Received: 11 November 2020 | Revised: 14 December 2020 | Accepted: 15 January 2021

DOI: 10.1111/csp2.366

PERSPECTIVES AND NOTES

Conservation Science and Practice
A journal of the Society for Conservation Biology | Open Access

WILEY

Insect fatalities at wind turbines as biodiversity sinks

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Abstract

Evidence is accumulating that insects are frequently killed by operating wind turbines, yet it is poorly understood if these fatalities cause population declines and changes in assemblage structures on various spatial scales. Current observations suggest that mostly hill-topping, swarming, and migrating insects interact with wind turbines. Recently, the annual loss of insect biomass at wind turbines was estimated for Germany to amount 1,200 t for the plant growth period, which equates to about 1.2 trillion killed insects per year, assuming 1 mg insect body mass. Accordingly, a single turbine located in the temperate zone might kill about 40 million insects per year. Furthermore, Scheimpflug Lidar measurements at operating wind turbines confirm a high insect activity in the risk zone of turbines. These numbers and observations are alarming, yet they require further consolidation, particularly across all continents and climate zones where wind energy industry is expanding. We need to understand (a) how attraction of insects to wind turbines affect fatality rates and interactions of insect predators with wind turbines. (b) We have to connect insect fatalities at wind turbines with source populations and evaluate if these fatalities add to the decline of insect populations and potentially the extinction of species. (c) We need to assess how fatalities at wind turbines change insect-mediated ecosystem services. An ever-growing global wind energy industry with high densities of wind turbines may have long-lasting effects on insects and associated trophic links if negative impacts on insects are not considered during the erection and operation of wind turbines.

KEYWORDS

biodiversity sink, green-green dilemma, renewable energy, sustainability goals, sustainable energy production, wind energy production, wind energy-biodiversity conflict

1 | INTRODUCTION

Energy production from renewable sources is increasing worldwide in an effort to reduce CO_2 emission and to avoid the risks associated with nuclear power production and waste management. Although labeled as environmentally friendly and thus as "green," some renewable energy sources are in conflict with biodiversity goals (Saidur, Rahim, Islam, & Solangi, 2011). For example, wind energy production has a record of generating high numbers of bird and bat fatalities (Grünkorn et al., 2017; Voigt, Lehnert, Petersons, Adorf, &

Bach, 2015). Indeed, recent trend analyses suggest that populations of affected species may collapse if no appropriate avoidance and mitigation schemes are practiced, for example, avoiding wind turbines in sensitive habitats and preventing species from colliding with spinning rotor blades (Bellebaum, Korner-Nievergelt, Dürr, & Mammen, 2013; Frick et al., 2017; Schaub, 2012). Efficient mitigation measures for airborne vertebrates involve camera or radar informed and context dependent operation schemes, which stop wind turbine operation when bird or bat activity is high (Arnett et al., 2016; Tomé, Canário, Leitão, Pires, & Repas, 2017). Despite our advanced understanding of how to avoid or mitigate the negative effects of wind energy production on airborne vertebrates, few scientific studies have ever addressed in a systematic manner if aerial invertebrates get also killed by wind turbines, and if these fatalities constitute a significant anthropogenic biodiversity sink. This is surprising because observations of arthropods being active at turbines and getting killed by rotating blades have been reported since the early days of wind energy production.

2 | FATAL COLLISIONS OF INSECTS WITH WIND TURBINES

After collision, most insects leave a layer of organic detritus on the leading edge of blades. This layer disrupts the laminar airflow, causing a significant drop in power production (Han, Kim, & Kim, 2018; Soltani, Birjandi, & Seddighi Moorani, 2011). Indeed, insect remains that stick to the leading edges of blades during low-wind periods can halve power generation during high-wind periods (Corten & Veldkamp, 2001). Consequently, insect contamination of blades constitutes a significant problem for wind energy companies (Wilcox & White, 2016), which led to the invention of cleaning techniques and the emergence of a service industry that removes insect and other detritus from blades (Deb, Patel, & Singh, 2017; Jeon, Kim, Park, & Hong, 2013; Figure 1). The contaminant layer of insect detritus on blades is an undisputable record of insect fatalities, yet the true number of insects killed at wind turbines may be even higher, because insects may be propelled away after impingement without leaving organic matter on blades. Among these, large-bodied insects are more likely to be found below wind turbines than small insects (Figure 2). Even if small insects fall to the ground next to turbines, they may be difficult to detect by searchers or they may be quickly removed by scavengers such as ants. Wind drift may push away carcasses of light insects, which complicates estimating how many insects and which species collide with wind turbines.

3 | HOW MANY INSECTS ARE KILLED BY WIND TURBINES?

Studies dealing with the question of how many insects are killed by wind turbines are difficult based on the reasons mentioned in the previous section. In a first pilot study conducted by the German Aerospace Center, Trieb and colleagues estimated for Germany's 30,000 onshore wind turbines that about 1,200 t of insect biomass is lost due to collisions with wind turbines during the plant growth period (April–October) (Trieb, 2018; Trieb, Gerz, & Geiger, 2018). Assuming an average wet mass of 1 mg for an insect (Hu et al., 2016), this equates to about 1.2 trillion insects killed per year for all onshore wind turbines in Germany, or 40 million insects killed

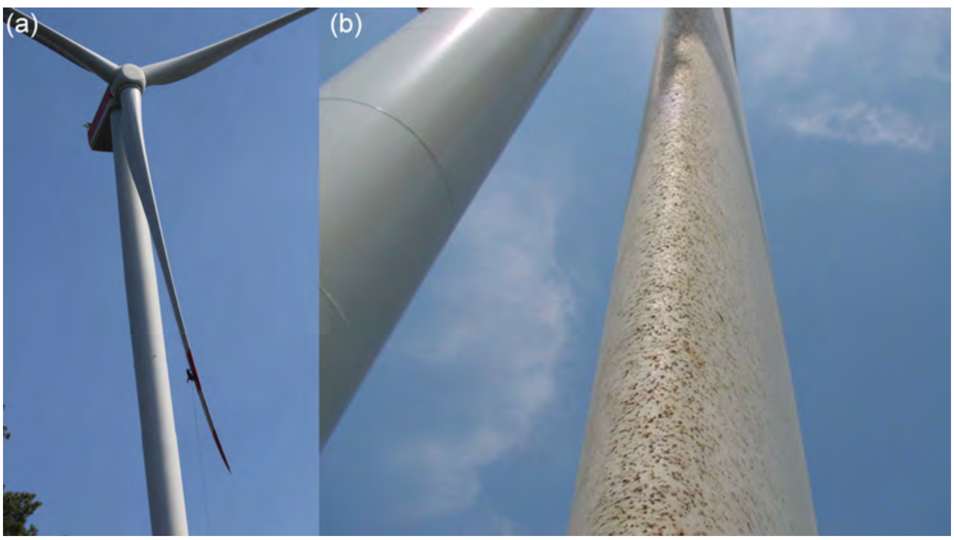

FIGURE 1 Wind turbine with a blade-cleaning maintenance worker (a). Insect detritus at the leading edge of blades (b) (Jose Luis Ruiz, Bladecleaning S.A.)

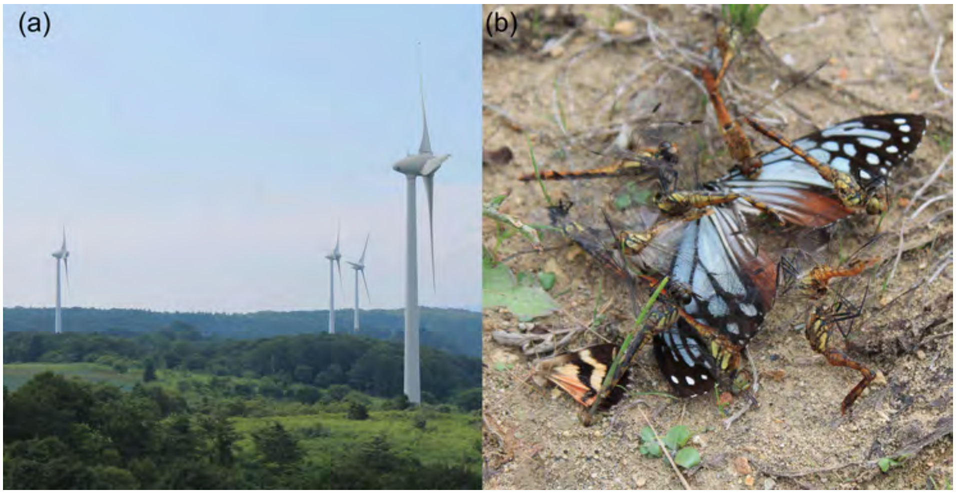

FIGURE 2 Wind park on a mountain top in Japan (a). Dead insects (b) collected during a 15-min search under a single turbine at site (a) included two butterflies (Lepidoptera) and dragonflies (Odonata) (note that insects were piled up for the picture and that some insects show physical injuries)

annually by a single wind turbine in Germany. It is important to note here that these estimates are sensitive to deviations from model assumptions, and thus they certainly require further confirmation based on robust empirical data. For example, these estimates may vary largely across regions, depend on the composition of local insect assemblages and on the relevance of insect migration in a specific region. Nonetheless, the postulated numbers hint at the magnitude at which insect fatalities might occur at wind turbines in the temperate zone. It is likely that this situation is aggravated in regions with a higher abundance of aerial invertebrates compared with Germany.

4 | WHICH INSECT SPECIES INTERACT WITH WIND TURBINES, AND WHY?

Besides looking at the aspect of insect numbers and biomass lost by wind turbine operation, it is equally important to understand which species or higher taxonomic groups may get killed by wind turbines. Currently, we do not know if certain insect taxa are more vulnerable at wind turbines than others, and if certain insect taxa are attracted to wind turbines. Attraction to wind turbines might happen particularly in swarming and hill-topping species. These may fly vertically along the turbine structure to higher altitudes, where they may collide with the spinning blades. Recently, Scheimpflug Lidar technique was used to document insect swarms in the operation range of blades (Jansson, Malmqvist, Brydegaard, Åkesson, & Rydell, 2020). Such data of high spatial and temporal resolution support earlier observations that insects get attracted to wind turbines (Long, Flint, & Lepper, 2011). In addition, insect aggregations at wind turbines have been observed specifically in summer and autumn, when insects migrate or when insects may rest at dusk on turbine structures that were heated up by sunshine. Some invasive insects also use wind turbine structures for overwintering, potentially helping these opportunistic species to expand their range by facilitating winter survival (Dudek, Dudek, & Tryjanowski, 2015).

5 | ECOLOGICAL CONSEQUENCE OF INSECT INTERACTIONS WITH WIND TURBINES

As swarming and migration are linked to mating and dispersal, respectively, fatalities at wind turbines may have profound effects on insect populations at various spatial scales. Some insects, such as hill-topping butterflies, may occur only in small populations at a local scale. Placing wind turbines close to these populations or to the corresponding mating areas of these insects, for example on a mountain ridge or hilltop (Figure 2), may largely affect local populations. In addition, decline of insect populations may also diminish their ecosystem function, including services like pollination. Currently, we lack data on how siting of wind turbines affect insect fatalities at turbines and thus, how turbine siting may impact local insect diversity and associated ecosystem functions. Migrating insects may get in contact with wind turbines when moving at aerial layers that are also suitable for wind energy production. A high fatality rate of migratory insects at wind turbines may have negative consequences for distant insect populations. However, it seems challenging to quantify the effect of turbine-related fatalities on populations of migratory insects because of the intrinsic difficulty in establishing connectivity between the site where insects are killed and the corresponding source populations. It is noteworthy that insect–wind turbine interactions may also affect predators hunting for insects at turbines. Aerial insectivores such as bats are well known for searching and hunting insects in proximity to wind turbines (Foo et al., 2017; Horn, Arnett, & Kunz, 2008; Johnson, 1957; Roeleke, Blohm, Kramer-Schadt, Yovel, & Voigt, 2016; Valdez & Cryan, 2013). Rydell and colleagues argued that the findings of diurnal flies in the stomachs of bat carcasses collected below wind turbines is indicative of bats hunting for flies resting on turbine structures (Rydell et al., 2016). Furthermore, it was argued that bat mortality at wind turbines is linked to insect migration in northern Europe (Rydell et al., 2010). Thus, insect attraction to wind turbines may impact trophic links associated with these insects, such as insect-mediated ecosystem functions and aerial predation of these insects at wind turbines. Concluding, interactions of insects with wind turbines have multifaceted consequences that reach across trophic levels and over larger spatial scales.

6 | FUTURE RESEARCH DIRECTIONS

More research is needed to better understand how insects interact with wind turbines. Using remote sensing devices such as Scheimpflug Lidar instruments seems to be a promising avenue. In addition, we need to improve our understanding of which species are affected by wind energy production, that is, which species are at high risk of colliding with wind turbines. Meta-barcoding of the contaminant layer on blades may reveal insect DNA, which would allow the identification of affected species and possibly also establishing connectivity between wind turbine sites and source populations. Identifying populations and species of concern will inform conservation managers about necessary measures for avoidance and mitigation, for example when choosing sites for wind turbines at critical distances to populations of threatened insect species of high collision risk. Identifying population level effects may be challenging for local populations, since the presence of wind turbines may impact local habitats as well. For example, building and maintaining wind turbines require large platforms and roads. On the one hand, platforms and roads may increase local habitat diversity with positive effects on some insect species. Yet, they may as well have negative effects on sensitive habitats and associated insect species because of disturbance and fragmentation. Overall, the direction of likely effects of infrastructure verges on insect diversity is controversially discussed in the literature (Villemey et al., 2018). It will become particularly important in future studies to disentangle these habitat-driven effects from fatality-driven effects on local insect populations. We also need to improve our knowledge about how insect fatalities at wind turbines vary between regions. This might help us identifying areas where wind turbines could operate without causing large numbers of insect fatalities and without affecting potentially insect diversity and their ecosystem functions. Overall, research in the outlined directions would allow us to better evaluate if we need to consider measures to protect insect diversity in our efforts to fight global climate change by promoting wind energy production.

CONFLICT OF INTEREST

The author declares no conflicts of interest.

DATA AVAILABILITY STATEMENT

This policy paper is presented without any original data.

ETHICS STATEMENT

Research for this paper did not involve any animal experiments.

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How to cite this article: Voigt CC. Insect fatalities at wind turbines as biodiversity sinks. *Conservation Science and Practice*. 2021;3:e366. https://doi.org/10.1111/csp2.366