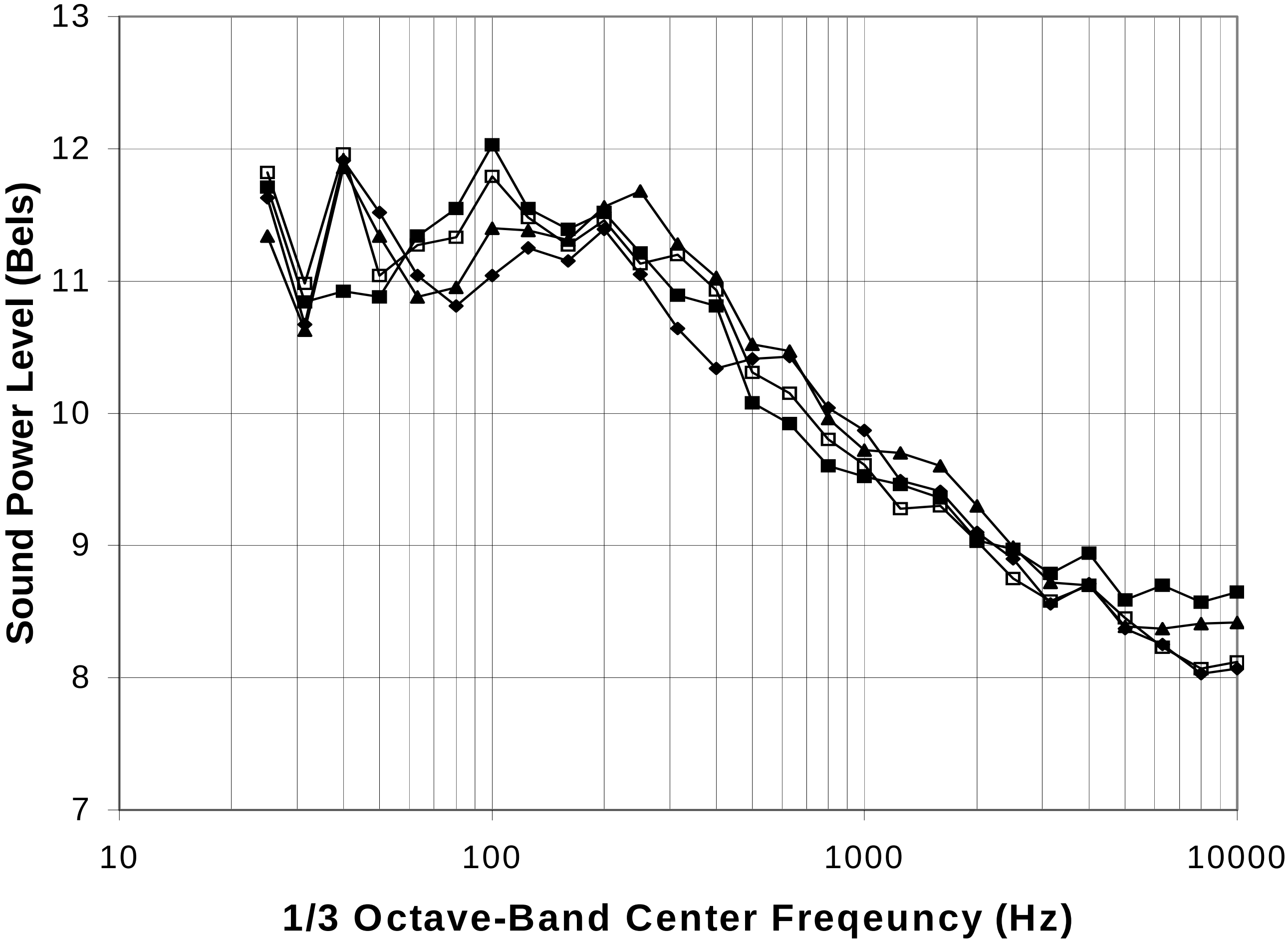


Figure 9. Estimated Sound Power Spectra of a Typical Piston-Type Compressor (Site T06) Based on Measurements from Four Directions.

zone (≥ 50 dBA; 0-150 m from the compressor) and a moderate noise zone (40-50 dBA; 150-400 m from the compressor). In the description of results, the words "significance" and "significant" refer to "statistical significance." Statistical analyses of bird and vegetation survey data are presented in Appendix D.

5.2.1 Effects of Site Type and Distance on Different Bird Species

The eight most abundant species listed above were included in statistical analyses that examined the relationship of the number of birds observed to species, site type, and distance from the well. For each 50-m of survey transect, the total number of birds of each species observed

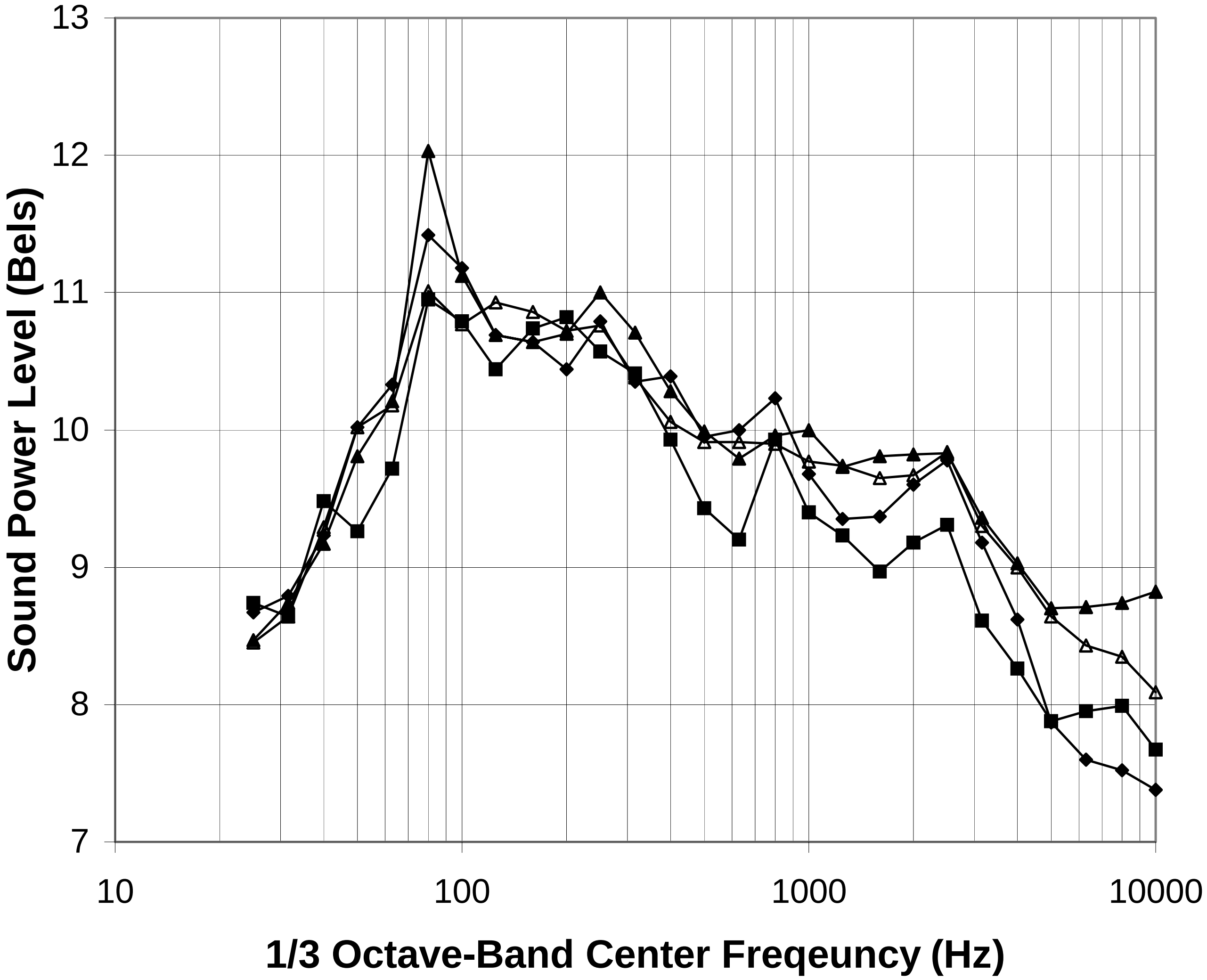


Figure 10. Estimated Sound Power Spectra of a Typical Screw-Type Compressor (Site T07) Based on Measurements from Four Directions.

during the course of the study (sum of number observed during three surveys of each transect) was determined. These values (number per species per 50 m) are presented in Table 6.

More birds were observed per species per 50 m on control sites (1.11) than on treatment sites (0.97), but this difference was not statistically significant. The number of birds observed per 50 m (control and treatment sites combined; Table 6) differed significantly among species. Bewick's wren and spotted towhee had significantly higher counts than bushtit, house finch, chipping sparrow, and western scrub jay; the mean number of the juniper titmouse and ash-throated flycatcher were intermediate. The spotted towhee was the only species for which a significant difference in the

Table 3. Estimated Sound Power Levels of Study Compressors and Sound Pressure Levels Predicted along the Bird Survey Transects.

Site	Rating (hp)	Sound Power Level (A-weighted bels)[a]	Sound Pressure Level (dBA) at Various Distances from Compressor							
			50 m	100 m	150 m	200 m	250 m	300 m	350 m	400 m
T01	320	11.0	61.7	54.7	50.5	47.5	45.1	43.0	41.2	39.6
T02	305	11.3	63.4	56.0	51.8	48.8	46.5	44.5	42.7	41.1
T03	305	11.4	64.4	57.1	52.9	49.9	47.5	45.5	43.7	42.2
T04	305	11.2	62.6	55.5	51.4	48.4	46.0	44.0	42.2	40.6
T05	320	11.1	62.7	55.4	51.0	47.7	45.0	42.8	40.8	39.0
T06	305	11.2	63.8	56.3	52.0	49.0	46.6	44.6	42.8	41.2
T07	95	10.9	62.4	55.3	51.2	48.1	45.7	43.6	41.7	40.0
T08	95	11.0	64.9	57.7	53.3	50.0	47.4	45.2	43.2	41.5
T09	305	11.1	62.9	55.7	51.5	48.5	46.0	44.0	42.2	40.5
T10	531	11.3	64.8	57.6	53.4	50.3	47.8	45.6	43.8	42.1
T11	660	-[b]	-	-	-	-	-	-	-	-
T12	450	11.0	63.2	56.0	51.6	48.2	45.5	43.2	41.2	39.4
T13	651	11.5	62.8	55.5	51.1	47.8	45.2	42.9	41.0	39.2
T14	461	11.3	63.4	56.3	52.2	49.3	46.9	44.8	43.0	41.4
T15	45	10.0	47.3	40.0	35.8	32.8	30.4	28.4	26.6	25.0
T16	461	11.3	61.9	54.8	50.7	47.8	45.5	43.5	41.7	40.2

[a] Average of sound power levels computed on basis of SPL measurements in four orthogonal directions. One bel equals 10 decibels.

[b] Not modeled because noise measurements were not made.

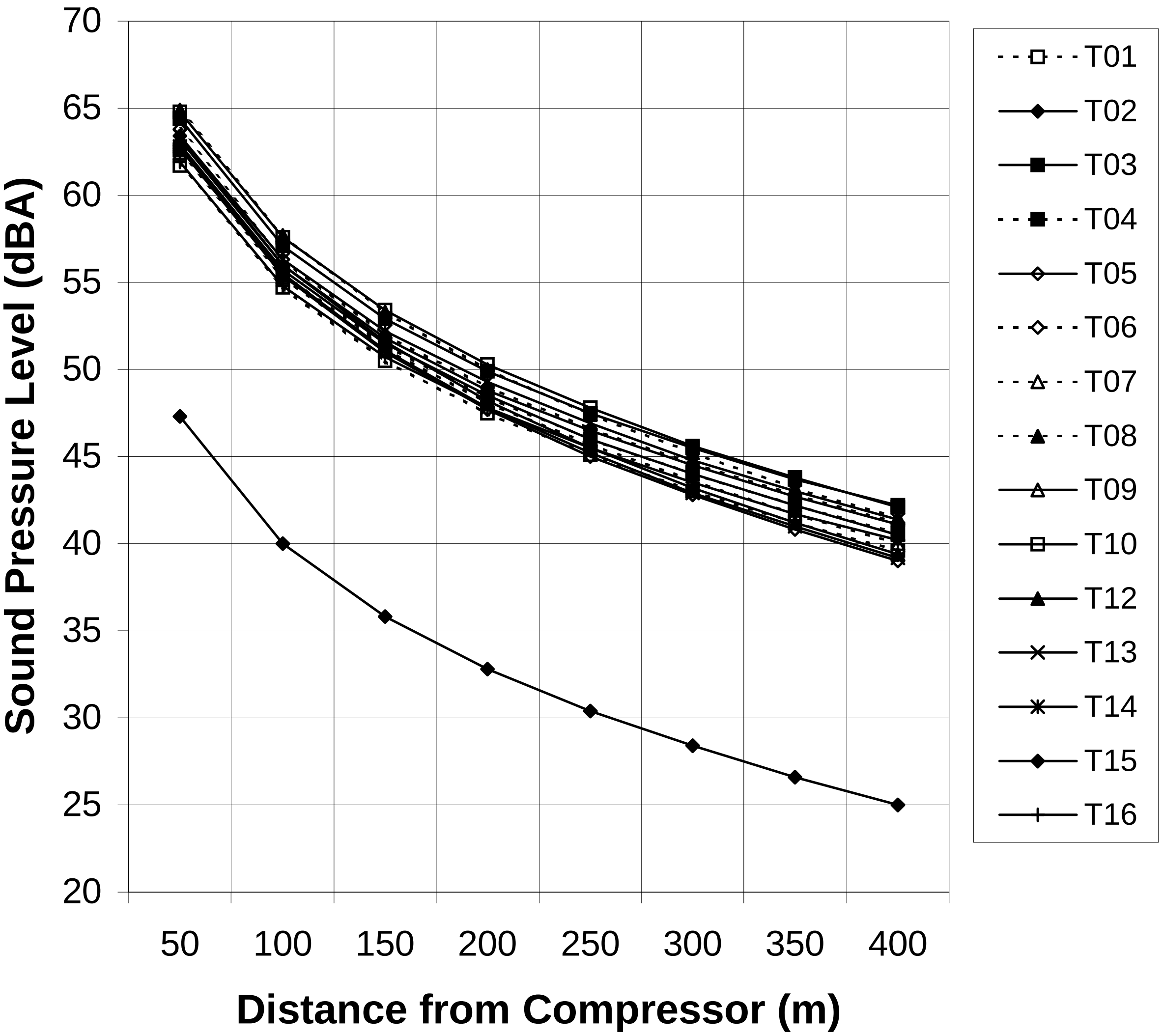


Figure 11. Estimated Sound Pressure Levels (dBA) on Each Treatment Site at Different Distances from the Compressor.

numbers observed on control and treatment sites could be detected (1.75 birds per 50 m on control sites vs. 1.28 birds per 50 m on treatment sites).

The number of birds observed per species per 50 m differed significantly at different distances from wells. The number of birds was greatest in the 51 to 100-m interval and least in the 151 to 200-m interval (Table 6). The relationship of the number of birds per species per 50 m to distance from the well was similar on control and treatment sites (Figure 13). The relationship of the number of birds per 50 m to distance from the well varied among species (Figure 14). For some

Table 4. Total Number of Individuals of Each Bird Species Observed on Study Sites — Control and Treatment Sites Combined.

Common Name[a]	Scientific Name	Total Number Observed[b]	Mean Total per Site[c]	Standard Deviation	Minimum	Maximum
Most Abundant Species						
Ash-throated flycatcher	*Myiarchus cinerascens*	200	8.3	3.1	3	15
Bewick's wren	*Thryomanes bewickii*	285	11.9	4.5	1	18
Bushtit	*Psaltriparus minimus*	157	6.5	5.4	0	20
Chipping sparrow	*Spizella passerina*	141	5.9	4.3	2	19
House finch	*Carpodacus mexicanus*	155	6.5	3.4	0	13
Juniper titmouse	*Baeolophus griseus*	207	8.6	4.2	0	18
Spotted towhee	*Pipilo maculatus*	276	11.5	4.9	4	22
Western scrub jay	*Aphelocoma californica*	140	5.8	3.7	1	18
Other Species						
American kestrel	*Falco sparverius*	2	0.1	0.3	0	1
Black-chinned hummingbird	*Archilochus alexandri*	12	0.5	0.9	0	3
Black-headed grosbeak	*Pheucticus melanocephalus*	27	1.1	1.2	0	4
Black-throated gray warbler	*Dendroica nigrescens*	28	1.2	1.8	0	7
Blue-gray gnatcatcher	*Polioptila caerulea*	32	1.3	1.8	0	8
Brewer's sparrow	*Spizella breweri*	1	0.04	0.2	0	1
Broad-tailed hummingbird	*Selasphorus platycercus*	2	0.1	0.3	0	1
Brown-headed cowbird	*Molothrus ater*	68	2.8	3.5	0	15
Cassin's kingbird	*Tyrannus vociferans*	6	0.3	0.6	0	2
Chimney swift	*Chaetura pelagica*	1	0.04	0.2	0	1
Cliff swallow	*Petrochelidon pyrrhonota*	6	0.3	0.5	0	2
Common nighthawk	*Chordeiles minor*	12	0.5	1.7	0	8
Common raven	*Corvus corax*	12	0.5	0.7	0	2
Cooper's hawk	*Accipiter cooperii*	3	0.1	0.3	0	1
Gray flycatcher	*Empidonax wrightii*	96	4.0	2.4	1	11
Gray vireo	*Vireo vicinior*	74	3.1	2.4	0	8
Hairy woodpecker	*Picoides villosus*	8	0.3	0.6	0	2
Lark sparrow	*Chondestes grammacus*	15	0.6	1.0	0	3
Lesser goldfinch	*Carduelis psaltria*	64	2.7	2.3	0	10
Mountain bluebird	*Sialia currucoides*	37	1.5	1.1	0	4
Mountain chickadee	*Poecile gambeli*	60	2.5	2.8	0	11
Mourning dove	*Zenaida macroura*	69	2.9	3.4	0	13
Northern flicker	*Colaptes auratus*	18	0.8	1.1	0	4
Northern rough-winged swallow	*Stelgidopteryx serripennis*	11	0.5	1.1	0	4
Pinyon jay	*Gymnorhinus cyanocephalus*	19	0.8	2.2	0	9
Plumbeous vireo	*Vireo plumbeous*	3	0.1	0.4	0	2
Pygmy nuthatch	*Sitta pygmaea*	1	0.04	0.2	0	1
Red crossbill	*Loxia curvirostra*	1	0.04	0.2	0	1

Table 4 (Continued)

Common Name[a]	Scientific Name	Total Number Observed[b]	Mean Total per Site[c]	Standard Deviation	Minimum	Maximum
Red-tailed hawk	*Buteo jamaicensis*	4	0.2	0.5	0	2
Sage sparrow	*Amphispiza belli*	1	0.04	0.2	0	1
Turkey vulture	*Cathartes aura*	19	0.8	1.3	0	4
Unidentified	Not applicable	59	2.5	2.6	0	10
Vesper sparrow	*Pooecetes gramineus*	1	0.04	0.2	0	1
Violet-green swallow	*Tachycineta thalassina*	48	2.0	2.6	0	9
Western tanager	*Piranga ludoviciana*	8	0.3	0.9	0	3
Western bluebird	*Sialia mexicana*	19	0.8	1.3	0	5
White-breasted nuthatch	*Sitta carolinensis*	55	2.3	2.4	0	8
White-throated swift	*Aeronautes saxatilis*	11	0.5	1.0	0	4
Wild turkey	*Meleagris gallopavo*	7	0.3	0.6	0	2

[a] Common and scientific names follow the nomenclature of the American Ornithologists' Union 7th edition of the *Checklist of North American Birds* (American Ornithologists' Union 1998).

[b] Total number of individuals observed along all transects during the course of the study.

[c] Each site was surveyed on three separate days and the number of birds of each species on each site was summed. Mean total per site is the mean of these totals and equals the total divided by 24 (number of sites).

species (e.g., Bewick's wren and western scrub jay), the number of birds showed little discernable relationship to distance. For both the chipping sparrow and house finch, the number of birds seen was highest near wells and declined with increasing distance, demonstrating their affinity for the open habitat of the well pad and the edge habitat at the pad-woodland boundary. Other species (e.g., bushtit and spotted towhee) exhibited a peak in numbers at some intermediate distance.

The results of the noise model were used to divide survey transects into areas with relatively high noise levels and those with more moderate noise levels. For all but site T15, the area between 0 and 150 m from the compressor had noise levels $\geq$ 50 dBA and the area between 151 and 400 m had noise levels between 40 and 50 dBA. On site T15, noise level was within background levels within 100 m of the compressor because the compressor at this site had a relatively low site power rating (45 hp). Because of this difference in noise output, site T15 was eliminated from this particular analysis.

The relationships among the number of birds observed and species and site type were different in the two distance zones (Figure 15). Within the 0 to 150-m zone (high noise level), the numbers of birds per species on control and treatment sites were not significantly different (3.7 vs. 3.5 birds/species, respectively). Spotted towhee, Bewick's wren, and house finch were the most abundant species in this zone; western scrub jay was the least abundant. Although most species

Table 5. Mean Total Number of Individuals of Each Bird Species Observed on Control and Treatment Sites.[a]

	Control		Treatment	
Species	**Mean Total per Site**	**Standard Deviation**	**Mean Total per Site**	**Standard Deviation**
Most Abundant Species				
Ash-throated flycatcher	9.0	3.1	8.0	3.2
Bewick’s wren	13.1	3.6	11.3	4.9
Bushtit	8.0	6.2	5.8	5.0
Chipping sparrow	7.3	6.5	5.2	2.7
House finch	5.8	4.9	6.8	2.5
Juniper titmouse	7.0	5.2	9.4	3.5
Spotted towhee	14.0	3.0	10.3	5.2
Western scrub jay	6.8	3.5	5.4	3.8
Other Species				
American kestrel	0.0	0.0	0.1	0.3
Black-chinned hummingbird	0.0	0.0	0.8	1.1
Blue-gray gnatcatcher	1.9	2.6	1.1	1.2
Brown-headed cowbird	3.6	5.0	2.4	2.6
Black-headed grosbeak	1.1	1.4	1.1	1.1
Brewer’s sparrow	0.0	0.0	0.1	0.3
Broad-tailed hummingbird	0.0	0.0	0.1	0.3
Black-throated gray warbler	1.3	2.4	1.1	1.5
Cassin's kingbird	0.0	0.0	0.4	0.7
Chimney swift	0.1	0.4	0.0	0.0
Cliff swallow	0.3	0.7	0.3	0.4
Cooper's hawk	0.3	0.5	0.1	0.3
Common nighthawk	1.3	2.8	0.1	0.5
Common raven	0.5	0.8	0.5	0.7
Gray flycatcher	4.8	3.2	3.6	2.0
Gray vireo	3.1	2.6	3.1	2.3
Hairy woodpecker	0.3	0.7	0.4	0.5
Lark sparrow	0.9	1.2	0.5	0.8
Lesser goldfinch	2.9	1.6	2.6	2.7
Mountain bluebird	1.6	1.1	1.5	1.1
Mountain chickadee	2.6	1.8	2.4	3.2
Mourning dove	3.1	4.2	2.8	3.0
Northern flicker	0.5	0.8	0.9	1.3
Pinyon jay	0.0	0.0	1.2	2.6
Plumbeous vireo	0.0	0.0	0.2	0.5
Pygmy nuthatch	0.1	0.4	0.0	0.0
Red crossbill	0.1	0.4	0.0	0.0
Red-tailed hawk	0.4	0.7	0.1	0.3
Northern rough-winged swallow	0.9	1.5	0.3	0.8
Sage sparrow	0.1	0.4	0.0	0.0
Turkey vulture	0.6	1.1	0.9	1.4
Unidentified	3.9	3.5	1.8	1.7
Vesper sparrow	0.0	0.0	0.1	0.3
Violet-green swallow	2.6	3.5	1.7	2.1
White-breasted nuthatch	1.4	1.3	2.8	2.8

Table 5 (Continued)

Species	Control Mean Total per Site	Control Standard Deviation	Treatment Mean Total per Site	Treatment Standard Deviation
Western bluebird	0.8	1.2	0.8	1.4
Western tanager	0.0	0.0	0.5	1.1
Wild turkey	0.5	0.9	0.2	0.4
White-throated swift	0.5	0.9	0.4	1.0
Total Birds[b]	101.8	11.4	91.9	24.3

[a] Each site was surveyed on three separate days and the number of birds of each species on each site was summed. Mean total per site is the mean of these totals. There were 8 control sites and 16 treatment sites.

[b] Includes all species listed above except for American kestrel, brown-headed cowbird, chimney swift, cliff swallow, common nighthawk, common raven, Cooper's hawk, northern rough-winged swallow, red-tailed hawk, turkey vulture, violet-green swallow, and white-throated swift. These species range widely during the breeding season while foraging and were typically seen flying over the study sites.

were more abundant on control sites, both the house finch and the juniper titmouse were more abundant on treatment sites (Figure 15).

Within the 151 to 400-m zone (moderate noise level), there were significantly more birds per species overall on control sites than on treatment sites (5.2 vs. 4.2 birds per species, respectively). Bewick's wren, spotted towhee, and juniper titmouse were the most abundant species in this zone; house finch and chipping sparrow were the least abundant. For all species in the moderate noise zone, the number observed was lower on treatment sites than control sites (Figure 15).

5.2.2 Effects of Site Type and Distance on Total Number of Birds

Relationships among total number of birds (all species combined) and site type and distance were examined. Several species were not included in this analysis because they range widely during the breeding season while foraging (Terres 1982) and were typically seen flying over the study sites. These characteristics make them less susceptible to the effects of noise and potentially poor indicators of any potential noise effect. Their inclusion in the total could mask any effect of noise on the bird community. Species that were not included in the analysis were the American kestrel, brown-headed cowbird, chimney swift, cliff swallow, common nighthawk, common raven, Cooper's hawk, northern rough-winged swallow, red-tailed hawk, turkey vulture, violet-green swallow, and white-throated swift.

Values for the mean total number of birds per 50 m of transect are presented in Table 6. No significant relationships were found between the total number of birds observed and site type or distance (Figure 16). This result is not surprising since species apparently responded differently to

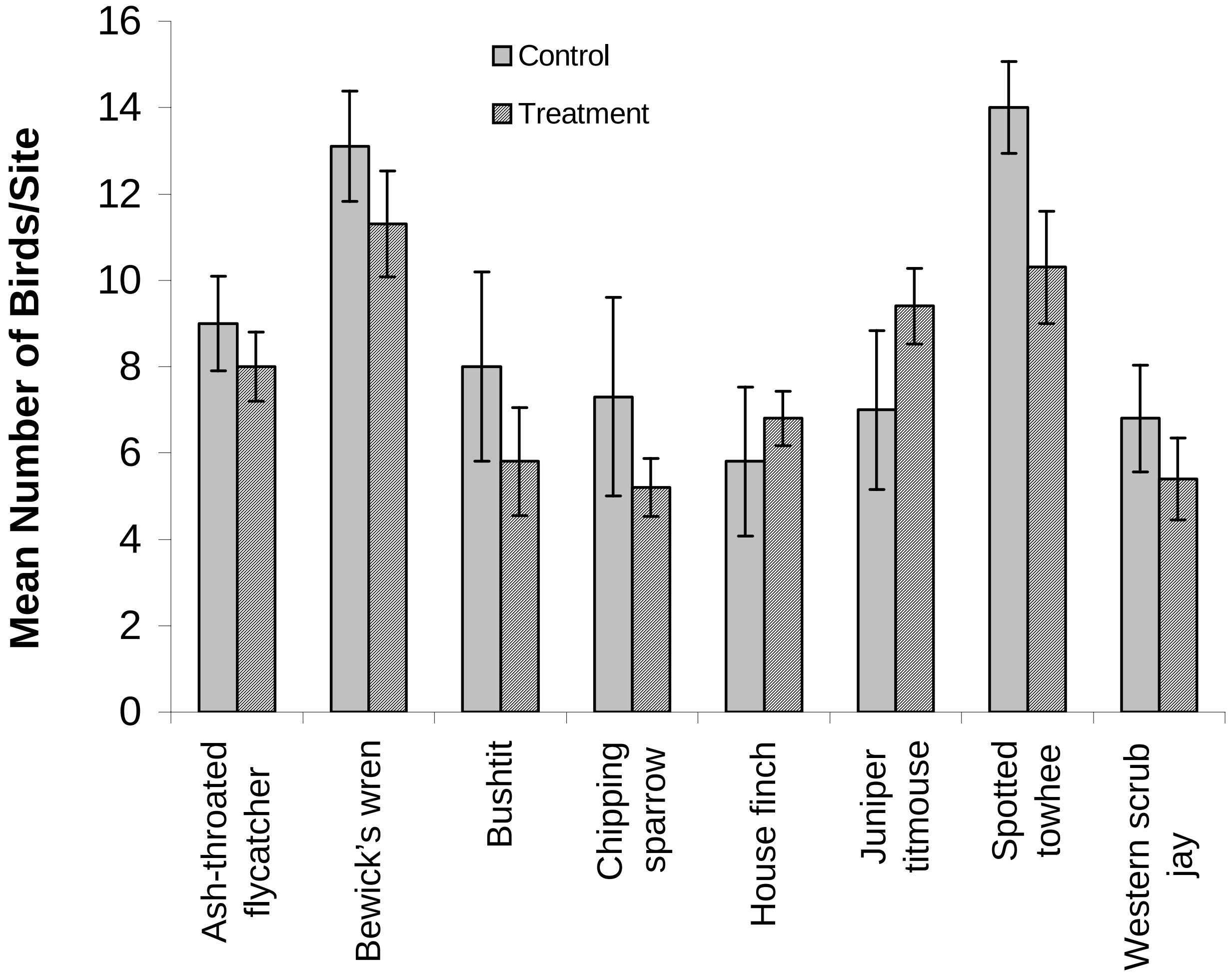


Figure 12. Mean Total Number of Birds Observed on Control and Treatment Sites for Each of the Eight Most Abundant Species. (± 1 standard error is shown as a vertical line around each mean; data from Table 5.)

compressors (some positively and some negatively), and the relationships of numbers to distance varied among species (see Section 5.2.1).

The total number of birds per site was also determined for each of the two distance zones discussed above — 0 to 150 m (exposed to ≥ 50 dBA on most sites) and 151 to 400 m (exposed to 40-50 dBA on most sites). For this analysis, site T15 was eliminated because of the low noise level there, as discussed in Section 5.2.1. In both zones, the difference between total number of birds per

Table 6. Mean Total Number of Birds per Species per 50-m Interval of Transect on Control and Treatment Sites and at Different Distances from the Well.

Category	Mean Total Number of Birds per Species per 50 m[a]									Mean Total Number of Birds per 50 m[c]
	Ash-throated Flycatcher	Bewick's Wren	Bushtit	Chipping Sparrow	House Finch	Juniper Titmouse	Spotted Towhee	Western Scrub Jay	All Species[b]	
Site Type										
Control	1.13	1.64	1.00	0.91	0.72	0.88	1.75	0.84	1.11	12.72
Treatment	1.00	1.41	0.73	0.65	0.85	1.18	1.28	0.67	0.97	11.48
Distance from Well (m)[d]										
0-50	0.88	1.42	0.58	1.75	2.63	0.71	1.17	0.46	1.20	14.54
51-100	1.54	1.54	0.71	1.00	0.96	1.79	2.00	0.50	1.26	13.67
101-150	1.25	1.29	2.04	0.88	0.79	0.75	1.71	0.67	1.17	13.25
151-200	0.83	1.71	0.46	0.33	0.46	0.54	1.38	0.75	0.81	10.71
201-250	1.21	1.46	0.42	0.33	0.29	1.63	1.13	0.88	0.92	10.71
251-300	0.75	1.17	0.71	0.67	0.46	0.63	1.29	1.00	0.83	9.71
301-350	1.08	1.46	0.54	0.33	0.42	1.00	1.21	0.71	0.84	10.42
351-400	0.79	1.83	1.08	0.58	0.46	1.58	1.63	0.88	1.10	12.17
All transects	1.04	1.48	0.82	0.73	0.81	1.08	1.44	0.73	1.02	11.90

See footnotes on next page.

Table 6 (Continued)

[a] Each site was surveyed on three separate days. The total number of birds observed along transects in each distance interval on these three days was determined for each study site. The mean of these values is presented here.

[b] Mean of values for each species category in columns to left.

[c] Number of birds summed across species categories.

[d] Data from control and treatment sites combined.

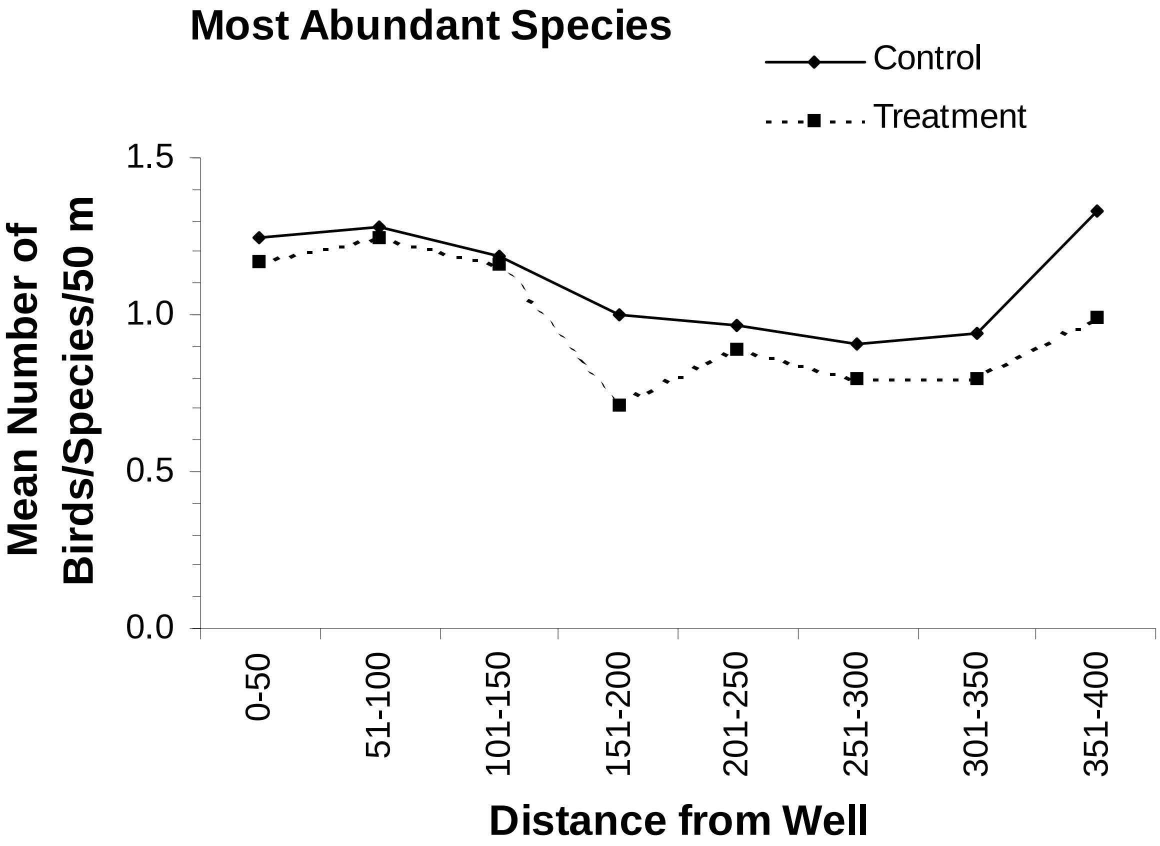


Figure 13. Mean Total Number of Birds Observed per Species per 50 m of Transect at Different Distances from the Well for Each of the Eight Most Abundant Species on Control and Treatment Sites.

site on control and treatment sites was not statistically significant (0 to 150 m zone: 42.8 and 39.5 birds per site on control and treatment sites, respectively; 151 to 400 m zone: 59.0 and 50.5 birds per site on control and treatment sites, respectively).

5.3 Vegetation Survey Results

Twenty-four cover types were identified along transects on study sites (Table 7). The most widely distributed plant cover types were pinyon (153 transects), Utah juniper (149 transects), forbs (131 transects), grasses (120 transects), and big sagebrush (75 transects). Mean percent cover was highest for pinyon (24%), Utah juniper (24%), pale wolfberry (22%), Gambel oak (22%), and fendlerbush (20%) when these vegetation types were present along a transect. Most transects (213 of 216) had at least some portion that was bare (no vegetation). On those transects, an average of 45% of the transect was bare.

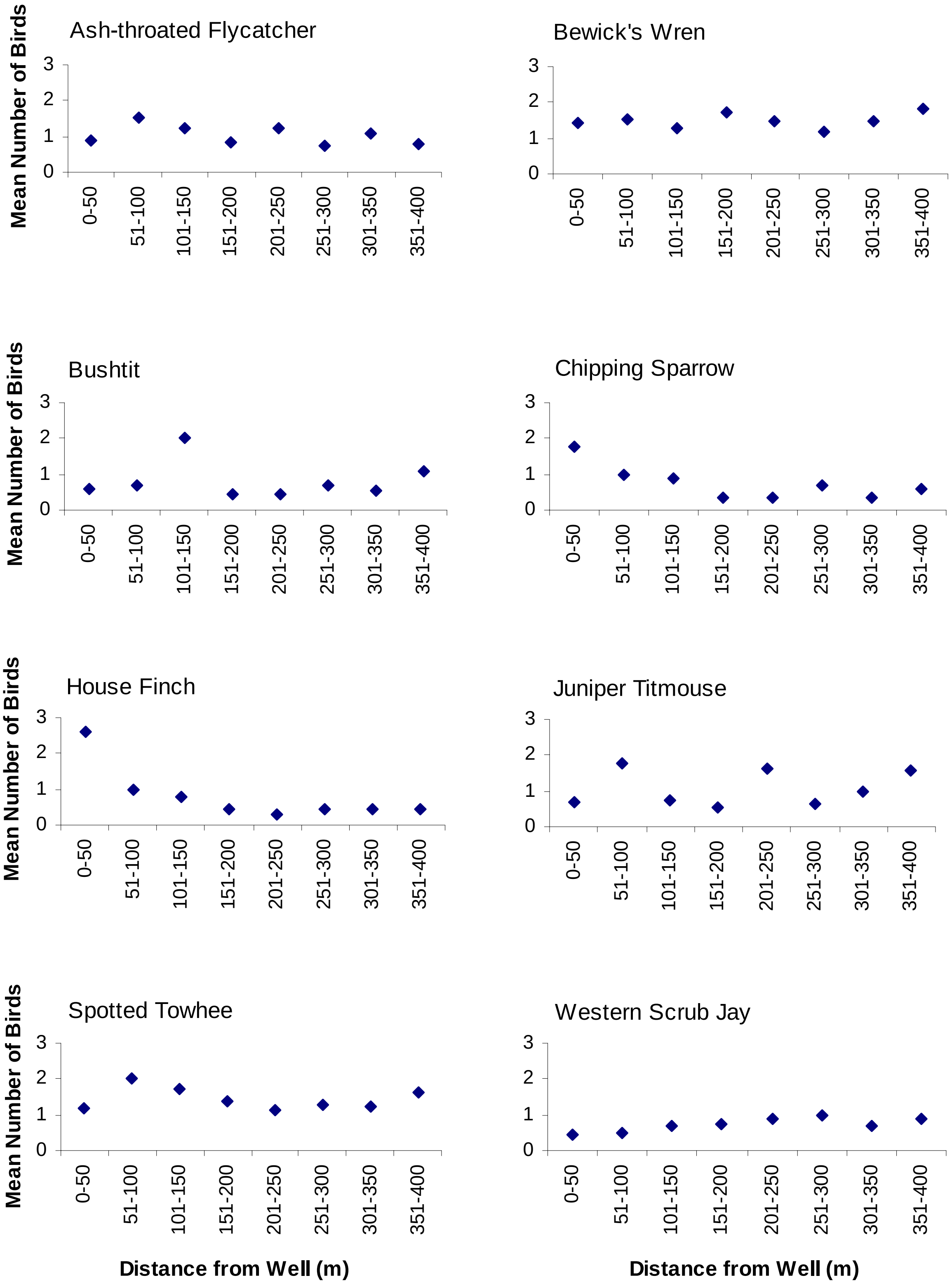
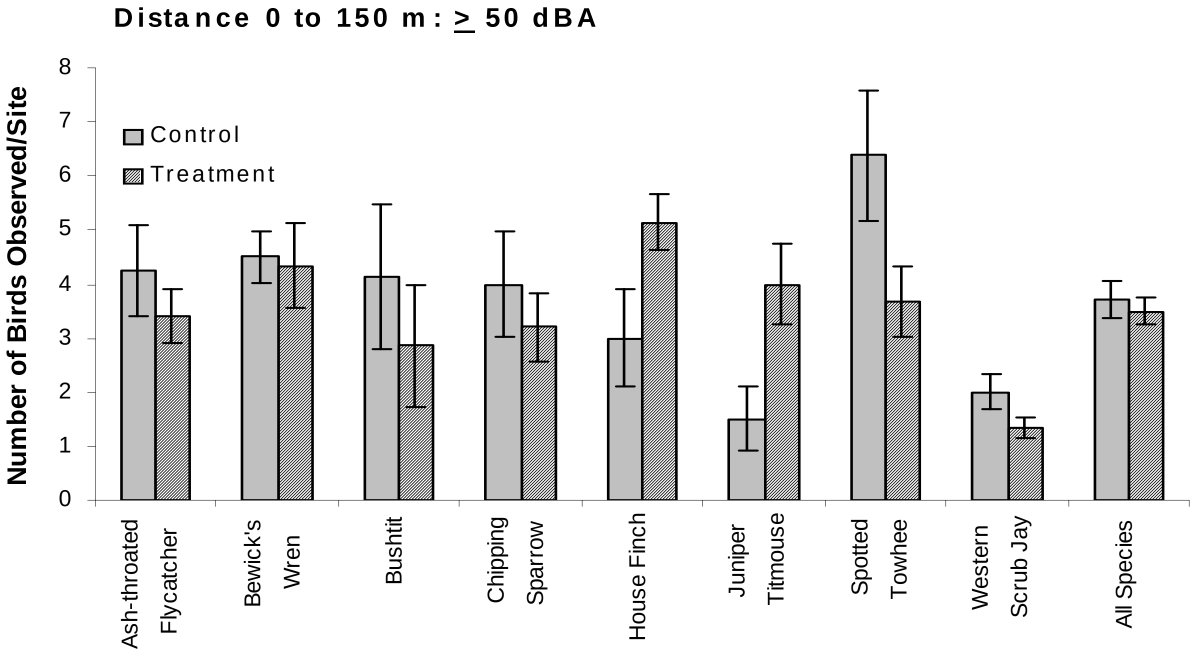


Figure 14. Relationships Between Mean Total Number of Birds and Distance from the Well for Each of the Eight Most Abundant Species. (Control and treatment sites are combined; data from Table 6.)



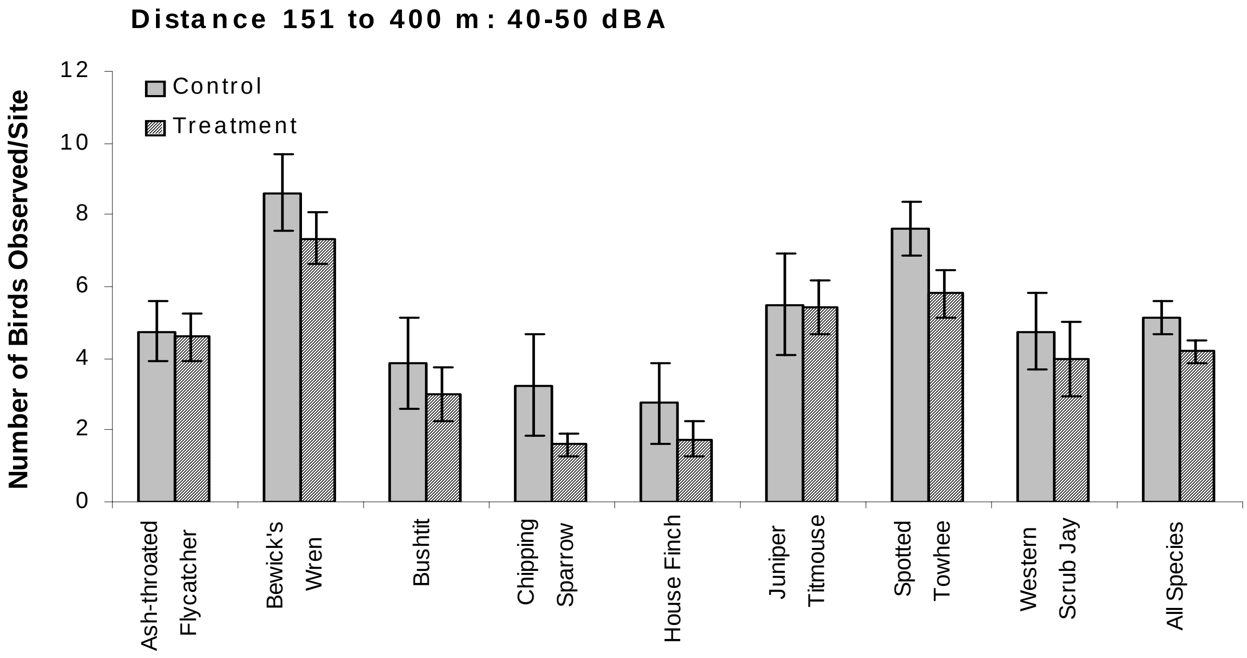


Figure 15. Mean Total Number of Birds Observed Per Site in Two Distance Zones that Relate to Noise Level on Treatment Sites. (± 1 standard error is shown as a vertical line around each mean.)

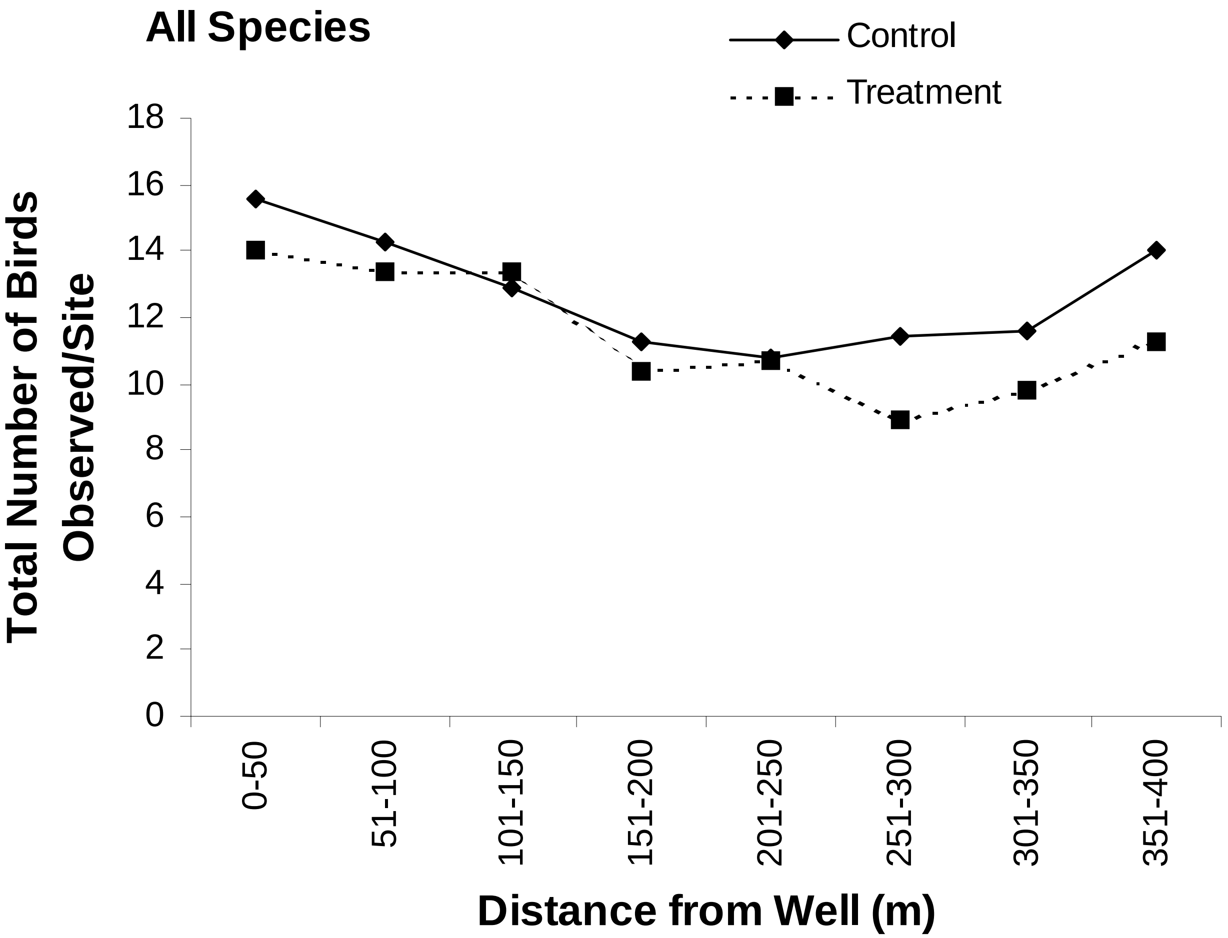


Figure 16. Mean Total Number of Birds Observed at Different Distances from the Well on Control and Treatment Sites.

The cover types presented in Table 7 were combined into the following categories—pinyon, juniper, shrubs, grasses, forbs, and bare. Mean percent cover values for each of these cover types on control and treatment sites and at different distances from the well are presented in Table 8.

Percent plant cover values for cover types (excluding bare areas) on treatment sites were not significantly different from those on control sites. Grasses and forbs had significantly lower percent cover values than pinyon, juniper, or shrubs on both control and treatment sites (Table 8). There was significantly less cover along transects adjacent to the study wells (0 m) than along transects farther from the well (Table 8). The relationship of percent cover to distance varied among cover types; some cover types did not occur adjacent to wells (pinyon and juniper), while others were more abundant there (forbs and grasses).

Table 7. Occurrence of Cover Types on Study Sites in the Rattlesnake Canyon Habitat Management Area, San Juan County, New Mexico.

Cover Type	Scientific Name	Number of Transects[a]	Mean Percent Cover[b]	Standard Deviation[b]	Min-imum[b]	Max-imum[b]
Bare (no vegetation)	Not applicable	213	44.7	22.9	2.5	100.0
Pinyon	*Pinus edulis*	153	24.4	16.2	3.0	79.0
Utah juniper	*Juniperus osteosperma*	149	24.0	15.4	2.0	81.5
Forbs (unidentified)	Not applicable	131	9.2	14.7	0.5	93.0
Grasses (unidentified)	Not applicable	120	14.0	17.1	0.5	74.0
Big sagebrush	*Artemisia tridentata*	75	15.5	13.0	0.5	58.0
Bitterbrush	*Purshia tridentata*	63	8.4	7.5	0.5	38.0
Mountain mahogany	*Cercocarpus montanus*	62	12.6	10.0	0.5	56.0
Broom snakeweed	*Gutierrezia sarothrae*	32	3.5	3.4	0.5	12.5
Gambel oak	*Quercus gambelii*	23	21.5	23.5	0.5	100.0
Central prickly pear	*Opuntia polyacantha*	18	1.5	1.2	0.5	5.0
Utah serviceberry	*Amelanchier utahensis*	16	10.8	8.9	1.0	36.5
Green ephedra	*Ephedra viridis*	16	3.3	2.6	1.0	9.5
Rubber rabbitbrush	*Chrysothamnus nauseosus*	8	5.0	2.7	1.5	9.5
Datil yucca	*Yucca baccata*	6	4.1	1.4	2.5	6.0
Shrubs (unidentified)	Not applicable	3	3.8	3.8	0.5	8.0
Moss (unidentified)	Not applicable	2	3.3	3.2	1.0	5.5
Skunkbush	*Rhus aromatica*	2	4.8	0.4	4.5	5.0
Mistletoe (unidentified)	Not applicable	1	0.5	--	0.5	0.5
Granite prickly phlox	*Leptodactylon pungens*	1	2.5	--	2.5	2.5
Claretcup	*Echinocereus triglochidiatus*	1	0.5	--	0.5	0.5
Fendlerbush	*Fendlera rupicola*	1	19.5	--	19.5	19.5
Creeping barberry	*Mahonia repens*	1	2.5	--	2.5	2.5
Pale wolfberry	*Lycium pallidum*	1	22.0	--	22.0	22.0

[a] Number of transects where cover type occurred out of 216 total transects.

[b] Mean percent cover, standard deviation, minimum, and maximum values are presented for those transects where the cover type was found. "--" indicates standard deviation could not be calculated because of sample size.

Table 9 and Figures 17 and 18 present percent cover values for vegetation in different height categories according to site type and distance from the well. Overall, percent cover of very short vegetation (0 to 0.5 m in height) and tall vegetation (> 2 m in height) was significantly greater than percent cover of vegetation of intermediate height (0.6 to 2 m in height; Table 9). Percent cover of vegetation in different height categories was similar on control and treatment sites, but differed significantly according to distance; as the distance from wells increased, the representation of shorter vegetation (0 to 0.5 m) decreased while that of taller vegetation increased (Figure 17). The relationship of vegetation height to distance from the well was significantly different between

Table 8. Mean Percent Cover per Transect for Cover Types on Control and Treatment Sites and at Different Distances from the Well.

	Mean Percent Cover[a]						
Category	**Pinyon**	**Juniper**	**Shrubs**	**Forbs**	**Grasses**	**Bare**	**All Plant Cover Types**[b]
Site Type							
Control	16.0	15.9	19.5	7.4	8.6	45.3	13.5
Treatment	17.9	16.9	14.1	4.9	7.4	47.8	12.3
Distance from Well (m)[c]							
0	0.0	0.0	0.5	11.5	3.0	85.1	3.0
50	10.8	8.5	11.3	19.6	21.9	39.4	14.4
100	20.8	19.1	21.1	2.9	16.1	38.6	16.0
150	20.9	19.3	20.5	3.9	12.2	36.5	15.4
200	17.8	17.1	19.8	4.6	6.5	44.1	13.1
250	22.3	24.4	19.5	3.0	2.0	45.9	14.2
300	16.0	25.0	18.4	1.8	1.9	46.9	12.6
350	20.2	20.9	16.4	1.7	3.5	46.6	12.6
400	26.8	15.0	16.0	2.6	2.8	42.4	12.7
All transects	17.3	16.6	15.9	5.8	7.8	47.0	12.7

[a] Percent cover was calculated as the total intercept length of a cover type on a transect divided by the length of the transect (20 m) x 100.

[b] Mean percent cover values for pinyon, juniper, shrubs, forbs, and grasses.

[c] Data from control and treatment sites combined.

control and treatment sites, with control sites having taller vegetation (> 2 m) nearer (100 to 200 m) the well than treatment sites (Figure 18).

Differences in vegetation between control and treatment sites in the high noise zones (0 to 150 m) and moderate noise zones (151 to 400 m) were also evaluated. These analyses indicated that vegetation characteristics were not significantly different between control and treatment sites in these two distance zones (see Section D.2 in Appendix D).

Table 9. Mean Percent Plant Cover in Different Height Categories on Control and Treatment Sites and at Different Distances from the Well.

	Mean Percent Cover in Height Categories[a]				
Category	**0 - 0.5 m**	**0.6 - 1 m**	**1.1 - 2 m**	**2.1 - 5 m**	**> 5 m**
Site Type					
Control	21.7	6.3	7.5	16.8	15.1
Treatment	16.7	5.9	7.3	14.6	16.8
Distance from Well (m)[b]					
0	13.2	0.6	1.1	0.0	0.0
50	44.7	5.8	4.4	9.2	8.0
100	25.9	6.7	9.0	17.8	20.5
150	23.3	6.1	8.5	18.0	20.9
200	18.2	8.3	6.8	17.6	14.8
250	9.6	8.7	10.4	13.6	28.8
300	8.4	6.1	10.5	20.1	17.9
350	9.8	6.8	9.5	21.4	15.3
400	11.9	5.4	5.7	20.7	19.7
All transects	18.4	6.1	7.3	15.4	16.2

[a] Percent cover was calculated as the total intercept length of a height category on a transect divided by the length of the transect (20 m) x 100.

[b] Data from control and treatment sites combined.

6 DISCUSSION

Our study quantified background noise levels and sound output from 15 compressors in the Rattlesnake Canyon Habitat Management Area. Noise from the compressors declined substantially at increasing distance, but was still noticeably above background at 400 m away. The apparent effect of this noise on adjacent bird communities was complex and differed among species. Compressor noise did not eliminate bird populations from adjacent habitat or drastically alter the species composition of those bird communities. Approximately the same number of species and the total number of birds observed on control and treatment sites was similar. At least one species, the house finch, nested on well equipment even when a compressor was operating. Birds could be heard singing in adjacent pinyon-juniper habitat while compressors were operating. Birds occupied habitat on and immediately adjacent (<25 m away) to well pads with active compressors.

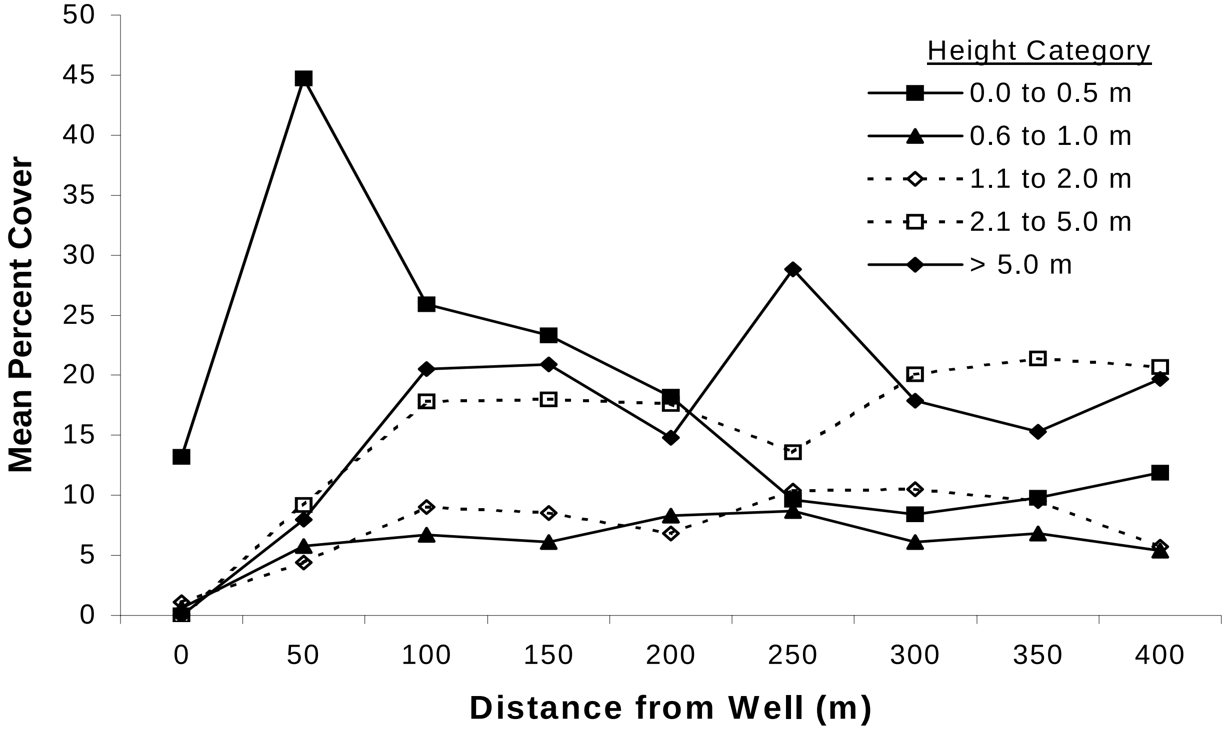
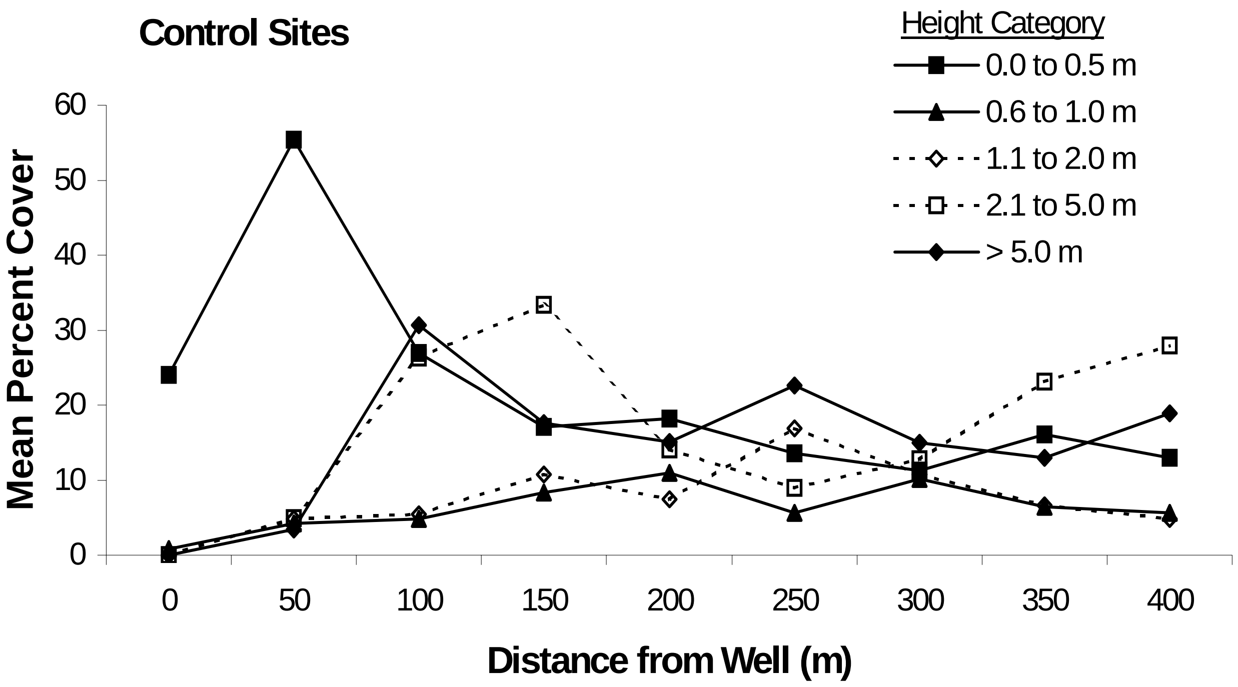


Figure 17. Mean Percent Cover of Vegetation in Different Height Categories on Transects at Different Distances from the Well — Control and Treatment Sites Combined. (Data from Table 9.)

However, it would be incorrect to conclude from these results that noise had no effect on pinyon-juniper bird communities. Our study detected significant differences in the numbers of some species on control and treatment sites that appear to be related to noise levels. For the most part, vegetation characteristics of control and treatment sites were not significantly different and could not account for the observed differences in bird communities. The only significant difference in the vegetation of control and treatment sites was the interaction between height, site type, and distance but this interaction did not correspond to any pattern in bird communities such as an interaction between species, site type, and distance or between site type and distance (see Appendix D). The few vegetation differences that were detected must be due to chance differences in the location of compressors rather than an effect of noise on vegetation since wells and compressors were placed relatively recently in established pinyon-juniper habitat.

In general, treatment sites appeared to have fewer birds per species than did control sites, but this difference was not statistically significant. This lack of significance does not suggest that noise had no effect on bird numbers, but instead results from species differences in their response to noise.



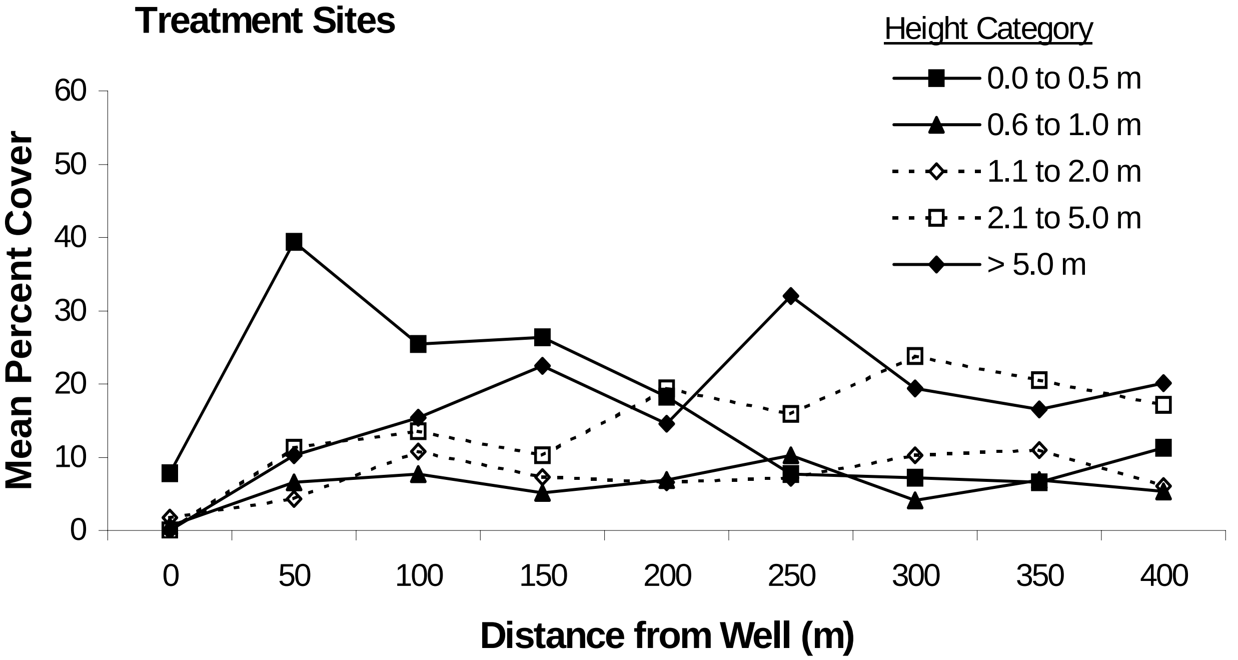


Figure 18. Mean Percent Cover of Vegetation in Different Height Categories on Transects at Different Distances from the Well — Control and Treatment Sites Separated to Show Interaction of Height, Site Type, and Distance.

Among the eight most abundant species on our study area (ash-throated flycatcher, Bewick's wren, bushtit, chipping sparrow, house finch, juniper titmouse, spotted towhee, and western scrub jay), six species were less abundant on treatment sites than on control sites, but the house finch and juniper titmouse were more abundant on treatment sites. The spotted towhee exhibited the greatest reduction in abundance on treatment sites. These observed species differences in response suggest different levels of tolerance to noise. Other researchers have observed species-specific differences in response to noise in other bird communities (van der Zande et al. 1980; Reijnen et al. 1995, 1996). Although we did not detect an effect of noise on species diversity, the observed species-specific differences in noise tolerance could produce such an effect over time as more tolerant species replace less tolerant species in an area.

One would expect to see a diminishment of any noise effect at increasing distance from the noise source. Figure 11 illustrates the exponential decrease in noise level as distance from the compressor increases. On the basis of this decrease in noise, one might predict that the number of birds per species would increase at increasing distances from the compressor and at some distance be indistinguishable from the number of birds per species observed on control sites (Reijnen et al. 1995, 1996). However, we did not observe this predicted relationship to distance. Detecting such an effect on the study area was made more difficult because the sharp transition between the cleared well area and the adjacent pinyon-juniper habitat had an overriding influence on the bird community and bird abundance. Consequently, on both control and treatment sites, the total number of birds was highest in the 50 m closest to the well, declined at increasing distances, reached a minimum number at about 300 m, and then increased in the final 100 m of the transect. This pattern in abundance along control and treatment transects is presumably an expression of the well-known edge effect where the number of individuals and species tends to be greater at zones of transition between habitats (Odum 1971; Smith 1980; Reese and Ratti 1988). It is possible that longer transects would demonstrate a decreasing effect of noise at distances greater than 400 m.

Although bird abundance did not increase as predicted at increasing distances from compressors along the 400-m transects, there were measurable differences in the apparent effect of noise in high noise zones ($\geq$ 50 dBA) and moderate noise zones (40 to 50 dBA). In the high noise zone of treatment sites (0 to 150 m from compressors), there were significantly more house finches (71% more) and juniper titmice (167% more) than there were on control sites at the same distance, and significantly fewer spotted towhees (42% fewer) than on control sites. In the moderate noise zone of the treatment sites (151 to 400 m from compressors) there were fewer birds per species relative to the same distance on control sites (19% reduction in the number of birds per species); there was no increase in the number of either the house finch or juniper titmouse; and the reduction in the number of spotted towhees relative to that on control sites was far less (24% fewer) than in the high noise zone. Other species exhibited little difference between control and treatment sites in either high or moderate noise zones. These results suggest that the effects of compressor noise on pinyon-juniper bird communities are strongest in areas where noise is over 50 dBA, but that even moderate noise levels (40 to 50 dBA) has some effect on these bird communities.

The increase in house finches and juniper titmice in high noise zones suggests a high tolerance to noise and a possible competitive advantage gained by these species in noisy environments. This result is not particularly surprising for the house finch, which frequents disturbed environments and human structures, but it is surprising for the juniper titmouse, which is characteristic of undisturbed pinyon-juniper woodland. We determined no apparent reason for the greater sensitivity of spotted towhees to noise.

It has been suggested that noise reduces habitat quality because it produces stress in exposed individuals and that stress avoidance results in lower population density on noisy sites (Reijnen et al. 1995, 1997; Reijnen and Foppen 1995a). Noise also could affect site selection if birds in noisy areas (1) expended more energy maintaining territories because vocalizations were less effective in deterring others from entering territories; (2) had greater difficulty obtaining food because aural cues were less effective; or (3) had lower reproductive success (e.g., noise resulted in early hatching of Japanese quail, *Coturnix japonica*; Woolf et al. 1976). All of these factors could affect the quality of the habitat, but not its carrying capacity.

If all other factors were equal, the avoidance of noisy habitats would result in lower population density in those habitats. However, reduced competition in noisy habitats could be attractive to species that were more tolerant of noise (this could explain the increase in the house finch and juniper titmouse in high noise areas on our study sites) or to individuals of a species who otherwise were at a competitive disadvantage. Foppen and Reijnen found that noisy habitats along roads in the Netherlands had fewer older and more yearling male willow warblers than less noisy habitats farther from the road (Foppen and Reijnen 1995; Reijnen and Foppen 1995a). They hypothesized that yearling males, which often cannot compete for territories against older males, took advantage of the reduced competition in the lower quality, noisy habitat.

These shifts in the species composition or age-structure of bird communities in response to noise exposure are potentially important effects of noise but may be difficult to detect. In the first case, no difference would be detected in the total number of birds (all species combined) on noise-exposed sites relative to controls if reductions in the densities of less tolerant species were matched by increases in the densities of more tolerant species. In the second case, the density of a species on noise-exposed sites might be the same as that on control sites because younger birds that were normally at a competitive disadvantage would take advantage of the reduced competition in areas exposed to noise. In both cases, it would be incorrect to conclude that noise had no effect.

If noise affects bird populations through changes in habitat quality, a density-dependent change in that effect might be expected (Reijnen and Foppen 1995b). If such were the case, differences in relative abundance between noisy and quiet environments would be noticeable only if a species' population was below carrying capacity, i.e., there were fewer individuals in the population than the available habitat could support. In this situation, high quality (low noise) habitats would fill, but low quality (high noise) habitats would not and there would be an observed difference in density between low noise and high noise habitats. If the population was at or above carrying capacity, however, low noise and high noise habitats might both fill and there would not be a detectable difference in the density of bird populations in the two habitat types. Reijnen and Foppen (1995b) observed an inverse relationship between population size and noise effect in bird populations along roads in the Netherlands. They cautioned that the adverse effects of traffic noise on habitat quality could be significantly underestimated if overall population size was high.

Differences in species' population size could explain some of the differences in the apparent sensitivity of different bird species to noise on our study site. Carrying capacity of the habitat is likely to differ considerably among species because of differences in body size and food habits. It is possible that the spotted towhee showed the most significant decrease in abundance in high noise environments because its regional population was below carrying capacity, while populations of the other species were not. However, the fact that the spotted towhee was one of the most abundant species on the study site would seem to argue against this explanation and support the idea that the species has an inherent sensitivity to noise.

Although we determined no apparent reason for the observed greater sensitivity of the spotted towhee to noise, this characteristic could make it a valuable indicator species for studies of noise effects in pinyon-juniper habitat. This species is one of the most abundant species in the study area and is easily detected because of its frequent conspicuous calls. Less vocal or rare species are much more difficult to detect, and even if they were affected by noise, it could be very difficult to demonstrate such an effect statistically.

Despite the apparent effects that noise had on pinyon-juniper bird communities, additional study is warranted. Our study is a snap-shot in time. The same response may not be observed in subsequent years because of changes in carrying capacity or population size as described above. Many factors affect population size and carrying capacity, including conditions in winter on the site and in other portions of the range of migratory species. Observations over several years would produce valuable information on the variability of the apparent response to noise. Birds in other habitats of the Rattlesnake Canyon Habitat Management Area (e.g., sagebrush) may respond differently as well, and we caution against applying our findings to other areas or bird communities.

Our study did not evaluate the reproductive success of birds present in areas adjacent to compressors. Even if adults are present in equal numbers in low and high noise habitats, a difference in reproductive success would be important. Future studies could focus on territory size, the number of territories, and the number of young fledged from nests within those territories. On the basis of the information we collected, the spotted towhee would appear to be an excellent subject for such studies.

The results of our study suggest that the adverse effects of compressors on some species extend well beyond the footprint of the well pad itself. When estimating the effects of future gas development on bird populations, it will be important to include a consideration of those effects. Noise models should be used to estimate the areas of high noise ($\geq$50 dBA) and moderate noise (40 to 50 dBA) levels when evaluating those impacts. To minimize the effects of compressor noise on bird populations, noise abatement measures could be used to reduce the noise level at the edge of pinyon-juniper habitat to 50 dBA or less.

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APPENDIX A

METHODOLOGY FOR ESTIMATING SOUND POWER LEVELS AND PREDICTING SOUND PRESSURE LEVELS

APPENDIX A

METHODOLOGY FOR ESTIMATING SOUND POWER LEVELS AND PREDICTING SOUND PRESSURE LEVELS

One of the fundamental techniques for estimating sound power of a source is to measure the sound pressure at a known distance great enough to be in the far-field (typically assumed to be greater than three times the greatest dimension of the source in the plane perpendicular to the measurement vector). The source sound power level is derived from the measured sound pressure level (SPL) in accordance with the general engineering expression for SPL (L_p) as a function of frequency, at a distance r from a simple (point) sound source with a measurement-vector directivity index (DI), emitting a sound power level (L_w) in free space (Beranek 1988):

$$L_p = L_w + DI - 10 \log (4\pi r^2) - A_e + C_r \qquad [1]$$

where:

L_p = sound pressure level at the receptor point (dB ref. 20 μPa);

L_w = sound power level of the sound-energy source (dB ref. 1 pW);

DI = directivity index; the sound-power flow in the direction of the straight-line vector from source to receptor, divided by the total sound power emitted by the source (dB);

r = straight-line vector path length from the source to the receptor (m);

$10 \log (4\pi r^2)$ = attenuation due to geometric divergence of sound in space (dB);

A_e = excess attenuation (dB) due to the sum of various loss mechanisms: air absorption (A_a), meteorological effects such as scattering due to air turbulence (A_s), refraction due to both vertical air-temperature gradients (A_t) and wind-speed gradients, as well as wind direction (A_w). Excess attenuation also includes terrain effects such as diffraction and reflection due to barrier and screening structures or topography (A_b), and ground-cover effects, including absorption and reflection due to porosity and vegetation (A_g). This summation can be expressed fundamentally as:

$$A_e = A_a + A_s + A_t + A_w + A_b + A_g \qquad [2]$$

C_r = correction term for characteristic resistance of the atmosphere; the characteristic resistance of the air at ambient temperature and barometric pressure divided by reference resistance of 400 mks rayls (dB).

The overall propagation equation 1, including the subsidiary relationship expressed by equation 2, is solved by the use of the computer program "ENSOUND" developed by Chang et al. (1999).

All computations of sound power level were made by assuming an average ASC height of 2 m and a microphone elevation of 1 m above ground level. Inner-ring data were used for all source sound-power computations, because the effects on inner-ring data of terrain and ground cover were minimal compared with outer-ring data. Measured meteorological conditions, such as temperature, relative humidity, and barometric pressure, were included in the computations. Flat terrain, with acoustically soft ground cover, and calm wind conditions (i.e., no wind and no atmospheric turbulence) were assumed. The ground-based temperature profile was assumed to be normal (i.e., no temperature inversion causing sound refraction downward).

For computations of SPLs along the bird survey transects, the assumed baseline propagation conditions were the same as those assumed above in sound power computations, with respect to terrain, ground cover, wind condition, and ground-based temperature profile. Receptor elevation was set at 2 m above ground level. Ambient temperature, relative humidity, and barometric pressure were respectively set at 80°F, 20%, and 820 mbar.

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APPENDIX B

MEASURED SOUND PRESSURE LEVEL SPECTRAL DISTRIBUTION AND SUMMARY NOISE DATA

APPENDIX B

MEASURED SOUND PRESSURE LEVEL SPECTRAL DISTRIBUTION AND SUMMARY NOISE DATA

Table B-1 presents sound pressure level data collected at each of 15 treatment sites on the Rattlesnake Canyon Habitat Management Area near Farmington, New Mexico. At each site, measurements were taken using the acoustical survey instrumentation described in Section 4.1.2 at two locations (inner and outer distances) and in four orthogonal directions. The make, model, and site rating (hp) of compressor engines are also presented. Figures B-1 to B-15 present sound pressure spectral data as measured at each of the treatment sites as well as schematic drawings of each site layout, and time and weather conditions when measurements were made.

Table B-1. Measured Sound Pressure Levels at Inner and Outer Measurement Distances at Treatment Sites.

Site	Well ID	Company	Compressor Engine Make/Model	Site Rating (hp)	Measure-ment Distance	Measured Sound Pressure Level (dBA)[a]				Median SPL (dBA)[b]
T01	Fed28#1	Phillips	Waukesha F18GL	320	Inner	66.4 (100')	70.3 (70')	67.5 (75')	69.8 (90')	66.8
					Outer	55.3 (200')	60.0 (144')	55.6 (150')	59.0 (180')	
T02	228	Phillips	Ajax DPC2802LE	305	Inner	67.7 (100')	68.1 (100')	68.6 (100')	68.4 (100')	68.3
					Outer	56.2 (200')	60.0 (200')	60.2 (182')	58.8 (200')	
T03	221	Phillips	Ajax DPC2802LE	305	Inner	76.2 (50')	71.2 (80')	70.7 (100')	69.2 (100')	69.8
					Outer	61.7 (150')	56.1 (180')	63.5 (200')	57.0 (190')	
T04	240	Phillips	Ajax DPC2802LE	305	Inner	71.2 (68')	71.7 (70')	66.8 (100')	68.1 (100')	68.0
					Outer	59.7 (156')	58.5 (150')	60.3 (200')	61.1 (156')	
T05	238	Phillips	Waukesha F18GL	320	Inner	68.0 (100')	67.4 (70')	70.2 (80')	66.6 (100')	67.3
					Outer	56.7 (200')	59.8 (140')	62.1 (160')	59.4 (200')	
T06	236	Phillips	Ajax DPC2802LE	305	Inner	66.3 (100')	67.7 (100')	69.0 (100')	67.5 (100')	67.6
					Outer	61.2 (200')	55.1 (200')	60.2 (200')	57.5 (200')	
T07	206	Phillips	CAT 3306NA	95	Inner	70.4 (64')	65.1 (80')	63.2 (150')	66.0 (100')	66.2
					Outer	60.0 (139')	54.4 (188')	60.0 (200')	58.1 (200')	
T08	202	Phillips	CAT 3306NA	95	Inner	66.1 (100')	67.2 (100')	69.7 (100')	63.3 (100')	66.7
					Outer	55.2 (200')	57.4 (200')	61.6 (200')	52.6 (200')	
T09	203	Phillips	Ajax DPC2802LE	305	Inner	68.0 (100')	52.1 (150')	66.1 (100')	66.9 (100')	66.5
					Outer	58.0 (200')	45.0 (300')	60.8 (200')	55.6 (200')	
T10	333	Burlington	CAT 398TA	531	Inner	71.1 (75')	72.4 (75')	66.8 (100')	71.8 (75')	68.9
					Outer	63.2 (150')	65.1 (150')	57.2 (200')	61.5 (150')	
T11	330	Burlington	CAT 3512TA	660	Inner	-[c]	-	-	-	-
					Outer	-	-	-	-	
T12	711	Burlington	Waukesha H24GL	450	Inner	69.4 (75')	66.0 (100')	67.8 (100')	67.5 (100')	67.2
					Outer	66.6 (130')	59.2 (200')	55.9 (200')	59.8 (200')	
T13	2C	Koch	Waukesha/Ariel JGK	651	Inner	68.3 (100')	66.4 (100')	74.3 (100')	69.5 (100')	67.3
					Outer	56.6 (200')	57.5 (200')	64.9 (190')	58.8 (200')	
T14	254	Burlington	Ajax DPC600	461	Inner	66.2 (100')	71.2 (100')	68.7 (100')	68.6 (100')	68.6
					Outer	60.3 (200')	65.5 (200')	62.2 (200')	60.4 (200')	

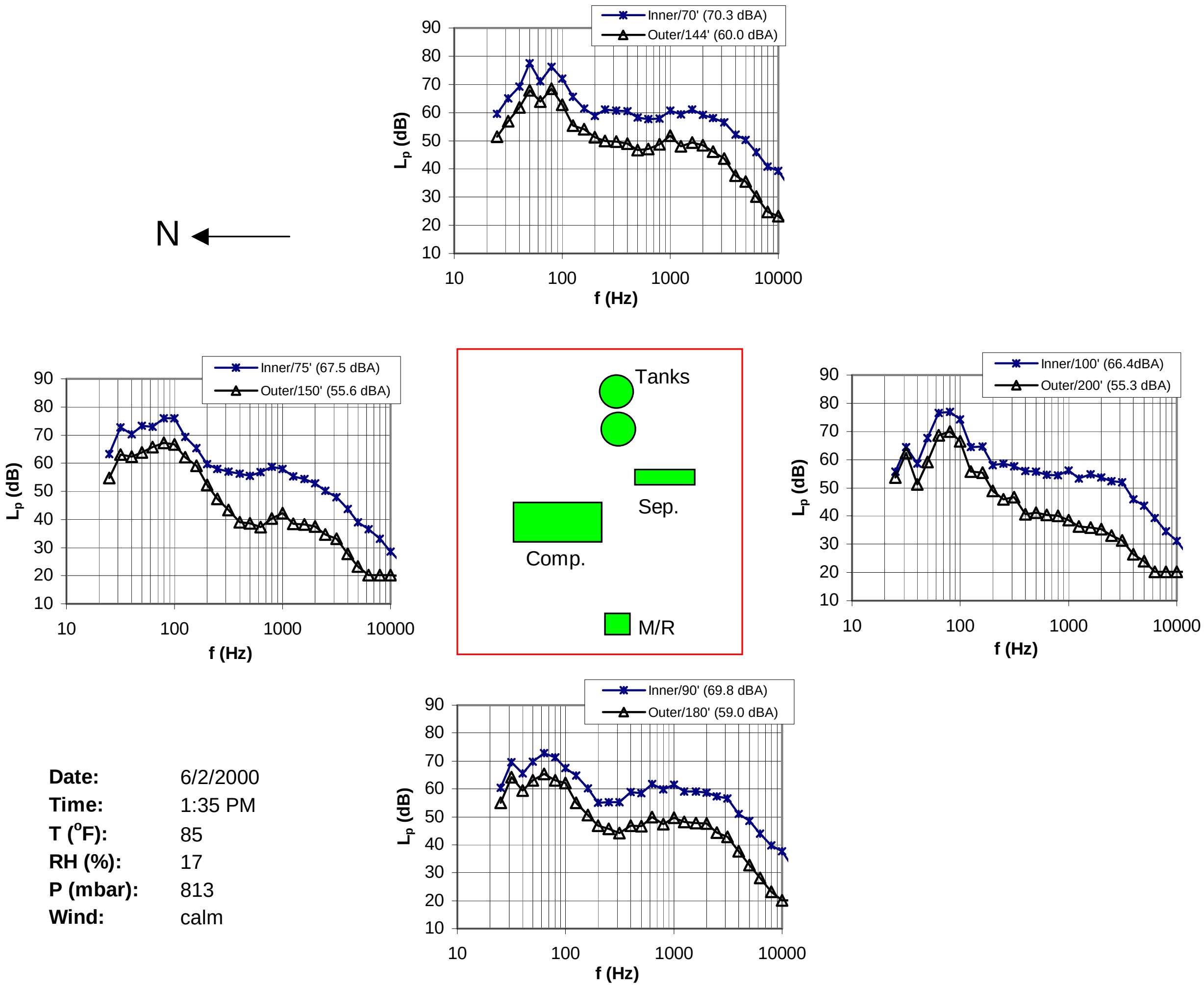
Table B-1 (Continued)

Site	Well ID	Company	Compressor Engine Make/Model	Site Rating (hp)	Measure-ment Distance	Measured Sound Pressure Level (dBA)[a]				Median SPL (dBA)[b]
T15	1R	Burlington	Ajax DPC60	45	Inner	60.4 (70')	58.7 (65')	57.4 (100')	53.2 (100')	56.2
					Outer	51.9 (140')	51.9 (130')	50.3 (200')	44.4 (200')	
T16	342	Burlington	Ajax DPC600	461	Inner	67.7 (100')	71.5 (85')	76.8 (50')	66.9 (100')	68.9
					Outer	62.0 (200')	60.8 (200')	66.8 (115')	57.4 (190')	

[a] SPLs measured in four orthogonal directions. Values in parentheses are actual radii of inner and outer rings in feet (refer to Figures B-1 to B-15).

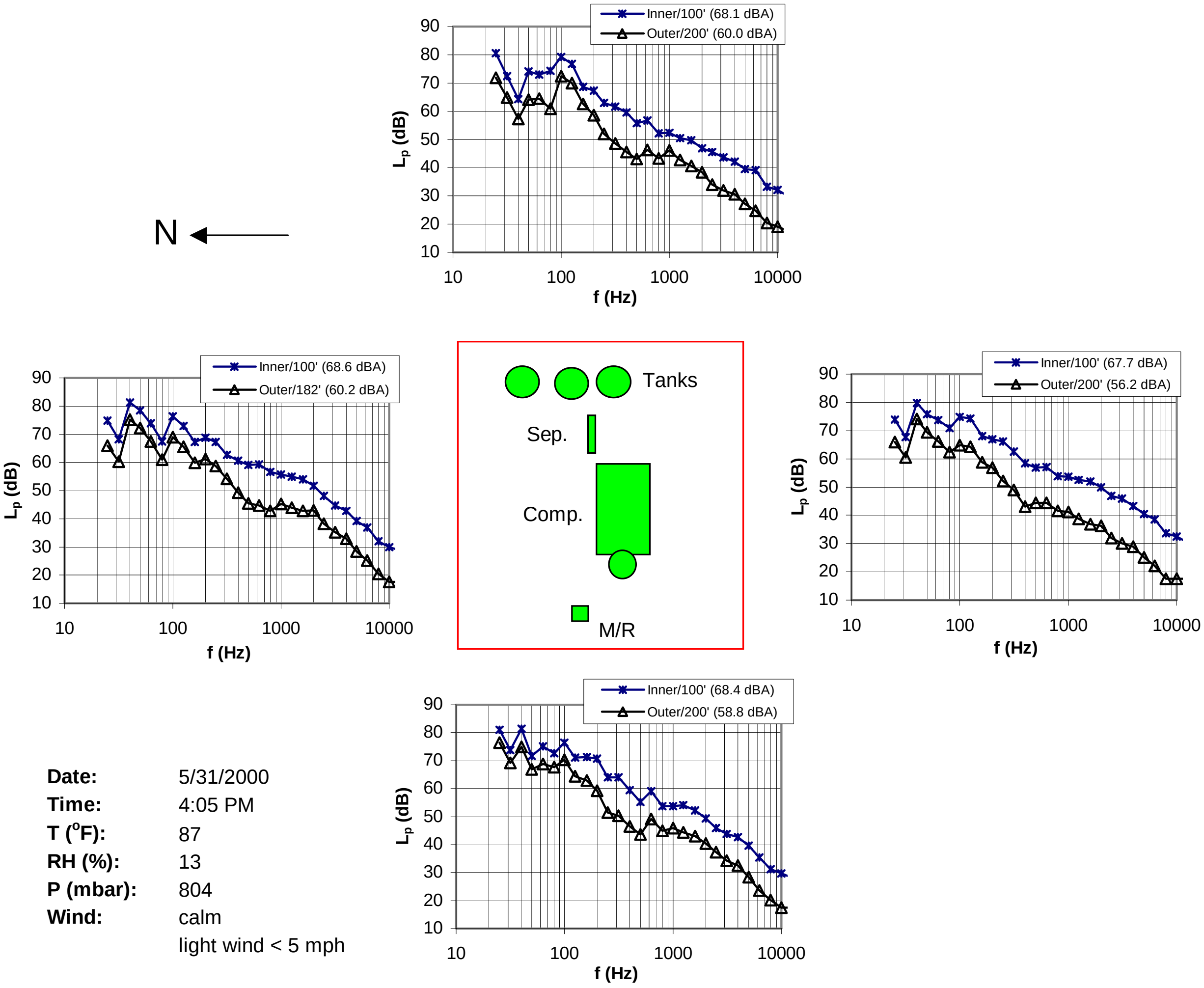
[b] Median value from four directional sound pressure levels normalized to 100 ft (30.5 m).

[c] Noise measurements were not made at this site.



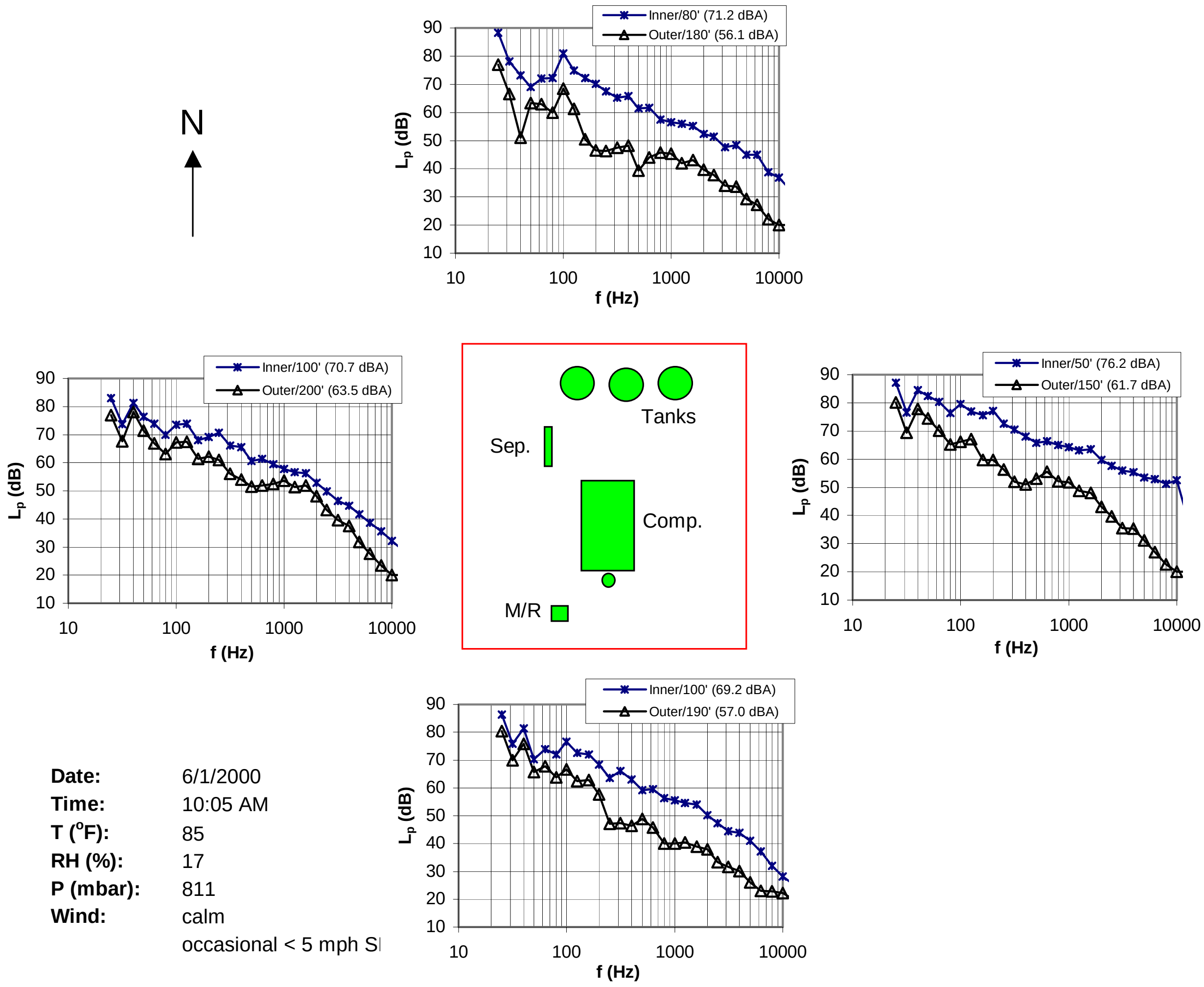
Date:	6/2/2000
Time:	1:35 PM
T (^{o}F):	85
RH (%):	17
P (mbar):	813
Wind:	calm

Figure B-1. Sound Pressure Spectral Data Measured at Site T01 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor, Sep. = separator, and M/R = meter run.)



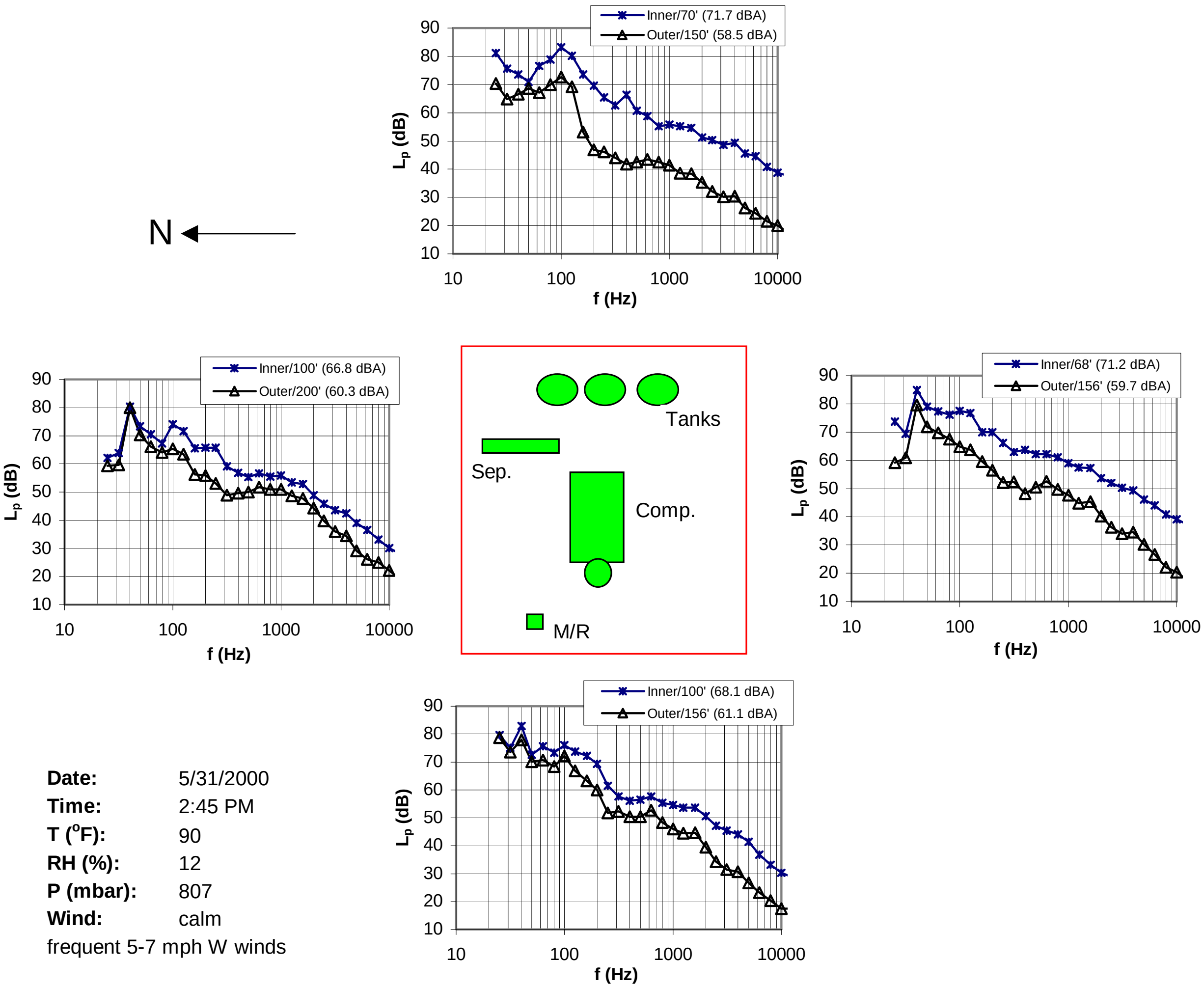
Date:	5/31/2000
Time:	4:05 PM
T (^{o}F):	87
RH (%):	13
P (mbar):	804
Wind:	calm
	light wind < 5 mph

Figure B-2. Sound Pressure Spectral Data Measured at Site T02 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor, Sep. = separator, and M/R = meter run.)



Date: 6/1/2000
Time: 10:05 AM
T (^{o}F): 85
RH (%): 17
P (mbar): 811
Wind: calm
occasional < 5 mph S

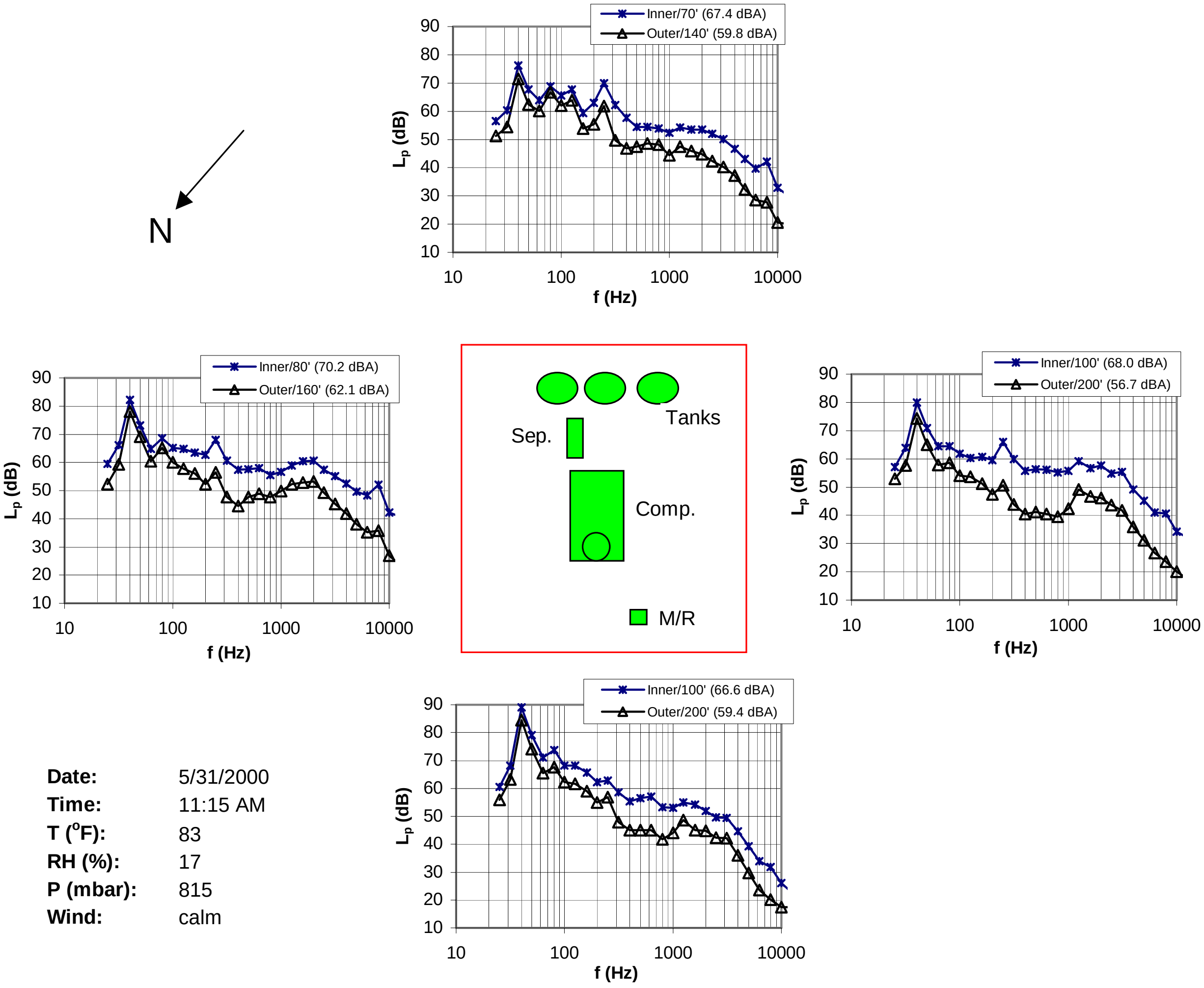
Figure B-3. Sound Pressure Spectral Data Measured at Site T03 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor, Sep. = separator, and M/R = meter run.)



Date:	5/31/2000
Time:	2:45 PM
T (°F):	90
RH (%):	12
P (mbar):	807
Wind:	calm

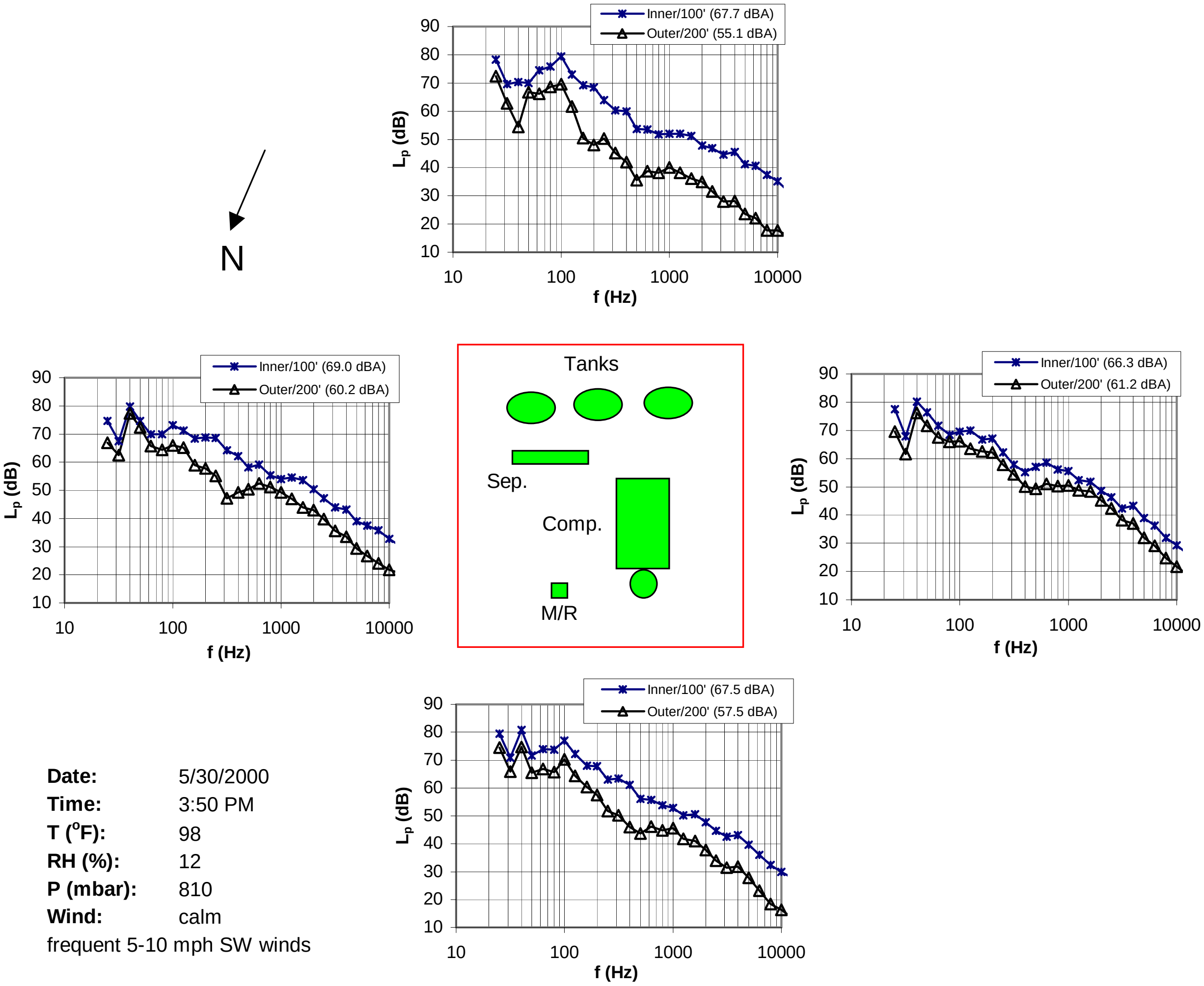
frequent 5-7 mph W winds

Figure B-4. Sound Pressure Spectral Data Measured at Site T04 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor, Sep. = separator, and M/R = meter run.)



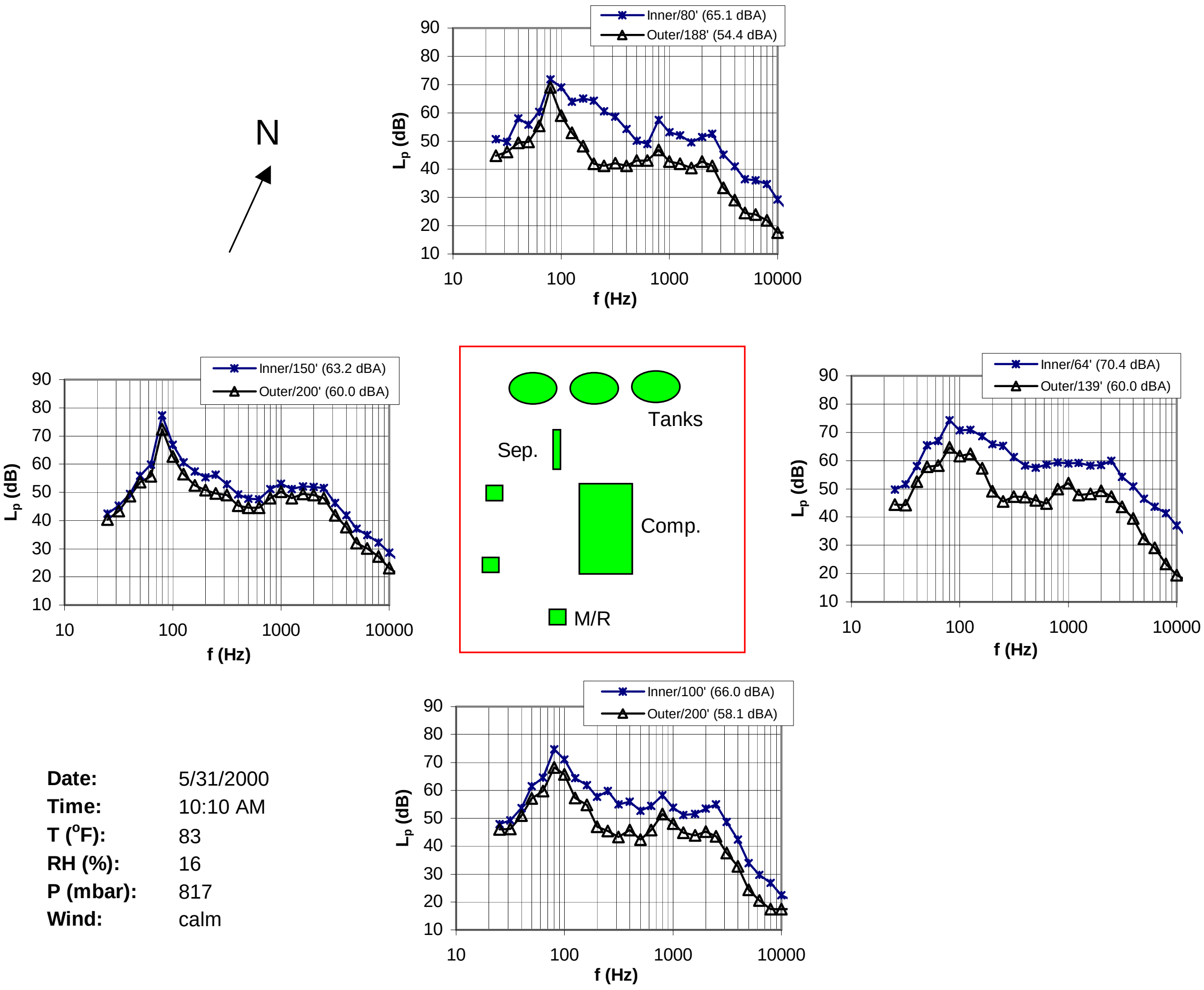
Date:	5/31/2000
Time:	11:15 AM
T (^{o}F):	83
RH (%):	17
P (mbar):	815
Wind:	calm

Figure B-5. Sound Pressure Spectral Data Measured at Site T05 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor, Sep. = separator, and M/R = meter run.)



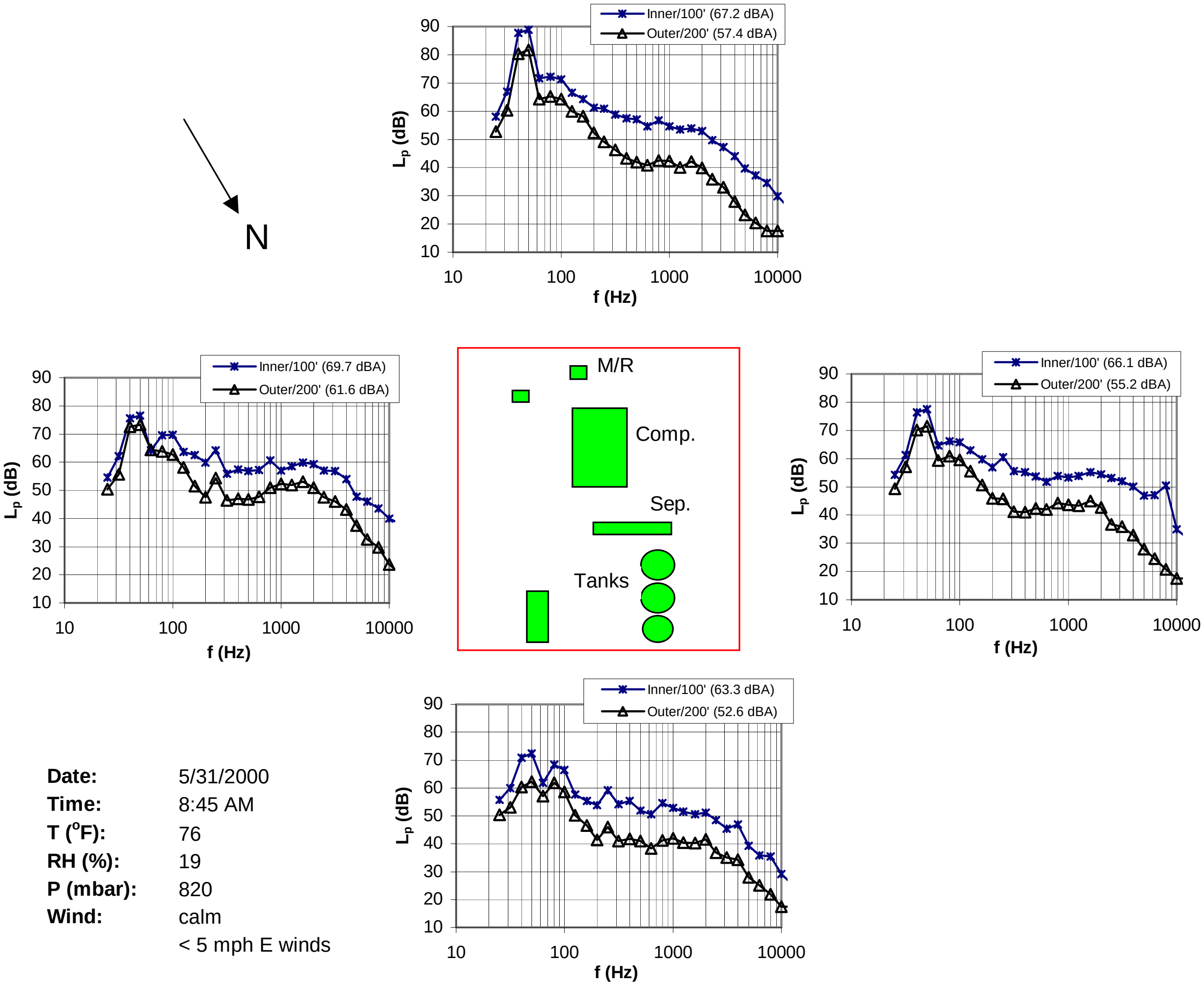
Date: 5/30/2000
Time: 3:50 PM
T (^{o}F): 98
RH (%): 12
P (mbar): 810
Wind: calm
frequent 5-10 mph SW winds

Figure B-6. Sound Pressure Spectral Data Measured at Site T06 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor, Sep. = separator, and M/R = meter run.)



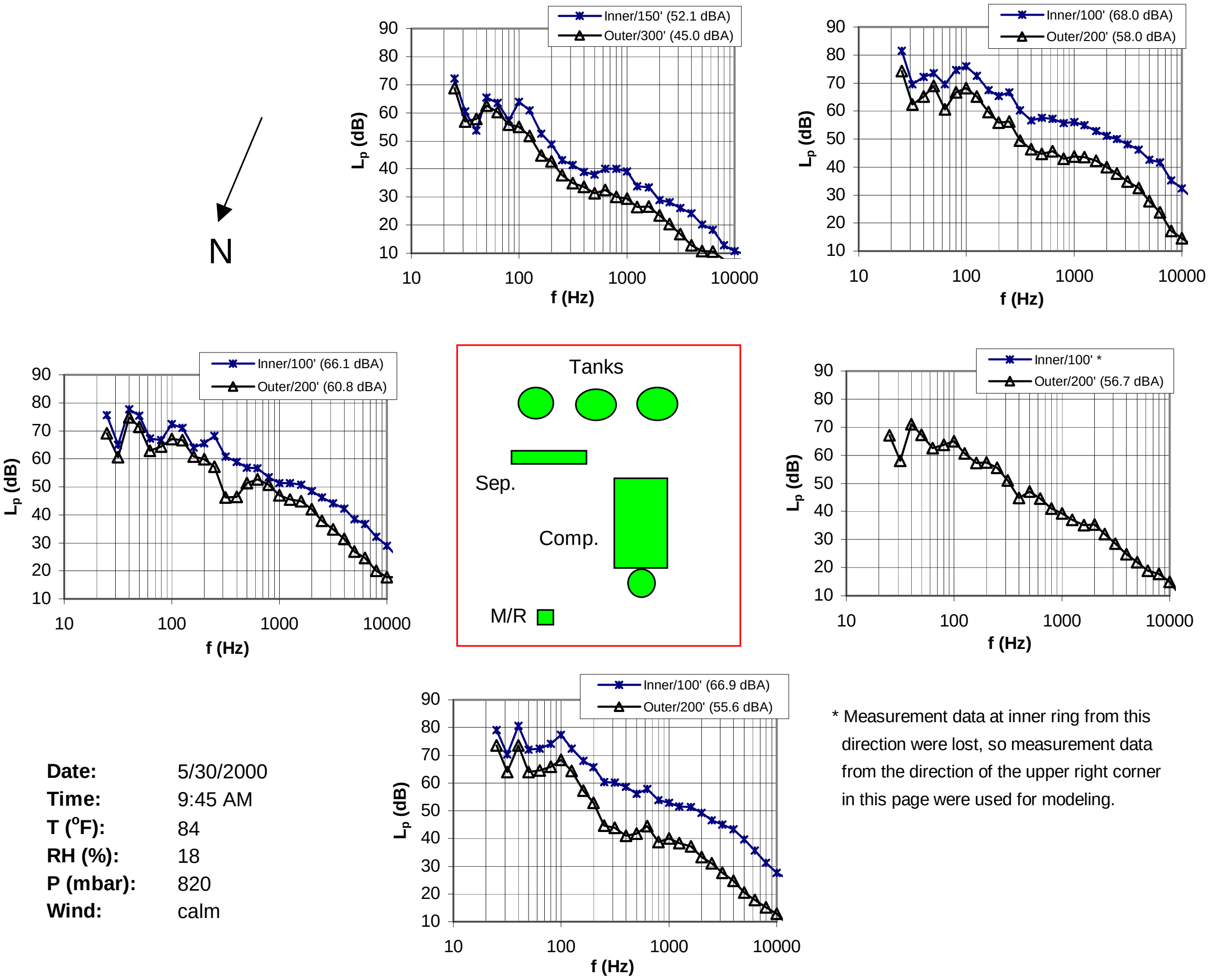
Date:	5/31/2000
Time:	10:10 AM
T (^{o}F):	83
RH (%):	16
P (mbar):	817
Wind:	calm

Figure B-7. Sound Pressure Spectral Data Measured at Site T07 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor, Sep. = separator, and M/R = meter run.)



Date: 5/31/2000
Time: 8:45 AM
T (^{o}F): 76
RH (%): 19
P (mbar): 820
Wind: calm
< 5 mph E winds

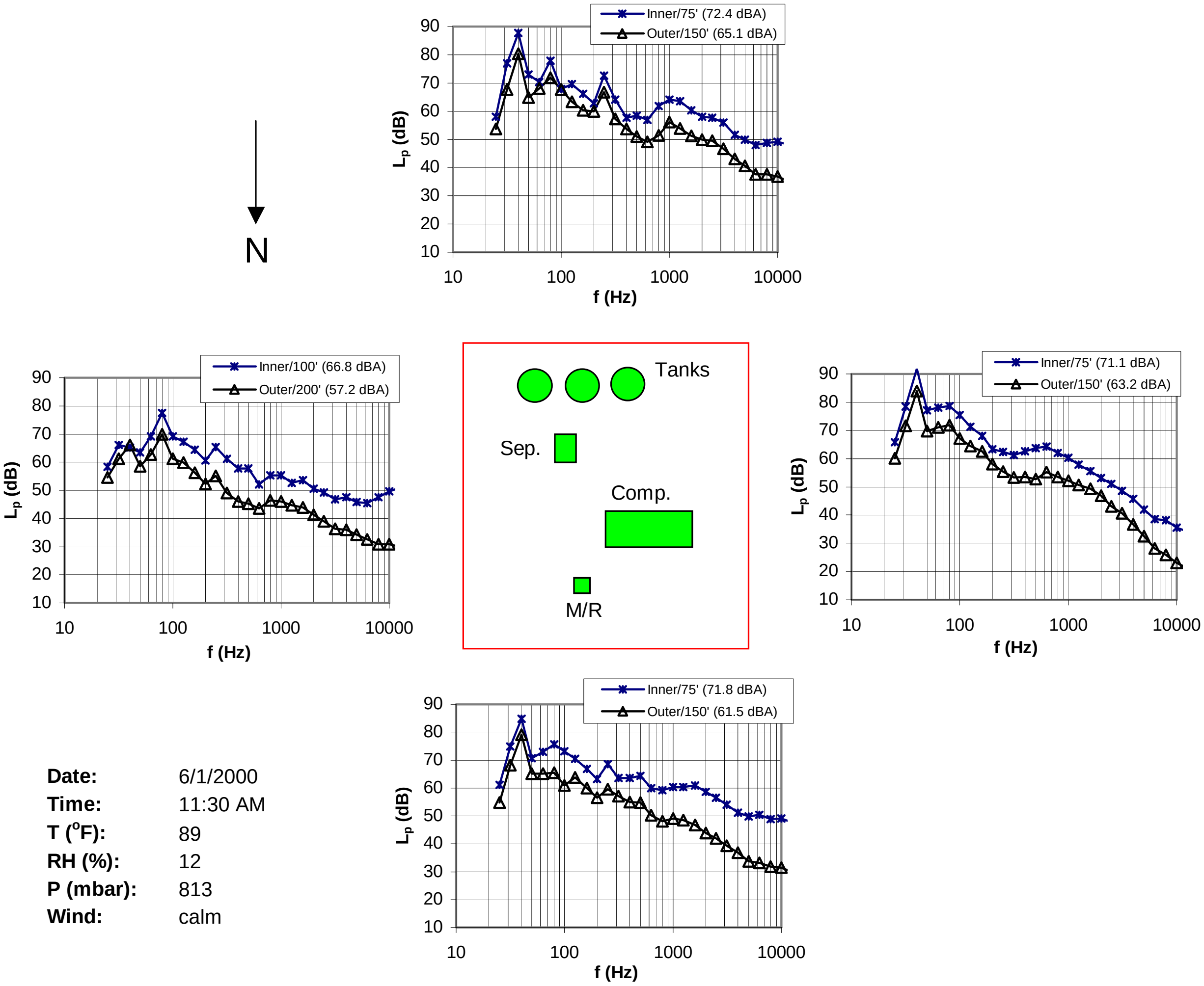
Figure B-8. Sound Pressure Spectral Data Measured at Site T08 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor, Sep. = separator, and M/R = meter run.)



Date:	5/30/2000
Time:	9:45 AM
T (^{o}F):	84
RH (%):	18
P (mbar):	820
Wind:	calm

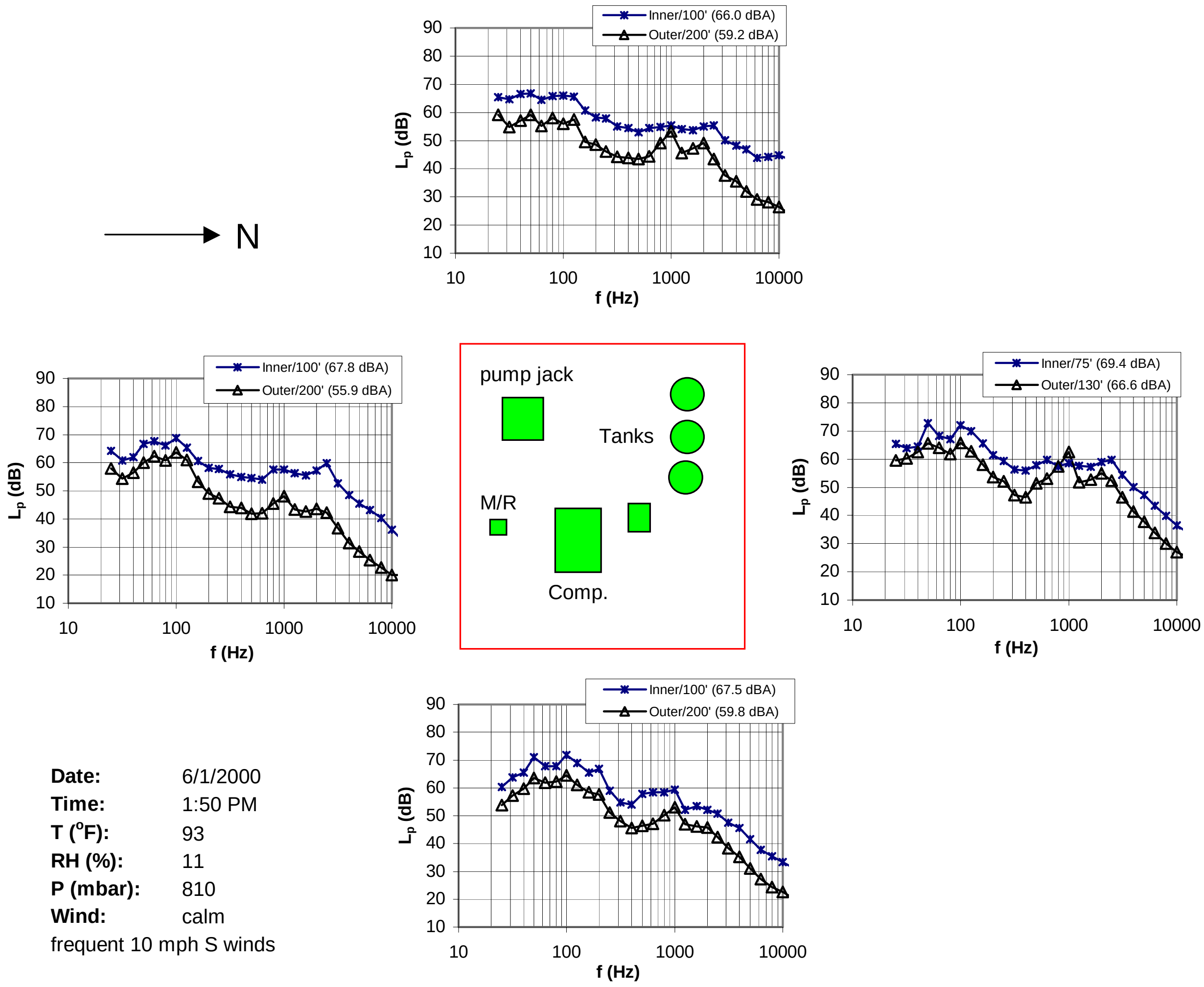
* Measurement data at inner ring from this direction were lost, so measurement data from the direction of the upper right corner in this page were used for modeling.

Figure B-9. Sound Pressure Spectral Data Measured at Site T09 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor, Sep. = separator, and M/R = meter run.)



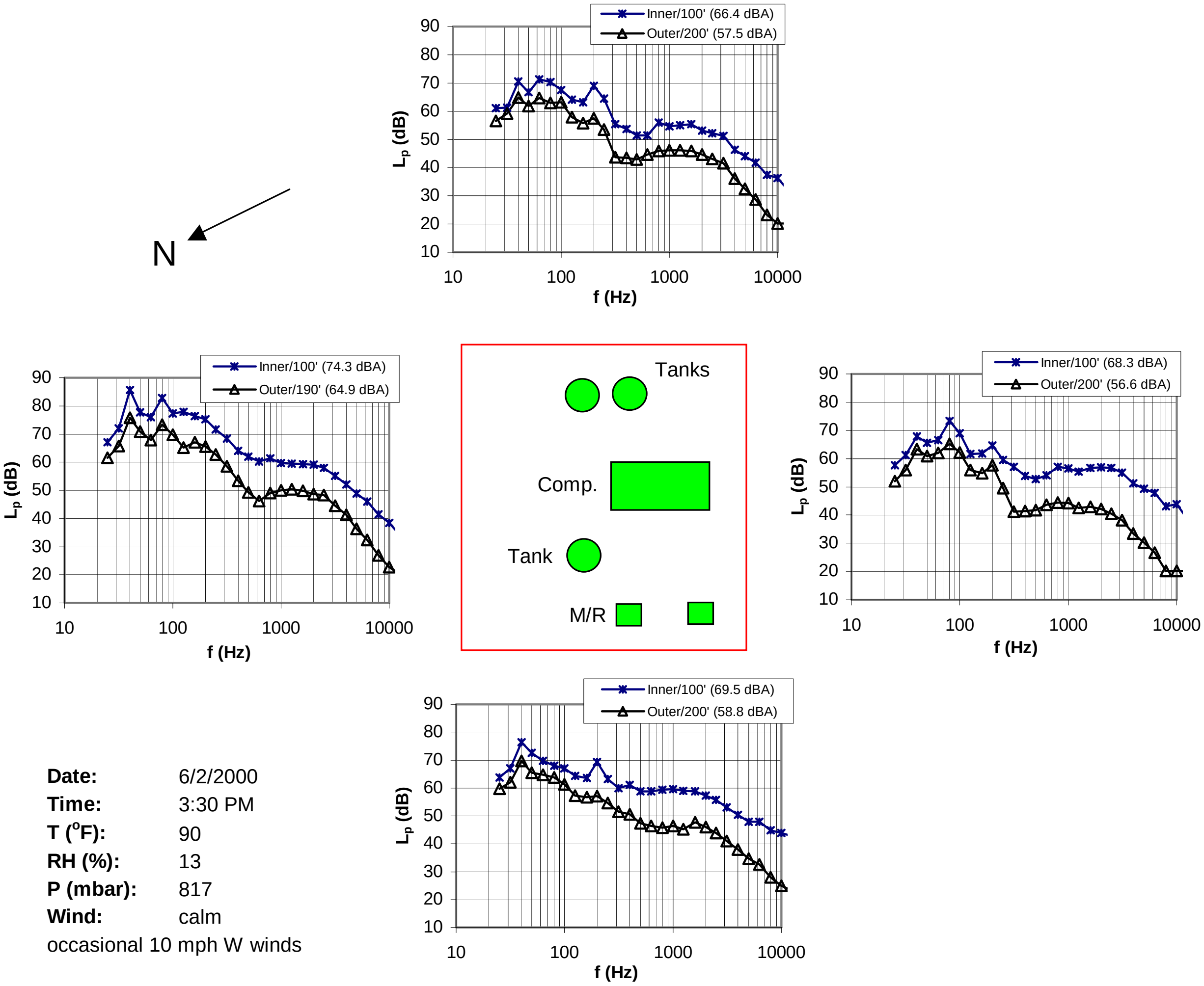
Date:	6/1/2000
Time:	11:30 AM
T (^{o}F):	89
RH (%):	12
P (mbar):	813
Wind:	calm

Figure B-10. Sound Pressure Spectral Data Measured at Site T10 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor, Sep. = separator, and M/R = meter run.)



Date: 6/1/2000
Time: 1:50 PM
T (°F): 93
RH (%): 11
P (mbar): 810
Wind: calm
frequent 10 mph S winds

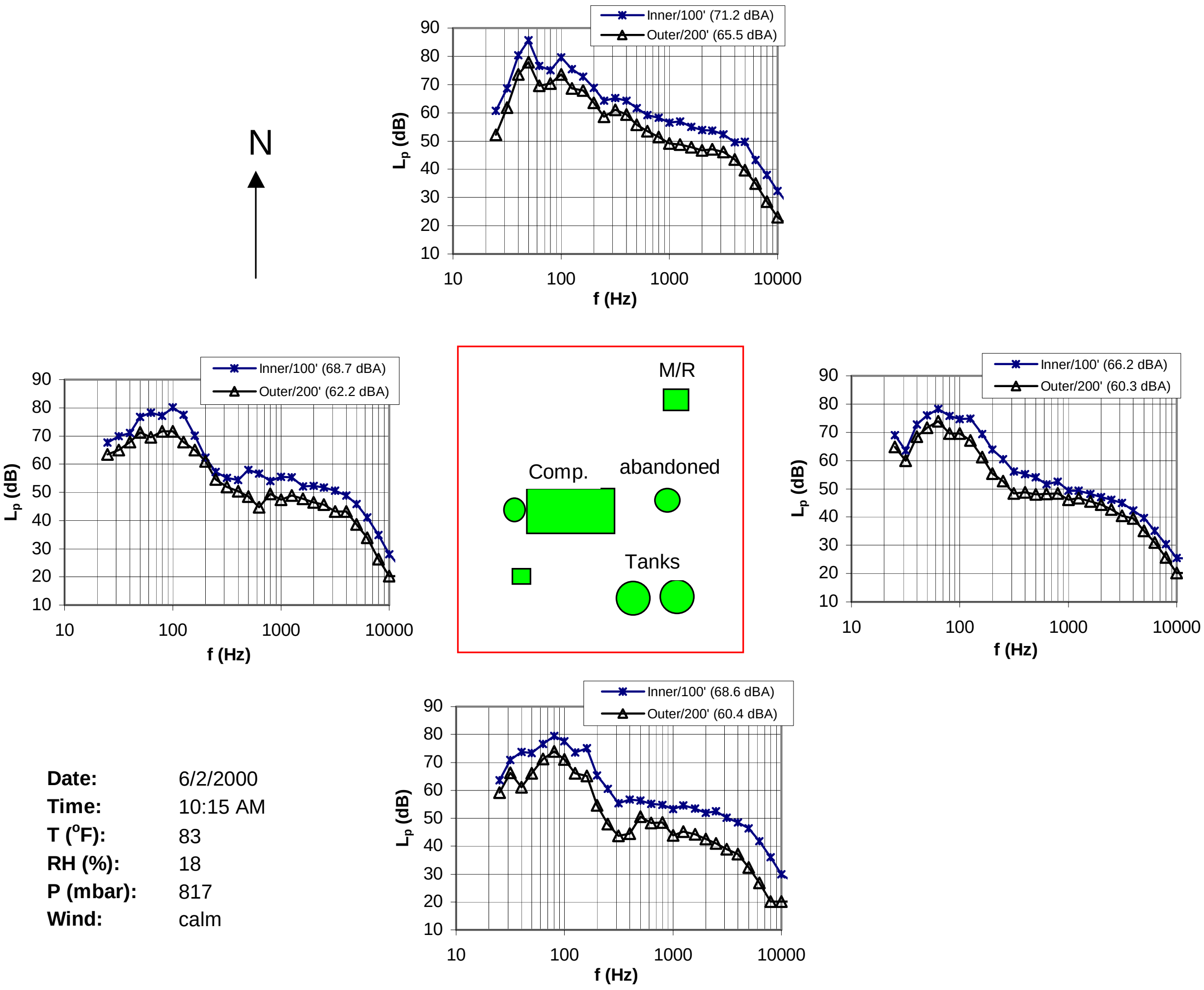
Figure B-11. Sound Pressure Spectral Data Measured at Site T12 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor and M/R = meter run.)



Date:	6/2/2000
Time:	3:30 PM
T (^{o}F):	90
RH (%):	13
P (mbar):	817
Wind:	calm

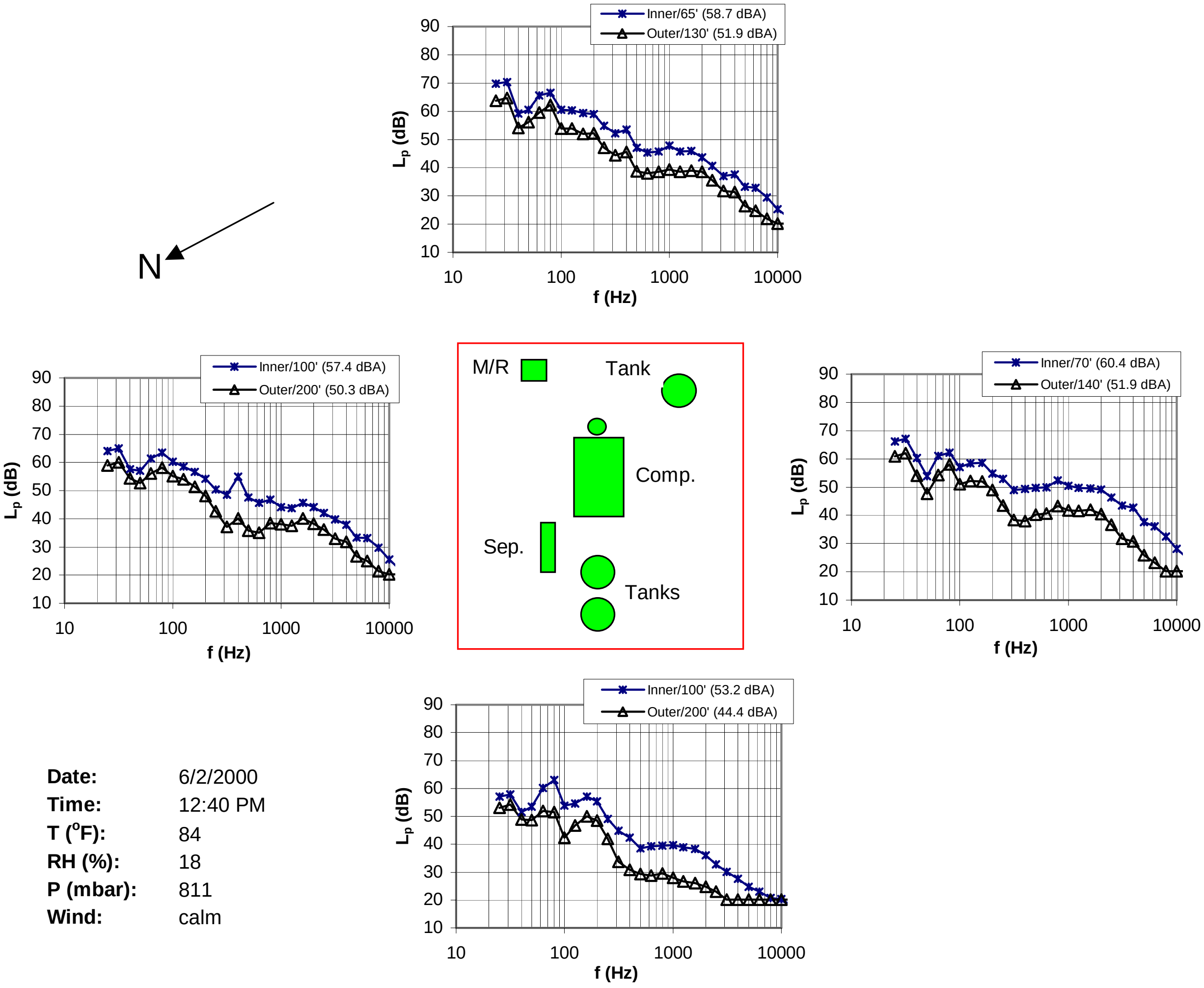
occasional 10 mph W winds

Figure B-12. Sound Pressure Spectral Data Measured at Site T13 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor and M/R = meter run.)



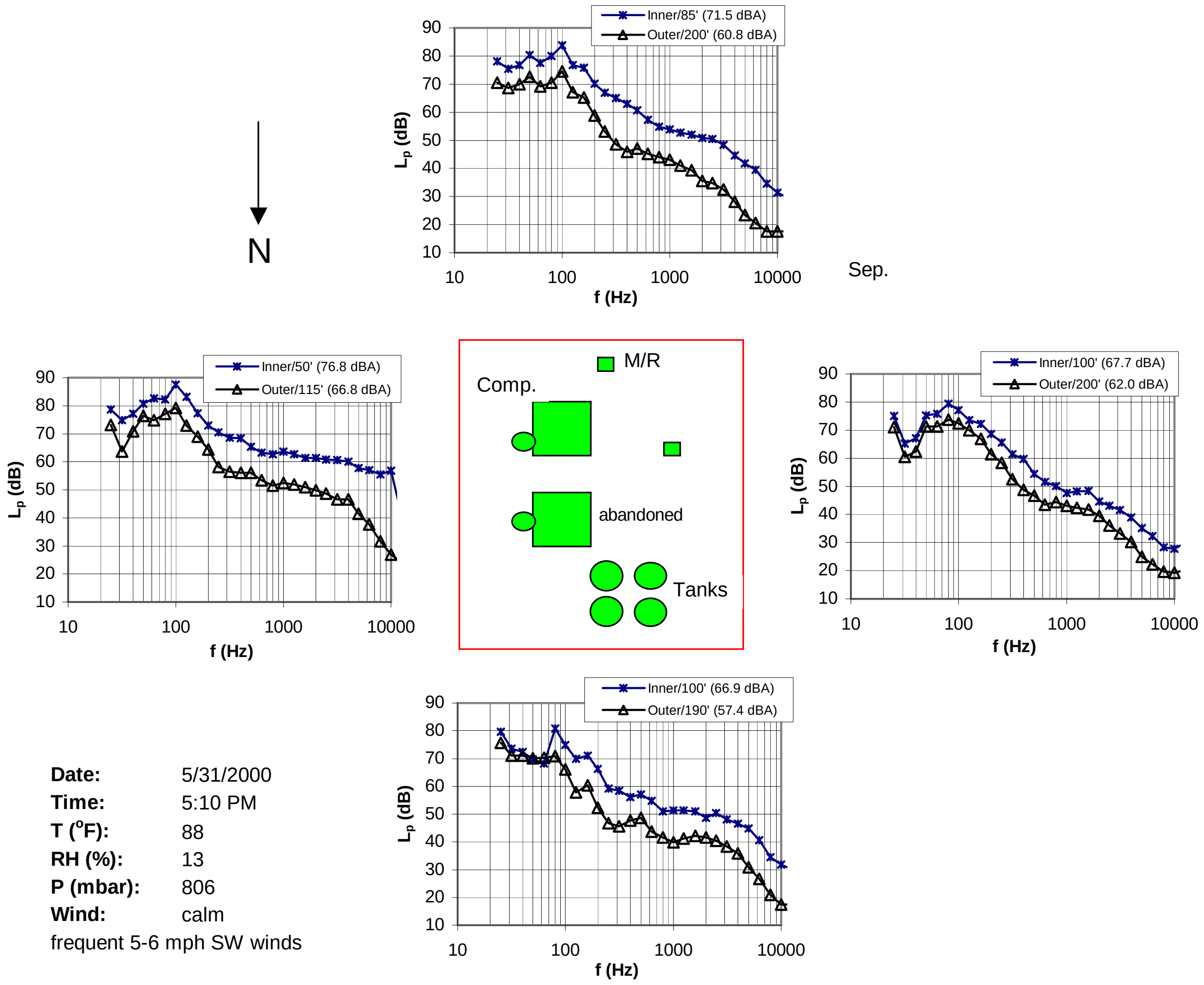
Date:	6/2/2000
Time:	10:15 AM
T (^{o}F):	83
RH (%):	18
P (mbar):	817
Wind:	calm

Figure B-13. Sound Pressure Spectral Data Measured at Site T14 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor and M/R = meter run.)



Date:	6/2/2000
Time:	12:40 PM
T (^{o}F):	84
RH (%):	18
P (mbar):	811
Wind:	calm

Figure B-14. Sound Pressure Spectral Data Measured at Site T15 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor, Sep. = separator, and M/R = meter run.)



Date:	5/31/2000
Time:	5:10 PM
T (°F):	88
RH (%):	13
P (mbar):	806
Wind:	calm

frequent 5-6 mph SW winds

Figure B-15. Sound Pressure Spectral Data Measured at Site T16 and Schematic Drawing of Site Layout. (In schematic, Comp. = compressor and M/R = meter run.)

APPENDIX C

SAMPLES OF DATA SHEETS USED IN COLLECTING VEGETATION AND BIRD SURVEY DATA

Effect of Compressor Noise on the Abundance and Distribution of Breeding Birds of Rattlesnake Canyon Habitat Management Plan Area, San Juan County, New Mexico

Vegetation Data Sheet

Site#______________________ **Transcript#** (Crossing Pt)______________ **Date**____________

Observer(s)_________________ **Page**____**of**______

Obs #	Species	Intercept Start (m)	Intercept End (m)	Height[*]
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				

[*] Height categories: 0-0.5m, 0.6-1m, 1.1-2m, 2.1-5m, > 5m

Effect of Compressor Noise on the Abundance and Distribution of Breeding Birds of Rattlesnake Canyon Habitat Management Plan Area, San Juan County, New Mexico

Bird Observation Data Sheet

Site#______________________ **Trtmnt/Cntrl**__________________ **Transect#**________________
Date_______________________ **Start Time (MDT)**______________ **End Time (MDT)**___________
Temp (ºC)__________________ **Sky Condition**________________ **Wind**_____________________
Observer___________________ **Page**________**of**___________

Obs #	Species	# Birds	Sex/Age	Seen or Heard	Distance on Transect	Distance from Transect	Behavior
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							

Effect of Compressor Noise on the Abundance and Distribution of Breeding Birds of Rattlesnake Canyon Habitat Management Plan Area, San Juan County, New Mexico

Bird Location Data Sheet

Site#________________________ **Trtmnt/Cntrl**___________________ **Transect#**__________________
Date_________________________ **Start Time (MDT)**_______________ **End Time (MDT)**____________
Temp (°C)____________________ **Sky Condition**__________________ **Wind**______________________
Observer____________________ **Page**_________**of**____________

On the schematic below, mark the location of bird observations using observation numbers from Bird Observation Data Sheet. Also mark the well pad/habitat boundary and any prominent features (e.g., habitat change, water, topographic feature). Use arrow to indicate trajectory of flying birds.

	>50	31-50	26-30	21-25	16-20	11-15	6-10	0-5	0-5	6-10	11-15	16-20	21-25	26-30	31-50	>50
376-400																
351-375																
326-350																
301-325																
276-300																
251-275																
226-250																
201-225																
176-200																
151-175																
126-150																
101-125																
76-100																
51-75																
26-50																
0-25																

Compressor
or Well Head

APPENDIX D

STATISTICAL ANALYSES OF BIRD AND VEGETATION SURVEY RESULTS

APPENDIX D

STATISTICAL ANALYSES OF BIRD AND VEGETATION SURVEY RESULTS

All statistical analyses of bird and vegetation data were performed with the SAS System for Windows, release 8.00 (SAS Institute 1999). Analysis of variance (GLM procedure of SAS) was used to determine the statistical significance of relationships of dependent to independent variables. Site type (control and treatment) and the distance from the well were included as independent variables in all analyses, because these two variables reflect compressor noise level. Type III sums of squares and associated F-values were used to test the significance of effects. Ad hoc means separations were performed using the Tukey's studentized range test. Two-sample t-tests (TTEST procedure of SAS) were used to test the difference in total number of birds on control and treatment sites in two distance zones (0 to 150 m and 150 to 400 m) that corresponded to high ($\geq$50 dBA) and moderate (40 to 50 dBA) noise levels on treatment sites. For all statistical analyses, effects that produced values of P that were less than or equal to 0.05 were considered statistically significant. Use of this P-value ensured that the probability of making a Type I error (i.e., declaring a difference between populations or groups when no such difference exists) was 5% or less. In the description of results, the words "significance" and "significant" refers to "statistical significance" (i.e., a detectable difference, $P \leq 0.05$, between groups or populations).

D.1 Analyses of Bird Survey Results

The following two sections discuss analyses conducted to determine the effects of site type and distance from the well on the eight most abundant bird species (Section D.1.1) and the total number of birds, regardless of species (Section D.1.2). Noise-level effects were examined by analyzing the number of birds (1) in each 50-m interval of the line transect and (2) in a high noise zone ($\geq$ 50 dBA; 0-150 m from the compressor) and a moderate noise zone (40-50 dBA; 150-400 m from the compressor).

D.1.1 Effects of Site Type and Distance on Different Bird Species

The eight most abundant species (Bewick's wren, spotted towhee, juniper titmouse, ash-throated flycatcher, bushtit, house finch, chipping sparrow, and western scrub jay) were included in statistical analyses that examined the relationship of the number of birds observed to species, site type, and distance from the well. For each 50-m of survey transect, the total number of birds of each species observed during the course of the study (sum of numbers observed during three surveys of each transect) was determined. These values (number per species per 50 m) are presented in Table 6 (Section 5.2.1). A three-way analysis of variance was used to determine the effects of site type, species, and distance from the well on the number of birds observed. The results of this analysis of variance are presented in Table D-1 and are described in the following paragraphs.

More birds were observed per species per 50 m on control sites (1.11) than on treatment sites (0.97), but this difference was not statistically significant ($F = 3.2$, $P = 0.07$; Table D-1). The number of birds observed per 50 m differed significantly among species ($F = 8.7$, $P < 0.0001$). Bewick's wren (1.48) and spotted towhee (1.44) had significantly higher counts than bushtit (0.82), house finch (0.81), chipping sparrow (0.73), and western scrub jay (0.73); the mean total number of the juniper titmouse (1.08) and ash-throated flycatcher (1.04) were intermediate (Tukey's range test).

The effect of distance on the number of birds observed per species per 50 m also was significant ($F = 2.8$, $P = 0.008$; Table D-1). The number of birds was greatest in the 51 to 100-m interval and least in the 151 to 200-m interval. Only the difference between the number of birds observed in these two intervals was statistically significant (Tukey's range test). The interaction between site type and distance was not statistically significant ($F = 0.3$, $P = 0.96$), indicating that the relationship of bird numbers to distance was similar on control and treatment sites (Figure 13, Section 5.2.1).

There was a statistically significant interaction between species and distance for the number of birds observed per species per 50 m ($F = 2.1$, $P < 0.0001$; Table D-1). This result indicates that the relationship of the number of birds to distance varied among species (Figure 14, Section 5.2.1). For some species (e.g., Bewick's wren and western scrub jay), the number of birds showed little discernable relationship to distance. For both the chipping sparrow and house finch, the number of birds seen was highest near wells and declined with increasing distance, demonstrating their affinity for the open habitat of the well pad and the edge habitat at the pad-woodland boundary. Other species (e.g., bushtit and spotted towhee) exhibited a peak in numbers at some intermediate distance. Other interactions in the analysis-of-variance model (species x site type and species x site type x distance) were not significant (Table D-1).

Separate two-way analyses of variance were performed for each species to test the effects of site type and distance on the number of birds (Table D-2). The spotted towhee was the only species for which a significant difference in the numbers observed on control and treatment sites could be detected (1.75 vs. 1.28 birds per 50 m, respectively). The relationship between the number of birds observed per 50 m and distance was significant only for the chipping sparrow and house finch; these two species were more frequently observed closer to the well, as noted above. The interaction between site type and distance was significant only for the house finch. This interaction reflected the fact that more house finches were observed in the 0 to 50-m interval on treatment sites (3.1 per 50 m) than on control sites (1.6 per 50 m) but in approximately equal numbers at other distances.

The results of the noise model were used to divide survey transects into areas with relatively high noise levels and areas with more moderate noise levels. For all but one site, the area between 0 and 150 m from the compressor had noise levels $\geq$ 50 dBA and the area between 151 and 400 m had noise levels between 40 and 50 dBA. Separate two-way analyses of variance were performed

Table D-1. Analysis-of-Variance Test of the Relationship of the Total Number of Individuals Observed per 50 m of Transect to Bird Species, Site Type, and Distance from the Well.

Factor[a]	Degrees of Freedom	Mean Square	*F*-Value	*P*-Value[b]
Species	7	17.2	8.7	< 0.0001
Site type	1	6.4	3.2	0.07
Distance	7	5.4	2.8	0.008
Species x site type	7	2.6	1.3	0.25
Species x distance	49	4.1	2.1	< 0.0001
Site type x distance	7	0.6	0.3	0.96
Species x site type x distance	49	1.9	1.0	0.56
Error	1,408	2.0		

[a] Factors in the analysis included species: ash-throated flycatcher, Bewick's wren, bushtit, chipping sparrow, house finch, juniper titmouse, spotted towhee, and western scrub jay; site type: control (without compressor), treatment (with compressor); and distance: 0-50, 51-100, 101-150, 151-200, 201-250, 251-300, 301-350, and 351-400 m from the well.

[b] *P*-values $\leq$ 0.05 were considered statistically significant.

Table D-2. Significance Levels from Two-Way Analyses of Variance Performed for Each of the Eight Most Abundant Bird Species to Test the Effects of Site Type and Distance, and Their Interaction, on the Total Number of Individuals Observed per 50 m of Transect.

	Significance Level (*P*-Value) for Effect in Two-Way Analysis of Variance[a]		
Species	Site Type	Distance	Site Type x Distance
Ash-throated Flycatcher	0.48	0.16	0.65
Bewick's Wren	0.27	0.73	1.00
Bushtit	0.35	0.08	0.96
Chipping Sparrow	0.17	0.0003	0.19
House Finch	0.46	<0.0001	0.05
Juniper Titmouse	0.22	0.06	0.42
Spotted Towhee	0.03	0.27	0.38
Western Scrub Jay	0.37	0.89	0.28

[a] *P*-values $\leq$ 0.05 were considered statistically significant. Site types were control (without compressor), treatment (with compressor); distances were 0-50, 51-100, 101-150, 151-200, 201-250, 251-300, 301-350, and 351-400 m from the well. For each species-specific analysis-of-variance, degrees of freedom = 1 for site type, 7 for distance, 7 for site type x distance, and 176 for the error term in the model.

for each of these two distance zones to examine the relationship of number of birds observed within the zone to species and site type. On site T15, the noise level was near the background level within 100 m of the compressor because the compressor at this site had a relative low site power rating. Because of this difference, site T15 was not included in this particular analysis.

The relationships between the number of birds observed and species and site type were different in the two distance zones (Table D-3; Figure 15, Section 5.2.1). Within the 0 to 150-m zone (high noise level on treatment sites), the mean total number of birds per species on control and treatment sites was not significantly different (3.7 vs. 3.5 birds per species, respectively; $F = 0.3$, $P = 0.58$). Spotted towhee, Bewick's wren, and house finch were the most abundant species seen in this zone; western scrub jay was the least abundant (significant species effect; $F = 3.2$, $P = 0.003$). Although most species were more abundant on control sites, both the house finch and the juniper titmouse were more abundant on treatment sites (Figure 15, Section 5.2.1; significant interaction between species and site type; $F = 2.3$, $P = 0.03$).

Within the 151 to 400-m zone (moderate noise level on treatment sites), significantly more birds were observed at control sites than at treatment sites (Figure 15, Section 5.2.1; 5.2 vs. 4.2 birds per species, respectively; significant site type effect; $F = 4.5$, $P = 0.04$; Table D-3). Bewick's wren, spotted towhee, and juniper titmouse were the most abundant species in this zone; house finch and chipping sparrow were the least abundant (significant species effect; $F = 9.9$, $P < 0.0001$). For all species, the number observed was lower on treatment sites than control sites (Figure 15, Section 5.2.1; species x site type interaction not significant; $F = 0.2$, $P = 0.97$).

D.1.2 Effects of Site Type and Distance on Total Number of Birds

The effects of site type and distance on total number of birds (all species combined) were examined. Several species were not included in this analysis because they range widely during the breeding season while foraging and were typically seen flying over the study sites. These characteristics make them less susceptible to the effects of noise and poor indicators of any potential noise effect. These species were the American kestrel, brown-headed cowbird, chimney swift, cliff swallow, common nighthawk, common raven, Cooper's hawk, northern rough-winged swallow, red-tailed hawk, turkey vulture, violet-green swallow, and white-throated swift.

The effects of site type and distance on the total number of birds were evaluated with a two-way analysis of variance. The mean total numbers of birds per 50 m of transect are presented in the last column of Table 6 (Section 5.2.1). Neither site type, distance, nor the interaction between site type and distance was significant (Table D-4; Figure 16, Section 5.2.2). This result is not surprising given the fact that species apparently responded differently to compressors (some positively and some negatively) and the relationships of species to distance were different.

Table D-3. Analysis-of-Variance Test of the Relationship of the Mean Total Number of Individuals Observed to Bird Species and Site Type at Two Distance Zones from the Well.

Factor[a]	**Degrees of Freedom**	**Mean Square**	***F*-Value**	***P*-Value**[b]
Distance Zone 0 to 150 m (≥ 50 dBA on treatment sites)				
Species	7	22.1	3.2	0.003
Site type	1	2.2	0.3	0.58
Species x site type	7	15.8	2.3	0.03
Error	168	6.9		
Distance Zone 151 to 400 m (40 - 50 dBA on treatment sites)				
Species	7	84.3	9.9	< 0.0001
Site type	1	38.3	4.5	0.04
Species x site type	7	2.1	0.2	0.97
Error	168	8.5		

[a] Factors in the analysis included species: ash-throated flycatcher, Bewick's wren, bushtit, chipping sparrow, house finch, juniper titmouse, spotted towhee, and western scrub jay; and site type: control (without compressor), treatment (with compressor).

[b] *P*-values ≤ 0.05 were considered statistically significant.

Table D-4. Analysis-of-Variance Test of the Relationship of the Total Number of Birds Observed per 50 m of Transect to Site Type and Distance from the Well.

Factor[a]	**Degrees of Freedom**	**Mean Square**	***F*-Value**	***P*-Value**[b]
Site type	1	65.0	1.8	0.18
Distance	7	63.9	1.8	0.09
Site type x distance	7	7.1	0.2	0.99
Error	176	35.5		

[a] Factors in the analysis included site type: control (without compressor), treatment (with compressor); and distance: 0-50, 51-100, 101-150, 151-200, 201-250, 251-300, 301-350, and 351-400 m from well.

[b] *P*-values ≤ 0.05 were considered statistically significant.

The total number of birds per site was also determined in each of the two distance zones — 0 to 150 m (exposed to $\geq$ 50 dBA on most treatment sites) and 151 to 400 m (exposed to 40-50 dBA on most treatment sites). Site T15 was eliminated from this analysis because of the low noise level on that site (as discussed in Section D.1.1). In both zones, the difference between total number of birds per site on control and treatment sites was not statistically significant (0 to 150 m zone: 42.8 vs. 39.5 birds per site on control and treatment sites, respectively; $t = 0.61$, $P = 0.55$; 151 to 400 m zone: 59.0 vs. 50.5 birds per site on control vs. treatment sites, respectively; $t = 1.49$, $P = 0.15$).

D.2 Vegetation Survey Results

Before statistical tests were performed on vegetation survey data, the cover types listed in Table 7 (Section 5.3) were combined into six categories (pinyon, juniper, shrubs, grasses, forbs, and bare) to avoid problems related to low sample size for many species. Mean percent cover for each of these cover types on control and treatment sites and at different distance categories is presented in Table 8 (Section 5.3).

Analysis of variance indicated that percent plant cover on treatment sites was not significantly different from that on control sites ($F = 1.7$, $P = 0.19$; Table D-5). Cover types differed significantly in their representation on study sites in general ($F = 25.7$, $P < 0.0001$); grasses and forbs had significantly lower percent cover values than pinyon, juniper, or shrubs (Table 8, Section 5.3; Tukey's range test). Distance from the well had a significant effect on percent cover ($F = 7.3$, $P < 0.0001$). This effect resulted from much lower percent cover values along transects adjacent to the study wells (0 m) relative to percent cover along transects farther from the well (Table 8, Section 5.3). The relationship of percent cover to distance varied among cover types (cover type x distance interaction, $F = 5.0$, $P < 0.0001$); this significant interaction results from the fact that some cover types (pinyon and juniper) did not occur adjacent to wells, while others (forbs and grasses) were more abundant there. No other significant main effects or interactions were detected (Table D-5).

Table 9 and Figures 17 and 18 (Section 5.3) present percent cover values for vegetation in different height categories according to site type and distance from the well. A three-way analysis of variance was used to determine the effect of height, site type, and distance on percent cover (Table D-6). Percent cover values of very short vegetation (0 to 0.5 m in height) and tall vegetation (> 2 m in height) were significantly greater than percent cover of vegetation of intermediate height (0.6 to 2 m in height; height effect; $F = 28.5$, $P < 0.0001$). Percent cover of vegetation in different height categories was similar on control and treatment sites (height x site type interaction; $F = 1.4$, $P = 0.25$), but differed significantly among transects at different distances (height x distance interaction, $F = 5.1$, $P < 0.0001$). This significant interaction results from the fact that as distance from wells increased, the representation of shorter vegetation (0 to 0.5 m) decreased, while that of taller vegetation increased (Figure 17, Section 5.3). The relationship of vegetation height to distance from the well was significantly different between control and treatment sites, with control

Table D-5. Analysis-of-Variance Test of the Relationship of Percent Plant Cover to Site Type, Cover Type, and Distance from the Well.

Factor[a]	**Degrees of Freedom**	**Mean Square**	***F*-Value**	***P*-Value**[b]
Site type	1	368.4	1.7	0.19
Cover type	4	5476.5	25.7	<0.0001
Site type x cover type	4	404.3	1.9	0.11
Distance	8	1545.0	7.3	<0.0001
Site type x distance	8	99.4	0.5	0.88
Cover type x distance	32	1069.2	5.0	<0.0001
Site type x cover type x distance	32	229.1	1.1	0.36
Error	990	213.1		

[a] Factors in the analysis included site type: control (without compressor), treatment (with compressor); cover type: pinyon, juniper, shrubs, grasses, and forbs; and distance: 0, 50, 100, 150, 200, 250, 300, 350, and 400 m from well.

[b] *P*-values $\leq$ 0.05 were considered statistically significant.

Table D-6. Analysis-of-Variance Test of the Relationship of Percent Plant Cover to Height, Site Type, and Distance from the Well.

Factor[a]	**Degrees of Freedom**	**Mean Square**	***F*-Value**	***P*-Value**[b]
Height	4	6407.1	28.5	< 0.0001
Site type	1	373.3	1.7	0.20
Distance	8	1544.6	6.9	<0.0001
Height x site type	4	304.1	1.4	0.25
Height x distance	32	1141.7	5.1	< 0.0001
Site type x distance	8	98.3	0.4	0.90
Height x site type x distance	32	342.3	1.5	0.03
Error	990	224.7		

[a] Factors in the analysis included height: 0.0 to 0.5 m, 0.6 to 1.0 m, 1.1 to 2.0 m, 2.1 to 5.0 m, and > 5 m; site type: control (without compressor), treatment (with compressor); and distance: 0, 50, 100, 150, 200, 250, 300, 350, and 400 m from the well.

[b] *P*-values $\leq$ 0.05 were considered statistically significant.

sites having taller vegetation (>2 m) nearer (100 to 200 m) the well than treatment sites (Figure 18, Section 5.3; height x site type x distance interaction, $F = 1.5$, $P = 0.03$). These differences in vegetation on control and treatment sites must be due to chance differences in the location of compressors rather than an effect of noise on vegetation since wells and compressors were placed relatively recently in established pinyon-juniper habitat.

Differences in vegetation between control and treatment sites in the high noise zones (0 to 150 m) and moderate noise zones (150 to 400 m) of treatment sites were also evaluated. Two, two-factor analyses-of-variance were performed. One tested the effects of site type and cover type on percent cover. The other tested the effects of site type and height on percent cover. These analyses indicated that vegetation characteristics were not significantly different between control and treatment sites in these two distance zones (Table D-7).

Table D-7. Significance Levels from Two-Way Analyses of Variance Performed for Two Distance Zones To Test the Effects on Percent Cover of Site Type and Plant Cover Type, and Site Type and Plant Height.

	Significance Level (*P*-Value) for Effect in Two-Way Analyses of Variance[a]	
Factor[b]	**0 to 150 m from Well**	**151 to 400 m from Well**
Site type	0.06	0.87
Cover type	0.55	< 0.0001
Site type x cover type	0.72	0.22
Site type	0.06	0.88
Height	< 0.0001	< 0.0001
Site type x height	0.41	0.32

[a] *P*-values $\leq$ 0.05 were considered statistically significant.

[b] Two, two-factor analyses-of-variance were performed. One tested the effects of site type and cover type on percent cover. The other tested the effects of site type and height category on percent cover. Factors included in the analyses were site type: control (without compressor), treatment (with compressor); cover type: pinyon, juniper, shrubs, grasses, and forbs; and height: 0.0 to 0.5 m, 0.6 to 1.0 m, 1.1 to 2.0 m, 2.1 to 5.0 m, and > 5 m.

Reference for Appendix D

SAS Institute, Inc., 1999, *SAS System for Windows, Release 8.00,* SAS Institute, Inc. Cary, N.C.