Renewable Energy Resources and Wildlife: Impacts and Opportunities

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Introduction

Fossil fuels currently provide more than 85 percent of all energy consumed worldwide. And, nearly two-thirds of electricity and virtually all transportation fuels used in the United States are derived from fossil fuels (Environmental Information Administration 2007, U.S. Department of Energy 2007a). Conventional power generation from fossil fuels has a host of well documented environmental impacts, the most notable being emissions of carbon dioxide (CO_2). Many climate-change models predict that increased atmospheric CO_2 concentrations could pressure flora and fauna to adapt to changing environmental conditions (Inkley et al. 2004). With rising costs and long-term environmental impacts from use of fossil fuels, the world increasingly is looking for alternatives to supply electricity and fuel for transportation (McLeish 2002, Bernstein et al. 2006, Kunz et al. 2007). Alternatives frequently considered are nuclear, coal with CO_2 sequestration (i.e., capture and storage of CO_2 and other greenhouse gases that otherwise would be emitted into the atmosphere), conservation and renewable energy.

Wind energy and production of biomass (e.g., agricultural crops, animal wastes, wood chips) are two fast growing renewable energy sources under development, in part due to recent technological advances and cost-competitiveness with conventional sources (Bernstein et al. 2006). Wind turbines are able to generate electricity without many of the negative, long-term environmental impacts associated with other energy sources (e.g., greenhouse gas emissions). The National Energy Modeling System (NEMS) model projects that installed capacity of wind turbines will grow to about 100,000 megawatts (100 billion j/s) over the next 20 years, but some wind experts project that wind energy could ultimately contribute 20 percent of the United States' electrical energy needs, as Denmark has already achieved (National Economic Council 2006). This would amount to more than three times the installed capacity projected by the NEMS model. Some energy analysts suggest, however, that while wind energy is growing exponentially in the United States, fossil-fuel-burning power plants also continue to grow exponentially, which raises questions about reduction of greenhouse gas emissions over time. Indeed, the proportion of fossil fuels in the world's energy mix, currently at 86 percent, is not projected to change by 2030 (Environmental Information Administration 2007).

Generally, biomass can generate energy in two forms: it can be burned directly for heat and the production of electricity or can be converted into solid, gaseous and liquid fuels using conversion technologies (Hall 1997). Biofuels produced from renewable feedstock are primarily used for transportation vehicles and include ethanol and biodiesel (Schnepf 2006); the primary source of ethanol in the United States is corn (Bernstein et al. 2006, Schnepf 2006). Corn-based ethanol production has increased dramatically in recent years and is expected to grow from nearly 4.5 billion gallons (17 million l) produced by the beginning of 2006 to 6.7 billion gallons (25.4 billion l) in 2007, a 49-percent increase in just one year (Schnepf 2006). Cellulose-based ethanol, produced from cellulose in plant-cell walls, is chemically identical to corn- or sugar-based ethanol, but it differs in the processing required to break cellulose down to sugars suitable for fermentation (U.S. Department of Energy 2007b). Cellulose-based ethanol can be derived from agricultural residues, such as wheat straw, from forestry residues, such as sawdust or logging slash, from municipal solid waste, from pulp and paper mill sludge, from other cellulose biomass feed, or from stocks, such as switchgrass (*Panicum virgatum*) (U.S. Department of Energy 2007b). The role of biomass fuel production is anticipated to expand considerably in future years. Congress recently established a technical advisory committee that envisions a 30-percent replacement of current petroleum consumption in the United States with biofuels by 2030 (Perlack et al. 2005).

Wind and biomass energy production offer more environmental benefits than other energy sources (e.g., less air and water pollution, less greenhouse gas emissions), potentially benefiting biodiversity. However, wind and biomass energy development is not environmentally neutral. Here, we present a synthesis of known and potential impacts of wind and biomass energy development on wildlife and, based on the current state of knowledge, offer suggestions for advancing these energy sources while avoiding, minimizing and mitigating impacts on wildlife.

Wind Energy and Wildlife

We discuss impacts of wind-energy development on wildlife resulting from collision fatality and habitat-related impacts. Much of our discussion on impacts of wind energy on wildlife comes from a recent review of the subject by The Wildlife Society (Arnett et al. 2007).

Wildlife Collision Fatality

Birds. Although fatalities of many bird species have been documented at onshore wind facilities, raptors have received the most attention (e.g., Orloff and Flannery 1992, Erickson et al. 2001). Initial observations of dead raptors at the Altamont Pass Wind Resource Areas (APWRA) (Orloff and Flannery 1992) triggered concern from regulatory agencies, environmental groups, wildlife resource agencies, and wind and electric utility industries about possible impacts to birds from wind-energy development.

Early studies on fatalities at wind facilities occurred in California because most wind power was produced by three California facilities (APWRA, San Gorgonio and Tehachapi) using small early generation turbines ranging from 40 to 300 kilowatts (40,000–300,000 j/s), with the most common turbine rated at approximately 100 kilowatts (100,000 j/s). Contemporary wind-power developers use a much different turbine than the older facilities discussed above. In addition, many facilities have been constructed in areas with different land use than existing facilities in California. Results from 14 avian fatality studies, where surveys were conducted using a systematic survey process for a minimum of 1 year and scavenging and searcher efficiency biases were incorporated into estimates, report a mean fatality rate of 0.04 raptors per megawatts per year (Table 1). Regional fatalities of raptors per megawatts per year were similar, ranging from 0.07 in the Pacific Northwest region to 0.02 in the East (Table 1). With the exception of two eastern facilities in forested habitats, the land use and

Table 1. Avian fatality rates from new generation wind facilities where standardized fatality monitoring was conducted.

	Project size		Turbine characteristics			Raptor fatality rates		All bird fatality rates		
Wind project	Number turbines	Mega-watts	Rotor diameter	rotor-swept area	Per megawatt	Per turbine	Per megawatt	Per turbine	Per megawatt	Source
Pacific Northwest										
Stateline, Oregon/Washington	454	300	47	1735	0.66	0.06	0.09	1.93	2.92	Erickson et al. 2004
Vansycle, Oregon	38	25	47	1735	0.66	0.00	0.00	0.63	0.95	Erickson et al. 2000
Combine Hills, Oregon	41	41	61	2961	1.00	0.00	0.00	2.56	2.56	Young et al. 2005
Klondike, Oregon	16	24	65	3318	1.50	0.00	0.00	1.42	0.95	Johnson et al. 2003b
Nine Canyon, Washington	37	48	62	3019	1.30	0.07	0.05	3.59	2.76	Erickson et al. 2003
Overall	586	438	56	2554	1.02	0.03	0.03	2.03	2.03	
Weighted averages	586	438	49	1945	0.808	0.05	0.07	1.98	2.65	
Rocky Mountain										
Foote Creek Rim, Wyoming phase I	72	43	42	1385	0.60	0.03	0.05	1.50	2.50	Young et al. 2003
Foote Creek Rim, Wyoming phase II	33	25	44	1521	0.75	0.04	0.06	1.49	1.99	Young et al. 2003
Totals or simple averages	105	68	43	1453	0.675	0.04	0.05	1.50	2.24	
Totals or weighted averages	105	68	43	1428	0.655	0.03	0.05	1.50	2.31	
Upper Midwest										
Wisconsin	31	20	47	1735	0.66	0.00	0.00	1.30	1.97	Howe et al. 2002
Buffalo Ridge phase I	73	22	33	855	0.30	0.01	0.04	0.98	3.27	Johnson et al. 2002
Buffalo Ridge phase II	143	107	48	1810	0.75	0.00	0.00	2.27	3.03	Johnson et al. 2002
Buffalo Ridge Minnesota phase III	139	104	48	1810	0.75	0.00	0.00	4.45	5.93	Johnson et al. 2002
Top of Iowa	89	80	52	2124	0.90	0.01	0.01	1.29	1.44	Jain 2005
Totals or simple averages	475	333.96	46	1667	0.67	0.00	0.01	2.06	3.13	
Totals or weighted averages	475	333.96	46	1717	0.53	0.00	0.00	2.22	3.50	

Table 1 (continued). Avian fatality rates from new generation wind facilities where standardized fatality monitoring was conducted.

Wind project	Project size		Turbine characteristics			Raptor fatality rates		All bird fatality rates		Source
	Number turbines	Mega-watts	Rotor diameter	rotor-swept area	Per megawatt	Per turbine	Per megawatt	Per turbine	Per megawatt	
Paast										
Buffalo Mountain, Tennessee	3	2	47	1735	0.66	0.00	0.00	7.70	11.67	Nicholson 2003
Mountaineer, West Virginia	44	66	72	4072	1.50	0.03	0.02	4.04	2.69	Kerns and Kerlinger 2004
Totals or simple averages	47	68	60	2903	1.08	0.02	0.01	5.87	7.18	
Overall (weighted average)	47	68	70	3922	1.45	0.03	0.02	4.27	2.96	

land cover in these studies were agricultural, Conservation Reserve Program (CRP) land, or shortgrass prairie.

Factors commonly associated with raptor collision risk are turbine type, turbine location and bird abundance; fatality rates for older turbines are unadjusted for searcher detection and scavenger removal, while rates from the 17 sites with newer generation turbines are adjusted for these biases (Figure 1). Three of the four studies at older generation sites report higher fatality rates than newer, larger turbine sites, even without bias adjustment. It is noteworthy that even though reported raptor fatalities are higher on average at older facilities, there is a rather dramatic difference among older facilities. Because the three facilities have similar technology, this difference may be influenced by other factors, likely raptor abundance (Figure 2). Additionally, it appears that siting of individual turbines may relate to risk of collision and raptor fatalities (e.g., Orloff and Flannery 1992, Young et al. 2003a, Smallwood and Thelander 2004) and turbine siting decisions during construction of a facility are important.

Fatalities of passerines from turbine blade strikes likely is not

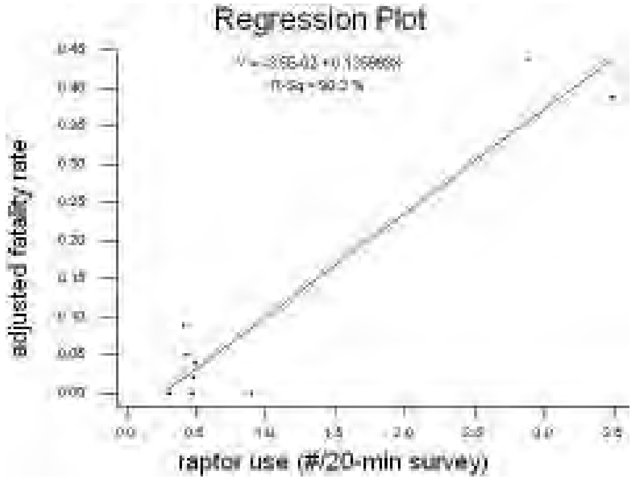

Figure 01. Fatality rates, adjusted for searcher efficiency and carcass removal bias, for raptors at four older generation turbines in California—Altamont Pass, Tehachapi Pass, Montezuma Hills and San Gorgonio (Howell 1997, Anderson et al. 2004, 2005,Smallwood and Thelander 2004)—and fatality rates, adjusted for searcher efficiency and carcass removal at 17 wind projects (Erickson et al. 2000, 2003, 2004; Howe et al. 2002; Johnson et al. 2002; Johnson et al. 2003b; Nicholson 2003; Young et al. 2003; Kerns and Kerlinger 2004; Young et al. 2005; Jain 2005) with newer generation turbines.

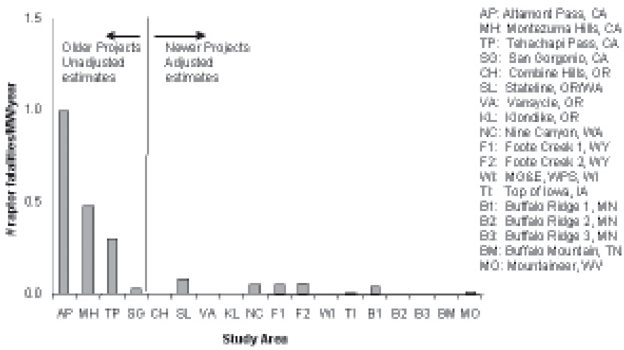

Figure 02. Relationship between raptor use and fatality at 12 facilities in North America (W. P. Erickson, personal communication)

significant at the population level (Erickson et al. 2001, Strickland et al. 2001). Erickson et al. (2001) reported that 78 percent of carcasses found at wind plants outside of California were passerines. And, the balance of fatalities was waterfowl (5.3 percent), waterbirds (3.3 percent), shorebirds (0.7 percent), diurnal raptors (2.7 percent), owls (0.5 percent), gallinaceous (4.0 percent) and others (2.7 percent)—protected under the Migratory Bird Treaty Act (MBTA) or state law—and unprotected birds were 3.3 percent. Estimates of bird fatality vary considerably among studies conducted at new-generation facilities (Table 1), but fatalities per turbine and per megawatts per year are similar for all regions represented by these studies. With the exception of raptors, most studies report that fatalities occur throughout the facility with no particular relationship to site characteristics. Approximately half the reported fatalities at new-generation, wind-power facilities are nocturnally migrating birds, primarily passerines.

Perhaps the most difficult task in interpreting fatalities is the estimation of exposure. For example, corvids are a common group of birds observed flying near the rotor-swept area of turbines (e.g., Erickson et al. 2004, Smallwood and Thelander 2004) yet are seldom found during carcass surveys. Clearly, the role of abundance relative to exposure of birds to collisions with wind turbines is modified by behavior within and among species and likely varies across locations.

Inclement weather has been identified as a contributing factor in avian collisions with other obstacles, including power lines, buildings and communication towers (e.g., Manville 2005). Johnson et al. (2002) found that most bird fatalities discovered at the Buffalo Ridge wind facility may have occurred in association with inclement weather, such as thunderstorms, fog and gusty winds. Federal Aviation Administration (FAA) lighting has been associated with an increase in avian fatalities at communications towers and other tall structures (e.g., Manville 2005), yet there is no evidence suggesting a lighting effect for passerine fatalities associated with wind power (Erickson et al. 2001).

Fatality studies almost universally report very few fatalities of waterfowl, shorebirds or gallinaceous birds, as previously noted by Erickson et al. (2001). In a review of five wind facilities, J. Fernley, J., S. Lowther, and P. Whitfield (unpublished report 2006) reported that (1) collision of medium to large species of geese with wind turbines is an extremely rare event (unadjusted rates of 0 to 4 per year for the 5 sites reviewed), (2) there appears to be no relationship between observed collision fatality and number of goose flights per year and (3) geese appear to be adept at avoiding wind turbines.

Bats. Recent surveys have reported large numbers of bat fatalities at some wind-energy facilities, especially in the eastern United States (e.g., Fiedler 2004, Kerns and Kerlinger 2004, Arnett 2005) and, more recently, in Canada (Brown and Hamilton, unpublished report 2006) and Oklahoma (Piorkowski 2006). Although bats collide with other tall anthropogenic structures, the frequency and number of fatalities reported is much lower than those for bat fatalities observed at wind turbines. Several plausible hypotheses relating to possible sources of attraction, to density and distribution of prey, and to sensory failure (e.g., echolocation), for example, have been proposed to explain why bats are killed by wind turbines (Arnett 2005, Kunz et al. 2007).

Estimates of bat fatalities from wind facilities in North America range from 0.2 to 53.3 bats per megawatt per year (Johnson 2005, Kunz et al. 2007). These estimates vary due, in part, to region of study, habitat conditions, sampling interval and bias corrections used to adjust estimates. Currently, two studies on forested ridges in the eastern United States at Mountaineer, West Virginia, and at Buffalo Mountain, Tennessee, and one study from open prairie habitat in southern Alberta have documented the highest fatalities of bats reported in North America (Kunz et al. 2007) and are higher than those reported from European studies (Dürr and Bach 2004, Brinkmann 2006). Eleven of the forty-five species of bats occurring in the United States and Canada have been among fatalities reported at wind facilities (Johnson 2005), and 10 species of bats have been reported killed by turbines in Europe (Dürr and Bach 2004). Bat fatalities appear heavily skewed to migratory tree roosting species that include the hoary bat (*Lasiurus cinereus*), eastern red bat (*Lasiurus borealis*) and silver-haired bats (*Lasionycteris noctivagans*; Johnson 2005, Kunz et al. 2007). In Europe, migratory species also dominate fatalities (Dürr and Bach 2004). No studies have been reported from wooded ridges in the western United States or in the Southwest (e.g., Arizona, Texas), where different species of bats may be more susceptible (e.g., Mexican free-tailed bats [*Tadarida brasiliensis*]). The only two investigations at wind facilities within the range of the Mexican free-tailed bat report high proportions of fatalities of that species (31.4 and 85.6 percent in California [Kerlinger et al. 2006] and Oklahoma [Piorkowski 2006], respectively). To date, no fatalities of a threatened or endangered species of bat (e.g., Indiana bat [*Myotis sodalis*]) have been found at existing wind facilities.

Bat fatalities appear to be higher during late summer and early fall when bats typically begin autumn migration (Griffin 1970, Cryan 2003, Fleming and Eby 2003); although, fatalities during spring have been reported (Fielder 2004). Migratory tree bats may follow different migration routes in the spring and fall (Cryan 2003), and behavioral differences between migrating bats in the spring and fall also may be related to fatality patterns (Johnson 2005). Kerns et al. (2005) found that timing of bat fatalities over a 6-week period at two sites located in Pennsylvania and West Virginia were highly correlated. These findings suggest broader landscape, perhaps regional, patterns of activity and migratory movement dictated by weather and prey abundance and availability.

Bats do not appear to strike the turbine mast, nonmoving blades, or meteorological towers (Arnett 2005). Bats have been observed with thermal imaging cameras attempting to and actually landing on stationary blades and investigating turbine masts (Horn et al. 2007), and they may be attracted to turbines. Activity and fatality of bats do not appear to be influenced by FAA lighting (Arnett 2005), and higher fatalities have been reported on nights with relatively low wind speed (Fiedler 2004; Kerns et al. 2005; Reynolds 2006; Horn et al. 2007). Studies in Europe also corroborate these findings (Brinkman 2006). These observed patterns offer promise toward predicting periods of high fatality and warrant further investigation to determine if risk can be reduced by curtailing turbine operation during high-risk periods.

Conclusions

Raptor fatalities are relatively low at most facilities studied, with the exception of APWRA, and are lower at new-generation wind facilities. Turbine characteristics, turbine siting, and bird behavior and abundance appear to be important factors determining raptor fatalities at wind-power facilities. Nevertheless, the number of studies of new-generation wind facilities is relatively small, and most have occurred in areas with low raptor density. In comparison with other sources, wind turbines appear to be a minor source of passerine fatalities, particularly for migrants, at current levels of development. Thus, thorough site evaluation during the site-selection process and site-development plans that consider bird use and bird habitats at the site should allow development that reduces risk to raptors and other birds. As turbine size increases and development expands into new areas with higher densities of passerines, the risk to passerines could increase. Therefore, it should continue to be evaluated, particularly in regard to migration during inclement weather.

While bat fatalities have been recorded at almost every wind facility where postconstruction surveys have been conducted, efforts to specifically estimate bat fatality rates have been rare. Bat fatalities vary by region and at some locations are sufficient to raise concern about potential population effects as many species of bats are believed to be in decline (Pierson 1998). Migratory tree roosting bats killed most frequently by turbines are not protected under federal law. Bats usually are protected under state laws pertaining to nongame animals, but most states do not enforce take of bats. Bats are long-lived and have exceptionally low reproductive rates (Kunz 1982). And, population growth is relatively slow, and their ability to recover from population declines is limited, thereby increasing the risk of local extinctions (Barclay and Harder 2003, Racey and Entwistle 2000, 2003). Although population impacts are unknown, given the level of fatalities at some wind facilities, biologically significant additive mortality must be considered for some species as wind power development expands and fatalities accumulate (Kunz et al. 2007).

Estimating exposure, particularly for migrating passerines and bats, is problematic. Radar studies to date have primarily been conducted preconstruction, in an effort to estimate potential impacts. Past studies using radar could not distinguish bats from birds, but modern equipment and software has advanced enough to accommodate this important information need. Those studies, if run concurrently with fatality studies, would help address the relationship of density and location of turbines with risk to nocturnal migrant birds and bats as a group. Model-based analysis of risk also may be helpful, but empirical data generally are lacking. Evidence suggests that risk to birds can be reduced through selection of development sites with reduced densities of birds at risk, particularly raptors. More research is needed on fatalities in regions with existing wind facilities that have been poorly studied (e.g., eastern forested ridges, the Southwest) and regions with new developments (e.g., coastal areas).

Wildlife Habitat Impacts

Little is known about habitat impacts from the development of wind facilities. Wildlife habitat impacts can be considered direct (e.g., vegetation removal or modification and physical landscape alteration, direct habitat loss) or indirect (e.g., behavioral response to wind facilities, hereinafter referred to as displacement or attraction). Impacts may be short-term (e.g., during construction and continuing through the period required for habitat restoration) and long-term (e.g., surface disturbance and chronic displacement effects for the life of the project). Duration of habitat impacts vary depending on the species of interest, the area impacted by the wind facility (including number of turbines), turbine size, vegetation and topography of the site, and climatic conditions in a particular region. Road construction, turbine pad construction, construction staging areas, installation of electrical substations, housing for control facilities and transmission lines connecting the wind facility to the power grid also are potential sources of negative habitat impacts. Presence of wind turbines can alter the landscape to change habitat-use patterns of wildlife, including avoidance or displacement of wildlife from areas near turbines.

Wind facilities can influence relatively large areas (e.g., several square kilometers) but have relatively low direct impact. The U.S. Bureau of Land Management programmatic environmental impact statement (U.S. Bureau of Land Management 2005) estimated that, on average, the permanent footprint of a facility is about 5 percent of the site, including turbines, roads, buildings and transmission lines. Some direct impacts are short-term, depending on the length of time required to reclaim a site, which varies depending on the climate, vegetation and reclamation objective. Ultimately the greatest impact from habitat modification may be reduced effectiveness due to displacement of wildlife. The degree to which this displacement results in impacts depends on the abundance behavioral response of individual species to turbines and human activity within the wind facility.

Relatively little work has been done to determine the effect of wind facilities on use of habitat by wildlife. Leddy et al. (1999) found that densities of birds along transects increased with distance from turbine strings with densities markedly lower at fewer than or equal to 80 meters (87.5 yds). Reduced avian use near turbines was attributed to avoidance of turbine noise and maintenance activities. And, the presence of access roads and large gravel pads surrounding turbines reduced habitat effectiveness (Leddy 1996, Johnson et al. 2000a). Other studies (e.g., Johnson et al. 2000b, Erickson et al. 2004) suggest that abundance of shorebirds, waterfowl, gallinaceous birds, woodpeckers and several groups of passerines is significantly lower at survey plots with turbines compared to those without turbines (Johnson et al. 2000b); although, grassland bird densities were reduced only within 100 meters (109.4 yds) of a turbine. Prairie grouse, which exhibit high site fidelity and require extensive grasslands, sagebrush and open horizons (Giesen 1998, Fuhlendorf et al. 2002), may be especially vulnerable to wind-energy development. Several studies indicate that prairie grouse strongly avoid certain anthropogenic features (e.g., roads, buildings, power lines), resulting in sizable areas of habitat rendered less suitable (e.g., Robel et al. 2004). The actual impacts of wind facilities on prairie grouse remain unknown but are currently under investigation.

Research on habitat fragmentation has demonstrated that several species of grassland birds are area-sensitive, prefer larger patches of grassland and tend to avoid trees. Area-sensitivity in grassland birds was reviewed by Johnson (2001); 13 species have been reported to favor larger patches of grassland in one or more studies. Other studies have reported an avoidance of trees by certain grassland bird species. Based on available information, it is probable that some disturbance or displacement effects may occur to grassland or shrub-steppe avian species occupying a site. The extent of these effects and their significance is unknown and hard to predict but could range from zero to several hundred meters.

While one study reported avoidance of wind facilities by raptors (Usgaard et al. 1997), other studies have found no impact on nesting raptors in California (Howell and Noone 1992), Wyoming (Johnson et al. 2000a) and Oregon (Johnson et al. 2003a). In a survey to evaluate changes in nesting territory occupancy, Hunt and Hunt (2006) found that, within a sample of 58 territories in the APWRA and surrounding area, all territories occupied by eagle pairs in 2000 were also occupied in 2005.

Wildlife response to habitat modification will be species specific. For example, forest-dependent species may be negatively impacted by openings in the forest, while edge-dependent species may benefit. For example, bats may actually benefit from modifications to forest structure and the landscape resulting from construction of a wind facility. Bats are known to forage readily in small clearings (Grindal and Brigham 1998, Hayes 2003, Hayes and Loeb 2007) like those around turbines. Forest-edge effects created by clearing also may be favorable to insect congregations and to a bat's ability to capture them in flight (Verboom and Spoelstra 1999). However, the removal of roost trees would be detrimental to bats. Disturbance to tree- and crevice-roosting bats from wind turbines is not known.

During construction at a wind facility, it is expected that large mammals will be temporarily displaced from the site due to the influx of humans, the heavy construction equipment and the associated disturbance (e.g., blasting). Roads associated with oil and gas development fragment otherwise continuous patches of suitable habitat, effectively decreasing the amount of winter range, for example, available for ungulates (e.g., Van Dyke and Klein 1996, Sawyer et al. 2006). However, these impacts depend on the level and duration of activity associated with development, and studies at wind facilities in Wyoming and Oklahoma found no evidence that turbines had significant impacts on use of the surrounding area by pronghorn (*Antelocapra americanus*) and elk (*Cervus elaphis*), respectively (Johnson et al. 2000, Walter et al. 2004).

Conclusions

Often overlooked are impacts resulting from loss of habitat for wildlife due to construction, the footprint of the facility and increased human access. While the footprint of a wind facility is small relative to the absolute area of a wind energy development, the greatest impact to wildlife from habitat modification may be due to displacement of wildlife in proximity to turbines and to fragmentation of habitat for several species of wildlife; although, these impacts have not been empirically measured for most species. These impacts could be negative and perhaps biologically significant if facilities are placed in the wrong locations, particularly if the affected area is considered a critical resource whose loss would limit populations. Future development of transmission lines to facilitate wind generation will exacerbate the impacts of wind energy development on wildlife.

Habitat impacts could be avoided by careful placement of wind facilities. For example, wind energy development in agricultural areas may have fewer impacts because these areas tend to be less important to most species of wildlife. Habitat impacts also can be mitigated. For example, much of the native prairie in the Midwest has been lost to agriculture or has been degraded as wildlife habitat by grazing of domestic livestock. On private lands, native habitats could be protected from further development as long as revenue for the landowner can be maintained, perhaps by supporting a wind facility, while degraded habitats could be improved through cooperative ventures between landowners and wind energy developers.

Offshore Wind Energy Development and Wildlife

Interest in establishing wind-generating facilities along portions of the Atlantic Coast, Lower Gulf Coast (LGC) of Texas, and the Great Lakes has increased in recent years because wind speeds that make a wind-generating facility economically viable occur during at least part of every day. Also, the terrain offshore (coastal shelf) in these areas is shallow for a relatively long distance from shore, allowing placement of towers into the bottom substrate. No facilities have been constructed offshore in North America and all existing information on wildlife impacts from offshore wind development come from European studies that have been summarized by Winkelman (1994), Exo et al. (2003) and Morrison (2006). These authors conclude that offshore wind turbines may affect birds as follows: (1) risk of collision, (2) short-term habitat loss during construction, (3) long-term habitat loss due to disturbance by turbines, including disturbances from boating activities in connection with maintenance, (4) formation of barriers on migration routes and (5) disconnection of ecological units, such as between resting and feeding sites for aquatic birds.

Collisions of birds with wind turbines at offshore wind facilities has not been measured but is thought to be a minor problem in Europe (Winkelman 1990). Winkelman (1994) summarized findings on disturbance and effect of turbines on flight behavior and found that up to a 95-percent reduction in bird numbers has been shown to occur between 250 and 500 m (273.4–546.8 yds) from the nearest turbines. While further studies are needed to better define risks, precautionary measures to reduce and mitigate such risks exist. For example, careful siting of wind facilities away from bird migratory paths, bird habitats and large concentrations of species at higher risk is possible.

Three migratory bird corridors converge immediately north of Corpus Christi, Texas, funneling tens of millions of birds along the LGC to wintering grounds in southern Texas and Latin America. In light of the absence of natural islands or other terrestrial habitats in the Gulf of Mexico, it seems inevitable that the installation of thousands of artificial islands in the northern Gulf must affect migrants in some fashion. For example, Russell (2005) found that migrants would sometimes arrive at certain oil platforms shortly after nightfall and proceed to circle those platforms for variable periods ranging from minutes to hours. This behavior, if repeated around offshore wind turbines, could increase risk of collision. Russell (2005) concluded that this circling behavior was related to attraction of birds to platform lights. Concern also exists regarding loss of important habitat due to avoidance of offshore wind facilities by birds. There are many important bird areas—locations that harbor a high number of birds or species of special concern (e.g., federally designated birds of conservation concern and federally listed threatened or endangered birds)—along the eastern seaboard.

Although seasonal activities of birds generally are known in areas where birds migrate through or concentrate, the specific timing, routes and altitudes of movement within and between resting and foraging areas and altitudes that migrants use are poorly known. Such information is needed to conduct assessments of the potential risk to birds from offshore wind development. Consequently, the impacts of wind facilities located on the LGC and Atlantic Coast could be different from each other and also different than terrestrial sites throughout the United States simply because the behavior, abundance and diversity of birds that migrate or reside on any wind-generating facility may be much different than inland facilities.

Conclusions

Offshore wind facilities have been established throughout Europe, but few studies have been conducted to determine direct impacts on animals. A major concern with offshore developments has been loss of habitat from avoidance of turbines and the impact that boat and helicopter traffic to and from the wind facility may cause with regard to animal behavior and movements. Although little is known about such effects, resident seabirds and rafting (resting) waterbirds appear to be less at risk than migrating birds, as they may adapt better to offshore wind facilities. The effects on marine mammals are currently unknown but warrant study and clarification. It is important that the actual impact of the first few offshore wind facilities, if built, be evaluated both for fatalities and displacement effects. However, there is reason to believe that areas with high concentrations of birds would present more risk than areas with lower densities of birds. The potential impact of wind-power development on bats is unknown; although, anecdotal accounts of bats occurring offshore suggest impacts are possible.

Biomass Energy Production and Wildlife

Potential impacts from the production of biomass energy sources were recently summarized by Bies (2006). These impacts include, but are not limited to, loss of habitat from land-use conversion, increased fragmentation, changes in structural complexity, increased demand on water supplies and potential increases in pollution from increased use of fertilizer.

Land Conversion

The potential for loss of habitat could result from converting (1) idle lands in the CRP, or other set asides, back to cropland (2) traditional crops to other biomass plants (e.g., switchgrass, hybrid poplar [*Populus* spp.]) and (3) native habitat to cropland or monocultures of biomass plants. Currently, nearly 36.4 million acres (14.7 million ha) are enrolled in the CRP program; the importance of these lands to a wide range of wildlife is well documented (e.g., Dunn et al. 1993, Best et al. 1997). Increasing corn ethanol production will require more land than currently is in production if other economic tradeoffs are to be balanced; expansion has limits before impinging on food supply, for example (Bernstein et al. 2006). The Biofuels Journal (2006) reported that 55 new ethanol production facilities are currently under construction in 17 states that will produce an estimated 3.7 billion gallons (14.7 billion l) of corn ethanol per year. Assuming that each bushel of corn produces 2.7 gallons (10.2 l) of ethanol (Schnepf 2006) and using the 2006 national average of 149 bushels of corn harvested per acre (U.S. Department of Agriculture 2007), approximately 9.3 million acres (3.8 million ha) of corn would be required to produce enough corn just for these new facilities alone. Based on this example, it seems plausible to expect major changes in land-use practices, including conversion of CRP lands into corn production to meet demands for ethanol.

Brown et al. (2000) suggested that biomass production on a scale permitting significant substitution of fossil fuels cannot be accomplished on marginal lands alone and will require large areas of prime agricultural land and the substitution of biomass crops for crops currently grown in some regions. Converting land from traditional crop production to mixed grasses or monocultures of switchgrass or hybrid poplars could result in positive or negative impacts on wildlife, depending on the type of biomass crop used, on what traditional crop is being replaced and on land use and habitat conditions prior to conversion. Converting croplands to a highly diverse mixture of native prairie plant species should provide better habitat for many species of wildlife. In Minnesota, degraded agricultural land planted with a diverse mixture of prairie grasses and other flowering plants produced 238 percent more bioenergy on average, than the same land planted with various single prairie plant species, including monocultures of switchgrass, potentially providing both energy and wildlife benefits, depending on timing and intensity of management. Bies (2006) suggested that frequency and timing of mowing grass fields would influence impacts on wildlife, particularly nesting and wintering birds, and that strip harvesting might reduce impacts and provide habitat for a diversity of species. By leaving some switchgrass or mixed-grass fields unharvested and by partially mowing others, a mosaic of grassland habitats could be managed with different physical characteristics to meet needs of diverse species of birds (Horn and Koford 2000).

In some areas, monocultures of switchgrass or hybrid poplars may benefit some species of wildlife (Bies 2006). Christian et al. (1997) reported few negative site-level effects on songbirds or small mammals resulting from replacement of rowcrop or small-grain fields with hybrid poplar, but they noted that their study did not address fragmentation or other landscape-level issues. Also, Christian et al. (1997) reported that birds appeared to be more strongly attracted to poplar plantations in agricultural regions than in forested landscapes. Moser et al. (2002) found that 1- to 3-year-old hybrid poplar plantations provide suitable habitat for certain small mammals, probably due to abundant understory vegetation. They suggested that creating habitat heterogeneity by maintaining a diversity of plantation ages within the complex may enhance small-mammal species diversity. Moser and KeithHilpp (2004) suggested that maintaining an older component of interior plantation habitat within a poplar plantation complex will likely create suitable wintering habitat for owls and other species.

Conversion of native habitats into biomass production will result in further loss of habitat and will extend fragmentation of landscapes. Area planted to dryland corn in northeastern Colorado increased from about 20,000 acres (8,093.7 ha) per year prior to 1990 to nearly 220,000 acres in 1999 (Agronomy News 2002). Current research and development of traditional crops requiring little or no irrigation could increase conversion of native habitats once considered unsuitable for agriculture. Converting native habitat to monocultures of switchgrass or a mixture of native grasses would likely have varying impacts on wildlife depending on management actions and intensity (Bies 2006).

Crop residues, sometimes referred to as stover in regard to corn (Sheehan et al. 2004), are left behind after harvest of grain and provide valuable habitat and food for many species of wildlife. Sheehan et al. (2004) reported that under the assumptions of their model that maximized amount of collectible stover, Iowa alone could produce approximately 2.1 billion gallons (7.9 l) per year of stover-derived ethanol. Removal of crop residues can increase soil erosion, reduce soil fertility and moisture, and reduce benefits to wildlife, especially to upland game birds (Bies 2006). The height of remaining stubble following a harvest will have direct impacts on both winter cover and available breeding cover the following spring for resident and migrant wildlife (Rodgers 2002).

Forest Management

Course woody debris (snags, downed logs, logging slash) are critical components of forest structure because they provide numerous ecological functions relating to energy flow, nutrient recycling, hydrological processes and wildlife habitat (Harmon et al. 1986, Carey and Curtis 1996). It has been estimated that forestlands in the contiguous United States could produce 368 million dry tons (333 billion kg) per year of biomass for energy production annually, including 64 million dry tons (58 billion kg) per year of residues from logging and site clearing operations (Perlack et al. 2005), which normally would be left on site and provide ecological functions. Estimates of biomass from forests also include 52 million dry tons (47.2 billion kg) per year of fuelwood harvested from forests and 60 million dry tons (54.4 billion kg) per year of biomass from fuel treatment operations to reduce fire hazard (Perlack et al. 2005). Although Perlack et al.'s (2005) estimates excluded all forestland not currently accessible by roads and all environmentally sensitive areas, changes in forest-management practices and policy to meet projected targets for biomass production could be anticipated. The impacts on wildlife associated with removal of snags and downed wood are well documented in forests throughout North America (e.g., Ohmann et al. 1994, Laudenslayer et al. 2002, Stephens 2004) and continued removal of woody debris for biomass production could negatively impact wildlife. Reducing hazardous fuels to meet ecological restoration objectives could benefit wildlife (Bies 2006), but management should ensure that some coarse, woody debris be retained for wildlife.

Water

In regions requiring irrigation, increasing acreage for producing biomass, especially for crops such as corn, could increase water use, particularly ground water, and could influence meeting wildlife objectives. Increased use of fertilizer may result in water-quality issues (Bernstein et al. 2006) that may influence wildlife as well. In 2005, ethanol plants in the United States consumed nearly 18 billion gallons (68 billion l) of water, and estimates for 2008 approach 30 billion gallons (113 billion l) (Keeney and Muller 2006). Conversion from traditional crops to biomass crops may have an influence on water consumption as well. Switchgrass, for example, generally consumes more water than do traditional crops under all climatic conditions and also reduces runoff (Brown et al. 2000), potentially affecting stream flow. However prairie grasses also may increase water infiltration deeper into the soil profile resulting in net groundwater recharge rather than runoff (Brye et al. 2000).

Conclusions

While the amount of land that might be converted into biomass production remains unknown, potential for extensive habitat loss and fragmentation resulting from conversion and removal of structure is plausible given the projected increase of biomass production (Schnepf 2006). Biomass production can impact wildlife in a number of ways, but most notably due to habitat loss from land-use conversion, to changes in structural complexity and to fragmentation. The impacts of biomass energy production on wildlife and its habitat, while potentially enormous, do not appear to be represented in the dialogue on trade-offs of this fuel source. Indeed, authors discussing environmental impacts associated with biomass production have focused on impacts to soil, water and air quality, cropping practices, and on greenhouse gas emissions (e.g., Hall 1997). We suggest that impacts to wildlife habitat must be analyzed and articulated when modeling the trade-offs of biomass production. Failure to do so may jeopardize wildlife-habitat objectives and may impose substantial impacts to many species of wildlife.

Recommendations

Developing renewable energy sources is important for meeting future energy demands while reducing negative environmental impacts associated with other energy sources. Wind power and biofuels can contribute to renewable energy portfolios, but poorly planned developments will result in cumulative, biologically significant impacts for some species of wildlife. We offer the following eight recommendations to assist managers and decision-makers with meeting the challenges of developing wind and biomass energy responsibly.

Develop federal and state guidelines. Developing consistent guidelines for siting, monitoring and mitigation strategies among states and federal agencies would assist developers with compliance with relevant laws and regulations and would establish standards for conducting site-specific, scientifically sound biological evaluations. Renewable portfolio standards should account for wildlife impacts and inclusion of guidelines in the permit process, and they would strengthen agency participation and implementation of guidelines.

Conduct priority research. Immediate, unbiased research is needed to develop a solid, scientific basis for decision making when siting wind facilities, for evaluating their impacts on wildlife and their habitats and for testing efficacy of solutions. Research priorities have been suggested for addressing wildlife impacts at wind-energy facilities (e.g., Arnett et al. 2007, Kunz et al. 2007, National Research Council 2007). Priority research for impacts of biomass energy development is needed. Establishing research partnerships and cooperative funding mechanisms among diverse stakeholders (e.g., Arnett and Haufler 2003) will be a critical step for implementing priority research.

Avoid siting wind facilities in high-risk areas. Wind-energy developers should follow criteria and standards established within siting guidelines that include avoidance of high-risk sites determined using the best available information. Siting wind facilities in areas where habitat is of poor quality or already is fragmented, for example, will likely result in fewer habitat-related impacts.

Maintain existing conservation programs. Biofuels should be developed in a way that ensures the continued existence of conservation programs, such as CRP. It may become necessary to revisit existing regulations (e.g., state forest practices) to ensure wildlife and fisheries management objectives are being met as biomass energy continues to develop.

Develop new incentive programs. New conservation incentive programs should be developed to address changes in energy policy and demand. For example, the National Wildlife Federation's Biofuels Innovation Program is designed to create a new Farm Bill energy title program to promote sustainable development of biomass energy.

Develop mitigation strategies for integrating biomass production and wildlife habitat objectives. Careful planning and implementation of mitigation measures could reduce impacts of biomass-energy development in many instances. Identifying important habitats and modeling existing and projected landscape patterns would be useful for planning different strategies for mitigation.

Conduct regional assessments and forecast cumulative land-use impacts from energy development. Given projected increases in multiple sources of energy development, including biomass, wind, oil and gas development, future conflicts surrounding land-use, mitigation and conservation strategies should be anticipated. Habitat mitigation options, for example, when developing wind energy in open prairie may be compromised by development of other energy sources. Regional assessments of existing and future land uses and planning of regional conservation strategies among industries, agencies and private landowners could reduce conflicts and could increase options for mitigation.

Improve public education and information exchange. There is an immediate need to insert wildlife impacts, especially regarding biomass energy, into the political dialogue, so all tradeoffs can be considered during decision making. Maintaining relationships with private landowners and communicating the importance of conservation efforts and their benefits will be critical toward developing renewable energy responsibly.

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