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Subcontractor Report

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July 1999 – December 2000

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Western EcoSystems Technology, Inc.
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NREL

National Renewable Energy Laboratory

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Introduction

Avian collisions with man-made objects have been estimated at 100 million to 1 billion per year (Klem 1990, Manville 2000). Collisions with wind turbines account for an estimated 33,000 birds and 333 raptors killed per year (Erickson *et al.* 2001). Although the proportion of birds killed by colliding with wind turbines is low relative to other sources of avian mortality, large numbers of raptor fatalities have been reported from a few wind plants in California (Howell and Didonato 1991, Orloff and Flannery 1992, Howell 1997). In contrast, very few raptor mortalities have been reported from wind turbines outside of California (Erickson *et al.* 2001). To reduce the numbers of avian collisions with wind turbines, several measures have been employed with various levels of success. One hypothesis is that painting turbine blades to increase their visibility may reduce avian fatalities, but few controlled experiments have been conducted (Howell *et al.* 1991, Hugh McIsaac, pers. comm., 1998).

Birds can visually detect wavelengths outside the range of human vision, including the UV spectrum (Jacobs 1992). The ability to detect UV light may assist birds in finding mates, avoiding predators, finding food, and orientating during migration (Andersson 1996, Andersson *et al.* 1998, Viitala *et al*. 1995, Bennett and Cuthill 1994). Some research has suggested birds may be more sensitive to UV light than to visible light (Kreithen and Eisner 1978, Burkhardt and Maier 1989, Chen *et al.* 1984). To date, no published reports have examined whether birds can detect man-made objects painted with UV-reflective paint more easily than objects with conventional (non-UV-reflective) paint.

This study examined the effects on bird use and mortality of painting wind turbine blades with UV-reflective paint at the Foote Creek Rim (FCR) Wind Plant in Carbon County, Wyoming. The primary objectives of the study were to:

- Review and critique published and unpublished information relevant to the study.
- Estimate spatial and temporal use and behavior of birds near turbines with blades coated with UV-reflective paint versus those coated with non-UV-reflective paint.
- Compare the number of carcasses found near turbines that had blades coated with UV-reflective paint versus those coated with non-UV-reflective paint.

A secondary objective of the study was to utilize the results of the study to provide recommendations for reducing bird mortality in wind plants.

Literature Review

In-depth studies of avian use and mortality at wind farms began in the mid-1980s. Many earlier studies involved only a few turbines or focused on nocturnal migrants (waterfowl or passerines) (see CEC 1995). In recent years there have been numerous studies in the United States and Europe that have intensively investigated the effects of wind turbines on birds, several specifically dealing with raptors at larger wind farms. However, few studies have addressed the effects of various turbine design features (treatments) or techniques that may reduce avian mortality rates. Additionally, few studies have addressed the visibility of turbines and blades (especially turning blades) to birds. Flight behavior around turbines has been examined (Clarke 1989; LGL 1995; Orloff and Flannery 1992, 1996; Winkelman 1995), but factors influencing flight patterns have not been well studied. One study examined the effect of varying turbine color patterns on avian-turbine collisions (Howell *et al.* 1991). Results suggested that design patterns on blades can increase and decrease the visibility of the blades. In addition, uniformly colored blades did not deter birds as well as patterned blades.

There is no information on the effects of UV paint on bird-wind turbine collisions. A literature search was conducted of studies involving birds and UV vision to determine whether painting turbine blades with UV-reflective paint could potentially decrease the number of avian collisions. The complete literature review and summary of relevant papers is provided in Appendix A. The following questions were addressed during the literature review: (1) What is UV light, and how much is available?; (2) Are birds sensitive to UV light?; and (3) Can birds better detect UV-reflective objects?

UV light can broadly be defined as light between the wavelengths 0 and 400 nm. Wavelengths below 300 nm are largely absorbed by ozone in the atmosphere (Huffman 1992), and wavelengths below 310 nm are absorbed by nucleic acids and proteins in the eye (Jacobs 1992). UV light available for vision is between 320 and 400 nm. Humans can only detect light between 400 and 700 nm (visible light). Birds have at least four types of cone visual pigments that absorb light in the UV range and transparent oil droplets associated with these cones allowing vision in this spectrum (Maier and Bowmaker 1993, Bowmaker *et al.* 1997, Hart *et al.* 1998, Bennet and Cuthill 1994). Based on the literature review, no study could be found which addressed the question of whether birds can better detect UV-reflective than non-UV reflective surfaces. Although it is documented that birds can detect UV light, controversy exists as to whether birds are more sensitive to UV or visible light. In some behavioral experiments, homing pigeons (*Columbia livia*) were more sensitive to UV than visible light (Kreithen and Eisner 1978). However, in some laboratory experiments, the spectral sensitivities of 15 species were highest in the visible spectrum, with a smaller peak in the UV spectrum (Chen *et al.* 1984). If birds do have higher spectral sensitivities in the UV range, it is not known whether they can better detect UV-reflective objects.

Study Area

Foote Creek Rim Wind Plant

Construction of the Foote Creek Rim Wind Plant began in the fall of 1997. Phase I of the project, as identified in the Environmental Impact Statement (BLM 1995), included construction of turbines in several construction units on the southern end of FCR. Between 1997 and 2000, a total of 133 turbines were completed in four construction units. The first three units (hereafter designated FCR I, FCR II, and FCR III), which were utilized in this study, were completed by the summer of 1999 and included 105 turbines and seven meteorological (met) towers, located on the southern two-thirds of the rim (Table 1, Figure 1). Construction of FCR I began in the fall of 1997 with the facility roads, plant headquarters/maintenance facilities, and turbine pads.

Actual turbine construction began in the summer of 1998. Turbine commissioning for FCR I began in August 1998, with all turbines operational by the end of December. Turbine pads for FCR II (turbines 70-72) and FCR III (turbines 73-105) were constructed in the spring of 1999, followed immediately by construction of the turbines. FCR II and III were fully operational by October 1999.

Vegetation Types at Foote Creek Rim Wind Plant

Vegetation in the project area consists primarily of mixed-grass prairie and sagebrush shrubland (BLM 1995). A band of aspen (*Populus tremuloides*) occurs along the east face of FCR, and the Rock Creek corridor to the east is predominantly cottonwood (*Populus angustifolia*), riparian, and agriculture (irrigated hay and livestock). FCR is a mesa-like rim with generally steep west and east slopes and a flat top of varying width (Figure 1). The vegetation type occurring on the rim top is "cushion plant" grassland (BLM 1995). As the rim progresses north, it becomes somewhat broken, and the slopes tend to flatten. Rock Creek parallels the rim on the east flank, and Foote Creek is located to the west (Figure 1). Surrounding vegetation consists of a mix of shortgrass and sagebrush steppe/shrubland intermixed with rocky ridges, greasewood flats, and riparian areas.

The cushion plant grassland on FCR is dominated by cushion plants (unreported species), black sagebrush (*Artemisia nova*), fringed sage (*A. frigida*), bluebunch wheatgrass (*Elymus spicatus*), western wheatgrass (*Elymus smithii*), and prairie junegrass (*Koeleria macrantha*) (BLM 1995). Surrounding sagebrush steppe/shrubland varies with location but is primarily stands of big sagebrush (*Artemisia tridentata*) or black sagebrush (*A. nova*) with common range grasses and forbs such as prairie junegrass, blue gramma (*Bouteloua gracilis*), needlegrass (*Stipa comata*), western wheatgrass, aster (*Aster spp.*), yarrow (*Achillea milleflium*), buckwheat (*Eriogonum umbellatum*), paintbrush (*Castilleja spp.*), pussy-toes (*Antennaria spp.*), and prickly pear (*Opuntia polyacantha*).

Rationale for Treatment and Site Selection

At the initiation of this study, Foote Creek Rim was an existing wind plant, which had been studied since the mid-1990s. In 1994, during development of the Environmental Impact Statement (EIS) for the then-proposed wind plant, background data were collected on avian use and populations in the area (Thomas *et al.* 1995). Between 1995 and 2000, a detailed wildlife monitoring protocol was followed to study avian use before and after construction of the wind plant (WEST 1995). Wind plant construction began in 1997, and turbine commissioning began in October 1998. Post-construction fatality monitoring began in November 1998 and continued through 2000 for this study, and through 2001 for a portion of Phase I (Young *et al.* 2001). Avian use data were collected through the construction phase and continued for two years during wind plant operation. The FCR protocol included collection of data on two reference areas (one permanent reference area and one potential future wind plant development area).

Because Phase I of the wind plant was constructed in separate units, design and implementation of a "treatment" study was made possible. Turbine blades within the initial construction unit, FCR I, were painted with a high-UV-reflective paint. The three turbines used in FCR II were identical, and the blades were also painted with high-UV-reflective paint. The paint was applied by the blade manufacturers at the factory and conformed to Mitsubishi Heavy Industries (MHI) standards for spectral reflectance of light wavelengths. The UV reflectance was approximately 60% as compared to standard paint, which reflects approximately 10% of UV light and absorbs the rest. Production of paint that reflects greater than 60% of UV light requires a highly polished finish. Turbine manufacturers typically do not produce highly polished finishes due to permitting requirements for "non-glare" finishes.

The blades for FCR I and II were from two sources and were installed in matched sets of three, so blades from the two sources were not mixed on the same turbine. About two-thirds of the blades were made at the MHI factory in Japan. These blades were finished with "V-TOP H TOP COAT SILVER" Polyurethane paint over gel coat. The paint was made by Dai Nippon Toryo Co., Ltd. About one-third of the blades were made under contract to MHI by Plastics Research Corporation in Santa Fe Springs, California, under an identical process as the one used by MHI in Japan. The Plastics Research blades were coated with a paint made by Lilly Industries. The UV reflectance of both paints ranged from approximately 25% to 70%, depending on specific wavelength (reflectance in the lower-UV wavelengths, 200-300 nm, was typically less than those between 300-400 nm).

Under the warranty agreement with MHI, the paint manufacturers are required to warrant the UV reflectance of the finish for 10 years. It is unlikely that during the term of the study, the UV reflectance substantially degraded because the study started within one to two years of wind plant construction.

A different turbine manufacturer was selected for construction of FCR III, and these turbines were painted with conventional paint. Conventional paint typically reflects less than 10% of UV light and absorbs the rest. Thus the basis for an impact-reference (treatment) study at the FCR wind plant was in place.

Study Design

During the permitting process for the initial construction phase of FCR, the U.S. Fish and Wildlife Service (USFWS) recommended that the turbine blades be painted with a UV-light reflective coat in an effort to minimize avian collisions. The effectiveness of UV-light reflective coat to reduce bird mortality had not been experimentally tested. This measure was implemented by the project developer for all turbines in FCR I and FCR II, without consideration for a rigorous control-impact study design to test its collision risk-reducing effectiveness. Once FCR III was constructed the basis for a comparison study was established but without control over the spatial distribution of turbines with UV reflective blades. In essence, the study design was dictated by recommendations from the USFWS without regard to future study design. Therefore, the overall study format is a quasi-experiment or observational study often referred to as an impact-reference design (Morrison *et al.* 2001). The impact-reference design is used for comparison of response variables measured on treated areas (area near UV turbines [UV area]) with measurements from reference areas (areas near non-UV turbines [non-UV area]). The impact-reference design was also chosen because relevant "before" construction data were not available for the areas near the turbines.

A total of six permanent stations were established in the study area. Two stations were placed in the section of the wind plant painted with conventional paint (FCR III, 33 turbines) and four stations were placed within the section where turbines were painted with a UV-reflective paint (FCR I, II, 72 turbines). These stations (sample plots) were placed to provide nearly a census in space of the area near turbines in the entire wind plant (Figure 2).

Study Components

The field study consisted of two components:

1. avian point count surveys
2. carcass (casualty) searches.

Relative use of the wind plant by avian species was measured through point count surveys conducted at each station twice each survey day during daylight hours. Activity and behavior of each bird observed was recorded, as well as other parameters related to the risk of birds near turbines such as distance from a turbine, flight height, and group size. Mortality was measured through carcass searches of plots centered on turbines.

Methods

Avian Use

The objective of the avian point count surveys was to estimate spatial and temporal use, and behavior by raptors, large birds, and species of concern near turbines treated with UV-reflective paint and conventional paint.

Avian use is considered an index to density and abundance (number of individuals per unit area) of the species using the study areas. Use was measured by making counts of birds observed within the study area. It was assumed that use was influenced by biological, physical, and temporal characteristics of the site, as well as life history characteristics of the bird, such as home range, behavior, prey species, etc. The location of each bird detected during counts was recorded in relation to existing or measured information regarding the physical and biological characteristics of the site (covariates) by mapping each observation on a field data map (see Appendix B). In addition, the bird position relative to turbines was estimated and recorded on the data sheet. The survey was primarily suited for raptors, corvids, and other large wide-ranging birds, but all birds observed were recorded.

Surveys were conducted once per week for 76 weeks from 1 July 1999 to 31 December 2000. Each survey consisted of visiting six plots (four near UV-painted turbines, two near conventional-painted turbines) twice each survey day to conduct avian point counts. Each plot was visited once during the morning hours (0600-1200) and once during the afternoon (1200-1800). Survey times were varied to approximately cover all daylight hours.

A survey consisted of point counts at each station. A point count station was located near a turbine but offset to the west (the direction of the prevailing winds at FCR) by 25 meters. During each count, the observer remained at the station for the full survey period but rotated in a fashion to allow observations in all directions. Each count lasted 40 minutes at each station. All birds detected during the 40-minute count were recorded; however, only locations and flight paths of raptors, large birds, and species of concern were mapped. Raptors and large birds that were mapped included all raptors, waterfowl, grouse, cranes, shorebirds, other waterbirds (e.g., herons, pelicans, loons, grebes, ibis), owls, goatsuckers (e.g., nighthawks), doves, and corvids (e.g., ravens). During each count, the observer concentrated his/her efforts in the area around turbines and within approximately 800 m of the survey point.

Data recorded at each station included species, number (group size), distance from the observer, closest distance to a turbine, flight height above ground, direction of flight, activity (behavior) of the bird, and the habitat the bird was in/over (see Appendix B). In addition, all raptors and large birds were plotted where first observed on a data map corresponding to the particular survey station, and the approximate flight path was also recorded on the map. A unique observation number was assigned to each sighting to identify the location when first observed. Other data recorded included the date of the survey, the observer, general weather conditions, start and stop time for each count, and any other notes or comments that were pertinent (see Appendix B). Estimates of flight height were made to the nearest meter when possible. Observations of flight height were recorded when first observed and when the bird was closest to a turbine. Any avoidance behaviors were also recorded.

Avian Mortality

Carcass Searches

The objective of the carcass searches was to compare mean number of carcasses by species and groups of species between turbines with UV-reflective paint and conventional paint.

A detailed study of avian fatalities at the first construction unit (FCR I) has been conducted since the fall of 1998 (Young *et al.* 2001). Data from this study were used to estimate the number of avian fatalities associated with the FCR I turbines. The search protocol was expanded to cover FCR II (UV) and FCR III (non-UV painted turbines). The same level of effort was used in all areas.

A fatality rate (mortality) was calculated as the number of carcasses/turbine/search. All carcasses located within areas surveyed, regardless of species, were recorded and a cause of death determined, if possible, based on field examination. Carcasses found within 60 m of a turbine whose cause of death was undetermined (e.g., feather spots) were considered turbine related.

Carcass removal trials were used to estimate the carcass removal rate. The carcass removal rate is not necessary for comparing the effects of UV paint on mortality, but it does influence the power of the statistical tests for making such comparisons. If the time interval between the carcass searches is much greater than the average length of time a carcass remains in an area before being removed, then it is estimated that a small percentage of the carcasses is likely to be detected by observers. Therefore the power to detect differences between treatments will be low, especially with few carcasses detected. Searcher efficiency trials were also conducted to evaluate the effectiveness of the searchers. Low detectability would have similar effects on power, as would high scavenger rates relative to the interval between searches.

Searches of all turbine strings were conducted every 28 days to locate and collect any carcasses found under the turbines; however, carcasses found at other times and places were also recorded as incidental carcass discoveries. For all carcasses found, data recorded included species, sex and age when possible, date and time collected, location, condition (e.g., intact, scavenged, feather spot), and any comments that indicated cause of death. All carcasses located were photographed as found and mapped on a detailed map of the study area for future reference and permit-reporting requirements.

The condition of each carcass found was recorded using the following condition categories:

- Intact: Carcass is completely intact, is not badly decomposed, and shows no sign of being fed upon by a predator or scavenger.

- Scavenged: At least a portion of the carcass shows signs of being fed upon by a predator or scavenger or portion(s) of a carcass in one location (e.g., wings, skeletal remains, legs, pieces of skin, etc.).

- Feather spot: A group of feathers at one location indicating predation or scavenging. If only feathers are found, 10 or more total feathers or two or more primaries must be discovered to be considered a carcass.

Biologists trained in proper search techniques conducted the searches. Rectangular plots (60 meters in all directions of the turbine) centered on a turbine were searched by walking parallel transects. Transects were set approximately 8-10 meters apart in the area to be searched (60 meters in all directions of the turbine). Searchers walked at a rate of approximately 45-60 meters a minute along each transect searching both sides out to 4-5 meters for casualties.

Carcasses found in non-search areas or found during other activities on FCR by study or wind plant personnel were treated as incidental discoveries. Data recorded during incidental finds were identical to data recorded when carcasses were found during scheduled carcass searches. All carcasses found were labeled with a unique number, tagged, bagged, and frozen for future reference and transmittal to the USFWS.

Carcass Removal Trials

The objective of the carcass removal trials was to estimate the length of time avian carcasses remained in the search area. Estimates of carcass removal rates were used to adjust the number of carcasses found for removal bias.

Carcass removal trials involved placing dead birds in known locations in the wind plant and monitoring these carcasses over time for removal or scavenging. Carcass removal included removal by scavenging or removal by other means (e.g., wind, unknown reasons). Carcass removal trials were conducted each season: (1) spring migration (15 March-30 April); (2) breeding season (1 May-31 August); (3) fall migration (1 September-31 October) and (4) winter (1 November-15 March).

Each season, 10 carcasses of birds of three size classes from commercial sources were randomly placed within the carcass removal trial plots. The carcasses consisted of 10 small-size carcasses (e.g., house sparrows or commercially available juvenile quail), 10 medium-size carcasses (e.g., rock dove), and 10 large-size carcasses (e.g., commercially available adult mallards). Three to four carcasses from each size class (10 total carcasses) were placed in the field three times each season. Thus, a trial was spread throughout a season to incorporate the effects of varying weather, vegetation characteristics, and scavenger densities. To minimize the possibility of attracting scavengers to the area and to preserve independence of data, no more than one carcass was placed in a plot.

Carcasses were checked over a period of 28 days to determine carcass removal rates. Carcasses were checked every day for the first four days, and on day 7, day 10, day 14, day 18, day 23, and day 28, conditions permitting. Carcasses were discreetly marked with a piece of dull colored electrical tape wrapped around the leg so they could be recognized as experimental and left undisturbed. At the end of the 28-day period, carcasses that were still in place were removed.

Searcher Efficiency Trials

The objective of the searcher efficiency trials was to estimate the percentage of avian fatalities found by searchers in carcass search plots. Estimates of searcher efficiency were used to adjust the number of carcasses found for searcher bias.

During each season, 15 carcasses of birds of three different size classes (same classes as in the removal trials, 45 total birds) were placed at random locations in the search area throughout the search period during scheduled carcass searches. Test carcasses (detection carcasses) were either whole carcasses or body parts (e.g., wing).

Personnel conducting searches did not know the location of the detection carcasses or the timing of the trials. All detection carcasses were placed at random locations within areas being searched and immediately prior to the carcass search on the same day. Detection carcass placement was spread over the entire season to incorporate effects of varying weather, vegetation characteristics, and searchers, but always occurred on a carcass search day. Detection carcasses were placed in a variety of postures to simulate true fatalities.

Each detection carcass was discreetly marked (as in scavenger removal trials) so that it could be identified as a study carcass after it was found. The number and location of the detection carcasses found during the carcass search were recorded. Detection carcasses not found by searchers were removed following the carcass search session for that day.

Data Analysis

A primary objective of this study was to describe and compare avian use, mortality, and the ratio of the two at turbines with UV-reflective paint and conventional paint. The objective of the data analysis was to describe a change (increase or decrease) in risk due to the treatment (UV paint). This was evaluated through the measurement of avian use, observed fatality rate, and to the extent possible, behavior (as measured by flight characteristics) at turbines with and without the treatment using standard statistical analyses for impact-reference designs (Skalski and Robson 1992).

Detailed analysis methods with examples for comparing data collected within two different treatment groups of sampling locations are described in Morrison *et al.* 2001. With the proposed sample point layout (Figure 2), there is nearly a census in space (i.e., all areas around turbines were surveyed each survey day), therefore, precision in estimates was based on variation from survey period to survey period. Each period was approximately 28 days based on the time between carcass searches. Approximately eight avian use surveys occurred per plot each survey period (surveys one day per week, two surveys per day, four weeks per survey period).

Data Compilation and Storage

An electronic database was established using Microsoft Access software to store, retrieve, and organize field observations. Data from field forms were keyed into the electronic data file using a predefined format. All field data forms, field notebooks, and electronic data files were retained for future reference.

Quality Assurance/Quality Control (QA/QC)

QA/QC measures were implemented at all stages of the study, including field data collection, data entry, and data analysis and report preparation. Observers were trained and tested in the field methods used and their ability to identify avian species, to estimate counts and flight heights of birds, and to estimate distance. At the end of each survey day, each observer was responsible for inspecting his or her data forms for completeness, accuracy, and legibility. Periodically, the study team leader reviewed data forms to insure completeness and legibility, and any problems detected were corrected. Any changes made to the data forms were initialized by the person making the change.

Following data entry, the electronic data file was compared to raw data forms, and any errors detected were corrected. Any irregular codes detected, or any unclear or ambiguous data, were discussed with the observer and study team leader. All changes made to the raw data were documented for future reference. Any problems identified in later stages of analysis were traced back to the raw data forms, and appropriate changes in all steps were made.

Avian Use, Mortality, and Risk

Data were tabulated and plotted to illustrate differences in avian use (u), observed fatality rate (f) and risk (r) between: (1) time periods, (2) locations (e.g., stations or turbine strings), and (3) treatments (turbines with and without UV-reflective paint). The number of raptors and other large birds seen during each point count survey was standardized to a unit area and unit time surveyed. Similar calculations were made for observations of birds within various distances of point count centers, and turbines with and without the treatment installed. For avian use calculations, only observations within 400 m of the observer were used.

The experimental unit used for the comparison of UV-painted turbines to conventional-painted turbines was a search period. Search periods were defined to encompass four-week survey periods, the time between carcass searches (Table 2). Mean use (number of birds per day, plot, and survey) and fatality rate were calculated by taxa, turbine type, and search. The risk ratio (r) by taxa and turbine type was defined as the mean fatality rate (f) over the mean use (u), where the means are averaged over the 19 carcass searches. The variance and 95% confidence intervals of mean use, fatality rate, and risk was calculated using a bootstrapping technique (Manly 1997). A bootstrap dataset was created for each taxa and turbine type by resampling the mean use and mean fatality rate by search with replacement 5,000 times. The average of the mean use and mean fatality rate was obtained over the search period for each bootstrap replication. The risk ratio was calculated for each bootstrap replication using these means. The bootstrap mean, 2.5^{th} and 97.5th percentiles were obtained for the mean use, fatality rate, and risk ratio.

Annual fatality rates expressed as the number of casualties per turbine per year was calculated by:

$$m = \frac{I * C}{k * \bar{t} * p}$$

where k is the number of turbines sampled, I is the interval between searches in days, C is the total number of carcasses detected for the period of study, $\bar{t}$ is the mean length of time the carcass remains in the study area before it is removed, and p is the observer detection rate.

Results

Avian Use

A total of 3,501 bird observations (individual birds) within 1,888 groups[1] (flocks) were recorded during the fixed-point surveys, regardless of distance from the observer, from 1 July 1999 through 31 December 2000 (Table 3). Thirty-eight species and 13 unidentified bird types (best possible identification, e.g., unidentified accipiter) were observed. More than 50% of the detections (1,915) and 48% of the groups (902) were horned larks, and 11% of the detections (394) and 18% of the groups (339) were golden eagles. Other species comprising more than 2% of the groups observed include red-tailed hawk, common raven, unidentified buteo, prairie falcon, and American kestrel (Table 3).

Mean use estimates (number of detections/40-minute survey) were calculated (using detections within 400 m of each point) by species and grouped by bird size due to differences in the detectability of small and large birds (Tables 4 and 5). Golden eagle (0.238), red-tailed hawk (0.144), Franklin's gull (0.101), common raven (0.097), prairie falcon (0.048), American kestrel (0.043), American white pelican (0.040), and ferruginous hawk (0.028) were the most abundant large birds observed. The relatively high use by Franklin's gull was primarily due to a few observations of large flocks. The most abundant small birds included horned lark (2.492), cliff swallow (0.093), Brewer's blackbird (0.068), mountain bluebird (0.054), and several unidentified passerine groups (unidentified passerine, unidentified warbler, unidentified swallow, unidentified blackbird). These groups were typically near the 400-meter margin at which identification of small birds was difficult.

Raptors

Based on standardized avian use (number of detections/40-minute survey), golden eagles were the most abundant raptor species observed (0.238/survey), followed by red-tailed hawk (0.201), American kestrel (0.043), prairie falcon (0.048), ferruginous hawk (0.028), Swainson's hawk (0.020), northern harrier (0.015), rough-legged hawk (0.013), and bald eagle (0.005). Several raptor species showed significantly higher use on the UV portion of the study area, including golden eagle, red-tailed hawk, prairie falcon, and northern harrier (Table 4).

Overall raptor use was significantly higher on the UV area (0.778) compared to the non-UV area (0.215), mainly due to the high estimates for golden eagles and red-tailed hawks (Table 6). Raptor use was generally highest in the August - October (fall) period during the first year, but it was fairly similar from spring through fall during the second year (Figure 3). The lowest raptor use occurred during the winter periods (November - March). Raptor use by distance from turbine was not significantly different between the UV and non-UV area (Figure 4).

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[1] Note: Group is defined as an observation of a species of bird regardless of number seen together—for example, a flock of eight horned larks flying together is a group, and so is an individual horned lark.

Passerines and Other Groups

Horned larks were the most abundant passerine species (2.313/survey), with use more than 20 times higher than the other species: cliff swallow (0.093), Brewer's blackbird (0.068), mountain bluebird (0.054) (Table 5). Several groups showed significantly higher use in the UV area, including swallows, thrushes, and the "other" group (Table 6). The differences for these passerines and the other group are likely due to the influence of the aspen groves on the east side of the rim near the UV area. Overall passerine use was not different between the two areas, primarily due to the offset of use in the non-UV area due to higher horned lark abundance in that area. Passerine use was the highest during the summer months of both years (Figure 5).

Avian Casualty and Bias Estimation

Observed Avian Fatalities

Twenty-seven species and three unidentified groups (unidentified passerine, unidentified warbler, and unidentified swallow) comprise the 84 fatalities found within the boundaries of the search plots (Table 7, see also Appendix C). No crippled or wounded birds were found during the study. Fifty-seven (68%) of the fatalities were recorded at the 72 UV turbines, 13 fatalities (15%) at the 33 non-UV turbines, and 14 (17%) at the 7 met towers (Table 8). Most of the casualties were passerines (78). Horned lark was the most abundant casualty observed (26), followed by rock wren (7), vesper sparrow (4), and Townsend's warbler (4). Three casualties of several species were also found (house wren, green-tailed towhee, Brewer's sparrow, chipping sparrow, American kestrel, Wilson's warbler). A total of six raptor fatalities were recorded, four near UV turbines (three American kestrels, one short-eared owl) and two near non-UV turbines (golden eagle, prairie falcon). One waterbird (western grebe) was also found near non-UV turbines.

No statistically significant differences existed between fatality rates for the UV and non-UV turbines (Table 9), although overall passerine fatality rates at the UV turbines were two times higher than at the non-UV turbines, primarily due to a higher number of horned lark casualties per turbine. Avian fatality rates by raptors were very similar (0.0029, 0.0031) between UV and non-UV turbines. The largest number of avian casualties observed at any one turbine during the study was four at turbine 65. One turbine had three casualties, 53 turbines had one or two casualties, and 50 turbines had no casualties observed (Table 8).

Avian Carcass Removal

During the study, 260 avian carcasses were used for carcass removal trials (Table 10). The mean length of time that carcasses remained in the study area prior to removal varied with carcass size and season. For all seasons combined, medium-sized birds lasted the longest (37 days), followed by large birds (29 days) and small birds (13 days). Mean length of stay for all size classes of birds combined was longest during the summer (42 days), followed by fall (26 days), spring (25 days), and winter (21 days). The overall mean length of stay for all carcasses and seasons was 29 days. Potential scavenger species observed in the project area include raptors, ravens, crows, magpies, coyotes, red foxes, badgers, white-tailed prairie dogs, ground squirrels, deer mice, and insects. During summer, one of the main causes of carcass removal was scavenging by insects, including beetles, ants, and maggots. Throughout the remainder of the year, either ground squirrels and/or deer mice appeared to be the primary scavengers of carcasses. During the fall and winter, common ravens were often observed foraging on trial carcasses.

Avian Searcher Efficiency

During the study, 462 avian carcasses were used in searcher efficiency trials (Table 11). Overall, searcher efficiency varied according to the size class of the bird: 59% of the small birds, 87% of the medium-sized birds, and 92% of the large birds were detected. The overall detection rate for all bird size classes combined was 80% (Table 11). Searcher efficiency was similar among seasons, averaging 79% in the spring, 80% in summer, 84% in fall, and 78% in winter.

Adjusted Avian Mortality

Annual mortality (fatality rate), expressed as the number of fatalities per turbine per year, varied by group (Table 12). The overall annual mortality per turbine for all birds for all 105 turbines was estimated to be 1.49; raptor mortality was estimated to be 0.042.

Avian Risk

The risk index of mortality (fatality rate) divided by mean use was calculated by avian group. The risk index was three times higher at the non-UV area compared to the UV area for raptors, but this was not statistically significant, and because there were only six raptor fatalities, the magnitude of the differences are probably not reliably estimated (Table 13).

Discussion

Avian Risk

Diurnally observed avian diversity on FCR is relatively low. Based on the fixed-point surveys, horned lark and golden eagle comprised approximately two-thirds (66%) of all birds observed. Red-tailed hawk and common raven comprised a little more than 11% of all observations. On average, slightly more than two horned larks were observed during every 40-minute survey, and approximately one golden eagle was observed every three surveys. The vast majority of species observed during the study comprised less that 2% of all birds detected (see Table 3).

Avian use varied between the UV and non-UV turbine areas. Overall raptor use was significantly higher in the UV area (0.778/survey) compared to the non-UV area (0.215/survey). This was influenced primarily by the high use by golden eagles and red-tailed hawk in the UV area (see Table 4). In contrast, passerine use did not differ between the UV and non-UV areas due mainly to the high abundance of horned larks across the whole rim. Horned lark use was more than 20 times greater than other passerines and thus had the greatest influence on use statistics.

Horned larks had the highest use estimates and were the most abundant fatality observed, suggesting some correlation between avian use and mortality. However, relationships between raptor species use and raptor species mortality were not apparent, likely due in part to the small number of fatalities recorded. Multiple carcasses were found of ten species, mostly passerines, but including three American kestrels. Only one golden eagle carcass was located during the study, despite the high golden eagle use. In contrast, American kestrels comprised approximately 5% of the raptors observed, but accounted for one-half of all raptor carcasses found. There was no significant difference between observed mortality between the UV and non-UV turbines. Observed passerine mortality at UV turbines was two times higher than the non-UV turbines but not significantly different.

The avian risk index, mortality divided by mean use, provides a relative measure of the risk of birds colliding with turbines. If there were no difference in the risk of collision between the UV and non-UV areas, we would expect similar risk indices for both areas (i.e., fatalities would be proportional to use for both areas). A difference between the indices for the two areas would suggest a difference in risk of collisions between the two turbine types. There was no significant difference between the risk index for different bird groups between the two areas (see Table 13). The risk index for raptors was approximately three times higher at the non-UV area, due to lower use estimates; however, this was not significantly different. Due to the small sample size of raptor fatalities (6), the magnitude of this difference is probably not reliably measured.

Avian behavior was addressed through observation of flight characteristics (e.g., distance from turbines). Qualitative observations of birds avoiding turbines were noted but not included in the analyses. There was no significant difference in raptor use in different distance bands from UV and non-UV turbines (see Figure 4), suggesting that there was no difference in the propensity of raptors to fly closer to one turbine type.

This was an observational study (Hurlbert 1984, Morrison *et al.* 2001) designed to provide statistical evidence regarding differences in fatality rates, use, and collision risk between turbines painted with UV-reflective or conventional paint. The true cause of significant differences in these endpoints is not discernible from an observational study. Differences in fatality rates, use, or risk could be due to factors other than the turbine-blade reflectance. An attempt was made to adjust for one factor, avian use, by calculating a risk index. Raptor fatality rates in the two areas were nearly identical, with higher raptor use apparent in the UV area. The higher use in the UV area may relate to the fact that the rim is narrower in most of the UV area compared to the non-UV area (see Figure 1). During previous studies at Foote Creek Rim, use has been documented much higher along the rim edge than over the top of the mesa (Johnson *et al.* 2000). The higher raptor use in the UV area may be linked to higher use of the rim edge away from the turbines. Because of the relatively low number of raptor casualties found, statistical evidence for true differences in fatality rates between the turbine types or differences between levels of other variables is weak.

The estimate of 0.04 raptor fatalities per turbine per year is lower than most raptor mortality estimates reported in California at Altamont and Montezuma Hills (Erickson *et al.* 2001). Furthermore, the turbines at Foote Creek Rim have a rotor swept area approximately 5 times larger than the average rotor swept area of turbines at Altamont[1]. By standardizing estimates for every 100,000 square meter of rotor swept area, Foote Creek Rim (3 raptor fatalities/100,000 m^2 RSA) estimates are approximately 3-7 times lower than at Altamont (9-22 raptor fatalities/100,000 m^2 RSA). For golden eagles, Foote Creek Rim (0.3 golden eagle fatalities/100,000 m^2 RSA) estimates are also approximately 3-7 times lower than at Altamont (1 to 2 golden eagle fatalities/100,000 m^2 RSA). Given the similar use estimates between these two sites for golden eagles (0.2 to 0.3 golden eagles per 20-minute observation period for each site), a combination of factors such as turbine characteristics, turbine layout, and/or project size, are more likely the cause of these differences. This is also suggested by golden eagle mortality data collected at Altamont (Hunt et al. 2002). Results from a multi-year radio-telemetry study suggested the older downwind 56-100 model turbine, which is a three-blade turbine with 9 meter blades and currently comprises almost half of the turbines at Altamont Pass, have a higher golden eagle fatality rate than other turbines. True experiments of the influence of the various factors (including turbine types) on golden eagle mortality have not been conducted.

Qualitative Avian Observations

Throughout the study, several instances were recorded in which birds were observed avoiding turbines. Avoidance behaviors fell into three general categories: altering flight paths, positioning to avoid turbines while not changing the basic flight path, and drastic maneuvers to avoid being struck or hitting turbines. In some cases, raptors were observed altering their flight paths to avoid turbines. Some raptors changed direction, and in one case, a golden eagle turned around completely and flew back the way it had come when it approached a turbine. Several different species of raptors and large birds were observed positioning themselves around turbines while maintaining the same flight course. Golden eagles were observed climbing above the level of the spinning blades to pass over turbines. In one case, a golden eagle was observed crossing two turbine strings in this manner, but while between the two strings, it flew below blade height. A prairie falcon was observed lowering its flight height to fly underneath the level of the turbine blades. Two common ravens were observed approaching a turbine string and moving to fly between two turbines at blade height. Several observations were made of raptors dramatically altering their flight path to avoid being struck. In a few instances, American kestrels were observed flying in high winds, which made it difficult for the birds to fly and forced them into drastic maneuvers to avoid being struck. In another instance, a prairie falcon was seen chasing a horned lark that flew near a turbine and forced the falcon to flare away to avoid being struck.

Conclusions and Recommendations

The current study does not provide strong evidence that there is a difference in bird use, mortality, or risk between turbine blades painted with a UV-light reflective paint and those painted with conventional paint. The low level of avian mortality observed and the non-controlled experimental design allow limited statistical inferences beyond the current study. Design of the study to be manipulative versus observational would provide control over some

[1] Foote Creek Rim turbines average approximately 1500 m^2 RSA. It was assumed Altamont turbines average approximately 300-400 m^2 RSA due to variety of smaller older-generation turbine types and sizes.

confounding variables, which may be influencing bird use more than turbine paint. Conclusions from the study are based strongly on professional judgment as opposed to statistical inference.

Several recommendations can be made in regards to the study design to strengthen the inferences from a study of this nature. If possible, a manipulative design would provide control of confounding variables over an observational study design. For example, a stronger design in this case would have been to apply UV paint to every other turbine, which would provide some control over site variables, such as the distance to the rim edge. Multiple years of study would increase the amount of data from rare events such as avian fatalities associated with turbine strikes. In addition, it was originally recommended that shorter-duration surveys at more observation stations be conducted, but this approach was not accepted. Better spatial representation, by providing a larger sample size of turbines, and more observations of raptors near turbines, would have been appropriate.

Because of the low mortality observed and the limited ability to draw strong statistical inferences, few recommendations can be made regarding wind plant design features to minimize avian impacts. Conceptually, painting turbines in a fashion that enhances the visibility of the structure to birds may reduce impacts. Based on the results of this study, there does not appear to be a difference in use, mortality, or risk to birds from the two turbine types. It may be that because birds can see light in the UV range, objects reflecting or emitting UV light are simply viewed as a different color to the avian eye. Other measures to enhance the visibility of the turbines to birds may be just as effective. The apparently lower mortality associated with larger turbines (newer generation) may be due to many possible factors including greater visibility of larger, slower turning blades. For example, Altamont Pass and FCR have similar estimates of golden eagle use. Orloff and Flannery (1992) estimated between 30 and 70 golden eagle deaths per year for the Altamont Pass wind plant. By standardizing estimates for every 100,000 m^2 RSA, Foote Creek Rim (0.3 golden eagle fatalities/100,000 m^2 RSA) estimates are approximately 3-7 times lower than at Altamont (1 to 2 golden eagle fatalities/100,000 m^2 RSA). This suggests there may be a difference in risk to eagles based on characteristics of the turbine (size, type, tower height, blade rpm's, proximity of blade to ground), which has also been suggested by Hunt (2002). True experiments to determine the influence of potential risk factors suggested above on golden eagle or other raptor mortality have not been conducted, but repowering efforts in Altamont may provide the opportunity for such experiments.

Guyed met towers at Foote Creek Rim had estimated per-structure bird fatality rates four to five times higher than either turbine type (Young *et al.* 2001). It is presumed that collisions with the guy wires are the primary cause of the fatalities. This result primarily applies to passerines; no raptors casualties were found at met towers. These results suggest guyed met towers, and presumably other guyed structures such as some communication towers, may be more of a risk to passerines on a per-structure basis than wind turbines. To the extent possible, un-guyed permanent met towers should be constructed in wind plants to minimize this source of avian mortality.

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Table 1. The Initial Three Construction Units within the Foote Creek Rim Wind Plant

	FCR I	FCR II	FCR III
Completion Date[1]	12/31/98	10/01/99	10/01/99
Turbine Type	Mitsubishi 600	Mitsubishi 600	NEG Micon NM 750-44
Paint on Turbine Blades	UV-light reflective	UV-light reflective	Conventional paint
Turbine Numbers (Total)	1-69 (69)	70-72 (3)	73-105 (33)
Total Capacity	41.4 MW	1.8 MW	24.75 MW
Tower Height	131 ft (40 m)	131 ft (40 m)	163.9 ft (50 m)
Tower Spacing	276 ft (84 m)	276 ft (84 m)	332 ft (101 m)
Rotor Diameter	138 ft (42 m)	138 ft (42 m)	144 ft (44 m)
Permanent Met Towers	5	1	1
Total Gross Project Area	≈1,960 acres	≈40 acres	≈560 acres
Actual Facility Area[2]	26.6 acres	1.2 acres	12.7 acres
Total Road Length [≈]	27,200 ft (5.2 miles)	1,000 ft (0.2 mile)	16,400 ft (3.1 miles)
Total Road Area [≈]	435,200 ft^2 (10.0 acres)	16,000 ft^2 (0.4 acre)	262,400 ft^2 (6.0 acres)

[1] Approximate date unit was fully operational
[2] Total area occupied by wind plant facilities: roads, turbine pads, substation, etc.

Table 2. Beginning and End Dates of Search Periods

Search/Survey	Begin	End
1	8-Jul-99	23-Jul-99
2	24-Jul-99	19-Aug-99
3	20-Aug-99	15-Sep-99
4	16-Sep-99	13-Oct-99
5	14-Oct-99	10-Nov-99
6	11-Nov-99	8-Dec-99
7	9-Dec-99	6-Jan-00
8	7-Jan-00	4-Feb-00
9	5-Feb-00	1-Mar-00
10	2-Mar-00	29-Mar-00
11	30-Mar-00	28-Apr-00
12	29-Apr-00	23-May-00
13	24-May-00	20-Jun-00
14	21-Jun-00	20-Jul-00
15	21-Jul-00	16-Aug-00
16	17-Aug-00	15-Sep-00
17	16-Sep-00	11-Oct-00
18	12-Oct-00	10-Nov-00
19	11-Nov-00	7-Dec-00

Table 3. Number of Groups and Total Detections by Species Recorded During the Study

Species/Group	UV Area # Groups	UV Area # Det.[2]	Non-UV Area # Groups	Non-UV Area # Det.	Overall # Groups	Overall # Det.	% Composition[1] # Groups	% Composition[1] # Det.
Horned Lark	574	1160	328	755	902	1915	47.8	54.7
Golden Eagle	252	288	87	106	339	394	18.0	11.3
Red-Tailed Hawk	120	138	16	18	136	156	7.2	4.5
Common Raven	65	95	18	38	83	133	4.4	3.8
Franklin's Gull	2	115	0	0	2	115	0.1	3.3
Canada Goose	2	101	0	0	2	101	0.1	2.9
Brewers Blackbird	19	64	8	12	27	76	1.4	2.2
Unidentified Buteo	47	58	15	16	62	74	3.3	2.1
Cliff Swallow	20	48	1	2	21	50	1.1	1.4
Prairie Falcon	32	35	8	9	40	44	2.1	1.3
Mountain Bluebird	28	42	0	0	28	42	1.5	1.2
American White Pelican	3	11	3	31	6	42	0.3	1.2
American Kestrel	23	24	16	16	39	40	2.1	1.1
Ferruginous Hawk	24	25	12	12	36	37	1.9	1.1
Unidentified Swallow	12	36	0	0	12	36	0.6	1.0
Unidentified Passerine	7	27	0	0	7	27	0.4	0.8
Unidentified Warbler	1	25	0	0	1	25	0.1	0.7
Rough-Legged Hawk	19	19	4	4	23	23	1.2	0.7
Swainson's Hawk	17	18	3	4	20	22	1.1	0.6
Unidentified Raptor	11	12	4	5	15	17	0.8	0.5
Northern Harrier	13	13	3	3	16	16	0.8	0.5
California Gull	1	11	1	1	2	12	0.1	0.3
Mountain Plover	0	0	9	11	9	11	0.5	0.3
Unidentified Blackbird	1	1	2	10	3	11	0.2	0.3
Brown-Headed Cowbird	2	10	0	0	2	10	0.1	0.3
Snow Goose	0	0	1	10	1	10	0.1	0.3
Vesper Sparrow	4	6	3	3	7	9	0.4	0.3
Turkey Vulture	6	6	1	1	7	7	0.4	0.2
Bald Eagle	5	5	1	1	6	6	0.3	0.2
Northern Flicker	5	6	0	0	5	6	0.3	0.2
Sandhill Crane	2	5	0	0	2	5	0.1	0.1
Great Blue Heron	2	2	1	1	3	3	0.2	0.1
American Robin	2	2	0	0	2	2	0.1	0.1

[1] Percent composition expressed as the percentage of total number of groups or detections
[2] Number of individual detections

Table 3. (continued)

Species/Group	UV Area		Non-UV Area		Overall		% Composition[1]	
	# Groups	# Det.[2]	# Groups	# Det.	# Groups	# Det.	# Groups	# Det.
Barn Swallow	2	2	0	0	2	2	0.1	0.1
Northern Rough-Winged Swallow	2	2	0	0	2	2	0.1	0.1
Pine Siskin	2	2	0	0	2	2	0.1	0.1
Unidentified Sparrow	2	2	0	0	2	2	0.1	0.1
Sage Grouse	0	0	1	2	1	2	0.1	0.1
Unidentified Gull	0	0	1	2	1	2	0.1	0.1
Broad-Tailed Hummingbird	1	1	0	0	1	1	0.1	0.0
Cooper's Hawk	1	1	0	0	1	1	0.1	0.0
Lark Bunting	1	1	0	0	1	1	0.1	0.0
Northern Shrike	1	1	0	0	1	1	0.1	0.0
Sharp-Shinned Hawk	1	1	0	0	1	1	0.1	0.0
Unidentified Accipiter	0	0	1	1	1	1	0.1	0.0
Unidentified Corvid	1	1	0	0	1	1	0.1	0.0
Unidentified Falcon	1	1	0	0	1	1	0.1	0.0
Unidentified Shorebird	0	0	1	1	1	1	0.1	0.0
Unidentified Small Falcon	1	1	0	0	1	1	0.1	0.0
Violet-Green Swallow	1	1	0	0	1	1	0.1	0.0
Western Meadowlark	1	1	0	0	1	1	0.1	0.0
Total	1,339	2,426	549	1,075	1,888	3,501	100.0	100.0

[1] Percent composition expressed as the percentage of total number of groups or detections
[2] Number of individual detections

Table 4. Avian Use by Species for Medium to Large Birds

	UV Area			Non-UV Area			Overall	
	Mean	95% C.I.		Mean	95% C.I.		Mean	
Species	Use	LL[1]	UL[2]	Use	LL	UL	Use	Sign.[3]
Golden Eagle	0.309	0.221	0.408	0.096	0.059	0.136	0.238	+
Red-Tailed Hawk	0.204	0.111	0.308	0.025	0.005	0.051	0.144	+
Franklin's Gull	0.151	0.000	0.454	0.000	0.000	0.000	0.101	
Common Raven	0.107	0.061	0.156	0.076	0.026	0.136	0.097	
Prairie Falcon	0.066	0.032	0.104	0.014	0.000	0.031	0.048	+
American Kestrel	0.040	0.018	0.068	0.050	0.015	0.096	0.043	
American White Pelican	0.022	0.000	0.066	0.076	0.000	0.229	0.040	
Ferruginous Hawk	0.031	0.013	0.053	0.020	0.003	0.043	0.028	
Swainson’s Hawk	0.029	0.011	0.051	0.000	0.000	0.000	0.020	+
Unidentified Buteo	0.025	0.009	0.043	0.004	0.000	0.013	0.018	
California Gull	0.024	0.000	0.072	0.000	0.000	0.000	0.016	
Northern Harrier	0.021	0.010	0.033	0.003	0.000	0.008	0.015	+
Rough-Legged Hawk	0.018	0.008	0.030	0.003	0.000	0.008	0.013	
Turkey Vulture	0.013	0.000	0.031	0.000	0.000	0.000	0.009	
Unidentified Raptor	0.010	0.002	0.019	0.000	0.000	0.000	0.007	+
Bald Eagle	0.008	0.001	0.016	0.000	0.000	0.000	0.005	+
Sage Grouse	0.000	0.000	0.000	0.013	0.000	0.039	0.004	
Common Nighthawk	0.004	0.000	0.012	0.000	0.000	0.000	0.003	
Unidentified Gull	0.000	0.000	0.000	0.005	0.000	0.016	0.002	
Sandhill Crane	0.003	0.000	0.008	0.000	0.000	0.000	0.002	
Canada Goose	0.002	0.000	0.007	0.000	0.000	0.000	0.001	
Cooper's Hawk	0.002	0.000	0.005	0.000	0.000	0.000	0.001	
Great Blue Heron	0.001	0.000	0.004	0.000	0.000	0.000	0.001	
Sharp-Shinned Hawk	0.001	0.000	0.004	0.000	0.000	0.000	0.001	
Unidentified Falcon	0.001	0.000	0.004	0.000	0.000	0.000	0.001	
Unidentified Small Falcon	0.001	0.000	0.004	0.000	0.000	0.000	0.001	

[1] Lower limit of 95% bootstrap confidence interval
[2] Upper limit of 95% bootstrap confidence interval
[3] Indication of statistical significant difference with “+” indicating higher use on UV area

Table 5. Avian Use by Species for Small Birds

	UV Area			Non-UV Area			Overall	
	Mean	95% C.I.		Mean	95% C.I.		Mean	
Species	Use	LL[1]	UL[2]	Use	LL	UL	Use	Sign.[3]
Horned Lark	2.081	1.269	2.921	2.777	1.304	4.733	2.313	
Cliff Swallow	0.136	0.000	0.370	0.009	0.000	0.026	0.093	
Brewers Blackbird	0.078	0.011	0.156	0.048	0.000	0.109	0.068	
Mountain Bluebird	0.081	0.031	0.144	0.000	0.000	0.000	0.054	+
Unidentified Swallow	0.055	0.013	0.112	0.000	0.000	0.000	0.037	+
Unidentified Passerine	0.041	0.007	0.082	0.000	0.000	0.000	0.027	+
Unidentified Warbler	0.041	0.000	0.123	0.000	0.000	0.000	0.027	
Vesper Sparrow	0.018	0.000	0.050	0.013	0.000	0.035	0.016	
Brown-Headed Cowbird	0.022	0.000	0.061	0.000	0.000	0.000	0.015	
Mountain Plover	0.000	0.000	0.000	0.038	0.000	0.083	0.013	
Unidentified Blackbird	0.002	0.000	0.007	0.033	0.000	0.099	0.012	
Northern Flicker	0.010	0.000	0.025	0.000	0.000	0.000	0.006	
N. Rough-Winged Swallow	0.009	0.000	0.026	0.000	0.000	0.000	0.006	
American Robin	0.004	0.000	0.013	0.000	0.000	0.000	0.003	
Barn Swallow	0.004	0.000	0.010	0.000	0.000	0.000	0.003	
Unidentified Sparrow	0.003	0.000	0.008	0.000	0.000	0.000	0.002	
Pine Siskin	0.003	0.000	0.008	0.000	0.000	0.000	0.002	
Broad-Tailed Hummingbird	0.002	0.000	0.007	0.000	0.000	0.000	0.001	
Lark Bunting	0.002	0.000	0.007	0.000	0.000	0.000	0.001	
Violet-Green Swallow	0.002	0.000	0.007	0.000	0.000	0.000	0.001	
Unidentified Shorebird	0.000	0.000	0.000	0.003	0.000	0.010	0.001	
Northern Shrike	0.001	0.000	0.004	0.000	0.000	0.000	0.001	
Western Meadowlark	0.001	0.000	0.004	0.000	0.000	0.000	0.001	

[1] Lower limit of 95% bootstrap confidence interval
[2] Upper limit of 95% bootstrap confidence interval
[3] Indication of statistical significant difference with "+" indicating higher use on UV area

Table 6. Avian Use by Species Group

	UV Area			Non-UV Area			Overall	
	Mean	95% C.I.		Mean	95% C.I.		Mean	
Species	Use	LL[1]	UL[2]	Use	LL	UL	Use	Sign.[3]
Blackbirds	0.102	0.025	0.196	0.080	0.009	0.169	0.095	
Corvids	0.107	0.062	0.155	0.076	0.027	0.138	0.097	
Finches	0.003	0.000	0.008	0.000	0.000	0.000	0.002	
Gamebirds	0.000	0.000	0.000	0.013	0.000	0.039	0.004	
Horned Larks	2.081	1.298	2.931	2.777	1.261	4.797	2.313	
Other	0.048	0.015	0.088	0.000	0.000	0.000	0.032	+
Raptors	0.778	0.568	0.991	0.215	0.139	0.291	0.590	+
Shorebirds	0.000	0.000	0.000	0.041	0.000	0.092	0.014	
Sparrows	0.022	0.003	0.055	0.013	0.000	0.035	0.019	
Swallows	0.210	0.040	0.464	0.009	0.000	0.026	0.143	+
Thrushes	0.086	0.032	0.156	0.000	0.000	0.000	0.057	+
Warblers	0.041	0.000	0.123	0.000	0.000	0.000	0.027	
Waterbirds	0.201	0.003	0.529	0.082	0.000	0.245	0.161	
Waterfowl	0.002	0.000	0.007	0.000	0.000	0.000	0.001	
Woodpeckers	0.010	0.000	0.025	0.000	0.000	0.000	0.006	
Wrens	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Passerines	2.707	1.634	3.875	2.996	1.438	4.976	2.803	

[1] Lower limit of 95% bootstrap confidence interval
[2] Upper limit of 95% bootstrap confidence interval
[3] Indication of statistical significant difference with "+" indicating higher use on UV area

Table 7. Avian Casualties by Plot Type and Species

Species/Group	Plot Type Met Tower	Non-UV Turbine	UV Turbine	Total
Horned Lark	3	2	21	26
Rock Wren	0	3	4	7
Vesper Sparrow	3	0	1	4
Townsend's Warbler	0	0	4	4
House Wren	1	1	1	3
Green-Tailed Towhee	0	1	2	3
Brewers Sparrow	2	0	1	3
Chipping Sparrow	2	0	1	3
American Kestrel	0	0	3	3
Unidentified Passerine	0	0	3	3
Wilson's Warbler	0	0	3	3
Chestnut-Collared Longspur	0	2	0	2
Brown Creeper	0	0	2	2
Mountain Bluebird	0	0	2	2
Sage Grouse	0	1	0	1
Dark-Eyed Junco	0	1	0	1
Golden Eagle	0	1	0	1
Prairie Falcon	0	1	0	1
American Robin	1	0	0	1
Common Poorwill	1	0	0	1
Western Tanager	1	0	0	1
Cliff Swallow	0	0	1	1
MacGillivray's Warbler	0	0	1	1
Ruby-Crowned Kinglet	0	0	1	1
Short-Eared Owl	0	0	1	1
Tree Swallow	0	0	1	1
Unidentified Swallow	0	0	1	1
Unidentified Warbler	0	0	1	1
Western Grebe	0	0	1	1
Yellow-Rumped Warbler	0	0	1	1
Total	15	13	57	84

Table 8. Distribution of Avian Fatalities Observed by Turbine and Met Towers

UV Turbines				Non-UV Turbines		Met Towers	
Turbine ID	# Fatalities	Turbine ID	# Fatalities	Turbine ID	# Fatalities	Met ID	# Fatalities
1	1	40	1	73	0	1	1
2	0	41	1	74	0	2	3
3	2	42	0	75	0	3	0
4	1	43	0	76	0	4	3
5	1	44	0	77	1	5	2
6	1	45	0	78	0	6	0
7	0	46	0	79	0	202	5
8	2	47	0	80	0	Subtotal	14
9	0	48	0	81	1		
10	1	49	0	82	0		
11	1	50	0	83	0		
12	1	51	0	84	1		
13	0	52	1	85	1		
14	0	53	1	86	0		
15	1	54	0	87	0		
16	0	55	1	88	1		
17	2	56	0	89	0		
18	1	57	0	90	0		
19	2	58	0	91	1		
20	1	59	0	92	0		
21	0	60	1	93	0		
22	2	61	0	94	0		
23	2	62	0	95	1		
24	1	63	0	96	0		
25	0	64	0	97	2		
26	1	65	4	98	1		
27	0	66	2	99	0		
28	1	67	1	100	2		
29	3	68	2	101	1		
30	1	69	2	102	0		
31	2	70	1	103	0		
32	1	71	2	104	0		
33	0	72	1	105	0		
34	1	Subtotal	57	Subtotal	13		
35	2						
36	0						
37	0						
38	1						
39	0						

Table 9. Fatality Rates (Number/Turbine/Search) for Avian Species Groups

	UV			Non-UV		
	Observed Fatality	95% Confidence Intervals		Observed Fatality	95% Confidence Intervals	
Species	Rate[1]	LL[2]	UL[3]	Rate	LL	UL
Blackbirds	0.000	0.000	0.000	0.000	0.000	0.000
Corvids	0.000	0.000	0.000	0.000	0.000	0.000
Finches	0.000	0.000	0.000	0.000	0.000	0.000
Gamebirds	0.000	0.000	0.000	0.002	0.000	0.005
Horned Larks	0.015	0.005	0.028	0.006	0.000	0.014
Other	0.004	0.001	0.008	0.000	0.000	0.000
Raptors	0.003	0.000	0.007	0.003	0.000	0.008
Shorebirds	0.000	0.000	0.000	0.000	0.000	0.000
Sparrows	0.004	0.001	0.007	0.003	0.000	0.008
Swallows	0.002	0.000	0.006	0.000	0.000	0.000
Thrushes	0.001	0.000	0.004	0.000	0.000	0.000
Waterbirds	0.001	0.000	0.002	0.000	0.000	0.000
Waterfowl	0.000	0.000	0.000	0.000	0.000	0.000
Warblers	0.007	0.000	0.018	0.000	0.000	0.000
Woodpeckers	0.000	0.000	0.000	0.000	0.000	0.000
Wrens	0.004	0.000	0.008	0.006	0.000	0.014
Passerines	0.038	0.021	0.056	0.016	0.005	0.029

[1] Observed number of fatalities/turbine/search
[2] Lower limit of 95% bootstrap confidence interval
[3] Upper limit of 95% bootstrap confidence interval

Table 10. Estimated Mean Length of Stay for Carcasses Used to Monitor Scavenger Removal Rates

Carcass Size Class	Season	N	% Remaining at 28 Days	Mean Length of Stay (Days)			
						95% C.I.	
				Mean	SE[1]	LL[2]	UL[3]
Small	Spring	16	13	9.75	2.53	5.32	14.18
	Summer	20	35	19.14	3.42	13.23	25.05
	Fall	20	20	15.44	2.41	11.27	19.62
	Winter	34	12	10.99	1.64	8.22	13.77
	Total	90	19	13.37	1.21	11.36	15.37
Medium	Spring	15	80	47.07	6.04	36.44	57.70
	Summer	20	80	50.83	6.14	40.21	61.46
	Fall	20	60	31.61	4.88	23.16	40.05
	Winter	32	59	30.79	3.53	24.81	36.78
	Total	87	68	37.33	2.46	33.23	41.42
Large	Spring	9	33	20.99	3.94	13.66	28.32
	Summer	20	85	57.68	6.55	46.36	69.00
	Fall	20	60	31.23	4.63	23.22	39.25
	Winter	34	44	22.63	3.03	17.50	27.77
	Total	83	57	29.45	2.19	25.81	33.09

[1] Standard error
[2] Lower limit of 95% bootstrap confidence interval
[3] Upper limit of 95% bootstrap confidence interval

Table 11. Number of Birds Detected During Searcher Efficiency Trials

Size Class of Bird	Season [November 1, 1998 - December 31, 2000] Spring	Summer	Fall	Winter	Total
Small	20[1]/33[2] (61%)	26/42 (62%)	15/22 (68%)	20/40 (50%)	81/137 (59%)
Medium	31/37 (84%)	48/53 (91%)	29/35 (83%)	36/40 (90%)	144/165 (87%)
Large	31/34 (91%)	43/48 (90%)	24/24 (100%)	37/40 (93%)	135/146 (92%)
Subtotal	82/104 (79%)	117/143 (82%)	68/81 (84%)	93/120 (78%)	360/448 (80%)
Total	82/104 (79%)	127/159 (80%)	68/81 (84%)	93/120 (78%)	370/464 (80%)

[1] Number detected by observers
[2] Number placed for experiment

Table 12. Avian Fatality Rates by Species Group

Species	Observed Fatality Rate[1]	Observed Annual Fatality Rate[2]	Searcher Efficiency Adjustment[3]	Scavenging Adjustment[4]	Adjusted Annual Fatality Rate[5]
Blackbirds	0.000	0.000	1.69	2.09	0.000
Corvids	0.000	0.000	1.09	1.00	0.000
Finches	0.000	0.000	1.69	2.09	0.000
Gamebirds	0.001	0.007	1.09	1.00	0.007
Horned Larks	0.013	0.163	1.69	2.09	0.578
Other	0.003	0.039	1.69	2.09	0.139
Raptors	0.003	0.039	1.09	1.00	0.042
Shorebirds	0.000	0.000	1.15	1.00	0.000
Sparrows	0.004	0.046	1.69	2.09	0.162
Swallows	0.002	0.020	1.69	2.09	0.069
Thrushes	0.001	0.013	1.69	2.09	0.046
Waterbirds	0.001	0.007	1.09	1.00	0.007
Waterfowl	0.000	0.000	1.09	1.00	0.000
Warblers	0.005	0.065	1.69	2.09	0.231
Woodpeckers	0.000	0.000	1.69	2.09	0.000
Wrens	0.005	0.059	1.69	2.09	0.208
Passerines	0.031	0.404	1.69	2.09	1.431
All Birds	0.035	0.456			1.489

[1] Observed number of fatalities/turbine/search
[2] Observed number of fatalities/turbine/year
[3] Expressed as 1/p, where p is the searcher efficiency rate used for that avian group
[4] Expressed as 28/t, where t is the mean removal time used for that avian group
[5] Expressed as the number of fatalities per turbine per year adjusted for carcass removal and searcher efficiency

Table 13. Avian Risk Indices by Species Group

Group	UV			Non-UV			Overall Risk Index
	Risk Index[1]	95% Confidence Intervals LL[2]	UL[3]	Risk Index	95% Confidence Intervals LL	UL	
Sparrows	0.165	0.037	1.458	0.242	0.000	1.091	0.191
Raptors	0.004	0.000	0.009	0.015	0.000	0.037	0.007
Swallows	0.010	0.000	0.016	0.000	0.000	0.000	0.007
Larks	0.007	0.003	0.013	0.002	0.000	0.008	0.006
Waterbirds	0.004	0.000	0.091	0.000	0.000	0.000	0.002

[1] Risk index expressed as the fatality rate/mean use
[2] Lower limit of 95% bootstrap confidence interval
[3] Upper limit of 95% bootstrap confidence interval

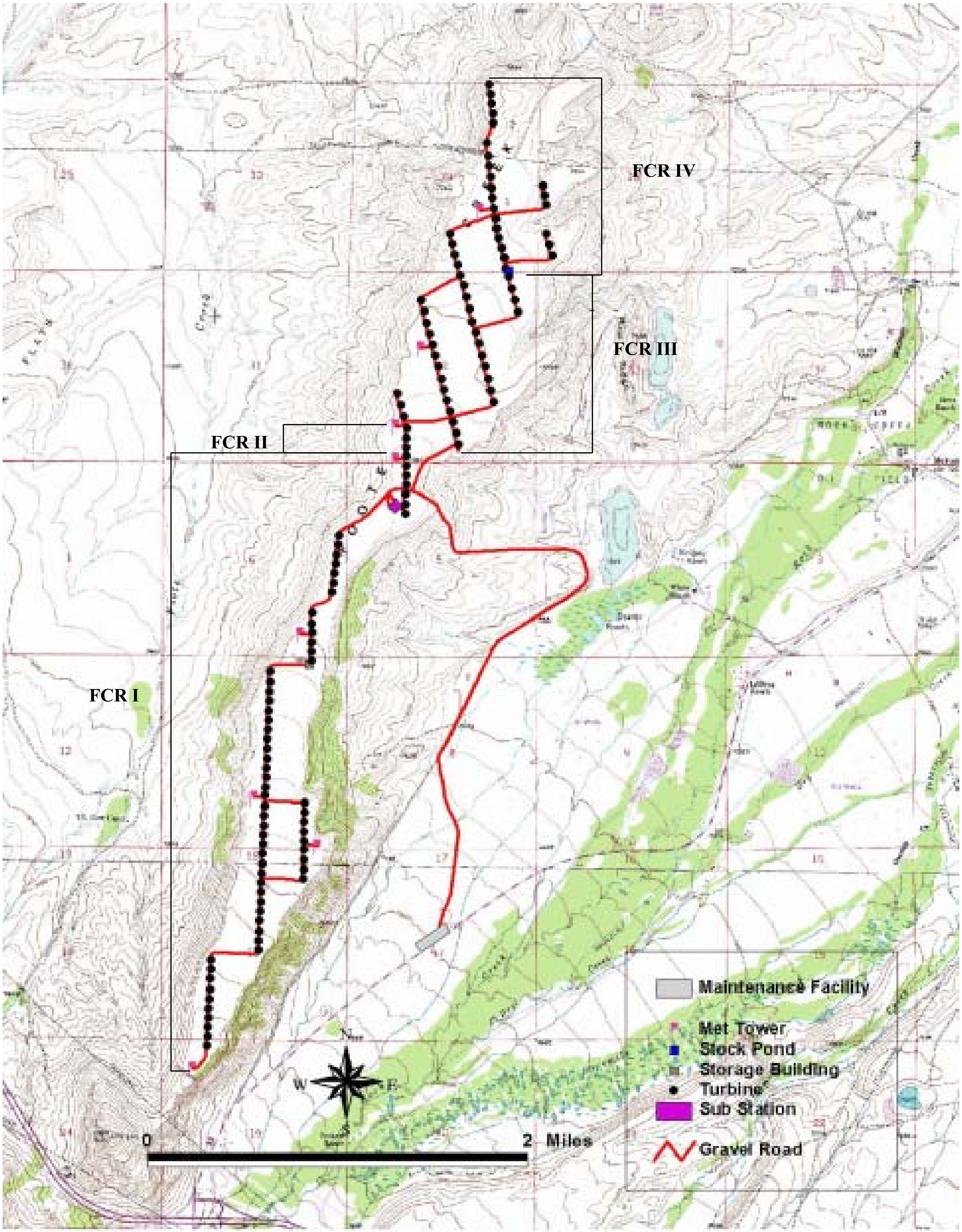


Figure 1. Foote Creek Rim Wind Plant and Construction Units

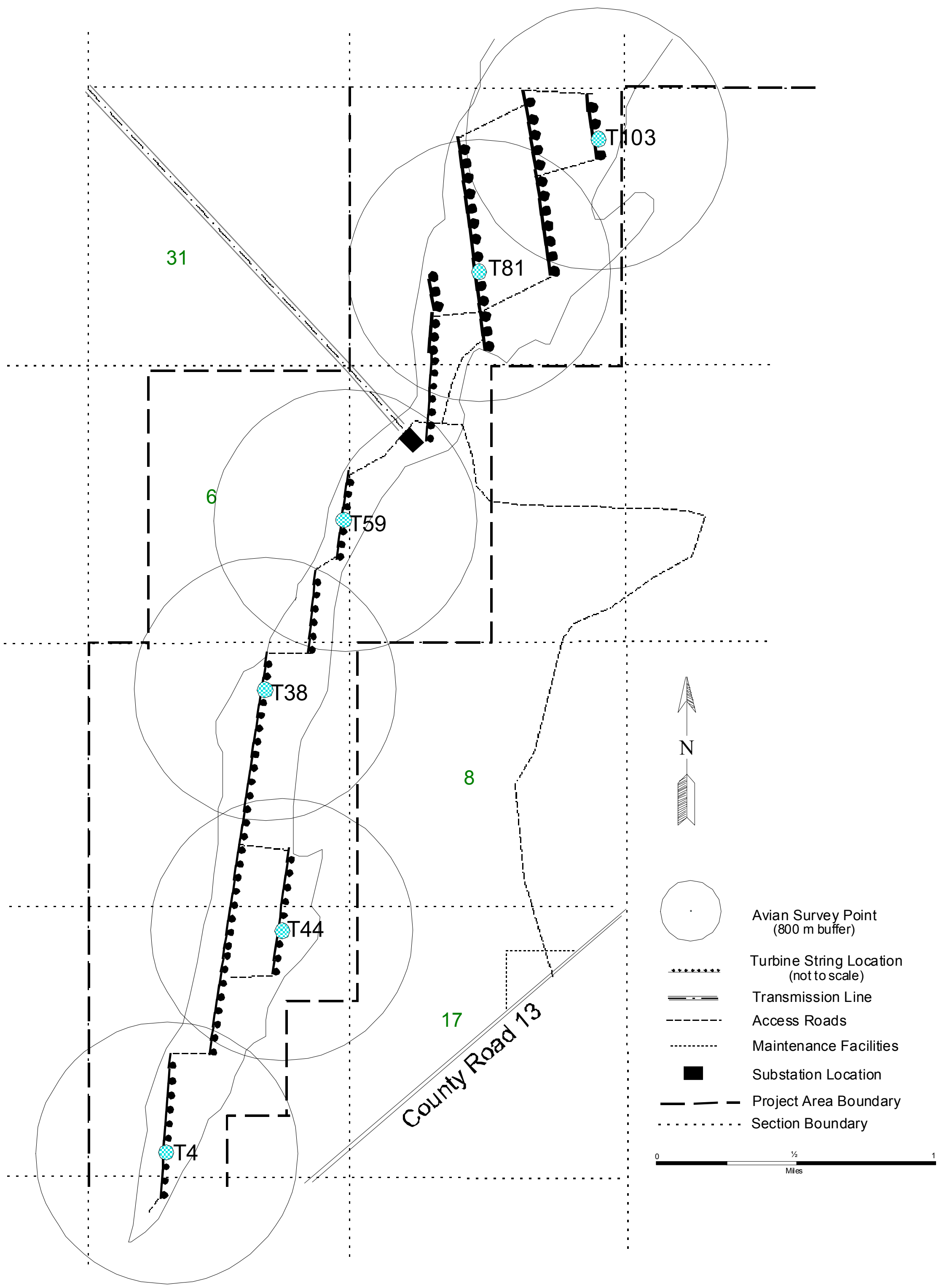


Figure 2. Avian Survey Point Layout

Raptors

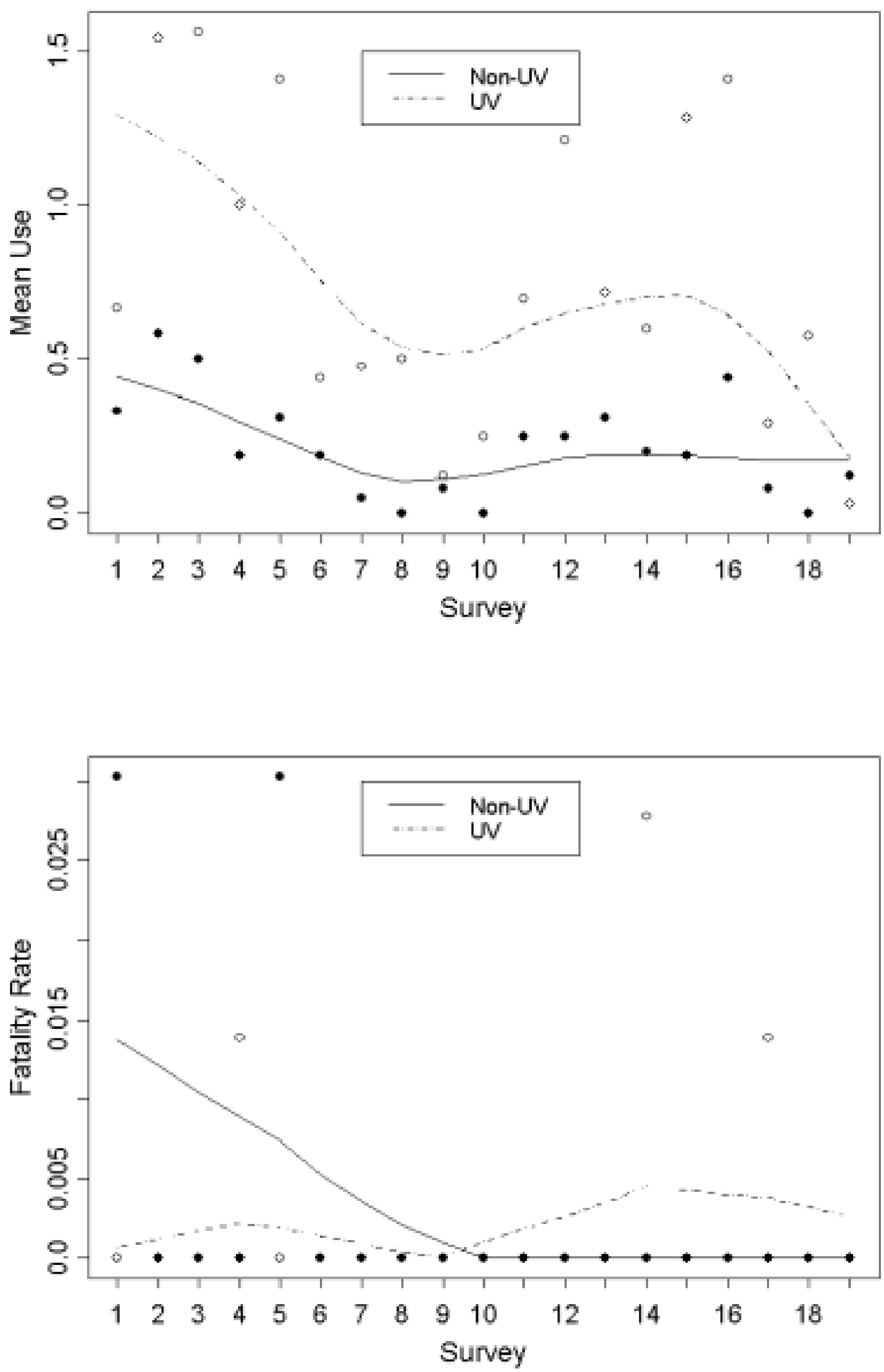


Figure 3. Raptor Use and Fatality by Survey Period for the UV and Non-UV Areas

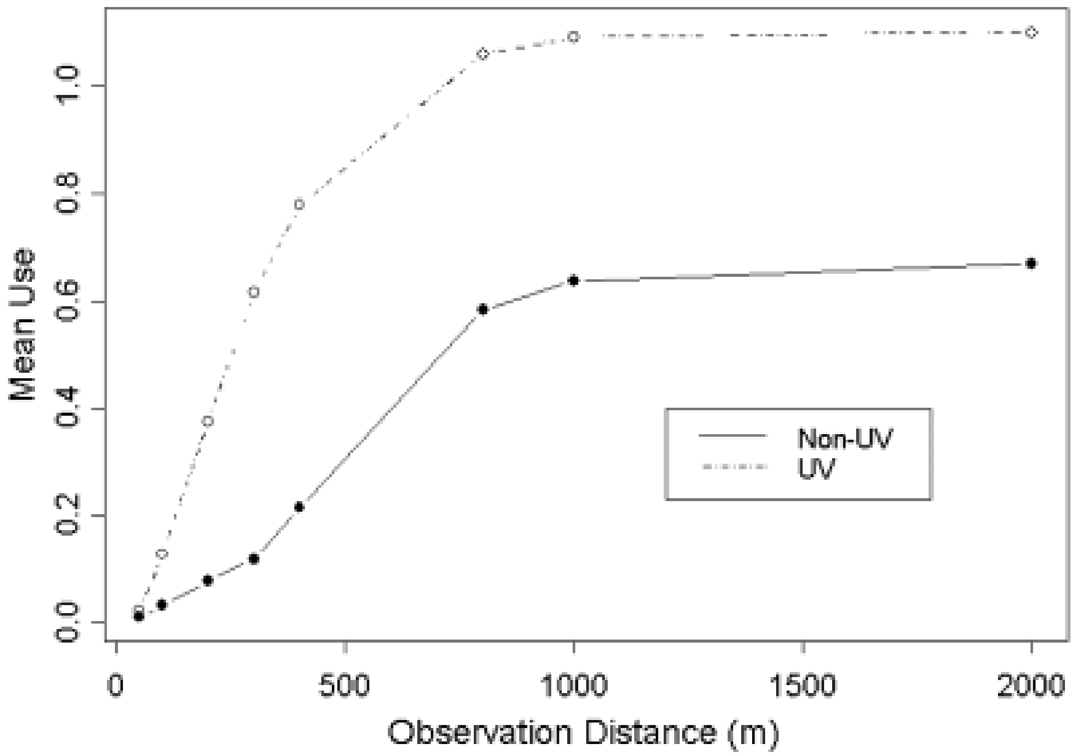
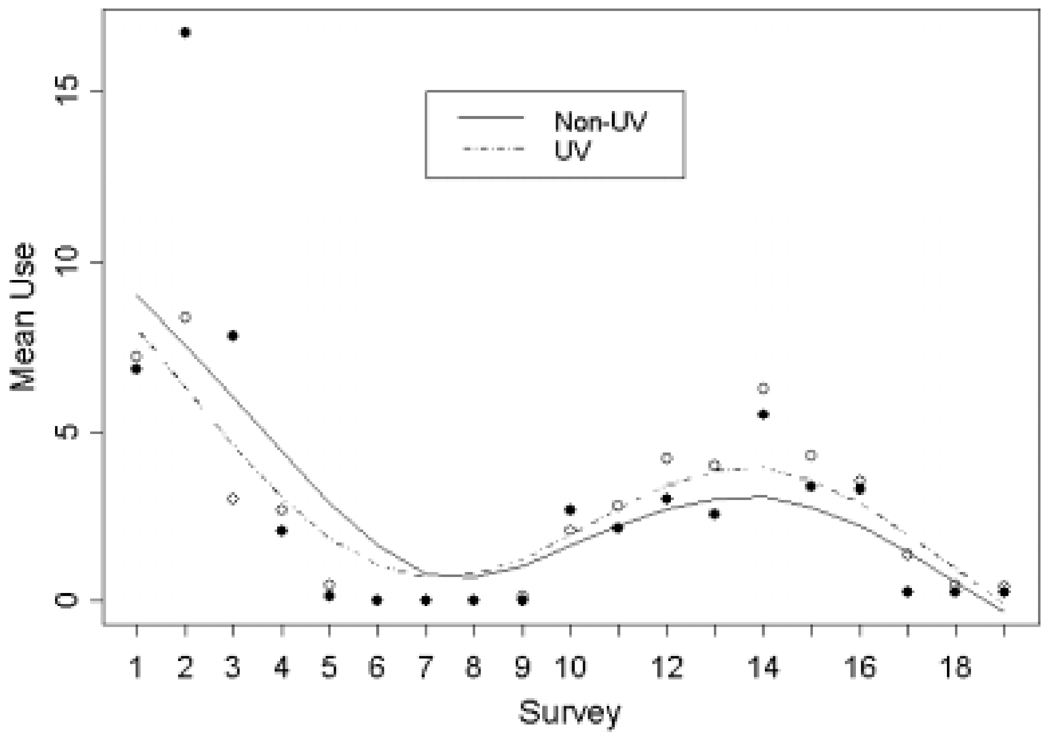


Figure 4. Raptor Use by Distance Band[1] from Turbines for UV and Non-UV Areas

[1] Plotted use is cumulative through distance bands.

Passerines



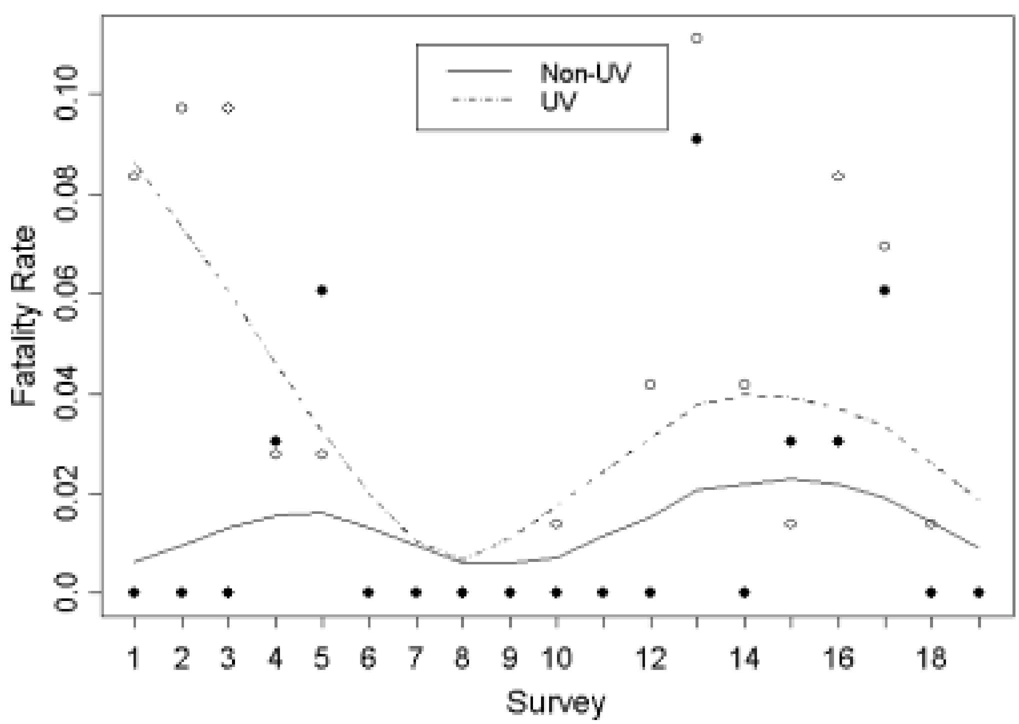


Figure 5. Passerine Use and Fatality by Survey Period for the UV and Non-UV Areas

Appendix A. Literature Review

LITERATURE REVIEW

PROPOSAL FOR STUDYING THE EFFECTS OF UV-LIGHT-REFLECTIVE PAINT APPLIED TO WIND TURBINES

Foote Creek Rim Wind Plant
Arlington, Wyoming

October 12, 2000

Prepared For:

National Renewable Energy Laboratory
Golden, Colorado 80401-3393

Prepared By:

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INTRODUCTION

Western EcoSystems Technology, Inc. (WEST) and the National Renewable Energy Laboratory (NREL) entered into a contractual agreement to study the effects of different turbine paint treatments on avian risk in the Foote Creek Rim wind plant in Wyoming. Two types of turbine treatments were tested at the facility: an ultraviolet (UV)-light-reflective paint and a conventional non-UV-reflective paint[1]. This study was undertaken because of growing concern over the number of bird deaths associated with utility development in the United States. The study evaluates whether there are differences in avian (particularly raptor) behavior, use, and mortality associated with the two turbine treatments, and therefore whether a treatment such as UV-reflective paint on turbines reduces the risk of avian collisions with wind turbines. In this paper, risk is defined as the chance of a bird colliding with a wind turbine and resulting in a fatality. If effective, UV-reflective paint may be a means for reducing the incidence of avian collisions with wind turbines.

A component of the overall study is a review of the literature and information available that address the project goal and objectives. This report is a review and critique of the available literature and data that address the issues relevant to the study. The review provides justification for the study design and sampling regime.

GOALS AND OBJECTIVES OF STUDY

The primary goal of the study is to evaluate the change in risk to avian species, particularly raptors, due to UV-light-reflective paint applied to wind turbines. The change in risk due to the treatment will be evaluated through measurement of avian behavior, use, and mortality within varying distances of turbines treated with UV-reflective-paint and conventional paint using standard statistical analyses for reference/impact designs (Skalski and Robson 1992).

The study has two components: avian surveys and carcass searching. The objective of the avian surveys is to estimate spatial and temporal use, and behavior by bird species (with an emphasis on raptors) near turbines treated with UV-reflective paint and conventional paint. The objective of the carcass searches is to compare mean number of carcasses per unit of avian use by species (and/or groups of species) among turbines treated with UV-reflective paint and conventional paint.

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[1]The Foote Creek Rim Wind Plant (the majority of which is owned by a variety of utilities) is operated by SeaWest Energy Corporation (SeaWest). At the time of this report, the existing wind plant consists of three units. *Foote Creek I* (41.4 MW) consists of 69 600-kW Mitsubishi turbines. *Foote Creek II* (1.8 MW) consists of 3 600-kW Mitsubishi turbines. The blades on these turbines, which are approximately 40 m high at the hub and have a 42-m rotor diameter, have been painted with a UV-light-reflective paint, which is presumed to enhance the visibility of the turbines to birds. *Foote Creek III* (24.75 MW) consists of 33 750-kW Micon turbines at the north end of Foote Creek I and II. These turbines are approximately 50 m high at the hub with a 44-m rotor diameter and have been treated with conventional, non-UV-reflective paint.

ADDITIONAL COMMENTS AND BACKGROUND

Raptors are vulnerable to collisions with turbine structures, and concern exists because of the potential for fatalities of these species in wind plants (Orloff and Flannery 1992). The wind industry and its regulators are attempting to reduce the number of deaths to avian species from windpower development. SeaWest is responsible for monitoring the effects of the Foote Creek Rim Wind Plant on avian use and mortality. Avian and other wildlife monitoring studies have been conducted on and around the Foote Creek Rim Wind Plant since 1995 (Johnson et al. 2000). Carcass searching studies have been under way since November 1998. Detailed background information exists describing avian use of the wind plant (Johnson et al. 2000). Risk estimates for individual species and groups of birds (e.g. buteos, eagles, falcons, waterfowl, etc.) have been calculated.

The study design currently proposed is primarily suited for wide-ranging species like raptors and waterfowl, but information will be obtained for other species of concern, such as mountain plovers (*Charadrius montanus*). The study is designed to measure avian use and mortality on plots containing turbines treated with UV-reflective paint and conventional paint. During the study, an outside reference area of similar size will be sampled for use to meet monitoring requirements and serve as a reference area for this study. All turbine strings, whether treated with UV-reflective or conventional paint, will be surveyed for avian use, behavior, and fatality. Although the study plan will focus primarily on field and analysis methods used to evaluate the effects of the UV-reflective treatment on risk of mortality to avian species, the data collected may also be used to estimate the impacts of the entire wind plant on avian species.

In this study, use will be evaluated as a function of distance to UV-reflective-painted turbines and conventionally painted turbines. Mortality will be measured through carcass searches. An estimate of mortality per unit of use will also be calculated.

LITERATURE REVIEW

In-depth studies of avian use and mortality at wind farms primarily began in the mid-1980s. Many earlier studies involved only a few turbines or focused on nocturnal migrants (waterfowl or passerines) (see CEC 1995). In recent years, there have been numerous studies in the United States and Europe that have intensively investigated the effects of wind turbine development on birds (see CEC 1996). Several of these studies specifically deal with raptors at larger wind farms. However, few studies have addressed the effects of various turbine design features (treatments) or techniques that may reduce mortality.

Few studies have addressed the visibility of turbines and blades, especially turning blades, to birds. Flight behavior around turbines has been examined (Clarke 1989, Orloff and Flannery 1992, LGL 1995, Winkelman 1995, Flannery 1996), but few have studied factors influencing flight patterns. One study looked at the effect of varying turbine color patterns on avian-turbine collisions with inconclusive results (Howell et al. 1991). The number of bird fatalities at five sites with painted turbines was compared with 10 sites with unpainted turbines. Carcass searches were conducted once per week at each site for 12 months. Mortality rates were low, resulting in small sample sizes. The authors suggested that design patterns on blades can increase and decrease the visibility of the blades. Also, uniformly colored blades did not deter birds as well as patterned blades.

No data exists on the effects of UV paint on bird/wind turbine collisions. We conducted a literature review of biological studies of birds and UV vision. The study design, results, and conclusions of relevant papers are described in Appendix A. The literature search was conducted in order to determine whether painting turbine blades with UV-reflective paint could potentially decrease avian collisions. In order to determine this, the following questions must be answered: (1) What is UV light, and how much is available?; (2) Are birds sensitive to UV light?; and (3) Can birds detect UV-reflective objects better?

What Is Ultraviolet Light, and How Much Is Available?

Ultraviolet (UV) light can be defined as light between the wavelengths 0 and 400 nm. Wavelengths below 300 nm are largely absorbed by ozone in the atmosphere (Huffman 1992). Ultraviolet light available for vision in birds is between 320 and 400 nm because light shorter than 310 nm is absorbed by nucleic acids and proteins (Jacobs 1992). We refer to UV light as light between the wavelengths 320 and 400 nm. Humans can only detect light between 400 and 700 nm (visible light).

The sun is the primary source of UV and visible light for the earth. Visible and UV light comprise 43.5% and 5.32 % respectively of the energy emitted by the sun (Miller and Thompson 1979). UV light is most prevalent during daylight hours; however, some UV light has been detected by satellites at night (Roach and Gordon 1973, Huffman 1992). Very little UV light above 320 nm is absorbed by the atmosphere (Huffman 1992). UV light is more prevalent at higher elevations (Lynch and Livingston 1995).

Are Birds Sensitive to UV Light?

Birds have at least four types of cone visual pigments that absorb light up to 362, 380, 355, and 371 nm in European starlings (*Sturnus vulgaris*), zebra finches (*Taeniopygia guttata*), Pekin robins (*Leothrix lutea*) and budgerigar (*Melopsittacus undulatus*) respectively (Maier and Bowmaker 1993, Bowmaker et al. 1997, Hart et al. 1998). Birds also have transparent oil droplets, which are associated with UV-sensitive cones (Bennet and Cuthill 1994).

Early studies of UV vision in birds focused on determining how many species were sensitive to UV light. Authors have found UV vision in at least 30 species of birds (see Bennett and Cuthill 1994 for a review). Most diurnal species are probably sensitive to UV light (Jacobs 1992), although nocturnal species are probably not sensitive to UV light (Jacobs 1992, Koivula et al. 1997). Later studies focused on the following functions of UV vision in birds: (1) sexual selection, (2) predator avoidance, (3) foraging/hunting, and (4) orientation and migration.

A) Sexual Selection

UV-reflective plumage may be important in sexual selection for many species of birds. Female blue tits (*Parus caeruleus*), bluethroats (*Luscinia s. svecica*), Pekin robins (*Leiothrix lutea*), and zebra finches (*Taeniopygia guttata*) select males for mating that have plumages which reflect more UV light (Maier 1993, Bennett et al. 1996, Andersson and Amundsen 1997, Andersson et al. 1998, Hunt et al. 1998, Johnsen et al. 1998). Species such as the blue tit, in which male and females are indistinguishable to the human eye, show sexual differences in UV reflectance

(Andersson et al. 1998, Hunt et al. 1998). Because most species of birds have UV-reflective plumage, it is likely that many species use UV cues in sexual selection.

B) Predator Avoidance

Although UV-reflective plumage appears to serve an obvious function in sexual selection, it may also play a role in predator avoidance. No studies have been conducted to test the predator avoidance hypotheses, but Andersson (1996) has provided some theories. The whistling thrushes (*Myiophonus spp*.) show much more coloration in the UV range than in visible wavelengths. Andersson (1996) presents some ecological theories for an almost total UV plumage. First, some birds live in UV-rich high altitude areas, which have a mix of open areas (rich in UV light) and shady forested areas (poor in UV light). The birds' UV-reflective plumage would be highly visible in open areas, perhaps playing a role in sexual selection. When threatened, the birds could move to the UV-poor shade, which makes them more cryptic. Second, most mammalian predators are not as sensitive to UV light, allowing the birds to hide from predators while being visible to other members of their species. Third, UV colors are more diffuse from long distances, providing some protection from raptor predation.

C) Foraging/Hunting

UV vision may allow birds to more efficiently locate prey. Eurasian kestrels (*Falco tinnunculus*) and rough-legged buzzards (*Buteo lagopus*) use vole urine trails, which are visible only in the UV spectrum, to locate hunting areas (Viitala et al. 1995, Koivula and Viitala 1999). Lemmings (*Dicrostonyx groenlandicus*) in the arctic tundra have countered the above adaption by urinating in underground passages (Boonstra et al. 1996). Foods often eaten by songbirds, such as berries, seeds, flowers, and insects, may reflect UV light (Eisner et al. 1978, Burkhardt 1982, Wilson and Whelan 1989, Chittka et al. 1994). Blue tits and redwings (*Turdus iliacus*) may use UV vision to help locate insects (Church et al. 1998) and berries (Siitari et al. 1999) when foraging.

D) Orientation and Migration

Bees use UV light for orientation, and authors have theorized that birds use UV light in similar ways (see Bennett and Cuthill 1994 for a summary). However, few studies have been conducted that investigate how birds may use UV light for orientation and migration. Pohl (1992) found that he could entrain circadian rhythms in domestic canaries (*Serinus canaria*) using UV light and theorized that UV light could be a zeitgeber for migration. Most songbirds migrate at night (Evans 1985), and it is not known whether there is sufficient UV light present at night for birds to detect. Birds may use other cues for orientation when migrating at night.

Can Birds Better Detect UV-Reflective Objects?

No study has been designed to specifically answer this question. Although it is well known that birds can detect UV light, controversy exists as to whether birds are more sensitive to UV or visible light. The Pekin robin and homing pigeon (*Columbia livia*) are more sensitive to UV light than visible light in behavioral experiments (Kreithen and Eisner 1978, Burkhardt and Maier 1989). Extracting bird eyes and measuring retinal responses, Chen et al. (1984) found the spectral sensitivities of 15 North American species (including the homing pigeon) to be highest in the visible spectrum, with a smaller peak in the UV spectrum. If birds do have higher spectral sensitivities in the UV range, it is not known whether they can better detect UV-reflective objects.

SUMMARY AND RELEVANCE TO THE STUDY

Most species of birds, including raptors, are probably able to detect UV light, a spectrum not detected by the human eye. UV vision is potentially important for most aspects of a bird's life, including sexual selection, predator avoidance, foraging or hunting, and orientation and migration. Painting turbine blades with UV-reflective paint could potentially reduce bird collisions by making the blades more visible to birds. Additionally, UV light may be more prevalent at Foote Creek Rim than other wind plant sites due to its elevation (approximately 7500-7900'), although the UV-painted blades may be hidden in a UV-rich background. Current research concerning birds and UV vision is now at the stage at which more applied studies are needed. The current turbine comparison study will help fill a void in the current literature by determining whether painting man-made structures with UV-reflective paint will help birds detect blades and avoid collisions.

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Review of Selected Papers Investigating the Significance of UV Vision to Birds

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Andersson, S. 1996. Bright ultraviolet colouration in the Asian whistling thrushes (*Myiophonus spp.*). Proceedings of the Royal Society of London Series B-Biological Sciences 263: 843-848.

The author measured the UV reflectance of five *Myiophonus* species (30 total specimens). The thrushes, which are dark blue-black to the human eye, show large amounts of contrast in the UV spectrum. The author suggests that few other species have shown as much UV contrast as the *Myiophonus* spp. and provides theories concerning UV perception, UV color production, and visual ecology. *Myiophonus* spp may use UV reflectance for communication.

Andersson, S. and T. Amundsen. 1997. Ultraviolet colour vision and ornamentation in bluethroats. Proceedings of the Royal Society of London Series B-Biological Sciences 264: 1587-1591.

The authors attempted to determine whether captive bluethroat (*Luscinia s. svecica*) females differentiated between captive males based upon the UV color or brightness of male throat patches. The throat patches of males were given one of two treatments: 1) a reduction in brightness and color of the throat patch using duck preen fat gland and UV-absorbing chemicals (NR); and 2) a reduction of brightness only, using the same substance but with the UV-absorbing chemicals replaced with an oxide black (UVR). A total of 30 males (with one male reused in pairing) were paired and given either the UVR treatment (n = 16) or the NR treatment (n = 16). A total of 21 females were used in choice trials. Sixteen trials (per female) lasting 30 minutes each were conducted. Females preferred males that had only the brightness reduced, suggesting UV color may play a more important role than brightness. Two-year-old male bluethroats also had higher UV reflectance than one-year-old males. However, the role of brightness in female choice could not totally be ruled out.

Andersson, S., J. Örnborg and M. Andersson. 1998. Ultraviolet sexual dimorphism and assortative mating in blue tits. Proceedings of the Royal Society of London Series B-Biological Sciences 265: 445-450.

The authors measured the UV reflectance of the crowns of 41 wild-captured blue tits (*Parus caeruleus*) against natural leaf litter and green vegetation backgrounds. Blue tits show sexual dimorphism in UV-crest reflectance. The authors also suggest that bluish early morning light enhances the UV visibility of the crest of displaying males.

Burkhardt, D. and E. Maier. 1989. The spectral sensitivity of a passerine bird is highest in the UV. Naturwissenschaften 76: 82-83.

The authors investigated the sensitivity of the Pekin Robin (*Leiothrix lutea*) to light wavelengths of 320 to 680 nm. The authors do not state how many birds were used in experiments, nor the duration of the trials. A total of 3,721 choices were evaluated. Birds were trained (rewarded with a food pellet) to choose a dark screen versus a screen lighted with various light intensities and wavelengths. Birds made the most correct choices at higher light intensities. The authors used the reciprocal of the intensity value for each wavelength at which 75% choices were correct as the bird's sensitivity (%) for a given wavelength. The only results given for sensitivity are a graph of the best-responding bird. The bird showed sensitivity to light at 380 nm that was five times that at 530 nm. The authors suggested that UV vision is important in behaviors guided by sight in birds.

Chen, D., J.S. Collins and T.H. Goldsmith. 1984. The ultraviolet receptor of bird retinas. Science: 225: 337-339.

The authors extracted the eyes from 15 species of North American birds to examine spectral sensitivities. The authors do not state how many birds of each species were tested. Eyes were stimulated with lights of various wavelengths and transretinal voltage responses measured. All species showed sensitivity peaks in the UV spectrum; however, the highest sensitivities were in the visible spectrum (510-580 nm). Species used in experiments included rock dove (*Columbia livia*), ruby-throated hummingbird (*Archilochus colubris*), blue jay (*Cyanocitta cristata*), barn swallow (*Hirundo rustica*), black-capped chickadee (*Parus atricapillus*), gray catbird (*Dumetella carolinensis*), brown thrasher (*Toxostoma rufum*), wood thrush (*Hylocichla mustelina*), American robin (*Turdus migratorius*), house sparrow (*Passer domesticus*), house finch (*Carpodacus mexicanus*), northern cardinal (*Cardinalis cardinalis*), red-winged blackbird (*Agelaius phoeniceus*), song sparrow (*Melospiza melodia*), and white-throated sparrow (*Zonotrichia albicollis*).

Church, S.C., A.T.D. Bennett, I.C. Cuthill and J.C. Partridge. 1998. Ultraviolet cues affect the foraging behaviour of blue tits. Proceedings of the Royal Society of London Series B-Biological Sciences 265: 1509-1514.

The authors investigated the effects of UV light on the foraging efficiency of captive blue tits *(Parus caeruleus*). Seven male blue tits were used in the experiments. A block design was used. Two blocks over eight days were used in cabbage moth experiments, and four blocks over 15 days were used in winter moth experiments. UV blocking and non-blocking filters were used in addition to various backgrounds as treatments. Cabbage moth larvae and winter moth larvae were used seperately in foraging experiments. Blue tits found the first prey item out of four more quickly in the UV-light environment. Blue tits were particularly efficient at finding cabbage moth larvae, perhaps because they showed greater differences in UV reflectance from the backgrounds used. The authors suggest that with the current state of knowledge, “Nevertheless, at this stage it would be unwise to claim that UV vision is somehow ‘special’ compared to human-visible wavelengths.”

Goldsmith, T.H. 1980. Hummingbirds see near ultraviolet light. Science 207: 786-788.

The author trained black-chinned (*Achilochus alexandri*), blue-throated (*Lampornis clemenciae*) and magnificent (*Eugenes fulgens*) hummingbirds to distinguish UV light (350-390 nm) from visible light when feeding from feeders. Experiments were conducted in the field on a population of approximately 90 wild birds. The authors do not state the time period over which the experiments were conducted.

Hunt, S., A.T.D. Bennett, I.C. Cuthill and R. Griffiths. 1998. Blue tits are ultraviolet tits. Proceedings of the Royal Society of London Series B-Biological Sciences 265: 451-455.

The authors measured UV reflectance of blue tits (*Parus caeruleus*) and mate choice of females. Plumage reflectance was measured in nine males and nine females for most characteristics. Female choice trials were conducted with seven females. Females were given a choice of two males that they had not encountered before. One trial per female was conducted for 10 hours. Male and female blue tits are almost identical to the human eye but show sexual differences in UV reflectance in the crest, tail, back, nape, and crown. Females preferred males that had the highest UV reflectance in their crests.

Johnsen, A., S. Andersson, J. Örnborg and J.T. Lifjeld. 1998. Ultraviolet plumage ornamentation affects social mate choice and sperm competition in bluethroats (Aves: *Luscinia s. svecica*): a field experiment. Proceedings of the Royal Society of London Series B-Biological Sciences 265: 1313-1318.

The authors conducted field experiments on male bluethroats *(Luscinia s. svecica*) to determine whether reduced UV reflectance of throat patches affected mating success. Male throat patches were treated with preen fat gland and UV-absorbing sunblock chemicals (UVR). Control males (C) were treated with the preen fat gland and oxide black or with only the preen fat gland. The experiment was conducted over two years, with 69 males (32 UVR, 37 C) studied during 1996 and 1997. Egg-laying dates were determined for 64 mates. Time budgets were recorded for 16 UVR and 27 C pairs. Pairs were observed for 20 minutes/day over two days. The mates of treatment males had delayed egg-laying dates, guarded their mates more closely, and had fewer extra-pair fertilizations.

Koivula, K., E. Korpimäki and J. Viitala. 1997. Do Tengmalm's owls see vole scent marks visible in ultraviolet light? Animal Behaviour 54: 873-877.

The authors conducted a laboratory study similar to Viitala et al. (1995) to determine whether Tengmalm's owls (*Aegolius funereus*) could detect vole urine in UV light. Experiments were conducted on 14 adult owls in October 1994 and 14 four- to five-month-old owls in August 1993. Experiments were conducted in a room with four arenas: 1) with vole urine and a blacklight, 2) without vole urine and with a black light, 3) with vole urine and ordinary 60-W light, and 4) without vole urine with an ordinary 60-W light. Each owl was introduced to the arenas for two sessions of 15 minutes. The owls showed no statistically significant preference for any of the treatments. The authors suggest that because Tengmalm's owls hunt largely at night and rely largely on acoustic signals, UV vision has not evolved. The authors also suggest that there may not be enough UV light available at night to allow for color detection.

Koivula, M., and J. Viitala. 1999. Rough-legged buzzard use vole scent marks to assess hunting areas. Journal of Avian Biology 30: 329-332.

The authors conducted field experiments in northern Finnish Lapland to determine whether rough-legged buzzards (*Buteo lagopus*) used plots treated with vole urine more often than control plots (500 m from treatment plots) treated with water. A total of 66 treatment plots over two years were observed. The total number of observation days was 36. The reflectance of treatment vole urine was measured and showed higher UV reflectance than the control 'treatments.' Buzzards and ravens (*Corvus corax*) were observed more often over treatment plots than control plots. The authors suggest buzzards may be able to observe the UV reflectance of vole urine to assess the quality of hunting areas.

Kreithen, M.L. and T. Eisner. 1978. Ultraviolet light detection by the homing pigeon. Nature 272: 347-348.

The authors measured the spectral sensitivity of the homing pigeon (*Columbia livia*) under laboratory conditions. Pigeons were conditioned to expect electric shocks at different wavelengths. The threshold intensity for different wavelengths was determined by finding the intensity at which a pigeon failed to respond 50% of the time. Six pigeons were tested with UV light and four pigeons (including one used in the UV testing) were tested using a filter that blocked UV light. The number of trials per bird is not given; however, the responses shown in a graph are taken from a bird tested more intensely than the other birds. Pigeons showed the highest sensitivity to UV light (325-360 nm).

Parrish, J., R. Benjamin and R. Smith. 1981. Near-ultraviolet light reception in the mallard. Auk 98: 627-628.

The authors used shock treatment to determine whether male and female mallards (*Anas platyrhynchos*) were sensitive to UV light. Eleven mallards (four male, seven female) were conditioned with shock treatments before being shown UV light. A total of 53 and 109 UV light trials and 44 and 38 trials with a UV light filter were conducted on male and female mallards respectively. Trials lasted 10 seconds. Mallard heart rates increased just prior to shocking when shown UV light.

Parrish, J.W., J.A. Ptacek and K.L. Will. 1984. The detection of near-ultraviolet light by nonmigratory and migratory birds. Auk 101: 53-58.

The authors determined whether migratory and non-migratory bird species were sensitive to UV light. Sensitivity to UV light was determined by using key-pecking, shuttle box, or shock avoidance techniques. A total of 24 birds of 11 species were tested. The experiments were conducted on birds trapped in 1980 and 1981. The duration of the tests is not stated; however, several shuttle box trials (minimum = 12 for white-crowned sparrow, maximum = 210 for house sparrow) were conducted for each species. The sensitivity to UV light was demonstrated for the non-migratory species blue jay (*Cyanocitta cristata*), house sparrow (*Passer domesticus*), and northern cardinal (*Cardinalis cardinalis*) and the migratory species brown-headed cowbird (*Molothrus ater*), Harris' sparrow (*Zonotrichia querula*), European starling (*Sturnus vulgaris*), common grackle (*Quiscalus quiscula*), dark-eyed junco (*Junco hyemalis hyemalis*), American tree sparrow (*Spizella arborea*), white-crowned sparrow (*Zonotrichia leucophrys*) and belted kingfisher (*Cerle alcyon*). The authors suggest UV vision is present and important for most diurnal birds.

Pohl, H. 1992. Ultraviolet radiation: A zeitgeber for the circadian clock in birds. Naturwissenschaften 79: 227-229.

The author investigated whether ultraviolet light affected the hopping activity of eight male domestic canaries (*Serinus canaria*). Birds were put individually in lightproof and soundproof boxes with a background light in the visible spectrum. UV light in two different ranges (350 - 400 nm and 400 - 440 nm) was introduced for 12 hours and hopping activity measured. UV light affected the hopping and feeding activity in seven of 11 tests. However, the UV light used in experiments increased the energy by 200% - 300%. Although light intensity was a confounding factor, the author concluded that changes in daily amounts of UV light found in nature are sufficient for affecting a bird's circadian rhythm.

Maier, E.J. 1993. To deal with the "invisible": On the biological significance of ultraviolet sensitivity in birds. Naturwissenschaften 80: 476-478.

The authors investigated whether captive female *Leiothrix lutea* could differentiate between captive male *Leiothrix lutea* based upon UV coloration. Six females and 11 males were used in experiments. Two males were placed behind adjacent Plexiglas, one which transmitted UV light and one which absorbed UV light. An Osram 5000 Daylight de Luxe and two halogen lights were used to light the room. Each female was tested against two pairs of males. Tests lasted two hours, and the number of visits to males were recorded. Female mean preference scores were significantly higher for the males behind UV-transmittance Plexiglas. The author concluded that UV light might be used for species recognition and sexual selection.

Siitari, H., J. Honkavaara and J. Viitala. 1999. Ultraviolet reflection of berries attracts foraging birds. A laboratory study with redwings (*Turdus iliacus*) and bilberries (*Vaccinium myrtillus*). Proceedings of the Royal Society of London Series B-Biological Sciences 266: 2125-2129.

The authors investigated whether redwings (*Turdus iliacus*) preferred UV-reflective bilberries (*Vaccinium myrtillus*) over non-UV-reflective bilberries in a laboratory setting. The waxy layer of bilberries reflects UV light. Rubbed berries do not reflect UV light. Trials were conducted with nine adults (captured from the wild) and 20 juvenile birds. Each bird was tested during two trials, one with UV light present and one with UV light absent. Adults preferred waxy berries in UV light, while juveniles showed no preference. Adults did not show any preference for waxy berries in non-UV light. The authors suggest that frugivorous birds use UV vision when foraging for certain species of berries and that learning may play a role in this behavior.

Viitala, J., E. Korpimäki, P. Palokangas and M. Koivula. 1995. Attraction of kestrels to vole scent marks visible in ultraviolet light. Nature 373: 425-427.

The authors conducted lab and field experiments in Finland to determine whether Eurasian kestrels (*Falco tinnunculus*) could detect vole urine trails using UV vision. A total of 19 kestrels were given two trials of 15 minutes/trial in lab experiments. The amount of time spent by kestrels perched above vole-urine-soaked and non-soaked straw was measured under UV and non-UV light. Fifteen nestboxes per treatment (three treatments) were used in field experiments. Field treatments included 1) artificial vole trails treated with vole urine and feces, 2) artificial vole trails without urine, and 3) no vole trails or urine. Field observations were conducted for 24 mornings, and each nestbox was observed for 15-30 minutes per morning. Vole urine trails are visible in UV light. Kestrels in lab settings preferred areas with vole urine and UV light. In the field, wild kestrels hunted most often from nestboxes in areas that had been treated with vole urine. Rough-legged buzzards (*Buteo lagopus*) were also seen in urine-treated areas more often than non-treated areas. The authors suggest that diurnal raptors can assess vole numbers by using UV vision to detect vole urine trails.

Appendix B. Example Data Sheet

RAPTOR & LARGE BIRD OBSERVATION DATA SHEET: *FIXED POINT TURBINES* SOUTH: T4 & T44

GENERAL: DATE ______________ OBSERVER_________ START TIME________ END TIME_______ PAGE_____of_____

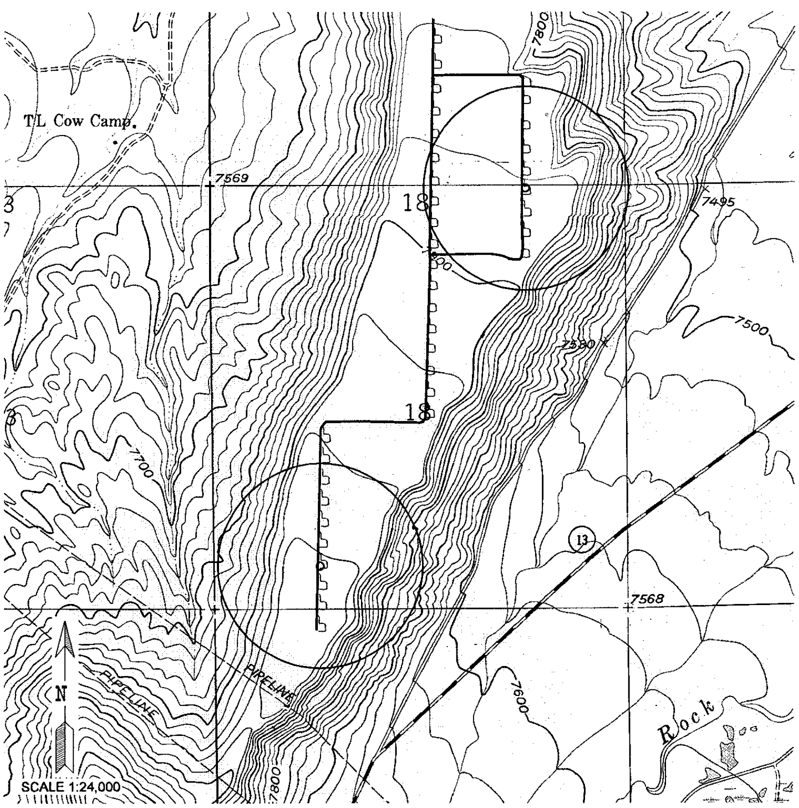
WEATHER: VISIBILITY(circle one) good fair poor CLOUD COVER(%)_________ TEMP(°C)_________

WIND: DIRECTION (circle one) N NE E SE S SW W NW n/a SPEED(kph) Low:_________ High:_________

PRECIPITATION(circle one) none light rain rain light snow snow sleet hail other_______________________

STATION: NUMBER: __________ TURBINE TYPE: ______________ OPERATING(circle one): YES / NO

Obs. no.	Species	Sex	Age	No. of individs	Distance (m) from observer (√/box <400m)	Activity	Flight Height (meters) P	1-18	19-62	63-100	>100	Direction of Flight	Habitat	Instant count (height/ distance)	Close. turb. (height/ dist.)	Avoid-ance Behav (√/note)
					☐	PE SO FL FH CS HU GL OT						N NE E SE S SW W NW CH GP	SB AS SG MM CO CR HA OT			
					☐	PE SO FL FH CS HU GL OT						N NE E SE S SW W NW CH GP	SB AS SG MM CO CR HA OT			
					☐	PE SO FL FH CS HU GL OT						N NE E SE S SW W NW CH GP	SB AS SG MM CO CR HA OT			
					☐	PE SO FL FH CS HU GL OT						N NE E SE S SW W NW CH GP	SB AS SG MM CO CR HA OT			
					☐	PE SO FL FH CS HU GL OT						N NE E SE S SW W NW CH GP	SB AS SG MM CO CR HA OT			
					☐	PE SO FL FH CS HU GL OT						N NE E SE S SW W NW CH GP	SB AS SG MM CO CR HA OT			
					☐	PE SO FL FH CS HU GL OT						N NE E SE S SW W NW CH GP	SB AS SG MM CO CR HA OT			



NOTES:

Data Entry			
Entered by:		Date entered:	
Record Nos:			

NREL - FOOTE CREEK RIM
TURBINE COMPARISON STUDY 1999-2000

Appendix C. Bird Casualties Recorded

Species/Group	Date	Scheduled Search	Plot Number	Plot Type	Distance to Structure
Horned Lark	07/05/1999	Yes	15	UV Turbine	15
Horned Lark	07/09/1999	Yes	35	UV Turbine	42
American Robin	07/19/1999	Yes	2	Met Tower	32
Horned Lark	07/19/1999	Yes	26	UV Turbine	4
Horned Lark	07/19/1999	Yes	28	UV Turbine	41
Horned Lark	07/19/1999	Yes	29	UV Turbine	10
Horned Lark	07/22/1999	Yes	71	UV Turbine	10
Prairie Falcon	07/23/1999	Yes	98	Non-UV Turbine	38
Brewers Sparrow	08/02/1999	Yes	17	UV Turbine	26
Horned Lark	08/02/1999	Yes	19	UV Turbine	19
Horned Lark	08/16/1999	Yes	2	Met Tower	21
Western Tanager	08/16/1999	Yes	2	Met Tower	18
Horned Lark	08/16/1999	Yes	3	UV Turbine	12
Unidentified Swallow	08/16/1999	Yes	8	UV Turbine	42
Unidentified Passerine	08/16/1999	Yes	23	UV Turbine	45
Cliff Swallow	08/17/1999	Yes	5	UV Turbine	20
Horned Lark	08/17/1999	Yes	52	UV Turbine	21
Wilson’s Warbler	08/31/1999	Yes	12	UV Turbine	27
Unidentified Passerine	08/31/1999	Yes	31	UV Turbine	18
MacGillivray’s Warbler	09/02/1999	Yes	60	UV Turbine	57
Rock Wren	09/09/1999	No	68	UV Turbine	19
Vesper Sparrow	09/13/1999	Yes	5	Met Tower	40
Vesper Sparrow	09/13/1999	Yes	5	Met Tower	26
House Wren	09/13/1999	Yes	65	UV Turbine	54.5
Wilson’s Warbler	09/13/1999	Yes	66	UV Turbine	55
Townsend’s Warbler	09/13/1999	Yes	67	UV Turbine	49
House Wren	09/13/1999	No	202	Met Tower	21
Chipping Sparrow	09/14/1999	Yes	202	Met Tower	29.5
Chipping Sparrow	09/14/1999	Yes	202	Met Tower	27
Rock Wren	10/11/1999	Yes	24	UV Turbine	61
Common Poorwill	10/11/1999	Yes	202	Met Tower	19
Horned Lark	10/11/1999	Yes	202	Met Tower	20
American Kestrel	10/12/1999	Yes	65	UV Turbine	22
Rock Wren	10/12/1999	Yes	65	UV Turbine	47
Unidentified Passerine	10/12/1999	Yes	68	UV Turbine	77
Unidentified Passerine	10/12/1999	Yes	72	UV Turbine	66
Dark-Eyed Junco	10/13/1999	Yes	88	Non-UV Turbine	27
Brown Creeper	10/21/1999	No	17	UV Turbine	31.5
Golden Eagle	10/21/1999	No	100	Non-UV Turbine	42
Brown Creeper	10/25/1999	Yes	18	UV Turbine	28
Western Grebe	10/26/1999	Yes	41	UV Turbine	44
Rock Wren	10/27/1999	Yes	77	Non-UV Turbine	53
Rock Wren	10/27/1999	Yes	95	Non-UV Turbine	42
Horned Lark	03/27/2000	Yes	4	UV Turbine	5

Appendix C (Continued). Bird Casualties Recorded

Species/Group	Date	Scheduled Search	Plot Number	Plot Type	Distance to Structure (m)
Sage Grouse	04/28/2000	Yes	84	Non-UV Turbine	45
Green-Tailed Towhee	05/22/2000	Yes	22	UV Turbine	44
Horned Lark	05/22/2000	Yes	29	UV Turbine	54
Brewers Sparrow	05/23/2000	Yes	4	Met Tower	9
Horned Lark	05/23/2000	Yes	4	Met Tower	25
Vesper Sparrow	05/23/2000	Yes	69	UV Turbine	39
Rock Wren	05/31/2000	No	101	Non-UV Turbine	45
Horned Lark	06/05/2000	Yes	19	UV Turbine	43
Green-Tailed Towhee	06/05/2000	Yes	20	UV Turbine	61
Ruby-Crowned Kinglet	06/05/2000	Yes	35	UV Turbine	30
Brewers Sparrow	06/06/2000	No	4	Met Tower	48
Horned Lark	06/06/2000	No	55	UV Turbine	30
Horned Lark	06/09/2000	Yes	91	Non-UV Turbine	59
Horned Lark	06/19/2000	Yes	1	UV Turbine	15
Horned Lark	06/19/2000	Yes	3	UV Turbine	40
Horned Lark	06/19/2000	Yes	10	UV Turbine	41
Horned Lark	06/20/2000	Yes	68	UV Turbine	10
Green-Tailed Towhee	06/20/2000	Yes	85	Non-UV Turbine	50
Tree Swallow	07/03/2000	Yes	8	UV Turbine	29
Mountain Bluebird	07/05/2000	Yes	22	UV Turbine	13
Horned Lark	07/05/2000	Yes	64	UV Turbine	65
Mountain Bluebird	07/06/2000	No	38	UV Turbine	48
Vesper Sparrow	07/10/2000	No	1	Met Tower	32
American Kestrel	07/14/2000	No	72	UV Turbine	16
American Kestrel	07/19/2000	Yes	34	UV Turbine	43
Horned Lark	07/31/2000	Yes	6	UV Turbine	31
Horned Lark	08/01/2000	Yes	97	Non-UV Turbine	58
Rock Wren	08/29/2000	Yes	23	UV Turbine	47
Townsend’s Warbler	08/30/2000	Yes	70	UV Turbine	13
Wilson’s Warbler	08/30/2000	Yes	71	UV Turbine	34
MacGillivray’s Warbler	08/30/2000	Yes	72	UV Turbine	78
Townsend’s Warbler	09/11/2000	Yes	11	UV Turbine	28
Unidentified Warbler	09/12/2000	Yes	31	UV Turbine	30
Townsend’s Warbler	09/12/2000	Yes	40	UV Turbine	61
House Wren	09/12/2000	Yes	81	Non-UV Turbine	.
Chipping Sparrow	09/27/2000	Yes	29	UV Turbine	25
Horned Lark	09/27/2000	Yes	30	UV Turbine	19
Horned Lark	09/27/2000	No	32	UV Turbine	53
Horned Lark	09/27/2000	Yes	66	UV Turbine	61
Yellow-Rumped Warbler	09/27/2000	Yes	69	UV Turbine	42
Short-Eared Owl	09/28/2000	Yes	53	UV Turbine	56
Chestnut-Collared Longspur	09/28/2000	Yes	97	Non-UV Turbine	45
Chestnut-Collared Longspur	09/28/2000	Yes	100	Non-UV Turbine	8
Unidentified Passerine	10/24/2000	Yes	65	UV Turbine	55
Unidentified Passerine	12/05/2000	Yes	32	UV Turbine	64

Appendix D. Bat Mortality

Bat Mortality

In addition to avian carcasses, 75 bat carcasses were found during the carcass searches. Although the study did not look at bat use, the calculated mortality estimates are reported here along with carcass removal and searcher efficiency trials conducted with bats.

Observed Bat Fatalities

Sixty-one bat carcasses were found at UV turbines and 12 at non-UV turbines (Table 1, see also list of bat casualties below). No bat casualties were observed at the met towers. Hoary bat was the most common species observed (63 fatalities), comprising 84% of the bat fatalities. Other species observed include little brown bat (four fatalities), silver-haired bat (three) and big brown bat (one). Two unidentified bats and two unidentified myotis species were also observed. Forty-eight of the 105 turbines had at least one bat fatality observed during the course of the study (Table 2). The largest number of bat casualties that were observed at any one turbine was four at turbines 40 and 44. Five turbines had three casualties (Turbines 5, 18, 32, 47, and 49). The observed fatality rate for the UV turbines (0.045 fatalities/turbine/search, LL[1] 0.013, UL[2] 0.090) was more than two times higher than at the non-UV turbines (0.019 fatalities/turbine/search, LL 0.003, UL 0.038) but not statistically different (p>0.10).

Table 1. Bat Casualties by Plot Type and Species

	Number of Fatalities			
Species/Group	Met Towers	Non-UV Turbine	UV Turbine	Total
Big Brown Bat	0	0	1	1
Hoary Bat	0	11	52	63
Little Brown Bat	0	0	4	4
Silver-Haired Bat	0	0	3	3
Unidentified Bat	0	0	2	2
Unidentified Myotis	0	1	1	2
Grand Total	0	12	63	75

[1] LL = lower limit of 95% bootstrap confidence interval
[2] UL = upper limit of 95% bootstrap confidence interval

Table 2. Distribution of Bat Fatalities Observed by Turbine

UV Turbines						**Non-UV Turbines**			
Turbine ID	# Fatalities	Turbine ID	# Fatalities	Turbine ID	# Fatalities	Turbine ID	# Fatalities	Turbine ID	# Fatalities
1	0	26	0	51	0	73	0	98	0
2	0	27	0	52	0	74	0	99	0
3	0	28	1	53	0	75	1	100	1
4	1	29	0	54	1	76	2	101	0
5	3	30	1	55	1	77	0	102	1
6	1	31	0	56	1	78	0	103	0
7	1	32	3	57	0	79	0	104	0
8	2	33	1	58	0	80	1	105	0
9	0	34	2	59	0	81	0	Subtotal	12
10	2	35	1	60	1	82	0		
11	0	36	1	61	0	83	1		
12	2	37	2	62	0	84	0		
13	0	38	0	63	1	85	0		
14	0	39	0	64	1	86	0		
15	2	40	4	65	0	87	0		
16	1	41	0	66	1	88	0		
17	1	42	0	67	0	89	0		
18	3	43	2	68	0	90	0		
19	1	44	4	69	2	91	0		
20	1	45	0	70	1	92	0		
21	0	46	1	71	0	93	2		
22	0	47	3	72	1	94	1		
23	1	48	0	Subtotal	63	95	2		
24	0	49	3			96	0		
25	0	50	1			97	0		

Bat Carcass Removal and Searcher Efficiency

Fifteen of the hoary bat carcasses found during the summer of 1999, which were fresh and in good condition, were retained for searcher efficiency and carcass removal trials for the following year. During the summer 2000 season, 10 hoary bat carcasses were placed in the field in a similar fashion to avian carcasses and monitored for scavenging. The mean length of stay for the hoary bat carcasses was 20 days[1], similar to the mean length of stay for small birds (19 days) during the summer. Also during the summer 2000 season, 16 hoary bats (some used more than once) were placed in the field for searcher efficiency trials. The mean detection rate for bats was 63% (10/16), similar to the overall mean detection rate for small birds in the summer (62%).

[1] N = 10, 30% remaining at 28 days; mean length of stay = 20.48 days, SE = 4.47, LL 95% C.I. = 12.29, UL 95% C.I. = 28.67.

Adjusted Bat Mortality

Annual mortality expressed as the number of fatalities per turbine per year was also calculated for bats (Table 3). Overall annual mortality per turbine (adjusted for searcher efficiency and scavenger removal) for the 105 turbines was estimated at 1.04 bats per turbine per year.

Table 3. Observed and Adjusted Bat Fatality Rates

Species	Observed Fatality Rate[1]	Observed Annual Fatality Rate[2]	Searcher Efficiency Adjustment[3]	Scavenging Adjustment[4]	Adjusted Annual Fatality Rate[5]
Bats	0.037	0.476	1.60	1.37	1.040

[1] Observed number of fatalities/turbine/search
[2] Observed number of fatalities/turbine/year
[3] Expressed as 1/p, where p is the searcher efficiency rate for bats
[4] Expressed as 28/t, where t is the mean removal time for bats
[5] Expressed as the number of fatalities per turbine per year adjusted for carcass removal and searcher efficiency

List of Bat Casualties Recorded

Species/Group	Date	Scheduled Search	Plot Number	Plot Type	Distance to Structure (m)
Hoary Bat	07/08/1999	No	80	Non-UV Turbine	35
Hoary Bat	07/14/1999	No	10	UV Turbine	33
Hoary Bat	07/19/1999	Yes	5	UV Turbine	65
Unidentified Myotis	07/19/1999	Yes	7	UV Turbine	34
Hoary Bat	07/19/1999	Yes	8	UV Turbine	35
Hoary Bat	07/19/1999	Yes	10	UV Turbine	86
Hoary Bat	07/19/1999	Yes	17	UV Turbine	19
Hoary Bat	07/19/1999	Yes	20	UV Turbine	12
Hoary Bat	07/19/1999	Yes	50	UV Turbine	12
Hoary Bat	07/28/1999	No	44	UV Turbine	48
Hoary Bat	08/02/1999	Yes	43	UV Turbine	23
Hoary Bat	08/05/1999	Yes	93	Non-UV Turbine	32
Hoary Bat	08/09/1999	No	30	UV Turbine	10
Hoary Bat	08/16/1999	Yes	28	UV Turbine	21
Hoary Bat	08/17/1999	Yes	54	UV Turbine	11.5
Hoary Bat	08/17/1999	Yes	55	UV Turbine	13
Hoary Bat	08/19/1999	Yes	72	UV Turbine	21
Hoary Bat	08/19/1999	Yes	75	Non-UV Turbine	20
Hoary Bat	08/30/1999	No	6	UV Turbine	31
Hoary Bat	08/30/1999	No	44	UV Turbine	13
Hoary Bat	08/31/1999	Yes	15	UV Turbine	11.5
Hoary Bat	08/31/1999	Yes	18	UV Turbine	39
Hoary Bat	08/31/1999	Yes	18	UV Turbine	38
Hoary Bat	08/31/1999	Yes	18	UV Turbine	18.5
Hoary Bat	08/31/1999	Yes	19	UV Turbine	13
Hoary Bat	08/31/1999	Yes	32	UV Turbine	8
Hoary Bat	08/31/1999	Yes	32	UV Turbine	15
Hoary Bat	08/31/1999	Yes	32	UV Turbine	42
Little Brown Bat	08/31/1999	Yes	33	UV Turbine	33
Big Brown Bat	08/31/1999	Yes	34	UV Turbine	22
Hoary Bat	08/31/1999	Yes	36	UV Turbine	11.5
Hoary Bat	08/31/1999	Yes	37	UV Turbine	21.5
Hoary Bat	08/31/1999	Yes	40	UV Turbine	9.5
Hoary Bat	08/31/1999	Yes	40	UV Turbine	27
Hoary Bat	09/01/1999	Yes	44	UV Turbine	10.5
Hoary Bat	09/01/1999	Yes	44	UV Turbine	21.5
Hoary Bat	09/01/1999	Yes	46	UV Turbine	27
Hoary Bat	09/01/1999	Yes	47	UV Turbine	35
Hoary Bat	09/01/1999	Yes	47	UV Turbine	10.5
Little Brown Bat	09/01/1999	Yes	49	UV Turbine	40
Hoary Bat	09/02/1999	Yes	56	UV Turbine	15
Hoary Bat	09/02/1999	Yes	60	UV Turbine	20
Unidentified Myotis	09/02/1999	Yes	93	Non-UV Turbine	14
Hoary Bat	09/02/1999	Yes	94	Non-UV Turbine	19

(Continued). Bat Casualties Recorded

Species/Group	Date	Scheduled Search	Plot Number	Plot Type	Distance to Structure (m)
Hoary Bat	09/02/1999	Yes	95	Non-UV Turbine	7
Hoary Bat	09/02/1999	Yes	95	Non-UV Turbine	6
Hoary Bat	09/13/1999	Yes	66	UV Turbine	20
Hoary Bat	09/13/1999	Yes	69	UV Turbine	21
Hoary Bat	09/14/1999	Yes	8	UV Turbine	11.5
Unidentified Bat	11/09/1999	Yes	64	UV Turbine	62
Unidentified Bat	01/04/2000	Yes	23	UV Turbine	25
Hoary Bat	07/19/2000	Yes	34	UV Turbine	30
Hoary Bat	07/19/2000	Yes	35	UV Turbine	41
Hoary Bat	07/19/2000	Yes	40	UV Turbine	10
Hoary Bat	08/01/2000	Yes	100	Non-UV Turbine	16
Hoary Bat	08/02/2000	Yes	63	UV Turbine	17
Hoary Bat	08/02/2000	Yes	69	UV Turbine	18
Hoary Bat	08/02/2000	Yes	70	UV Turbine	32
Hoary Bat	08/02/2000	Yes	83	Non-UV Turbine	32
Hoary Bat	08/03/2000	No	4	UV Turbine	40
Hoary Bat	08/14/2000	Yes	12	UV Turbine	16
Hoary Bat	08/14/2000	Yes	12	UV Turbine	51
Hoary Bat	08/15/2000	Yes	43	UV Turbine	15
Hoary Bat	08/15/2000	Yes	47	UV Turbine	12
Little Brown Bat	08/15/2000	Yes	49	UV Turbine	39
Hoary Bat	08/15/2000	Yes	76	Non-UV Turbine	10
Hoary Bat	08/16/2000	Yes	102	Non-UV Turbine	17
Hoary Bat	08/28/2000	Yes	5	UV Turbine	62
Silver-Haired Bat	08/28/2000	Yes	5	UV Turbine	33
Silver-Haired Bat	09/11/2000	Yes	15	UV Turbine	36
Hoary Bat	09/11/2000	Yes	16	UV Turbine	13
Hoary Bat	09/12/2000	Yes	37	UV Turbine	55
Little Brown Bat	09/12/2000	Yes	40	UV Turbine	31
Silver-Haired Bat	10/10/2000	Yes	49	UV Turbine	29
Hoary Bat	10/11/2000	Yes	76	Non-UV Turbine	32

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13. ABSTRACT *(Maximum 200 words)*
To reduce the numbers of avian collisions with wind turbines, several measures have been employed with various levels of success. One hypothesis is that painting turbine blades to increase their visibility may reduce avian fatalities. This study examined the effects of painting wind turbine blades with UV-reflective paint on bird use and mortality at the Foote Creek Rim Wind Plant in Carbon County, Wyoming.

14. SUBJECT TERMS
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