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Establishment and Maintenance of Power Lines are Important for Insect Diversity in Central Europe

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Open habitats are disappearing from European forests. This is mainly due to various management-related practices, such as afforestation and the maintenance of closed canopy plantation forests. Open forests are also declining as a result of the abandonment of traditional forest use practices and natural succession. The effects of the establishment and maintenance of power lines as highly artificial but open habitats in forests on native insect biodiversity remain relatively poorly investigated. We investigated differences in biodiversity between forests and open habitats under power lines in Poland. Namely, we focused on nine insect taxa using the most suitable methods for data collection, *i.e.*, observation and trapping. The studied habitats were forests used for timber production dominated by Scots pine, which is the most commercially important tree species in Poland. In total, we recorded the presence of more than 400 insect species. We found that butterflies as well as ground beetles were significantly more biodiverse under the power lines compared with the forest interior. Furthermore, jewel beetles, long-horned beetles, weevils and bark beetles, rove beetles and darkling beetles appeared to be more species rich under the power lines, click beetles were indifferent, and only lady-bird beetles appeared to be more abundant in forests. Additionally, ground beetles with a strict affinity for forests were surprisingly not negatively affected by power lines. We highlighted the importance of forest-free areas under power lines for the improvement of native forest biodiversity. Artificial and relatively intensive management activities related to the distribution of electric energy play important roles in creating novel or alternative habitats for many insects. Our paper contributes much to the knowledge about the importance of artificial open areas for the diversity of insects.

Key words: Open habitats, Linear clearings, Power line right-of-way, Saproxylic insects, Butterflies.

BACKGROUND

The modern world has an increasing demand for electric energy (International Energy Outlook 2017). Electricity is mainly transmitted through overhead power lines built in various habitats on Earth, including forests, where they create considerable disturbances related to the creation of linear clear-cut areas (Richardson et al. 2017). One of the most important characteristics of power lines is the long-term maintenance of low vegetation, mainly herbaceous and shrubby, which results in altered climatic and habitat conditions compared to the adjacent forest interior (Luken et al. 1992; Russell et al. 2005; Wagner et al. 2014).

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Dozens of studies have documented the negative impacts of power lines on the environment. In general, the construction of transmission lines results in habitat fragmentation, alteration of the plant community and disturbance of natural processes (Richardson et al. 2017). Power lines are responsible for collisions and electrocutions of birds and bats (Bevanger 1998; Bevanger and Brøseth 2004; Manville 2016). The barrier effect is another reason for criticism since power lines impede the migration of some animals (Bartzke et al. 2014 2015). At the same time, corridors beneath power lines facilitate the dispersal of invasive plant species (Dubé et al. 2011; Lampinen et al. 2015). Electromagnetic fields (EMFs) generated by power lines can potentially have detrimental effects both on wildlife (Fernie and Reynolds 2005) and humans (Draper et al. 2005). Finally, transmission towers and wire conductors deteriorate the landscape and thus have negative aesthetic impacts (Navrud et al. 2008). Nevertheless, due to altered environmental conditions, areas along power lines provide habitats for many species that are absent or less common in surrounding sites (*e.g.*, compared to adjoining closed-canopy forests); beneficiaries include mammals (Clarke et al. 2006; Storm and Choate 2012), birds (King and Byers 2002; Confer and Pascoe 2003; Yahner et al. 2003; Askins et al. 2012), insects (Russell et al. 2005; Hollmen et al. 2008; Lensu et al. 2011; Berg et al. 2016) and plants (Wagner et al. 2014; Lampinen et al. 2015).

A large proportion of forest organisms depends on sun-exposed sites (Jonsell et al. 1998; van Swaay et al. 2006; Hédl et al. 2010; Streitberger et al. 2012; Douda et al. 2016; Miklín et al. 2018). At the same time, open woodlands (*i.e.*, forests with sparse trees or loose canopy cover) and other open habitats within forests (*e.g.*, meadows, clearings) are declining in Central Europe (Vera 2000; Miklín et al. 2018). Several studies indicate that natural disturbances (*e.g.*, windthrows, floods, insect outbreaks, typhoon) and human-related activities (*e.g.*, grazing of animals, prescribed burning, coppicing) are the main factors responsible for the creation and maintenance of open habitats in forests (Vera 2000; Hultberg et al. 2015; Chen and Shaner 2018). However, modern forestry practices, mainly the creation of closed-canopy forests for timber production and the abandonment of traditional forest use techniques, have led to a substantial decline of open forests. Open habitats are also vanishing from protected forests due to natural succession and scarcity of disturbances (Hilszczański and Jaworski 2018). It is now generally accepted that the restoration and maintenance of open habitats in forests require active methods of protection. In addition to conservation-oriented programmes, the utilization of maintained corridors under power lines may be beneficial from this perspective.

Previous research on the effect of power lines on biodiversity concerned several groups of organisms, but the response of insects remains poorly understood. Thus, we investigated the influence of forest-free areas under the power lines conducted in mature Scots pine (*Pinus sylvestris*) stands in Poland on the species richness and abundance of selected insect groups. We used a novel approach using a multi-taxon comparison of influence with a more detailed overview of ground beetles as taxa with many bioindicator species. Our general scientific question was: how do power lines influence native forest biodiversity?

MATERIALS AND METHODS

Study sites

The study was carried out at four study sites situated in eastern Poland (Table 1, Fig. 1). Most power lines in woodland areas in Poland are situated in forests dominated by Scots pine, *Pinus sylvestris*, which is the main tree species in the country. Thus, all study sites were selected in managed, pine-dominated stands aged 60–127 years. All study sites were characterized by a relatively small amount of dead wood, mainly in the form of stumps and small branches left after selective cuttings and thinning of the forest stand.

Study organisms

Our research focused on selected groups of insects, *i.e.*, butterflies (Lepidoptera: Rhopalocera) and several families of beetles (Coleoptera), namely ground beetles (Carabidae), jewel beetles (Buprestidae), long-horned beetles (Cerambycidae), ladybirds (Coccinellidae), bark beetles and weevils (Curculionidae), click beetles (Elateridae), rove beetles (Staphylinidae) and darkling beetles (Tenebrionidae). Most butterflies require open landscapes (*e.g.*, grasslands, meadows, roadsides), and only a few species are associated with dense forests (van Swaay et al. 2006). Beetles, on the other hand, are a diverse group regarding habitat requirements. Some of them are associated with forests, *e.g.*, dead wood-dependent (saproxylic) species (Gimmel and Ferro 2018), while others prefer open areas (Heliölä et al. 2001). Furthermore, some species of beetles develop in forests in the larval stages and adults migrate to more open areas, which is typical for anthophilous species in the families Cerambycidae and Buprestidae (Sakalian and Kuzmanov 1993; Walczak et al. 2014). Carabids provide yet another diverse group with many

Fig. 1. Illustration of the study sites: I (a), II (b), III (c), IV (d). For basic characteristics of study sites, see table 1.

Table 1. Basic characteristics of study sites

Study site	Latitude, longitude	Width of corridor under power line (m)	Habitat beneath power line	Ground vegetation cover beneath power land	Habitat of surrounding forest	Ground vegetation cover in surrounding forest
I	51.514401, 21.925837	35	sandy dune	herbaceous plants and grasses 20%	semi-dry coniferous	mosses 20%
II	51.479727, 21.957351	35	heathland	herbaceous plants and grasses 75%	fresh coniferous	herbaceous plants and grasses 20%, mosses 75%
III	51.441182, 23.513837	20	semi-humid	herbaceous plants and grasses 95%, mosses 15%	fresh coniferous	shrubs (up to 3 m) 55%, herbaceous plants and grasses 45%, mosses 5%
IV	50.668543, 22.403563	10	raised bog	herbaceous plants and grasses 60%, mosses 100%	wet coniferous	herbaceous plants and grasses 65%, mosses 100%, individual shrubs

species specialized with respect to successional stage of a habitat (Koivula 2011). Thus, we investigated the response of the model groups of insects (differing in terms of habitat preferences, behaviour, and dispersal abilities) to increased the levels of habitat openness related to the creation of power lines.

Sampling methods and experimental design

The species richness and abundance of butterflies were assessed by census along line transects (van Swaay et al. 2015) from mid-April to the end of August 2014 at approximately monthly intervals (5 observations). At each study site, two parallel transects with a length of approximately 200 m each were designated. One transect ran directly under the power line, and the other was located in the adjacent forest. The distance between the transects was approximately 100 m to minimize the potential influence of 'edge effects'. The survey consisted of walking at a constant pace along transects and counting all observed butterflies. Some individuals were caught with an entomological net for identification and then released. Observations were conducted in suitable weather conditions, usually in the early afternoon, during the period of highest activity for adult butterflies. The duration of inventory on each transect lasted 15–20 minutes.

Beetles were sampled from mid-April to the end of August 2014 using three types of traps. Flying beetles were caught using flight interception traps consisting of a semi-transparent triangular foil stretched between plastic panels (Komosiński and Marczak 2018). A bottle containing a solution of ethylene glycol and water (1:1) was attached at the bottom of the trap, and some detergent was added to reduce the surface tension of the liquid and thus prevent collected insects from escaping. The traps were installed approximately 2 m above ground level by hanging them on a rope between trunks of neighbouring trees. Yellow pan traps were used to capture beetles that feed on the pollen of flowering plants (*i.e.*, anthophilous/floricolous species) (Plewa et al. 2017). The trap consisted of a yellow plastic bowl of ca. 1000 ml volume. A mixture of ethylene glycol and water (1:1) with added detergent was also used to preserve captured insects. Yellow pan traps were installed by hanging them on the lower branches of trees. Pitfall traps were also used to collect ground-living beetles (mainly Carabidae) (Wang et al. 2014). The pitfall trap consisted of a plastic jar (volume of ca. 250 ml) covered with a roof and half-filled with ethylene glycol-water (1:1) solution.

Beetles were collected using an identical trapping design for each study site, namely 6 barrier traps, 6 yellow pan traps, and 12 pitfall traps at each site. Half of the traps of each type were installed in the forest at a distance of ca. 100 m from the edge of the forest to minimize the impact of the open area under the power line (*i.e.*, edge effect) with approximately 100 m distance between traps of the same type. The remaining traps were placed directly under the power line (pitfall traps) or on its edge (because they were installed between/on trees) with approximately 100 m between traps of the same type. Traps were checked and emptied at approximately monthly intervals.

Butterflies were identified by TJ. Beetles were identified by RP, except ground beetles, which were identified by GT and categorized as 'forest specialists' and 'open habitat specialists' based on the studies of Szyszko (1983), Leśniak (1997) and Tarwacki (2004).

Statistical analyses

We focused on independent predictors, which were testable only within a limited spatial scale, *i.e.*, the study was conducted under the power lines and in surrounding forests, thus within a limited landscape. Unreplicated treatments were the only option for our study (Oksanen 2001). We employed randomized techniques for species richness data (Gotelli and Colwell 2001), as recommended, and used in previous studies (Oksanen 2001; Klimes et al. 2011; Horák and Safarova 2015). We compared study treatments (habitat types) using sample-based species rarefactions (Mao Tau function) with 95% confidence intervals (Colwell 2006) for the analysis of species richness of each insect group. The number of randomizations was set to 1,000. Singletons (*i.e.*, species observed or trapped in only one individual) were omitted from the analyses. All analyses were performed in EstimateS 8.2.

RESULTS

We collected 385 beetle species representing eight families: Buprestidae (12 species), Carabidae (64), Cerambycidae (24), Coccinellidae (22), Curculionidae (33), Elateridae (28), Staphylinidae (184) and Tenebrionidae (18). We also recorded 21 species of butterflies (Appendix 1).

The numbers of species of ground beetles (Fig. 2a) and butterflies (Fig. 2i) were significantly higher under the power lines than in the forest. The difference in response of all other groups was not significant; however, jewel beetles, long-horned beetles, weevils and bark beetles, rove beetles and darkling beetles (Fig. 2b, c, e, g, h, respectively) were more species-rich under the power lines than in the forests. Click beetles (Fig. 2f) were indifferent to site, and lady-bird beetles (Fig.

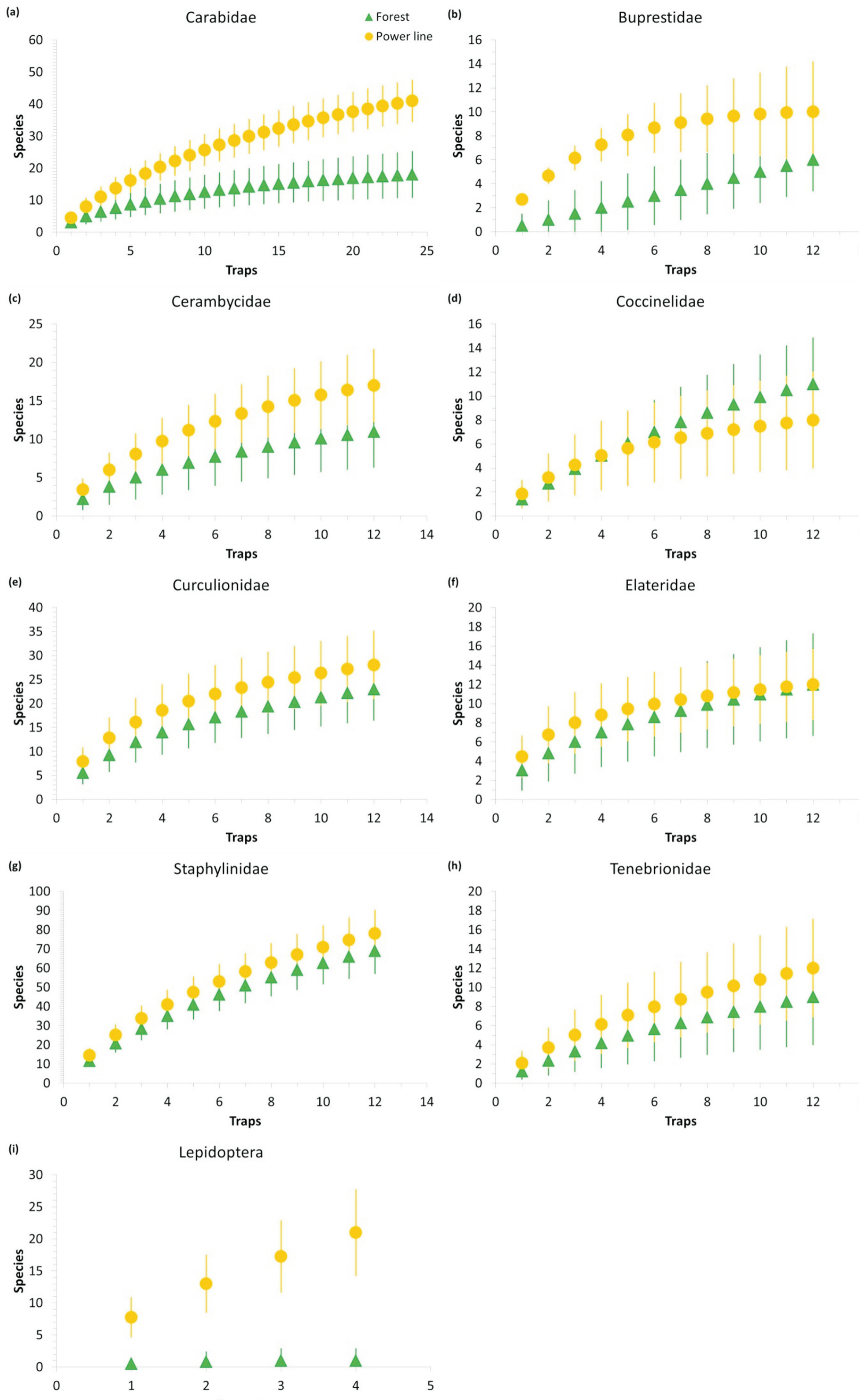

Fig. 2. Differences in the response of selected insect groups to power lines and forests in investigated study sites in Poland: (a) ground beetles (Carabidae), (b) jewel beetles (Buprestidae), (c) long-horn beetles (Cerambycidae), (d) lady-bird beetles (Coccinellidae), (e) weevils and bark beetles (Curculionidae), (f) click beetles (Elateridae), (g) rove beetles (Staphylinidae), (h) darkling beetles (Tenebrionidae), (i) butterflies (Lepidoptera). Circles and triangles indicate results for power lines and forest interior, respectively. Whiskers represent 95% confidence intervals.

2d) were more abundant in forests.

The results further indicated that the number of open habitat specialist ground beetles was higher under the power lines, while the number of forest specialists did not show a significant response to habitat (Fig. 3).

DISCUSSION

Based on our research on insect biodiversity, we found that the majority of studied groups responded positively to the power line environment. The importance of forest-free areas under power lines for biological diversity has rarely been studied. In forested landscapes, tree felling due to construction and management of power lines results in a significant transformation of the forest structure (Hollmen et al. 2008); therefore, power lines are traditionally viewed as negatively interfering with the environment. Nevertheless, recent studies demonstrate the benefits that power lines can provide for biodiversity conservation. Berg et al. (2016) revealed that the abundance and species richness of butterflies, including red-listed species, were higher around power lines than with other types of areas in Sweden. A positive effect of power lines on the population of endangered butterfly species was also documented in North America (Forrester et al. 2005). In Norway, Mikalsen (2012) observed higher diversity of various groups of beetles in areas under power lines than in the neighbouring forest interior. Power line corridors were used by ground beetles to colonize new areas and to serve as migration routes between different environments (Hollmen et al. 2008).

The results of the present research are mostly in line with previous studies on other taxa. Namely, we observed that the application of clearings in forests under power lines led in general to an increase in insect biodiversity. Two groups of insects significantly thrived as a result of activities related to the creation and/or maintenance of power lines; five other groups were also more species-rich, one was indifferent, and only one group was non-significantly more abundant under the forest canopies.

Our results may be interpreted in several ways. First and foremost, the removal of trees and shrubs due to the creation and management of power lines increases the structural heterogeneity of the previously continuous forest, which enhances species diversity by increasing the number of available niches (MacArthur and MacArthur 1961). Activities related to the maintenance of power lines are also conducive to the formation of early-successional habitats, which may further support open habitat insect species, *e.g.*, butterflies (Wagner et al. 2014; Berg et al. 2016) and some beetles (Hollmen et al. 2008). Furthermore, power lines serve an important role for many flowering plants, which in turn support the diversity of pollinating insects (Russell et al. 2005; Wojcik and Buchmann 2012; Komonen et al. 2013; Hill and Bartomeus 2016). The observed high diversity of several families of beetles, mainly saproxylic (*e.g.*, Cerambycidae, Buprestidae), may be explained by another important feature of power lines, namely the accumulation of dead wood due to more frequent cycles of cutting compared with neighbouring forest (Mikalsen 2012). In addition, dead wood left in corridors under power lines is usually more sun-exposed, which has been well documented to positively influence the

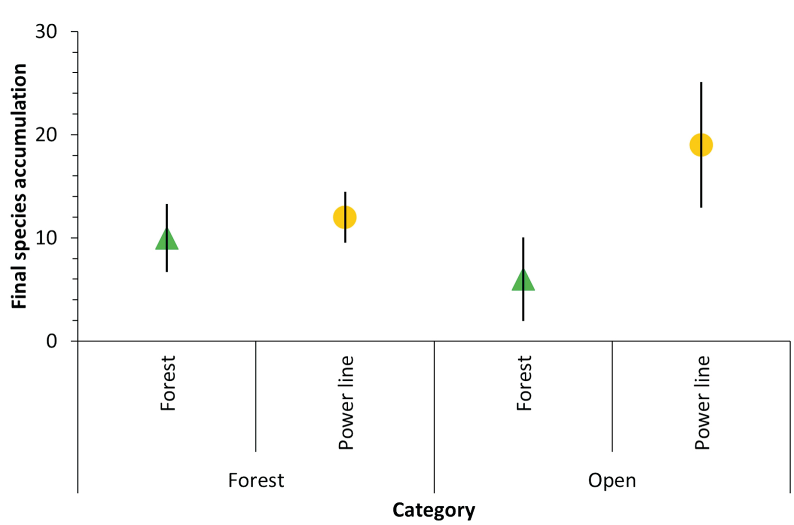

Fig. 3. Differences in the response of forest specialists (Forest) and open habitat specialists (Open) of ground beetles (Carabidae) to power lines and forests in Poland. Circles and triangles indicate results for power lines and forest interior, respectively. Whiskers represent 95% confidence intervals.

abundance and diversity of saproxylic beetles (Kaila et al. 1997; Lindhe et al. 2005). Finally, power lines may function as corridors for some insect species that may disperse from surrounding habitats (Hollmen et al. 2008), and this dispersal process might have also been responsible for the increased diversity of some insects in our study.

CONCLUSIONS

Our research indicates that forest-free areas under power lines increase forest biodiversity and can also provide a substitute environment for species that depend on open habitats. Activities related to the management of power lines ensure the long-term maintenance of open spaces in forests, which is fundamental in conditions where the natural and artificial disturbances that otherwise promote these valuable habitats are scarce or unpredictable. The different requirements of species dependent upon open habitats necessitate the development of detailed strategies for managing power lines in forests.

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REFERENCES

Askins RA, Folsom-O'Keefe CM, Hardy MC. 2012. Effects of vegetation, corridor width and regional land use on early successional birds on powerline corridors. PLoS ONE **7(2):**e31520. doi:10.1371/journal.pone.0031520.

Bartzke GS, May R, Bevanger K, Stokke S, Røskaft E. 2014. The effects of power lines on ungulates and implications for power line routing and rights-of-way management. Int J Biodivers Conserv **6(9):**647–662. doi:10.5897/IJBC2014.0716.

Bartzke GS, May R, Solberg EJ, Rolandsen CM, Røskaft E. 2015. Differential barrier and corridor effects of power lines, roads and rivers on moose (*Alces alces*) movements. Ecosphere **6(4):**1–17. doi:10.1890/ES14-00278.1.

Berg Å, Bergman K-O, Wissman J, Żmihorski M, Öckinger E. 2016. Power-line corridors as source habitat for butterflies in forest landscapes. Biol Conserv **201:**320–326. doi:10.1016/j.biocon.2016.07.034.

Bevanger K. 1998. Biological and conservation aspects of bird mortality caused by electricity power lines: a review. Biol Conserv **86:**67–76.

Bevanger K, Brøseth H. 2004. Impact of power lines on bird mortality in a subalpine area. Anim Biodiv Conserv **27(2):**67–77.

Chen C-L, Shaner P-JL. 2018. Effects of greenfall on ground-dwelling arthropods in a subtropical forest. Zool Stud **57:**44. doi:10.6620/ZS.2018.57-44.

Clarke DJ, Pearce KA, White JG. 2006. Powerline corridors: degraded ecosystems or wildlife havens. Wildlife Res **33:**615–626. doi:10.1071/WR05085.

Colwell RK. 2006. EstimateS: Statistical estimation of species richness and shared species from samples. Version 8. http://viceroy.eeb.uconn.edu/estimates. Accessed 5 May 2010.

Confer JL, Pascoe SM. 2003. Avian communities on utility rights-of-ways and other managed shrublands in the northeastern United States. Forest Ecol Manage **185:**193–205.

Draper G, Vincent T, Kroll ME, Swanson J. 2005. Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study. Brit Med J **330(7503):**1290. doi:10.1136/bmj.330.7503.1290.

Douda J, Boublík K, Doudová J, Kyncl M. 2016. Traditional forest management practices stop forest succession and bring back rare plant species. J Appl Ecol **54:**761–771. doi:10.1111/1365-2664.12801.

Dubé C, Pellerin S, Poulin M. 2011. Do power line rights-of-way facilitate the spread of non-peatland and invasive plants in bogs and fens? Botany **89(2):**91–103. doi:10.1139/B10-089.

Fernie KJ, Reynolds SJ. 2005. The effects of electromagnetic fields from power lines on avian reproductive biology and physiology: a review. J Toxicol Env Heal B Crit Rev **8(2):**127–140. doi:10.1080/10937400590909022.

Forrester JA, Leopold DJ, Hafner SD. 2005. Maintaining critical habitat in a heavily managed landscape: effects of power line corridor management on Karner blue butterfly (*lycaeides melissa samuelis*) habitat. Restor Ecol **13(3):**488–498. doi:10.1111/j.1526-100X.2005.00061.x.

Gimmel ML, Ferro ML. 2018. General overview of saproxylic Coleoptera. *In*: Ulyshen MD (ed) Saproxylic Insects: diversity, ecology and conservation. Zoological Monographs, vol. 1. Springer, Cham, pp. 51–128.

Gotelli NJ, Colwell RK. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecol Lett **4:**379–391. doi:10.1046/j.1461-0248.2001.00230.x.

Hédl R, Kopecký M, Komárek J. 2010. Half a century of succession in a temperate oak wood: from species-rich community to mesic forest. Divers Distrib **16(2):**267–276. doi:10.1111/j.1472-4642.2010.00637.x.

Heliölä J, Koivula M, Niemelä J. 2001. Distribution of carabid Beetles (Coleoptera, Carabidae) across a boreal forest-clearcut ecotone. Conserv Biol **15:**370–377.

Hill B, Bartomeus I. 2016. The potential of electricity transmission corridors in forested areas as bumblebee habitat. Royal Soc Open Sci **3(11):**160525. doi:10.1098/rsos.160525.

Hilszczański J, Jaworski T. 2018. Biodiversity conservation in the Białowieża Forest in the context of natural and anthropogenic disturbances dynamics. Sylwan **162(11):**927–932. (in Polish)

Hollmen A, Välimäki P, Itämies J, Oksanen J. 2008. The value of open power line habitat in conservation of ground beetles (Coleoptera: Carabidae) associated with mires. J Insect Conserv **12:**163–177. doi:10.1007/s10841-007-9076-7.

Horák J, Safarova L. 2015. Effect of reintroduced manual mowing on biodiversity in abandoned fen meadows. Biologia **70(1):**113–120. doi:10.1515/biolog-2015-0009.

Hultberg T, Gaillard MJ, Grundmann B, Lindbladh M. 2015. Reconstruction of past landscape openness using the Landscape Reconstruction Algorithm (LRA) applied on three local pollen sites in a southern Swedish biodiversity hotspot. Veg Hist Archaeobot **24(2):**253–266. doi:10.1007/s00334-014-0469-8.

International Energy Outlook. 2017. https://www.eia.gov/outlooks/ieo/pdf/0484(2017).pdf. Accessed 14 Sept. 2017.

Jonsell M, Weslien J, Ehnström B. 1998. Substrate requirements of red-listed saproxylic invertebrates in Sweden. Biodivers Conserv **7:**749–764.

Kaila L, Martikainen P, Punttila P. 1997. Dead trees left in clear-cuts benefit saproxylic Coleoptera adapted to natural disturbances in boreal forest. Biodivers Conserv **6:**1–18.

King DI, Byers BE. 2002. An evaluation of powerline rights-of-way as habitat for early successional shrubland birds. Wildl Soc Bull **30:**868–874.

Klimes P, Janda M, Ibalim S, Kua J, Novotny V. 2011. Experimental suppression of ants foraging on rainforest vegetation in New Guinea: testing methods for a whole-forest manipulation of insect communities. Ecol Entomol **36(1):**94–103. doi:10.1111/j.1365-2311.2010.01250.x.

Koivula MJ. 2011. Useful model organisms, indicators, or both? Ground beetles (Coleoptera, Carabidae) reflecting environmental conditions. Zookeys **100:**287–317. doi:10.3897/zookeys.100.1533.

Komonen A, Lensu T, Kotiaho JS. 2013. Optimal timing of power line right-of-way management for conservation of butterflies. Insect Conserv Diver **6(4):**522–529. doi:10.1111/icad.12009.

Komosiński K, Marczak D. 2018. Four species of Ptiliidae (Coleoptera) new to Poland. Coleopts Bull **72(1):**151–156. doi:10.1649/0010-065X-72.1.151.

Lampinen J, Ruokolainen K, Huhta A-P. 2015. Urban Power Line Corridors as Novel Habitats for Grassland and Alien Plant Species in South-Western Finland. PLoS ONE **10(11):**e0142236. doi:10.1371/journal.pone.0142236.

Lensu T, Komonen A, Hiltula O, Päivinen J, Saari V, Kotiaho JS. 2011. The role of power line rights-of-way as an alternative habitat for declined mire butterflies. J Environ Manage **92:**2539–2546. doi:10.1016/j.jenvman.2011.05.019.

Leśniak A. 1997. Metody analizy zgrupowań biegaczowatych (Carabidae, Col.) w zooindykacji procesów ekologicznych. *In*: VI Sympozjum Ochrony Ekosystemów Leśnych. Waloryzacja ekosystemów leśnych metodami zooindykacyjnymi. Fundacja, "Rozwój SGGW", pp. 29−41.

Lindhe A, Lindelöw Å, Åsenblad N. 2005. Saproxylic beetles in standing dead wood density in relation to substrate sun-exposure and diameter. Biodivers Conserv **14(12):**3033–3053. doi:10.1007/s10531-004-0314-y.

Luken JO, Hinton AC, Baker D. 1992. Response of woody plant communities in power-line corridors to frequent anthropogenic disturbance. Ecol Appl **2:**356–362.

MacArthur RH, MacArthur JW. 1961. On bird species diversity. Ecology **42:**594–598.

Manville AM. 2016. Impacts to birds and bats due to collisions and electrocutions from some tall structures in the United States – wires, towers, turbines, and solar arrays: state of the art in addressing the problems. *In*: Angelici FM (ed) Problematic wildlife – a cross-disciplinary approach. Springer, New York, pp. 415–442.

Mikalsen JE. 2012. Impact of frequent cutting of trees in power-line corridors on biological diversity of beetles (Coleoptera). Master thesis, Norwegian University of Life Science.

Miklín J, Sebek P, Hauck D, Konvicka O, Cizek L. 2018. Past levels of canopy closure affect the occurrence of veteran trees and flagship saproxylic beetles. Divers Distrib **24(2):**208–218. doi:10.1111/ddi.12670.

Navrud S, Ready EC, Magnussen K, Bergland O. 2008. Valuing the social benefits of avoiding landscape degradation from overhead power transmission lines: Do underground cables pass the benefit–cost test? Landscape Res **33(3):**281–296. doi:10.1080/01426390802045921.

Oksanen L. 2001. Logic of experiments in ecology: is pseudoreplication a pseudoissue? Oikos **94:**27–38.

Plewa R, Jaworski T, Hilszczański J, Horák J. 2017. Investigating the biodiversity of the forest strata: The importance of vertical stratification to the activity and development of saproxylic beetles in managed temperate deciduous forests. Forest Ecol Manage **402:**186–193. doi:10.1016/j.foreco.2017.07.052.

Richardson ML, Wilson BA, Aiuto DAS, Crosby JE, Alonso A, Dallmeier F, Golinski GK. 2017. A review of the impact of pipelines and power lines on biodiversity and strategies for mitigation. Biodivers Conserv **26(8):**1801–1815. doi:10.1007/s10531-017-1341-9.

Russell KN, Ikerd H, Droege S. 2005. The potential conservation value of unmowed powerline strips for native bees. Biol Conserv **124(1):**133–148. doi:10.1016/j.biocon.2005.01.022.

Sakalian V, Kuzmanov B. 1993. Anthophilous species of Coleoptera (Insecta) in Bulgaria. Acta Zool Bulg **46:**79–88.

Storm J, Choate J. 2012. Structure and movements of a community of small mammals along a powerline right-of-way in subalpine coniferous forest. Southwest Nat **57(4):**385–392. doi:10.1894/0038-4909-57.4.385.

Streitberger M, Hermann G, Kraus W, Fartmann T. 2012. Modern forest management and the decline of the Woodland Brown (*Lopinga achine*) in Central Europe. Forest Ecol Manage **269:**239–248. doi:10.1016/j.foreco.2011.12.028.

Szyszko J. 1983. State of Carabidae (Col.) fauna in fresh pine forest and tentative valorization of this environment. Warsaw Agricultural University Press, Warszawa.

Tarwacki G. 2004. Zróżnicowanie gatunkowe zgrupowań biegaczowatych (Carabidae) w monokulturach sosnowych po zastosowaniu ogniskowo-kompleksowej metody ochrony lasu. Leśne Prace Badawcze **1:**103−118.

Wagner DL, Metzler KJ, Leicht-Young SA, Motzkin G. 2014. Vegetation composition along a New England transmission line corridor and its implications for other trophic levels. Forest Ecol Manage **327:**231–239. doi:10.1016/j.foreco.2014.04.026.

Wang XP, Müller J, An L, Ji L, Liu Y, Wang X, Hao Z. 2014. Intra-annual variations in abundance and species composition of carabid beetles in a temperate forest in Northeast China. J Insect Conserv **18:**85–98. doi:10.1007/s10841-014-9617-9.

Walczak M, Woźniak A, Szczepański WT, Karpiński L. 2014. The structure of anthophilous longhorn beetles (Col.: Cerambycidae) visiting hawthorns (*Crataegus* spp.) in the Western Palearctic. Baltic J Coleopterol **14(2):**205–217.

Wojcik VA, Buchmann S. 2012. Pollinator conservation and management on electrical transmission and roadside rights-of-way: a review. J Pollinat Ecol **7(3):**16–26.

Van Swaay C, Regan E, Ling M, Bozhinovska E, Fernandez M, Marini-Filho OJ, Huertas B, Phon C-K, Kőrösi Á, Meerman J, Pe'er G, Uehara-Prado M, Sáfián S, Sam L, Shuey J, Taron D, Terblanche R, Underhill L. 2015. Guidelines for standardised global butterfly monitoring. Group on Earth Observations Biodiversity Observation Network, Leipzig, Germany. GEO BON Technical Series 1, p. 32.

Van Swaay C, Warren M, Loïs G. 2006. Biotope use and trends of European butterflies. J Insect Conserv **10(2):**189–209. doi:10.1007/s10841-006-6293-4.

Vera FWM. 2000. Grazing Ecology and Forest History. CABI Publishing, Wallingford.

Yahner RH, Hutnik RJ, Liscinsky SA. 2003. Long-term trends in bird populations on an electric transmission right-of-way. J Arboricult **29:**156–161.

Supplementary material

Appendix 1. List of insects. (download)