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Recent technological improvements of wind turbines have reduced costs to build and maintain turbines while increasing the amount of energy produced (Osborn 2000). This reduction in cost, along with state and federal tax incentives, have increased interest in using wind power as an alternative energy source to coal and petroleum (Risser et al. 2007). The amount of electricity generated from wind power has increased dramatically in the United States, from 1,848 megawatts (MW) in 1998 to 11,603 MW by the end of 2006 and this number has continued to rise (AWEA 2006). As demand of energy is predicted to increase 21% over the 2007 levels by 2030 (World 2006) and oil discoveries have been falling since 1965 (Campbell 2000), wind power will be in greater demand in the future.

While wind energy is generally viewed as environmentally friendly, it has also been associated with the killing of birds and bats from colliding with the turbines (Erickson et al. 2001) and wires that transmit the energy generated (Orloff and Flannery 1992). There have been many studies on wind projects that have been running for over 25 years to better understand what causes higher bird and bat mortalities in the hopes to significantly reduce them. Much of the controversy with regards to wind turbines occurred at older wind facilities, where many of them were constructed in areas prior to understanding the avian use patterns (AWEA 1995). As a result, some of these wind farms are placed in areas where birds and bats frequent, resulting in higher risks of turbine collisions (AWEA 1995). There have been continuous efforts since the heedless installation of these wind farms, however, to reduce the impact that wind energy has on bird and bat species.

Wind turbines are not the only human structures that cause bird and bat mortality. It has been estimated that 100 million to over 1 billion birds are killed each year in the United States due to collisions with man-made structures (Erickson et al. 2001). As shown in Table 2, there is a wide range in total mortality for each source. The high variability within each source is due to the limited amount of data available on these subjects. The difference between the sources is related to the abundance of the structures in each of the categories:

> 4 million miles of road, 4.5 million commercial buildings and 93.5 million houses, 500,000 miles of bulk transmission lines (and an unknown number of miles of distribution lines), 80,000 communication towers and 15,000 wind turbines (by end of 2001) [are] in the U.S. (Erickson et al. 2001).

Even if wind turbines were more numerous at the time that this data was collected, they would most likely contribute to only a few percent of the total deaths related to human structures. There are many other sources that were not included in the table that contribute to avian and bat mortality. House cats, for example, kill an estimated 100 million birds per year (Erickson et al. 2001). Many of the studies on avian mortality caused by human structures were done in response to high rates of avian collisions causing the statistics to possibly be skewed and not true for all manmade structures. This would mean that using the averages of these numbers would place the amount of bird fatalities higher than the actual amount. Furthermore, the estimates listed for the causes of avian mortality were “based on subjective models and are very speculative” (Erickson et al. 2001).

The estimates of avian and bat mortality at wind plants, however, have usually been adjusted for variables such as scavenging and observer bias; they were not typically factored into the studies calculating mortality caused by collisions with vehicles, buildings and windows and communication towers. This would make the turbine data more accurate than most of the information that is available for other sources of collision (Erickson et al. 2001). Using current estimates, it is believed that bird fatality induced by wind turbines represents 0.01% to 0.02% of the annual mortalities in the United States (Erickson et al. 2001). This number, while a small portion of the total human-induced avian mortality, is still a significant amount of bird deaths and should not be discounted due to the low percent. As detailed in this paper, there have been continuous efforts to further reduce the amount of avian and bat mortality caused by wind turbines and these achievements should help in further minimizing the negative effect that wind turbines have on avian species.

One of the most documented bird mortality cases occurred at a wind farm in the Altamont Pass of California (Howell & Didonato 1991), which has prompted the investigation of other wind projects (Orloff and Flannery 1996). This wind farm is located in the Altamont Pass of the Diablo Range in Central California, which is mainly composed of rolling hills and contains 4,930 small turbines of several types (California, 2011). Most of the turbines in the Altamont Pass are of older models, since the wind farm was constructed in the early 1980s. Located next to the world's densest golden eagle (*Aquila chrysaetos*) nesting area, the Altamont Pass is situated in a deadly position (Quiros 2007). The Altamont Pass also has large populations of the western burrowing owl (*Athene cunicularia*) and these birds experience high mortality rates as well (Smallwood et al. 2007). Burrowing owls are protected under the Migratory Bird Treaty Act, which protects avian species migrating between the United States and Canada, thus causing them to be of special concern in turbine-induced mortality cases (Quiros 2007). In the study conducted by Smallwood et al (2007), it was found that mortality might equal or exceed the rate that owl populations can maintain a sustainable population. If the burrowing owls are dispersing from their natal populations beyond the Altamont Pass, then they could replace the owls killed by the turbines. In this situation, local owl numbers might not be in decline but neighboring populations are decreasing as the surrounding inhabitants migrate to the Altamont Pass. Impact studies such as these created serious concern for bird mortality which led to the delay of many wind projects, on occasion to a point where the wind farms were not developed at all (Erickson et al. 2002).

From the time when the first large wind plants were constructed in California, the design of wind turbines have undergone significant change. Since studies regarding the Altamont Pass and other older wind farms have been published, newer facilities have undergone much scrutiny in order to reduce the number of bird mortalities as greatly as possible. By understanding behaviors such as migratory flight patterns and hunting behaviors, scientists are better able to predict where birds will be more susceptible to collisions (Erickson et al. 2002). Also, altering the wind turbines' composition such as the tower, rotor, height and blade speed should help to reduce mortality (Byrne 1983; Orloff & Flannery 1992). These improvements of wind turbines, which will be investigated in more detail, have been effectively decreasing avian mortality, thereby making wind power a more compelling source of energy.

The most common wind turbines currently in use are horizontal-axis wind turbines (HAWT) and these will be the primary focus in this paper (Figure 1). There are three rotor blades to a HAWT, which act as barriers to the wind (Thresher and Dodge, 1999). The blades are connected at the rotor hub. When the wind moves the blades, the energy is transferred to the rotor. There have been deviances from this basic "barrier" method, with ridges and other designs being implemented in order to obtain more energy from the wind.

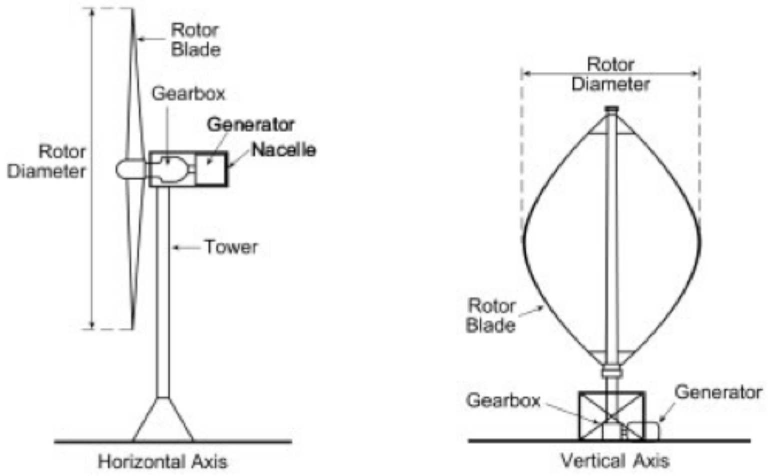

Figure 1: Horizontal-axis and vertical-axis wind turbine diagrams showing the major parts.

The modern turbine blades are similar in shape to airplane wings, where one surface of the blade is slightly rounded, while the other side is flatter. When the wind travels across the rounded side of the blade, the air has to move faster in order to reach the end of the blade at the same time as the air on the flat surface. This faster air creates a low-pressure area, pulling the blade in the downwind direction and is also known as Bernoulli's principle. The implementation of Bernoulli's principle added aerodynamics to the blades and increased the efficiency of wind turbines. The face of the turbine will also rotate towards the wind, increasing the amount of energy that can be captured. There are other important components to the turbines such as the shaft, which connects to the center of the rotor, transferring the mechanical energy of the rotors to the electrical generator. The generator produces electrical voltage, which drives the electrical current through power lines. The generator is housed inside the nacelle, which is located behind the rotor hub. A vertical-axis wind turbine (VAWT) is similar to a HAWT except that the main rotor shaft is vertical to the tower (Figure 1). This allows the blades to be effective without facing the wind (Thresher and Dodge, 1999).

One of the structural and design features that is believed to increase bird mortality are lattice towers. Lattice towers are freestanding framework towers while tubular towers consist of one solid cylinder as the tower. Lattice towers are more suitable for birds to perch on as compared to tubular towers (Osborn et al. 1998). If a bird perches or nests on the tower, the amount of time spent near the rotating blades increases greatly. If a bird nests on these towers, then the chicks will be exposed to rotating blades when they are most vulnerable: as they are learning to fly. If the frequency of high-risk situations is effectively decreased, then avian mortality should lessen as well. Therefore, installing tubular towers instead of lattice towers are believed to decrease rates of fatality.

One of the birds most influenced by wind turbine developments are raptors, or birds of prey (Erickson et al. 2002). Raptors are one of the most common baseline birds, which are used to estimate the overall impact wind turbines will have on all bird species. There is an absence of raptor mortality at the Buffalo Ridge Wind Resource Area, which contains tubular wind turbine towers (Osborn et al. 1998). Buffalo Ridge, located in southwestern Minnesota, consists of sloping hills and has about 340 wind turbines located in four clusters. It is believed that the small populations of raptors in the area, as well as the tubular tower design, are the main reasons behind this lack of mortality (Higgins et al. 1996). With lower local populations of raptors, the mortality will be low as well, helping with the zero mortality, but this alone would not eliminate raptor deaths. Raptors perching on lattice frame towers have been observed at California's Altamont Pass as well as on non-operating blades. American kestrels (*Falco sparverius*) were also seen perching on turbine blades as they rotated slowly (Orloff and Flannery 1992). Osborn et al (1998) did not witness any perching on the turbines at Buffalo Ridge, but did observe raptors commonly on utility poles, trees and meteorological towers in the vicinity. The combination between the availability of nearby perching sites, along with the difficulty to perch upon tubular towers, may have helped in the zero mortality rate at Buffalo Ridge.

Another study by Barrios and Rodriguez (2004) argues that there is no significant difference in mortality when discussing the physical structure of the tower. This research takes place at the first two wind farms to be installed in the Straits of Gibraltar, which is a main migratory passage for birds migrating between Africa and Europe (Moreau 1972). Most of the avian mortality occurred in two rows of turbines, with approximately 200m, a small distance, between them (Barrios and Rodriguez 2004). There were no deaths recorded, however, at another set of turbines located in the same spatial arrangement

(Barrios and Rodriguez 2004). Barrios and Rodriguez (2004) therefore believed that the physical structures themselves had little influence on bird mortality. More research is necessary in order to fully understand the impact that the physical structure of the turbine has on bird populations. Trends in recent research, however, are supporting the hypothesis that the structures have less influence on avian mortality than what was previously thought. Since the effect that the physical structure of the turbine has on bird mortality is not yet fully understood, it is still best to take precautions. Installing tubular towers, for example, would reduce the likelihood of perching and the amount of time birds are exposed to the blades.

American kestrels were observed nesting inside the nacelles and perching on the towers of older wind turbines in the Altamont Pass (Howell 1997). These older turbines had their blades removed since they were identified as being the most hazardous, but the tower and gearbox were left intact. These sightings of American kestrels nesting in the gearboxes and on the towers shows that old turbines left intact can still be hazardous to birds since they can still perch on them, increasing their exposure to the blades. After learning this information, there have been serious efforts to disassemble old turbines in the Altamont Pass, which has been reducing the mortality of birds (Quiros 2007). This is one of the many measures taken to decrease avian fatality.

Another recent improvement with regards to wind turbines is their size. The heights of turbines are now averaging 50 to 70 meters, with many experts hoping to reach 100 meters in the near future. It is believed that this greater height will place the blades above both the daily and migratory flight paths of most birds (Quiros 2007). Western burrowing owls, for example, are killed disproportionately more at blades 15m tall (Smallwood et al. 2007). The increase in blade height has decreased collision rates since the rotor blades are located above most of the owl flight paths. This increase in height, however, has caused red-tailed hawks (*Buteo jamaicensis*) to die three times as often as compared to the previous, lower height (Quiros 2007). As the height of the tower is extended, more energy will be captured because wind speed increases with elevation since objects at ground level can decrease wind currents. Scientists estimate that with each doubling of elevation there is a 12% increase in wind speed (Layton 2006).

The taller turbines also have larger blades, which move at lower revolutions per minute (rpm) and are believed to be more visible as compared to the older, smaller turbines (Erickson et al. 2002). This increased visibility to birds will make it more likely that the blades will be avoided. This was not true, however, with western burrowing owls, which were killed significantly more often by slower moving blades than faster ones (Smallwood et al. 2007). One hypothesis for these higher mortality rates by slower moving blades might be because the owls think that there is enough time to fly between the blades if they move at slower speeds. This would cause the turbines deemed safer to actually be more hazardous. No other studies were found showing that other species of bird were similarly affected.

The effect blade speed has on birds was also studied at the Klondike Wind Farm located in Oregon. It has 125 turbines of different types in a flat, agricultural area. At this wind farm, the blades on the 1.5 MW turbines turn about 20 rpm, while the Kenetech 56-100 turbines at the Altamont Pass turn 60 rpm (Risser et al. 2007). Research by Howell (1997) and Hunt (2002) indicate that the Kenetech 56-100 turbines have higher raptor mortality rates when compared to large turbines. Golden eagles, one of the primary birds negatively affected in these studies, fly low to the ground when foraging. Their foraging heights are similar to the rotating blades', which Hunt (2002) believes may be the cause for the higher mortality rates. The Kenetech 56-100 is also a downwind turbine, meaning the blades are on the downwind side of the nacelle. If a bird perches on the downwind turbine, it could be blown in the direction of the blades when flying from its perch (Risser et al. 2007). This is a severe disadvantage to the older turbines and another reason to explain the high mortality rates in the Altamont Pass.

Howell (1997) compared different types of wind turbines in the Altamont Pass and Montezuma Hills, California. The Montezuma Hills Wind Farm is located in low-elevation hills by the Sacramento River Delta in Solano County, California. The peaks of the hills range from 164 to 279 feet and there are hundreds of wind turbines located here. New variable speed turbines (KVS-33) with a 33m blade diameter were installed to replace the smaller and older KCS-56 turbines with an 18.5m blade diameter. For the next 7 years, avian mortality at the adjacent sets of turbines was compared. Both turbines had mortality rates proportionally similar to each other, leading Howell (1997) to believe that mortality took place on a "per-turbine basis". Since the KVS-33 turbines produce more energy than the KCS-56 turbines, replacing the KCS-56 would reduce mortality while providing more energy. If the KCS-56 were replaced with the newer KVS-33, mortality would be reduced by 66% while producing the same amount of energy (Howell 1997). Table 1 shows the relationship between increases in turbine rotor blade diameter and the power output. The newer KCS-56 turbines were constructed in 1992, meaning that the turbines installed today are creating more energy per turbine, thus continuing the trend of a decrease in mortality.

As turbines become more efficient, fewer turbines will be needed to produce the same amount of energy; this will lessen the barrier effect turbines can have on migrating bird populations if the turbines are installed densely (Dirksen et al. 1998). Although

Barrios and Rodriguez (2004) found that turbines located close together may increase bird mortality, the distance Dirksen et al (1998) discussed was about 300m, which was not found to be hazardous by Barrios and Rodriguez (2004). Smaller rows of turbines in migrating passageways could allow birds to more easily move around the turbines, lessening the barrier effect. In a study conducted by Osborn et al (1998) at the Buffalo Ridge Wind Resource Area, it was found that birds often adjusted their patterns of flight when the wind turbines were rotating and usually made no alterations when the blades were not rotating. This suggests that birds are able to detect blade movement either through sight, sound or both, which was also hypothesized by Erickson et al (2002). There have also been some experiments in order to see if the color or pattern of the blade would affect its conspicuousness (McIsaac 2001). It was found that patterns running across the blades' widths were less visible to kestrels than patterns running the lengths of the turbine blades. There were no tests on colors other than white and gray, which were less visible to the kestrels as compared to the patterned blades (McIsaac 2001). Researchers hope to implement this valuable information in the near future in the hopes that patterned blades could significantly reduce avian mortality.

In Denmark, Desholm and Kahlert (2005) investigated whether geese and ducks could avoid offshore wind turbines. They studied migration patterns of the birds using radar in order to see if the amount of flocks entering the wind farm decreased from preconstruction to operation; activity decreased by a factor of 4.5 (Desholm and Kahlert 2005). This radar study demonstrates avoidance response by migrating geese and ducks, with less than 1% of the birds flying close to the turbines that would risk collision. Desholm and Kahlert (2005) also believe that the estimate of birds in danger may be inflated as many birds could have flown through the turbines without being detected or harmed. The turbines could greatly affect migratory patterns through the Altamont Pass as the birds flying from areas without wind farms would not be as familiar with the turbines and blades, possibly making them more susceptible to collisions.

Other studies, such as De Lucas et al's (2004) project at the Strait of Gibraltar agrees with the findings that avian species alter their flight paths when they detect turbines. It was found that 71.2% of soaring birds adjusted their flight paths when nearing wind turbines and more often changed direction when the turbines were rotating as compared to when they were not. Species' path heights such as the short-toed eagle (*Circaetus gallicus*), black kite (*Milvus migrans*), griffon vulture (*Gyps fulvus*) and common kestrel (*Falco tinnunculus*) differed when entering and exiting the wind farms, possibly to circumvent the turbines (Dirksen et al. 1998). The birds were found to cross the turbine line 9% of the time in between the turbines and 18% of birds turned away from the turbines (Dirksen et al. 1998). Studies such as these suggest that certain birds' abilities to detect turbines are more effective than previously thought and the detection ability could largely be dictated by the location and visibility of the turbines.

The type of turbine can also impact bird behavior and the exposure of birds to the turbine blades since different types of turbines have varying structures. Flight, perching and turbine collisions of the burrowing owls occurred most often among vertical axis wind turbines, secondarily among lattice turbines and least often among windwall turbines (Smallwood et al. 2007). Windwall turbines are horizontal axis wind turbines, with their axis in a fixed position so wind is caught in one direction (Figure 2). They are installed on two lattice towers "to achieve a greater height domain of wind capture within a single row of turbines" (Smallwood et al. 2007). While windwall turbines can be more efficient than standard HAWTs, the inability for windwall turbines to capture wind from more than one

Figure 2: A picture of a windwall turbine, which is a horizontal axis wind turbine, with the axis in a fixed position so wind is caught in one direction.

direction decreases the turbine's productivity. The owl activity at the turbines corresponded with visibility through the other side of the blades: VAWT turbines are the least visible while windwall turbines are the most. This shows that owls are able to distinguish between the structural differences of turbines and blades and helps to identify what attracts and deters the owls (Smallwood et al. 2007). They also only perched on turbines when they were not operating, further showing the owls' awareness of turbine operation. Taking advantage of the elements that cause the owls to avoid turbine areas could be a large step forward in protecting them.

While western burrowing owls are known to be one of the birds most studied with regards to turbine-induced mortality, raptors are one of the most common baseline birds. Sites in Condon, Oregon, Stateline, Oregon and Washington and Foote Creek Rim, Wyoming have been relocated or not developed at all due to raptor use patterns (Erickson et al. 2002). Since raptors are apex predators, a decrease in their numbers can severely alter the populations of their prey, which consist of most other species of birds. In Erickson et al's (2002) study conducted, the total raptor use was estimated and standardized by each study area and season. Some of the areas reviewed with the highest raptor use were: Altamont Pass, California, Columbia Hills, Washington, the Stateline Reference Area, Oregon, Foote Creek Rim, Wyoming and the Tehachapi Pass, Oregon. The total raptor use in any season correlated strongly with the yearly estimates, showing that any one season's estimates can be representative of all seasons (Erickson et al. 2002). This means that raptor use is relatively stable in these areas, allowing shorter studies to be conducted in more places.

Estimates of raptor mortality in the Altamont Pass by Thelander and Rugge (2000) are 0.10 fatalities per turbine per year. At newer sites such as Montezuma Hills in California, the average is 0.048 fatalities per turbine. It would take about 3 to 8 of the turbines in the Altamont Pass to equal the rotor swept area (RSA) of one new wind turbine at Montezuma Hills (Erickson et al. 2002). The RSA is the size of the area the turbine blades span. At Foote Creek Rim there are an estimated 0.04 raptor fatalities each year, which equals 3 fatalities per 100,000 m^2 RSA, or 3-7 less than estimates at Altamont Pass, which has 9-22 raptor fatalities per 100,000 m^2 RSA (Erickson et al. 2002). These mortalities will continue to decrease as the RSA of wind turbines continue to increase and the wind turbines become more efficient at producing energy.

Red-tailed hawks have been a raptor species focused on in studies, as previous studies have shown that they appear to be extremely susceptible to fatalities related to wind turbines (Orloff and Flannery 1992; Barrios and Rodriguez 2004). Hoover and Morrison (2005) investigated their flight behavior in order to see if this increased the risks of turbine-related fatalities. Conducted in the Altamont Pass, 15 plots were studied, with livestock grazing the dominant form of land use. There were no shrubs and few trees in the immediate area, which resulted in mostly human-made structures such as turbines, utility poles and fences for birds to perch upon. Seventy-six percent of the observed raptor sightings were red-tailed hawks, whose behaviors were described in three broad categories: perching, soaring and kiting (Hoover and Morrison 2005). Kiting occurs when a bird uses updrafts of air to assist in flight. Kiting behavior by the hawks can be dangerous since this is usually done about 15-35 m from ground level, similar to the heights of turbine blades. Kiting is also utilized most often during strong winds, which can produce severe and unpredictable gusts. Since kiting is a static form of flight, these strong gusts could thrust the hawk close to the rotating blades, increasing the chances of injury. Hoover and Morrison (2005) also noted that a disproportionate amount of red-tailed hawk fatalities occurred on the slopes where most of the kiting behavior took place. On 4% of the slopes surveyed, 14% of the red-tailed hawk collisions were found, indicating that the turbine collisions might be correlated to slope characteristics. Red-tailed hawks were seen most often during the fall, with an average of 31.5 sightings for the season with the winter sightings of 9.8 being the second most frequent season. Knowing the abundance of red-tailed hawks at certain times throughout the year can help reduce mortality by powering down some of the wind turbines during this time.

Wind speed was also an important factor in influencing the behavior of red-tailed hawks (Hoover and Morrison 2005). The hawks were observed to be perched nearby turbines 2.8 times more often during weak winds as compared to when they were strong. Perching in these locations increases a bird’s exposure to the blades, thus increasing the chances of a collision. During strong winds hawks were seen perched on the ground or on low-lying objects like boulders almost twice as often. These areas are lower than the blades of the turbines, making it less likely for the birds to be swept near the blades during strong gusts. In some cases, birds could be safer in strong winds since they are further from the moving blades. The hawks studied by Hoover and Morrison (2005) were seen more often perching on wind-protected slopes, especially during strong winds, where 86% of perches seen were on protected slopes, as compared to 72% during weaker winds. Wind-protected slopes do not have many turbines installed on them since winds in these areas are minimal, thus making them an ideal place for hawks to perch during strong winds (Hoover and Morrison 2005).

There were also noticeable differences in flight behavior during the various wind strengths (Hoover and Morrison 2005). Kiting was 6.5 times more common during strong winds and soaring was 3.5 times greater during weak winds. Red-tailed hawks showed kiting behavior more often on windward slopes and flapping behavior on protected slopes. They were also seen gliding almost 3 times as often on the steepest inclines as compared to the other slope levels (Hoover and Morrison 2005). This information indicates that the behavior of the red-tailed hawk is highly influenced by both wind conditions and topography. Soaring and kiting were the two most common flight behaviors witnessed and the use of each flight type depended on wind conditions. Soaring was observed more often in weak winds, likely because soaring relies on warm rising air masses (thermals), which are often disrupted when wind velocities are too high. When the thermals are interrupted, they are no longer able to provide sufficient lifting power (Preston 1981). The hawks kited almost solely in strong winds on windward slopes, using the updrafts for lift (Hoover and Morrison 2005). Kiting is a static form of flight and this behavior increases the chances that a hawk will be swept into the rotating blades.

The differences in distribution of the red-tailed hawks throughout the seasons could be explained by the changes in wind currents during these times (Hoover and Morrison 2005). Red-tailed hawks were observed to be aerially hunting more often in the summer months when wind speeds were highest. In the other three seasons, wind speeds were lower, which is when the hawks were observed to be perched more frequently when hunting. They would mostly face downhill, which protected them from the wind and may have also aided them in avoiding updrafts when flying in for the kill.

These high red-tailed hawk fatalities are not widespread, however, and appear to be cases unique to certain sites. This has led to the hypothesis that a low raptor presence at some sites might be due to a lack of prey. In a study by Hoover (2001), there was a significantly lower density of red-tailed hawks in slopes that had low squirrel density. These areas underwent routine squirrel control treatments unlike other areas in this study. Conducting small mammal surveys prior to the installation of turbines can help in understanding the abundance of red-tailed hawk prey and thus the presence of these hawks in the area.

The western burrowing owl's abundance in the Altamont Pass area was also highly influenced by the density of ground squirrels. Since both animals use the burrowing systems, their abundances are positively correlated. Smallwood et al (2001) found that burrowing owl density increased highly when there were ground squirrel burrows within 55m of the wind turbines. There were also higher rates of burrowing owl collisions in areas where burrow systems were within 90m of the turbines and fewer collisions where there was intense rodent control (Smallwood et al. 2001). Of the sample taken, 23% of the owl fatalities occurred where there were high burrow system densities (Smallwood et al. 2001). Controlling the squirrel abundance would help in reducing owl mortality, but would also lead to habitat loss, thus displacing the burrowing owls and any other organisms that rely on these tunnel systems. The most effective measure that should be taken, therefore, is to conduct small mammal surveys so that turbines can be sited where small mammal density is low.

Cattle can also be an indicator for raptor and burrowing owl density in the area. As cattle graze the land surrounding the turbines, they leave behind dung, which attracts insects as well as birds that eat these insects (Quiros 2007). Cattle grazing is a common occurrence near turbines as areas surrounding the turbines are mostly grasses and devoid of forests, creating a good habitat for cattle. It has been noted in the Altamont Pass that areas where cattle graze have higher densities of birds that feed on insects. Burrowing owls feed on grasshoppers and lizards, which are attracted to the cattle dung (Smallwood et al. 2007). More owls were seen perching and flying closer to the wind turbines that had cattle grazing nearby and a disproportionately high amount of owls were killed where dung was within 20m of the turbines (Smallwood et al. 2007). It is also believed that the owls collect cattle dung to display around the entrance of their burrows to lure dung beetles (Levey et al. 2004). If this is a common habit of the burrowing owls, then dung is a large attractant for the birds thus grazing should be limited near turbines to reduce owl mortality. Reducing the density of cattle near the turbines would help greatly in limiting owl concentrations and their exposure to the turbines. Another side effect of cattle grazing is the shortened grass length, which better reveals ground animals sought after by birds of prey (Quiros 2007). The shortened grass length makes the areas surrounding the turbines more inviting for raptors to hunt near, thus increasing their exposure to hazardous blades. The raptor prey density in areas surrounding the turbines might be an excellent indicator of raptor density and thus avian density as a whole.

These relationships between flight behavior, wind currents and topography were also identified by Barrios and Rodriguez (2004) when they found that mortality of griffin vultures (*Gyps fulvus*) at wind farms in Campo de Gibraltar, Spain were associated with slope and wind currents. The vultures in this study experienced higher rates of mortality in the winter and fall because the thermals used to help lift them above the rotating turbine blades were absent during these months. In times of weaker winds other birds such as common buzzards (*Buteo buteo*) were seen circling with the vultures but did not approach the turbines as closely as the vultures and rarely collided with the blades. Barrios and Rodriguez (2004) believed that the cause of this change in behavior was due to the common buzzards' lower wing loadings as compared to vultures. This allows them to better use the rising air currents to gain altitude faster, distancing themselves from the turbines. Installing "flight diverters as tall poles erected in parallel beyond the rotor planes of the end-of-row turbines" could help in steering the flight paths away from the higher risk turbines (Smallwood and Thelander 2004).

Figure 3: Flight diverters installed on parallel lines.

These flight diverters are also important because end-of-row turbines led to higher mortality rates than interior turbines and flight diverters could help reduce mortality in these cases as well (Smallwood et al. 2007).

Similar to red-tailed hawks, western burrowing owl activity in the Altamont Pass also fluctuated with the seasons, as mortalities caused by wind turbines were highest in the fall and early winter (Smallwood et al. 2007). The winter is the least productive season of the Altamont Pass and shutting down the turbines from November to February is believed to reduce owl fatalities 35% annually; this would only decrease the annual generation of electricity by 14% (Smallwood et al. 2007). In a similar study, it was estimated that a full winter shutdown would result in a 40-44% annual avian mortality reduction (Quiros 2007). Select turbines are also at a higher risk than others as 29% of the turbines in the Altamont Pass studied by Smallwood (2007) killed 71% of the dead owls found. These turbines were located in areas where higher owl activity was also documented. Powering down select turbines will help greatly in continuing to reduce avian mortality (Quiros 2007).

As shown with understanding which turbines are located in high activity areas, it is important to know how raptors and western burrowing owls interact with their surrounding environments in order to help predict how wind turbines will affect them. As more studies similar to Hoover and Morrison (2005) and Barrios and Rodriguez (2004) are conducted, information such as topographical features and weather variables could help to calculate the danger turbines will present to the birds. Understanding the strong updrafts and how the slope of hills and other local features affects updrafts would let those installing the wind turbines know where to avoid placing turbines. For wind farms already installed, such as in the Altamont Pass, understanding the turbines that place raptors most at risk could lead to powering them down. This would allow the majority of the turbines to continue to run, while eliminating those that cause the most damage.

While raptors are arguably the most well know birds negatively affected by wind turbines, the protected passerine (Passeriformes) species, which excludes European starlings (*Sturnus vulgaris*), rock doves (*Columba livia*) and house sparrows (*Passer* *domesticus*), have been the most common type of bird killed at wind farms outside of California (Erickson et al. 2002). Over 80% of turbine-related mortality reported comprised of these passerines and these mortalities have been reported throughout many different wind farms (Erickson et al. 2001). At Buffalo Ridge, Minnesota, forty-two fatalities in twenty-one different species were recorded within a four-year period. In Vansycle, Oregon, seven out of ten mortalities were passerines, and in Foote Creek Rim, Wyoming, there were eighty-seven deaths from twenty-six different species (Johnson et al. 2000). It has been noted that passerines are more productive closer to wind turbines and Leddy et al (1999) found a linear positive relationship with breeding density of birds and distance from the wind turbines (De Lucas et al. 2004). Passerines include more than half of the bird species, increasing the likelihood of exposure to hazards such as wind turbines. They are also known to perch often, which is dangerous in areas where there are inactive turbines and other manmade structures nearby. Using knowledge such as flight patterns and hunting behavior of passerines can help in their conservation by understanding which areas pose a greater threat to them. Information gained from other species can also assist in better understanding passerine habits. Additional research is necessary to better comprehend how passerine species react to different weather patterns and human-induced disturbances in order to improve protection.

Other types of birds that have not received much publicity are the waterfowl, shorebirds and seabirds; the presence of water near wind farms can be a significant factor in determining their abundance (Erickson et al. 2001). Similar to perch abundance and cattle density, large expanses of water is a habitat necessity for these birds. If these favorable habitats are located near the wind farms, then their exposure to the blades increases greatly. Expanses of water such as lakes and oceans are also habitats for many organisms that might be prey for other avian species, thus increasing the danger to these birds as well. Although weather patterns that are more prone to heavy forms of precipitation and wind can affect all avian species, waterfowl, shorebird and seabird movements are especially limited by these weather systems (Nelson and Curry 1995). These conditions will decrease visibility and better conceal the turbines, making it more likely for birds to strike the turbines. The high winds also increase the chances of a bird that is flying near the turbines to be blown closer to the hazardous blades.

Heavy fog is also an important factor that should be included when discussing weather systems (Osborn et al. 2000). The possible sudden decrease in visibility can be hazardous to birds flying during this time and towers that have lights can be more dangerous. This applies to overcast skies as well, where birds have been noted to being drawn to the bright lights during these times (Avery et al. 1976). The most likely reason for this is that the birds are drawn to these lights from a distance and the moisture droplets in the air during the overcast skies refract the light, increasing the illuminated area and thus the attraction. This draw might be because the birds believed this light was that of stars since other celestial cues are unavailable during this period. If lights draw more birds closer to the turbines, then the chances of mortality will increase. Removing lights off of turbines could help in reducing the birds' attraction and is just one more way to protect them. Nocturnal migrants are at a greater risk even if there are no lights on the wind turbines. It is estimated that about 50% of fatalities at new wind turbine projects are from birds that migrate during the nighttime (Erickson et al. 2001). This is a significant portion of the mortalities and finding a way to reduce these numbers is crucial in limiting wind turbine impacts on birds. Flashing lights have been found to reduce avian collisions during the night since blinking lights do not resemble celestial cues (Gehring et al. 2009).

Implementing these lights on communication towers, wind turbines and airplanes have successfully decreased the mortality rates of avian species.

Understanding the behaviors of avian species has helped with the large effort to create standardized methods for constructing wind farms and monitoring the turbines' impacts on birds (NWCC 2002). This effort has led to increased monitoring of nesting and flight patterns prior to the construction of new developments (Erickson et al. 2001). This data has helped to predict the effects of turbine projects on habitats and wildlife as well as for installing more turbines within an existing site. This knowledge is helping to improve the capability of accurately predicting the impact of projects, resulting in little to no raptor mortality at the new projects (Erickson et al. 2002). The installation of monitoring programs at wind farms such as Stateline, Oregon and Washington, Klondike, Oregon and Buffalo Mountain, Tennessee are increasing the data available to help protect all species of bird.

A concern regarding wind turbines that is overlooked by many is the disturbance construction will have on the surrounding area for both bird and bat species. During the construction process, the land will be torn apart and heavy machinery will be used. The physical abuse on the land could displace birds that burrow in the area or rely on the vegetation for protective cover or food. This could displace the birds to habitats less suitable for them to survive and reproduce (Frid and Dill 2002). Even if the birds and bats are not physically displaced from the development, their foraging abilities might decrease significantly due to a decrease in vegetation. This reduction in vegetation could then lead to further degradation of the habitat as erosion increases in areas that lack vegetation. The disturbance can also come from operation noise of vehicles and machines and this will travel beyond the areas directly impacted by the construction. The access roads will contribute to this disturbance and will also help in producing new ones. Once the roads are already created, the land will be more accessible for other means such as agriculture and recreation, thus promoting further degradation to the land (Langston and Pullan 2003).

It is possible to lessen the impact of wind turbine construction on the surrounding habitats. Only clearing the areas necessary for wind turbine development and making the area rounded will expose less edge of the original habitat. Edges of habitats are most vulnerable, as they are less protected from the elements. If the area that the turbines are being installed on is devoid of large vegetation such as trees, then preventing soil degradation will be most important. If the soil rich in nutrients is removed, then the effects on initial construction will be sustained for longer and will be more severe. By understanding these consequences, it is possible to greatly reduce these impacts. Measures such as replanting vegetation can help improve the fertility of the land, making it a healthier environment for animals to live on.

It has been documented that wind farms can also negatively affect bat populations after the construction process has ceased. Bat mortality rates fluctuate more per season as compared to birds: close to 90% of the bat fatalities recorded occurred from mid-July through September and over 50% of the turbine-induced collisions happened in August (Erickson et al. 2002). Although there was a strong correlation with regards to the timing of most of the collisions, no patterns have been found with regards to the distribution of collisions among the turbines (Johnson et al. 2000; Young et al. 2001). This lack of pattern shows that it is migratory bats, not the local populations, that are most impacted by the wind turbines. If it were the local bats being negatively affected, there should be patterns of mortality, since the corridors most traveled by the local populations should experience higher rates of mortality due to more exposure (Erickson et al. 2002). Studies have shown that it is the fall migrants that make up the mortality, as there is an increase in turbine-induced death during this timeframe (Keeley et al. 2001). The foraging heights of bats are usually less than 10 meters from the ground, which is below most blades (Erickson et al. 2002). This demonstrates that migrating bats and not foraging bats comprise of most of the collisions. Similar to avian species, understanding the fluctuation of bat activity can allow for the shutdown of turbines deemed a greater risk during times of higher rates of activity.

Studies have shown that bats are better able to detect moving objects as compared to stationary objects with echolocation since echolocation is used to detect moving prey (Jen and McCarty 1978). Since foraging bats use echolocation to locate prey, it is unlikely that they would not be able to detect the moving turbines. Another study, however, shows that bats use vision over echolocation for long-distance echolocation (Mueller 1968; Williams and Williams 1970; Fenton 2001). If bats navigated through wind farms using only their sight, then the causes of turbine collisions are likely to be similar to that of bird species, making the two easier to manage together.

Bat mortalities were also found to highly depend on the surrounding habitat (Johnson et al. 2002). In the study that took place at Buffalo Ridge, bat activity was highest in areas that were surrounded by habitats that bats frequented such as wetlands and woodlands. The more suitable areas had bat activity that was 15 times higher and had higher rates of mortality as compared to less suitable areas (Johnson et al. 2002). Understanding the types of landforms and surrounding areas that attract bats can help in limiting construction in these locations frequented by bats.

Baerwald et al (2008) believes that the main cause of bat mortality is due to changes in pressure resulting from the rotating blades. Known as the decompression hypothesis, it is believed that the bat mortality is a result of barotrauma triggered by sudden reductions in air-pressure by the moving blades (Kunz et al. 2007). Barotrauma consists of damage to the tissue of "air-containing structures" due to sudden large changes in pressure. Baerwald et al (2008) found that 90% of bat deaths had internal hemorrhaging which is consistent with barotrauma and direct contact with the blades was only found in half of the deaths. As the turbine blades rotate, pockets of low pressure are created, which cannot be detected by either bats or birds. Barotrauma has only been suggested as a cause of bat fatalities because the respiratory anatomy between birds and bats are different. Bats have large lungs that are extremely pliable and expand when there is a sudden decrease in pressure, which causes damage to the tissue. Birds, however, have rigid, compact lungs that do not fluctuate as greatly when there is a drop in air pressure (Baerwald et al. 2008). The research on barotrauma is relatively new and mitigation to reduce bat mortality caused by sudden drops in pressure have not yet been formed. The factors that affect both bats and birds, while not identical, are very similar and must be taken into account in order to reduce the high rates of mortality.

While wind energy has recently been the focus on avian and bat mortality, other forms of energy production such as coal and oil severely affect these populations both directly and indirectly by polluting water sources, decreasing air quality and destroying large spans of habitat. These practices are more widespread than wind energy and the deadly effects cannot be quantified as easily since most of the side effects do not kill the birds and bats immediately and instead usually decrease the fitness of the birds and bats by weakening them and making them sick. This lack of ability to directly quantify the deaths can make coal and oil seem less intrusive, when the opposite is actually the case. Coal and oil have also been a more common occurrence throughout people's lives, while wind energy has only been becoming more abundant fairly recently. Since wind turbines are new and relatively unknown to the public, this also causes greater amounts of concern to be raised as compared to older and more traditional means of energy production.

Wind energy is the most easily quantifiable energy production source, causing its negative effects to seem more pronounced as compared to other sources of energy. It is also a relatively new obstruction as compared to communication towers, vehicles and buildings and windows, furthering this notion that wind turbines kill large masses of birds and bats, whose losses cannot be sustained. Most people are only aware of the negative impacts that wind turbines have on avian and bat populations and do not realize that other human structures contribute so highly to bird and bat fatality rates. The truth is, though, that wind turbines only make up a small fraction of human-induced avian deaths (0.01-0.02%) and this figure would come as a shock to many people since wind turbine-related mortalities of birds and bats is covered frequently by news reports (Erickson et al. 2001). Therefore, it is important to educate people about the effects other forms of energy and human structures have on these populations.

Another common misconception is that all wind farms are as harmful to birds as the Altamont Pass in California is. This wind farm, along with other early projects, were not built with the necessary research and surveying needed to properly evaluate the effects that wind turbines will have on bats and local and migratory birds. Since these wind farms were built in the early 1980s, thirty years ago, mortality rates have been dramatically reduced as changes in turbine structure and placement, as well as studies regarding specific avian species behavior, have helped to build safer and more strategically located turbines (Erickson et al. 2001). As wind energy continues to increase in demand, research to reduce the overall impact of turbines on birds will greaten, resulting in lower turbine-induced avian and bat mortality. It is important that wind energy continues to increase in energy production per year, as it is one of the safest and most viable renewable energy sources available today.

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