NOCTURNAL BEHAVIOR OF RAPTORS
AT WIND ENERGY FACILITIES

by

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In

Biology

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Nocturnal Behavior of Raptors
at Wind Energy Facilities

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ABSTRACT

Wind power is an environmentally clean, efficient and economical form of alternative energy, however its use has been associated with avian mortality. I conducted an observational study of the nocturnal behavior and habitat use by raptors around wind turbines using night vision devices. Between 20 September 2006 through 8 November 2006 there were 42 individual raptors observed during 210 10/20 minute point count events. Eight of these raptors were diurnal and 34 were nocturnal. Most of the diurnal raptors were found within the area around wind turbines that posed a high mortality risk. 36 percent of the nocturnal raptors were in high mortality risk areas. I used logistic regression to model use of raptors around wind turbines from presence/absence data and found that percent of lunar illumination, ambient temperature and vegetation grouping were significant predictors of raptor presence. Multinomial logistic regression was used to model flight/perching behaviors. Duration of occupancy was significantly affected by flight behavior. Raptor species and vegetation grouping significantly affected perching behavior. These data indicate that raptors are active at night. Further studies need to be conducted to correlate time of mortality with nocturnal behavior and habitat use by raptors around wind turbines that would provide information for management and conservation of these raptor species.

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MS Program: Biology
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(Russell, 1991; DeCandido and Allen, 2006). However, little is known about the mortality and behavior of raptors at night near wind turbine facilities. Therefore, a better understanding of the nocturnal mortality threat to raptors posed by wind turbines, and the mechanisms of those mortality risks, may be useful in improving management and design of wind generation facilities to minimize impacts to raptors.

I used night-vision devices (NVD) to observe the nocturnal presence, activity, and behavior of nocturnal (owls) and diurnal (hawks and kestrels) raptors at a commercial wind turbine facility to address the following questions. Are raptors (nocturnal and diurnal) active in using the areas around wind turbines at night? Are raptors exhibiting nocturnal behaviors, such as flying near turbines or perching on turbines that put them at risk? Are raptors flushed off wind turbines when the turbines are powered up at night? (Thelander, 2005 pers. comm.)

If nocturnal behavior of raptors at wind energy facilities poses a significant mortality risk, then information from this study may lead to potential conservation and management solutions.

**Raptor Species**

Raptor species found on the study site are shown in Table 1. Five raptor species differing morphologically, behaviorally and ecologically (Johnsgard 1990, 2002; Bleidstein, 1987), were studied: Red-tailed Hawk and American Kestrel (diurnal), Barn Owl and Great Horned Owl (nocturnal) and Burrowing Owl
Wind power has been cited as a clean, economical and important form of alternative energy (AWEA, 2007; NREL, 2006; Alvarez-Farizo and Hanley, 2002; Kennedy, 2005; Krewitt and Nitsch, 2003). However, wind energy facilities (e.g. Altamont Pass Wind Resource Area) have been shown to cause high avian mortality and raptors appear to be one group of birds most affected by wind turbine operations (Thelander and Smallwood, 2004; WEST Inc, 2006). Examples of the types of injuries to raptors that are attributed to wind turbines include decapitation, broken wings and legs, and severed torso, wings, tail, and legs (Thelander and Smallwood, 2004).

The particularly high risk to raptors is apparently a consequence of flight and perching behaviors characteristic of the group (Thelander and Smallwood 2004), resulting from raptors using the habitat and winds found around wind turbines. Previous studies have found raptor mortality associated with wind turbines (Bryne 1983; Orloff and Flannery, 1992, 1996; Howell and Noone, 1992; Gauthreaux, 1994; Howell, 1997; Johnson et al., 2006). These studies quantified mortality, but did not address issues concerning how, when, or why raptors are killed by wind turbines, or the behaviors that contribute to increased raptor mortality risk. Raptor mortality due to the interaction of wind turbines may occur because raptors cannot see, hear or avoid the physical forces generated by wind turbines. Mortality risk may be enhanced at night, when nocturnal raptors, such as owls, are active. Furthermore, light and wind conditions during the night may present different mortality risks. Even nominally, diurnal raptors may be active at night.
(generally considered diurnal, but active day and night). These raptors were selected because of their differences in size and shape, which allows them to be identified at night. These differences include light/dark patterns and silhouette (size and shape) profiles that can be differentiated using night vision devices (NVD).

Mathematical models have been developed to predict the probability of a bird collision with a wind turbine and to develop safe turbine designs (Tucker, 1996). Wind turbine strikes may occur because raptors experience forces that cannot be aerodynamically/energetically compensated for by the raptor in the presence of wind turbines. Aerodynamic forces generated by the wind turbines lead to disruptions in pitch, roll and yaw control, that can cause the bird to be rotated upside down, tumbled, and in general, lose their ability to maintain a controlled flight posture. These forces include wind shear, helical vortex wakes and wake structures (Spera, 1998; Burton et. al., 2001).

Wind shear may occur when the raptor is flying in proximity to the front of the rotating wind turbine blades, forcing the raptor to the ground due to a loss of lift. Helical vortex wakes occur at the terminal end of the wind turbine rotating blades (Spera, 1998), tumbling the raptor into the wake structure/rotating blade. Wake structures are chaotic forces occurring on the downwind side of the rotating blades (Spera, 1998), causing the raptor to be tumbled, losing both lift and yaw control and thrown into the ground or rotated into a rotating blade. Two other causes of raptor collisions with wind turbines are interference with vision (motion
smear) and hearing interference (i.e. avoiding rotating blades) (McIsaac, 2000; Hodos, 2003; Dooling, 2002). Motion smear occurs when the image (i.e. rotating blade) on the back of the retina becomes larger as the bird flies closer to the rotating blade, causing the terminal end of the blade to disappear, and the raptor to be struck or experience a wind vortex while attempting to fly around the turbine (Hodos, 2003). This is where most mortality occurs (Thelander and Smallwood, 2004). Hearing interference may be caused by the ability of the raptor to detect the sounds (signal-to-noise ratio) produced by rotating wind turbines (Dooling, 2002), and may contribute to a mortality. In addition to risks associated with flight, raptors may be using the wind turbines as perches, which would provide a platform for hunting.

I investigated the nocturnal behavior and activity of raptors within a commercial wind turbine facility with Horizontal-axis Wind Turbines (HAWT) (Figure 1), using Generation III (Gen III) Light Intensifying Night Vision Devices (Figure 2). Light Intensifying Night Vision Devices work by converting electrons to high-energy photons and, passing them through an imaging tube, microchannel plate (MCP), and onto a phosphor screen, producing a visible image (Bass et. al., 1995). NVD have been used to study birds (Russell, 1991; Henson and Cooper, 1994; Russell et. al, 1991; Black and Collopy, 1982; King and King, 1994). I selected Generation III NVD because advancements in light-intensifying technology, improvement of the light intensifying tube, optical resolution, coating and density of glass (Biass and Gourley, 2001; Efkeman, 2006 pers. comm.), have made it
possible to identify most raptors to species at distances of at least 150 meters. Additionally, Gen III NVD produce low “visual noise” because of the improvements in the MCP (Bass, et.al, 1995), allowing light to be intensified over 50,000 – 100,000 times, and changes in the imaging tube from tri-alkaline cathode to gallium arsenide cathode (Biass and Gourley, 2001). These characteristics along with high quality optics allow Gen III NVD to produce an extraordinarily clear image. The use of NVD does not require direct interaction such as capturing and marking the raptors, which reduces bias of flight/perching behavior.

Other techniques considered for this study included Radar and Radio-telemetry. Radar is capable of providing an avian signature, but has some limitations (Kunz, et al., 2007). If the bird hovers, contours or flies close to the ground or a stationary object, the signature may drop off due to ground bounce (Cooper, 2005 pers. comm.). Current Radio-telemetry methods do not have the fine scale capabilities needed to track birds in close proximity to wind turbines (Kenward, 2001).

**Study Area**

I conducted observational field studies at the EnXco 5 site in the Montezuma Hills near Birds Landing, California, a commercial wind generation facility operated by the EnXco Corporation. The site (Figure 3) is northeast of San Francisco near Highway 12 between Suisun and Rio Vista, California. The terrain consists of low rolling clay hills, dominated by agricultural land with grain/hay crops in the
summer and wheat and sheep grazing in the winter. This site was chosen because of it accessibility and the presence of raptor species.

Methods

Plot 1 consisted of six General Electric 1.5 MW turbines that were divided into two sections, because these larger turbines required a different survey design than the smaller Kenetech 56 (100) turbines. These turbines were arranged in two groups of three turbines per group and were 100 meters apart. Their towers are 80 meters high and their blades have a 77 meter rotor diameter. These turbines have a maximum blade tip speed of 294 kph. Plots 2 -6 consisted of 37 Kenetech (56) 100 kW wind turbines arranged in linear strings (6 -9 turbines per row), 30 meters apart. Their towers are 18.5 and 24.6 meters high and their blades have a 17.5 meter rotor diameter. These turbines have a maximum blade tip speed of 246 kph.

I used a complex survey combining several survey methods to quantify presence/absence, flight/perching of raptors observed during the survey period. The double sampling technique, where two observers are recording data of the same area or plot (Thompson, 1992) was used to reduce bias in detecting raptors and provide a complete visual coverage of the plot. I used the Visual Corridor Observation (VCO) design (Gauthreaux 1996), (Figure 4), to observe raptors within study plots; this design allowed the two observers to view the area from 0 - 50 meters away from a point parallel to the wind turbines. I integrated 10 and 20 minute point-counts (PCs) (Ralph, 1995), to measure occupancy
(Mackenzie et. al, 2006) of raptors, the time at which a raptor remains in the plot, measured in minutes and seconds was used to account for activity around the wind turbine. The longer the raptor remained in the area around a wind turbine the higher the mortality risk. One observer was located at each end of the turbine string, at synchronized points. Two 10 minute raptor point-counts, one on each side of the turbine string were conducted with a 5 minute break between counts. This break allowed the observers to locate the next observation point and provided a short break from observing through the NVD. There were four permanent observation points per turbine string (A-D), arranged in a clockwise pattern at the end of the turbine string using the VCO design beginning from where the road entered the plot. The variable circular plot (VCP) design (Reynolds, 1980) was integrated with instantaneous sampling (Martin and Bateson, 1993), a method used to determine the point at which a raptor is first detected within the plot, between 50 and 150 meters from the observers point (A-D). These observation points were located where the observer could view all of the turbines within the string and where the observer could scan one side of the plot (Figures 5 and 6).

I arrived by vehicle at each at each plot several hours before dark to determine presence of raptors. After dark, I observed and recorded raptors using the area before conducting the 10 or 20 minute PC. Before approaching a plot, I scanned with NVD to reduce the possibility of missing a raptor perched on a wind turbine from within the plot as I approached the plot to conduct surveys.
I selected a total of six plots, consisting of a string of turbines, and the area around the turbines out to a distance of 150 meters. These plots represent a cross-section of the wind turbine field; this cross-section included both types of turbines and included turbine groups and strings from the northwest edge to the southeast edge of the entire EnXco 5 site. I selected three levels (low, medium and high) of raptor occurrence determined by pre-survey estimates. These estimates were determined by observing raptors during the daytime before conducting the nocturnal surveys and consulting with EnXco managers familiar with raptors at this site.

Having trained observers familiar with the study species and flight/perching behavior (Kepler and Scott, 1981) and the NVD (Stark, 2006 pers. comm.) was necessary for an accurate survey. The same two observers (James Castle and Charlene Burge) surveyed all study plots. Both had at least five years of experience with the natural history, taxonomy and observing the study species and both had training in observing the study species using NVD.

The arrangement of turbines at site 1 required a modification of methods, because of the larger 1.5 MW turbines. I used the VCO method with modified observation points, that were 300 meters from the center of the wind turbine plot and located to provide an equal view for the observer on each side of the turbines. I used 20 minute point counts to normalize survey effort between all plots. This normalization of survey effort was important in order to compare my results with other studies (Mackenzie et. al, 2006). I used fixed-point field
markers to establish distances out from the center of the turbine field and used 100 meter PC protocols. In some cases, these distances were measured from objects in the plot such as another turbine string, a road corner or a solitary hay bale. Two small pocket lights (visible to both observers) were placed (plots 2-6) on an eight foot wooden stake, supported by a four foot metal fence stake at 50 meters to delineate a zone of high risk. Mortality risk becomes greater as the raptor moves closer to the wind turbines due to motion smear (Hodos, 2003), and studies indicate that some diurnal raptors may experience the effect of noise interference from wind turbines at 50 meters (Dooling, 2002). In addition, when flying within 50 meters of a wind turbine string, there may be little time for the raptor to avoid rotating turbine blades, based on their flight behavior especially if the wind is fluctuating.

A total of 80 hours of nocturnal raptor surveys were conducted including 208 point observations in plots 1 - 6 between 20 September and 10 November 2006 between the hours of 6 p.m. and 12 a.m. (PDT). Start time for nocturnal surveys varied, beginning at the end of civil (nautical) twilight in the western sky (Ekferman, 2007, pers. comm). In September, surveys began after 9 pm and in November at 6 pm.

Nocturnal observations were made using Star Tron Pocket Scope Model 7B Generation III Light Intensifying Night Vision Device (NVD) with a 75mm, f1/4 waterproof objective lens, providing 2.78X magnification. An image of the Kenetech 56 (100) wind turbines demonstrates the resolution of this NVD (Figure 7).
I developed ethograms for flight and perching behavior specific to this study. I grouped flight behavior into the following categories: flying (forward flapping flight, gliding, soaring and contouring), flushed (raptor flew returning to the same or nearby perch within 10 seconds), flying and hunting, and flying (forward flapping flight, gliding) after being flushed (not returning to the perch). I grouped perching behavior, according to perching location, into eight categories. These were ground perching with high mortality risk (within 50 meters of turbine), ground perching with low mortality risk (outside of 50 meters from turbine), fence post, electrical boxes (between turbines or under turbine), turbine superstructure (tower) (lower, middle and upper sections), distribution power pole, transmission crossarm of tower and nacelle (cover on the turbine power train, located at top of turbine).

I recorded flight and perching behavioral data for species observed during 10 and 20 minute PC. Weather data [temperature (wind chill factor) and average wind speed] was measured at each plot, before each observation using a Kestrel 2000 portable weather station. Percent of cloud cover was estimated from horizon to horizon (180 degree arc across the sky). Illumination on the plots (artificial ambient light and moon light) was categorized as present/absent. Percent lunar illumination (0 -100) was determined from astronomical data for the San Francisco Bay area (Thorsen, 2006). Vegetation in the area of the study plots was visually assigned to four categories: 1). Little vegetation < 10% cover, fallow, bare ground. 2). Vegetation < 15 cm. high, heavy grazing, weedy and/or
cut fallow hay field, some denuded areas. 3). Average vegetation, 15 -30 cm.
high, medium grazing, some denuded areas. 4). Greatest amount of vegetation,
vegetation > 30 cm. high with 100% coverage on land around the roads and
turbine structure.

Communication between observers was maintained using Motorola Talkabout
Model T5710 hand-held radios. All distance measurements (observation points to
turbine, reference lights to turbine, distances between turbines and distances of
structures [i.e. transmission/distribution towers/poles, fence post, etc]) were
made using a Leica Rangemaster 900 scan Laser Range Finder. Fixed point
objects (wind turbines, observer points and light distance references) were
delineated using a submeter GeoExplorer 3 GPS device.

To determine the distance at which raptor species could be identified using
NVD, I conducted a calibration experiment a posteriori on 10 December 2006
using captive raptors at the Bird Rescue Center (BRC) in Santa Rosa, California
(CADFG and USFWS certified facility). Four raptor species (Red-tailed Hawk,
American Kestrel, Barn Owl and Great-horned Owl) were identified at known
distance (50 – 150 meters), established with Leica 900 scan LRF and under
constant light conditions with 100 percent cloud cover with available ambient
light. I estimated that lighting condition at BRC was approximately 50 percent
less light as compared to the lowest light conditions on the project site. These
experiments provided a reference for visual acuity and validation of species
identification at distance under lighting conditions that were lower than lighting
conditions during the study.

The strength of inference of study designs used to generate system dynamics (models) range from strong (manipulative experiments) through constrained design studies to weak (observation studies). These observational studies (a priori/posteriori hypotheses) are used when natural variation could not be manipulated/constrained (MacKenzie et al, 2006). The general appearance (silhouette and size) of the raptor, wing beat duration and patterns of light and dark feathers provide information to key a raptor to species using NVD. Additionally, information as to the distribution of raptors spatially and temporally in the study area provides additional clues. For example, one may observe a Buteo, Falcon or Owl and further identify based on appearance, morphology or behavior. In my study I was able to identify an American Kestrel perched on a wind turbine at a distance greater then 50 meters, because the kestrel dove and presented a “drawn bow silhouette” unique to this species flight behavior (Smallwood and Bird, 1995).

**Statistical Analysis**

I analyzed all data using SPSS 11 for Macintosh OS X Tiger Platform (SPSS, 2005). Logistic Regression was selected as the statistical method to model these data (Zar, 1996; Glantz and Slinker, 2001). I used presence/absence to determine if raptors were utilizing the area around wind turbines and flight/perching behavior to determine mortality risk. After screening variables for significance, models were selected using backward stepwise regression from a
global model with factors and covariates. Effects were retained in the model if significant ($p < 0.05$).

**Results**

**Calibration Experiment**

The *a posteriori* calibration experimental data indicates that Red-tailed Hawks, Great-horned Owl and Barn Owl could be identified from a distance of at least 150 meters using Gen III NVD. American Kestrels could be identified from a distance at least 50 meters (Table 2).

**Presence/Absence**

Over a total of 80 nighttime observational hours, I observed 42 raptors. The most commonly seen diurnal raptor was the Red-tailed Hawk and the most commonly seen nocturnal raptor was the Barn Owl (Figure 8).

The time after sunset (Thorsen, 2006), of raptors observed during point counts ranges from one to four hours and indicates that all raptors species were seen throughout the range of time (Figure 9). Date of observations of raptors during point counts indicates that most diurnal raptors were seen earlier in the survey and nocturnal raptors were seen throughout the survey (Figure 10).

I tested a model predicting presence/absence with percent lunar illumination, ambient temperature, wind speed and vegetation groupings as effects indicated, significant positive effects of lunar illumination and ambient temperature on presence of raptors ($LR \chi^2 = 8.0, 4.5; p = 0.005, 0.033$). Vegetation grouping had a significant effect, with increasing presence of raptors the vegetation increased
(LR $\chi^2 = 4.1$, $p = 0.044$). Wind speed was not a significant predictor of the presence of raptors (LR $\chi^2 = 0.08$, $p = 0.772$).

**Flight Behavior**

I observed 38 raptors demonstrating various flight behaviors. Flying and flying after being flushed (flying from a perch such as a wind turbine, fence post or ground and not returning to that perch) were the most commonly observed flight behaviors and flying while hunting was the least commonly observed flight behavior (Figure 11). I tested a model that examined the effects of vegetation grouping, duration of occupancy and lunar illumination on flight behavior. This model revealed significant effects of the duration of occupancy on flight behavior (LR $\chi^2 = 21.3$, $p = 0.011$). Lunar illumination and vegetation grouping did not significantly influence flight behavior (LR $\chi^2 = 51.1$, 5.5; $p = 0.246$, 0.136) on flight behavior. My behavioral observation suggests that nocturnal behaviors of raptors around wind turbines pose a risk. One of the Red-tailed Hawks sighted was observed flying approximately eight meters above the ground at 9 p.m. between two Kenetech 56 (100) turbines that were operating. Two American Kestrels were flushed from a Kenetech 56 (100) turbine when that turbine was powered up. In both cases, diurnal raptors were exposed to turbine-related risk because of nocturnal behavior.

**Perching Behavior**

I observed 30 raptors demonstrating various perching behaviors (Figure 12). Perching on the ground in low risk areas was the most frequent observation and
perching on the nacelle was the least frequent observation of perching behavior. I tested a model that examined the effects of species and vegetation grouping on perching behavior. The model revealed a significant effect of species, most of the diurnal raptors were seen in plots 5 and 6 (LR $\chi^2 = 24.9, p = 0.001$) and a marginally significant effect of vegetation grouping (LR $\chi^2 = 13.5, p = 0.060$), on perching behavior.

**Discussion**

My data suggest that both diurnal and nocturnal raptors are occupying the area around wind turbines for movement, perching and hunting at night. This nocturnal behavior and occupancy of raptors with wind turbine mortality risk was not previously identified.

**Presence/Absence**

When comparing my presence/absence surveys at the EnXco 5 site to those surveys conducted at APWRA (Thelander and Smallwood, 2004), there are a comparable number of raptors present at the two sites, normalizing survey effort (Mackenzie et. al, 2006). Between May 1998 and May 2003 there were 213 Red-tailed Hawks, 70 Burrowing Owls, 59 American Kestrels, 50 Barn Owls and 18 Great-horned owls fatalities caused by wind turbine collisions at APWRA (Thelander and Smallwood, 2004). Sixty percent of these raptors are Red-tailed Hawks. These are five of the six most abundant mortalities reported in the APWRA and species I observed during nocturnal surveys at my study site. Comparing Red-tailed Hawks between sites and normalizing survey effort, there were 213 Red-tailed Hawks fatalities in 5 years; this equals an average of about
43 Red-tailed Hawks per year or 3.6 Red-tailed Hawks per month. There were two Red-tailed Hawk fatalities (found by wind facility technicians) during my survey in the two month period, averaging one raptor per month, this implies that 0.25 percent less fatalities at my study site compared to APWRA, with abundance of raptors between sites being equal. The survey effort between sites was one and a half times the number of hours surveying (120 vs. 80), four times the length of survey (8 months vs. 2 months) and one and a half longer on point counts (30 vs. 20 min). Therefore, at APWRA 598 raprots were present based on their survey effort. I observed 42 raprots, normalizing survey effort (42 raprots x 1.5 hours x 4 length of survey x 1.5 point count) = 378 raprots. This is a maximum estimate of the raprots that could be seen based on normalizing survey effort. This difference is 1.5 times greater in the APWRA compared to EnXco 5 site. However this difference may be because surveys at APWRA were conducted in the day, where observers could detect raprots at a greater distance with unaided vision and using 8x25 binoculars a factor of three times the power and binocular of the NVD that were 2.75x and monocular.

With increasing lunar illumination, I observed a greater number of raprots. Lunar illumination may increase the raprots, ability to detect prey more effectively. Owls may spend significantly less time searching for prey as lunar illumination increases (Clarke, 1983). These effects of search time with increasing lunar illumination may apply to diurnal raprots if these raprots are active at night. I suspect that increasing lunar illumination may give diurnal raprots the opportunity to extend their hunting activity into night hours. Despite
low occupancy for diurnal raptors, these data suggest that diurnal raptors are active at night, which may place them at higher mortality risk than previously reported.

Ambient temperature had a positive influence on raptor presence. This may be an effect of raptors being more active with increasing temperatures. Red-tailed hawks may use thermals to reduce cost of transport to (Videler, 2006); this may account for presence around wind turbines because of thermosensitivity, the ability to regulate body temperature (Whittow, 2000) and compensate for the reduced nocturnal temperatures, this may allow the raptor to maintain their presence in the study area. Occupancy of the area by the raptor may be influenced by transient thermal characteristics. Occupancy of kestrels may be influenced by temperature and other environmental factors (Koplin et al, 1980). Thermals occurring in the area afford the opportunity for the diurnal raptor to utilize these for soaring and gliding. I found that as the ambient temperature increased more diurnal raptors were seen.

Vegetation grouping had a significant effect on occupancy. This may be related to an increase in prey density with increasing cover (Preston, 1990). Raptor occupancy may depend on density of prey items, however search time may increase with increasing vegetation cover and this may relate to foraging time. As the vegetation becomes denser, raptors may spend more time searching for prey.

Surprisingly, wind speed did not influence raptor occupancy. This may be due
to lack of significant variation in average wind speed (0-8m\(^3\)) during the study. However, average wind speed was used in the model and actual wind speed fluctuated over short time periods. Fluctuation in wind speed may increase mortality risk if a raptor is flying in a high risk posture relative to the wind turbine. For example, if a raptor is flying one or two meters below or above a rotating blade and experiences a sudden wind fluctuation (up/downdraft). This may force the raptor into the rotating blades.

**Flight Behavior**

Flight behavior was likely the most important variable considered, relative to mortality risk to the raptor. The duration of occupancy of raptors in the plot suggests that raptors were spending a significant portion of time flying within the study site. Forward flapping flight behavior may cause the raptor to fly into the turbine because of motion smear (Hodos, 2003) and/or hearing interference due to increasing noise (signal-to noise ratio) generated by the rotating turbine (Dooling, 2002). Gliding, soaring and contouring behavior may cause the raptor to be exposed to vortex turbulence and/or wake structure. Lunar illumination and vegetation grouping did not significantly influence the raptor flight behavior. Raptor flight activity has been reported to decrease with increases in wind speed and decrease with decreased temperatures (Preston, 1981). I found as the temperature increased and the wind speed decreased, I observed more raptors present.
**Perching Behavior**

Perching behavior is another important component of raptor mortality risk.

Perching behavior is a function of the raptor location. Raptors selected perches in high and low mortality risk locations. Species (diurnal and nocturnal) had a significant impact on perching behavior and vegetation was marginally significant. Vegetation has been linked to foraging and prey biomass, implying that vegetation cover increases foraging effort in raptors (Preston, 1990). The diurnal raptors appeared to perch on structures that afforded them the opportunity to increase their attack speed and return to consume their prey. These structures included wind turbines and utility structures such as distribution poles and transmission towers. Nocturnal raptors chose all types of perches and did not appear to have a preferred perch type.

Wind variations that cause turbines to be powered up or down by operators at random times may afford raptors the opportunity to perch on wind turbines while the turbines are not operating; this may pose the greatest mortality risk because of the proximity of the perched raptor to the rotating wind turbine blades, when the turbine restarts. Risk increases in other perches (ground or within 50/100 meters of the turbine) as the raptor becomes closer to the wind turbine and if the turbine is actively rotating. I found that 36 percent of the raptors were perching in locations of high mortality risk.
My study suggests that there is a raptor mortality risk, however I was not able to measure mortality directly in this study for the following reasons. Mortality surveys require a scavenger rate study to determine the frequency of the mortality survey. Sheep occupied all study plots, except site 2. There was concern that placing carcasses of birds on the site may create a health issue for the livestock and since the research site is leased by the rancher this was of concern to managers of the site.

**Management Implications**

I have demonstrated that diurnal raptors are present and active around wind turbines at night. Nocturnal raptors are using the area around wind turbines, in greater numbers but for the same purposes. This nocturnal activity may pose a mortality risk to raptors. The nocturnal period has been largely ignored in studies of avian mortality from wind turbines, primarily because there were inadequate methods to study behavior of raptors at night. My results suggest several possible management actions that should be investigated further. Vegetation removal within 50 meters of wind turbines may reduce prey in areas that place foraging raptors in high mortality risk situations. Although new turbines designs are better for reducing perching opportunities, the lattice style turbines could be modified to reduce perching and/or artificial perches could be constructed outside of 50 meters. Finally, selected wind turbines (i.e. corners of strings) could be turned off during periods of maximum lunar illumination, when raptors are most
active.

This study has provided a foundation for further studies involving NVD and other methods. Further advancements in NVD technology and greater availability of this technology will provide more information that will allow and managers to make better decisions at wind energy facilities. I recommend that NVD are used in conjunction with Radar and mortality surveys be conducted with NVD observations. With wind turbines having the potential to mitigate global warming (Keith et. al, 2004), and the advancements in wind turbine design we have the opportunity to develop alternative energy technologies that will provide energy solutions for the future while avoiding unnecessary avian mortality.
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Literature Cited


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<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
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<tr>
<td>Turkey Vulture</td>
<td><em>Cathartes aura</em></td>
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<td>White-tailed Kite</td>
<td><em>Elanus leucurus</em></td>
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<tr>
<td>Northern Harrier</td>
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<td><em>Buteo swainsoni</em></td>
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<tr>
<td>American Kestrel *</td>
<td><em>Falco sparverius</em></td>
</tr>
<tr>
<td>Merlin</td>
<td><em>Falco columbarius</em></td>
</tr>
<tr>
<td>Peregrine Falcon</td>
<td><em>Falco peregrinus</em></td>
</tr>
<tr>
<td>Barn Owl *</td>
<td><em>Tyto alba</em></td>
</tr>
<tr>
<td>Great Horned Owl *</td>
<td><em>Bubo virginianus</em></td>
</tr>
<tr>
<td>Burrowing Owl *</td>
<td><em>Athene cunicularia</em></td>
</tr>
<tr>
<td>Spotted/Barred Owl</td>
<td><em>Strix species</em></td>
</tr>
</tbody>
</table>
Table 2. Observations of the captive raptors at Bird Rescue Center on 10 December 2006 with no moon and 100% cloud cover. Distance is in meters. Perching is raptor position on perch with wing folder against body and flapping is raptor with fully extended wings and flapped wings in place.

<table>
<thead>
<tr>
<th>Species</th>
<th>Distance</th>
<th>Perching</th>
<th>Flapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTHA</td>
<td>50</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>RTHA</td>
<td>100</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>RTHA</td>
<td>150</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>AMKE</td>
<td>50</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>AMKE</td>
<td>100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>AMKE</td>
<td>150</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>GHOW</td>
<td>50</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>GHOW</td>
<td>100</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>GHOW</td>
<td>150</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>BAOW</td>
<td>50</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>BAOW</td>
<td>100</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>BAOW</td>
<td>150</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

RTHA = Red-tailed Hawk, AMKE = American Kestrel, GHOW = Great-horned Owl and BAOW = Barn Owl

(+) = resolution to species identification  
(-) = 0 resolution to species identification
Fig. 1. Shows the two types of wind turbines on the research site. a). General Electric 1.5 MW b). Kenetech 56 (100) kW.
Fig. 2 Light- Intensifying Night Vision Device. Model 7 Pocketscope with 75 mm. f1/4 2.75X magnification, waterproof lens (Star Tron Corporation).
Fig. 3   General overview of research site.  This site is located approximately 3 miles east of Birds Landing, CA between Bird Landing and Collinsville, CA.  7 miles south of the intersection of Hwy 12, with Fairfield to the west and Rio Vista to the east.  Plot 1 (black dots) represent 6 GE 1.5MW Turbines and Plots 2- 6 (red and green dots) represent the 24.6 and 18.5 meter kenetech (56) 100 kW turbines
Fig 4. This photograph represents an example of the VCO design is used to collect data during the 10 minute point counts for the observation of raptors at plots 2-6. A). The triangle represents the view of the observer for one of four observation points within the plot. B). Represents an imagery line where the reference light intersects the observation point.
Fig. 5 Represents the study design for plots 2 – 6 (turbine string). Observer points A – D are arranged in a clockwise pattern, beginning where the road enters the plot. The buffer represents the VCP portion of the design where distance of detection varies from 50-150 meters.
Fig. 6. Represents the study design for Plot 1. Note observers are in line with each other and observer an area that includes 100 meters on both sides of the wind turbine group. This modification of design allows a 20 minute point count that normalized survey effort between plot 1 and plots 2-6.
Fig. 7. Shows a Night Vision Photograph of Wind Turbines taken through the Model 7 NVD (sheep for scale) using digiscoping with an Olympus C – 7000 camera. This photograph was taken on a full moon night with no cloud cover at 9 p.m. on 10 December 2006.
Fig. 8. Distribution of species during 10/20 minute point counts. Barn Owl was the most abundant. The significance of species numbers 1, 2 & 7 (n = 4, 2 and 2) is that these species were all diurnal raptors demonstrating activity during nocturnal periods.
Fig. 9. Date of observation of raptors. Diurnal raptors were seen early in the season and nocturnal raptors were seen later in the season.
Fig. 10. Time after sunset of raptors observations. September through November 2006. Red-tailed Hawks were active throughout the survey period, American kestrels and Burrowing Owls were active earlier in the survey period. These times are well after sunset.
Fig. 11. Flight behavior distribution of raptors observed during survey period. (n = 38) all categories demonstrate flight behavior that may lead to a mortality.
Fig. 12. Locations of raptors observed perching during survey period (n = 30). 36% (n = 11) were at high mortality risk based on perch location.