Male greater sage-grouse displaying at a lek (gathering of males) in Wyoming. *Photo from LuRay Parker, Wyoming Game and Fish, National Renewable Energy Laboratory (NREL) 20649*

Grouse and Land-Based Wind Energy Development in the United States

Grouse

Several species of grouse occupy prairie and sagebrush habitat across the western United States. Sharp-tailed grouse (*Tympanuchus phasianellus*), greater prairie-chicken (*Tympanuchus cupido*), and lesser prairie-chicken (*Tympanuchus pallidicinctus*) reside in the grassland prairies of the Great Plains. In the Intermountain West, greater sage-grouse (*Centrocercus urophasianus*) and Gunnison sage-grouse (*Centrocercus minimus*) inhabit the expansive sagebrush plains (Johnsgard 2008). During the mating season, male grouse perform elaborate courtship displays in communal breeding areas known as leks. These areas are often used each year and tend to be large, open patches of land with minimal vegetation, offering greater visibility for males (Connelly et al. 2011). Female grouse create nests on the ground under sagebrush or within clumps of grass. Females can lay between 5 and 15 eggs depending on the species. Once hatched, chicks consume mostly insects, but shift their diets to primarily eat vegetation as they become adults (www.allaboutbirds.org/guide/). These grouse species require extensive, intact native habitats to complete their life cycle (Pruett et al. 2009a; Rowland et al. 2006; Sandercock et al. 2011; Wisdom et al. 2011). Given the close connection between grouse and their habitat, they are considered indicator species, or species whose presence indicates ecosystem health (Carlisle et al. 2018; Rowland et al. 2006).

Disturbance and alteration of habitat can result in abandonment of breeding and nesting grounds or delayed reproduction. Multiple stressors on grouse have resulted in population declines across their range. Stressors include conversion of natural habitat, climate change, spread of invasive species, and land use change including energy development (Garton et al. 2011; Hovick et al. 2014; LeBeau et al. 2020a; Schroeder et al. 2000; Wilsey et al. 2019).

In 2014, the U.S. Fish and Wildlife Service listed the Gunnison sage-grouse as threatened, and in 2022, the agency listed the southern distinct population segment and the northern distinct population segment of the lesser prairie-chicken as endangered and threatened, respectively. Conservation status for each species varies from state to state. In addition, several species of grouse are listed on the International Union for Conservation of Nature's Red List of Threatened Species.

Interactions Between Grouse and Wind Energy Development

The continued deployment of wind energy across the United States, particularly in prairie and sagebrush habitats, may result in a myriad of impacts to grouse species, although there is a high degree of uncertainty regarding the extent of the impact (Coppes et al. 2020; LeBeau et al. 2020a; Lloyd et al. 2022). Development directly impacts grouse through the loss and alteration of habitat and mortality through collisions with fences, powerlines, and vehicles (Hovick et al. 2014; Robinson et al. 2016). Grouse also display avoidance behavior around wind energy infrastructure, even in the absence of actual land cover change, which can lead to further functional habitat loss (Coppes et al. 2020). Sources of indirect impacts include noise from construction and operation, vehicular traffic, and addition of transmission lines and other structures that increase perching opportunities for avian predators (Gibson et al. 2018; LeBeau et al. 2014; Raynor et al. 2017; Smith et al. 2016; Whalen et al. 2018). The degree of these indirect impacts is difficult to quantify for a variety of reasons including the complexity of ecosystem interactions and time lags between cause and effect. The majority of research studies looking at the interaction of grouse and wind energy have focused on changes to individual vital rates or to patterns of habitat use (Lloyd et al. 2022).

Greater Prairie-Chicken

Several studies have found that greater prairie-chicken adult survival is not related to distance to wind turbines (Smith et al. 2017; Winder et al. 2014) and that there is no relationship between nest survival and distance to a turbine (Harrison et al. 2017; McNew et al. 2014). In Kansas, the habitat selection

Male greater prairie-chicken at a lek, Tallgrass Prairie National Preserve, Chase County (Flint Hills), Kansas. *Photo from Mark Herse, Kansas State University, NREL 27968* patterns of female greater prairie-chickens shifted away from wind turbines during the breeding and brood-rearing seasons, but habitat use during other times of the year was unaffected. Average home range size for females increased following construction of a wind energy facility (Winder et al. 2014). Winder et al. (2015) found that leks within 8 kilometers of a wind turbine were more likely to be abandoned, although the probability of lek persistence across the entire study area did not vary between pre- and postconstruction. In Nebraska, male greater prairie-chickens adjusted the acoustic properties of their lek vocal communications in the presence of noise created by nearby wind turbines, although associated impact to breeding success is unknown (Whalen et al. 2018). Males at leks closer to wind energy facilities spent less time performing nonbreeding behaviors (e.g., standing and walking). One potential mechanism for the positive indirect effects (i.e., increased adult survival and breeding behavior) on the greater prairie-chicken is a reduction in predation close to development, although further research is required to support this hypothesis (Smith et al. 2016). In 2022, a study in Oklahoma found that greater prairie-chickens avoided manmade infrastructure in both the postnesting and nonbreeding season. Individuals also specifically avoided crossing linear features (e.g., roads and transmission lines) (Londe et al. 2022).

Lesser Prairie-Chicken

According to the U.S. Geological Survey's Wind Turbine Database (2023) and the Western Association of Fish and Wildlife Agency's Estimated Occupied Range Polygons (2022), an estimated 2,221 wind turbines overlap lesser prairie-chicken habitat in the United States (Hoen et al. 2018; Nasman et al. 2022). Lesser prairie-chickens have already lost more than 90% of their historic range in the United States, mostly from anthropogenic development (Crawford 1980; Giesen 1994). In addition to this direct habitat fragmentation, lesser prairie-chickens show avoidance of powerlines and transmission towers on the landscape even at far distances up to several kilometers (Peterson et al. 2020; Pruett et al. 2009b). A study in Kansas documented no changes in habitat selection nor any decrease in lesser prairie-chicken nest and adult survival in the 3 years following the development of a new wind energy facility located in cultivated cropland (LeBeau et al. 2020b). In addition, a 2023 study found that avoidance and demographic impacts to lesser prairie-chickens were minimal when wind development was placed in cultivated cropland, suggesting that placing turbines in such areas may be an important siting measure in lesser prairie-chicken range (LeBeau et al. 2023).

Sharp-Tailed Grouse

As a result of their extensive range, sharp-tailed grouse are exposed to the most wind energy development of any of the grouse species (BirdLife International 2017; Lloyd et al. 2022; Rand et al. 2020). Despite this, there is little documented research on how energy development impacts sharp-tailed grouse. Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*), one of the six extant subspecies in North America, occupy less than 10% of their historic range (Stevens et al. 2023). Their population decline has mostly been attributed to habitat loss, and most of the breeding population currently resides in Idaho (Schroeder et al. 2000; Stevens et al. 2023). Between 2014 and 2015, radio-tagged females were monitored near a large wind energy facility in eastern Idaho. Proett et al. (2022) did not detect any influence on nest-site selection or nest survival from wind energy infrastructure. However, a study looking at brood success and chick survival from the same individuals found that the probability of an individual chick surviving to 42 days decreased by 50% with more than 10 turbines within 2,100 meters of the nest. The number of wind turbines within the late brood-rearing home range negatively impacted 42-day brood success (Proett et al. 2022).

Greater Sage-Grouse

LeBeau et al. (2014) monitored greater sage-grouse nests and broods over a 2-year period (2009–2010) near a wind energy facility in south-central Wyoming. They found that the nest and brood success were negatively impacted by distance to the nearest wind turbine. However, a concurrent, longer-term (6-year) study failed to detect any negative effect of wind energy on nest or brood-rearing success, indicating the importance of temporal variability in survival models. They concluded that the variability of survival in the initial study was more likely due to natural temporal variability. Additionally, they found that adult survival was higher closer to the wind energy facility and that female greater sage-grouse avoidance of wind energy facility infrastructure increased through time, indicating a potential time lag in response (LeBeau et al. 2017b). An 11-year study found that male lek attendance was not impacted by proximity to a wind energy facility (LeBeau et al. 2017a). In 2020, Kirol et al. suggested that exposure to press disturbance (i.e., long-term disturbances associated with energy development) during

Lesser prairie-chicken (*Tympanuchus pallidicinctus*) on a lek in northern Oklahoma. *Photo from Getty Images 1308093718*

nesting and brood rearing was related to lower nest and brood survival. This type of disturbance metric may become increasingly common and relevant as wind energy and its associated infrastructure (e.g., transmission lines) develops across the country.

Gunnison Sage-Grouse

There are currently no wind energy facilities overlapping with Gunnison sage-grouse populations. The species close relation to greater sage-grouse suggests that populations may show similar responses. The small and fragmented nature of the remaining Gunnison sage-grouse populations makes them vulnerable to disturbance.

Risk Monitoring

The current state of knowledge on the effects of land-based wind energy development on ground-nesting birds (including grouse) is based on a handful of studies published over the last 15 years, many of which are of a short duration and lack comparisons of pre- and postconstruction data. One common technique to assess these impacts is using radio telemetry to track female birds and their chicks to monitor breeding success and survival rates. Lek surveys are another common way to measure and monitor grouse populations and assess any change in response to wind energy development. The statistically robust method to measure the potential impact of wind energy, or other stressors, is to conduct Before-After-Control-Impact (BACI) studies. These studies allow researchers to assess the status of a population before development (e.g., preconstruction) relative to after development (postconstruction), and how a reference population (i.e., control) compares to the impacted population (i.e., population in proximity to the development). Additionally, postconstruction mortality monitoring provides accurate estimation of mortality rates.

Risk Management

The first way to reduce potential impacts on grouse populations is to avoid wind energy development and transmission within established concentrations of grouse and their habitats. This should happen at the macroscale by siting entire wind energy facilities away from core grouse habitat and at the microscale by micrositing specific wind turbines or wind turbine strings. Minimizing construction and operations activity, including the presence of on-site staff and traffic, may further reduce disturbance during sensitive periods (e.g., nesting). Postconstruction monitoring of a wind energy facility is also necessary to assess impacts of operation and

Pine Tree Wind and Solar Farm is part of NREL's 100% Renewable Energy Study. *Photo by Dennis Schroeder, NREL 50710*

long-term changes. These results should be incorporated into an adaptive management framework with conservation goals. These adaptive frameworks can improve management plan decisions in relation to grouse conservation and wind energy development in the future. Mitigating the impact (e.g., restoring an area of suitable grouse habitat at least as equal to the footprint of the wind energy facility) can help support no net loss in habitat and biodiversity.

Research Priorities

The state of knowledge on the impact of wind energy on grouse is limited and results can conflict because of differences in study design, species, and location. To reduce uncertainty, each project must be evaluated on a case-by-case basis. This approach is necessary because of the variations in habitat conditions from site to site and the different behavioral responses by species to the presence of wind turbines. However, it is possible to improve the reliability and comparability in results by developing a consistent and robust methodology that can be adopted regardless of location and species of interest. This methodology should include collecting data for multiple consecutive years across a variety of sites and making results publicly available. Strategic siting of new developments may be the most cost-effective approach to reducing potential impacts to grouse and their habitat. Finally, the rapid development of wind energy technology (e.g., increasing wind turbine height) is an additional challenge in understanding and mitigating impacts to grouse populations.

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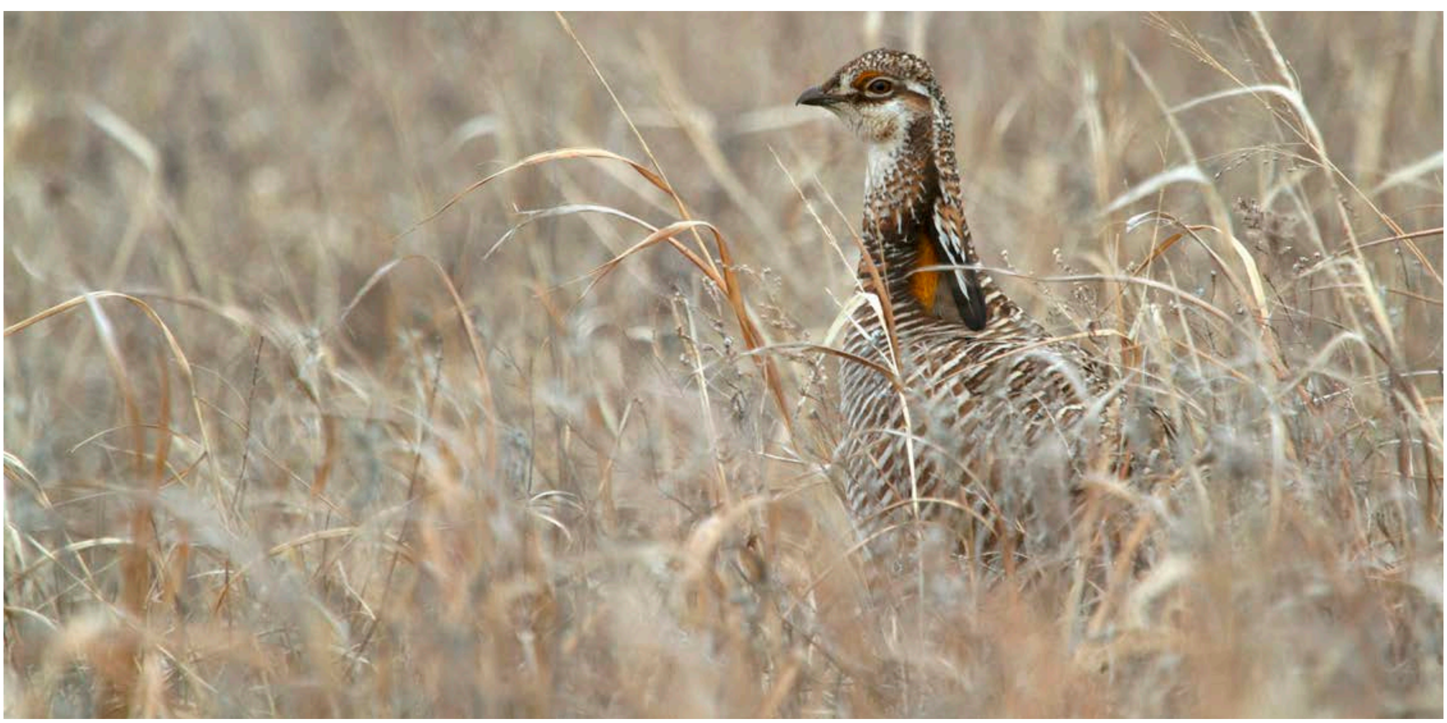

Greater prairie-chicken at a lek, Tallgrass Prairie National Preserve, Chase County (Flint Hills), Kansas. *Photo from Mark Herse, Kansas State University, NREL 27971*

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