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Short communication

Vegetation response to forest ditch reconstruction: Promoting a potential habitat for insect-pollinated plant species?

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Abstract. In a managed forest landscape, the high degree of human intervention has caused significant shifts in natural processes, and preservation of remaining natural ecosystem features is crucial to safeguard ecosystem functioning and support ecosystem services. While drainage ditches, subject to regular maintenance, are anthropogenically created and maintained infrastructure elements, they may still support diverse environmental conditions and provide habitats for a variety of plant species, including flowering plants important for pollinators. We assessed vegetation composition changes on recently reconstructed and unmanaged forest ditches and ditch edges in a commercial forest in Central Latvia in two surveys (one and five years after the ditch reconstruction). We used generalized linear mixed-effects models to analyze the impact of environmental variables on species richness and detrended correspondence analysis to analyze plant species composition. We found higher total plant species richness and insect-pollinated plant species richness along recently reconstructed ditches. The differences were mainly explained by better light availability beside reconstructed ditches. Anthropogenically created and managed ecosystems may support biodiversity and directly and indirectly contribute to the provision of different ecosystem services, including pollination.

Key words: ditch reconstruction, species richness, species diversity, flowering plants.

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Introduction

During previous centuries, the human impact on nature has been steadily increasing. The result is a high degree of intervention in previously undisturbed ecosystems, bearing with it significant alterations of natural processes (Jackson & Jackson, 2000; Marsh, 2003; Goudie, 2018). It is often impossible to revert these ecosystems back to their near-natural state, and it is increasingly important to safeguard their remaining natural features and to ensure that they support the ecosystem processes in the best possible way (Jackson *et al.*, 2009). For that, a profound understanding of the functioning of these novel ecosystems is of crucial importance.

In countries with a developed forest industry, linear forest infrastructure objects, such as forest roads and ditches constructed primarily to increase forest productiv-

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ity and improve accessibility, are among the most widespread examples of human-altered ecosystems (Avon *et al.*, 2013; Lõhmus *et al.*, 2015), and drainage networks are common linear elements in forest landscapes all over Europe (Paavilainen & Päivänen, 1995; Rydin & Jeglum, 2006; Päivänen & Hånell, 2012). These anthropogenically created and maintained features may cause significant changes in forest ecosystem functions, for example, by disrupting population connectivity, acting as a barrier to dispersal, altering ecological community composition and decreasing community diversity at landscape level, and acting as pathways for the spread of invasive alien species (Smart *et al.*, 2006; Flory & Clay, 2009).

At the same time, due to more varied micro-site conditions, ditches and ditch edges support higher species diversity, providing habitats for plants with different ecological requirements (Zielińska, 2007; Zielińska *et al.*, 2017; Karim & Mallik, 2008). They are of a special importance for hygrophilous bryophytes and may help to preserve rare species in a managed forest landscape (Staniaszek-Kik *et al.*, 2016). Zielińska *et al.* (2017) highlight the importance of forest ditch edges in increasing the habitat diversification for vascular plants and bryophytes at meso- and microscales. In landscapes heavily influenced by human activity ditch networks may enhance the functional connectivity of populations (Favre-Bac *et al.*, 2016).

To address the decline of pollinator populations, measures resulting in the establishment of flowering plant communities with the primary aim of improving the nutrition basis for larvae and adult insects have been implemented in Europe and North America (Wratten *et al.*, 2012). Ditch slopes and verges may positively contribute to this objective, as they provide habitats for a variety of flowering vascular plants (Rasran & Vogt, 2018), in this regard being more suitable for pollinator communities (especially bees, flies and butterflies) than closed forests and woodlands, moreover, linear forest structures are facilitating the dispersal of pollinators across the landscape (Hanula *et al.*, 2016; Phillips *et al.*, 2020). Thus, they may serve as ecological corridors and stepping-stones for pollinator communities: a significant aspect in the light of the increasing importance of pollination as essential ecosystem service with a declining tendency due to the intensification of agriculture practices, expansion of parasites, more frequent biological invasions, habitat loss and fragmentation (Liss *et al.*, 2013; Porto *et al.*, 2020). At the same time, linear infrastructure elements may promote the dispersal of invasive alien species, potentially acting as competitors for pollination services (Hanula *et al.*, 2016). Knowledge about the specific effects that the creation and management of linear forest infrastructure elements have on vascular species' composition and its role in providing habitats and as food base for pollinating insects is still scarce.

It is hypothesized that ditch reconstruction could increase the plant species diversity on forest ditch edges, in turn affecting the abundance of flowering plant species. The aim of our study was to monitor changes in plant species composition on drainage forest ditches and ditch edges, with emphasis on quantifying the amount of insect-pollinated plants, potentially beneficial to pollinator communities. This paper reflects the results of the analysis of flora along managed forest drainage ditches 3–5 years after reconstruction works, when the plant communities have re-established.

Materials and Methods

Study area

The study was conducted in the forested catchment of Zalve stream (Figure 1), located in the central part of Latvia (hemi-boreal vegetation zone) and actively managed by JSC (Latvia's State Forests). The catchment is dominated by conifer stands, with

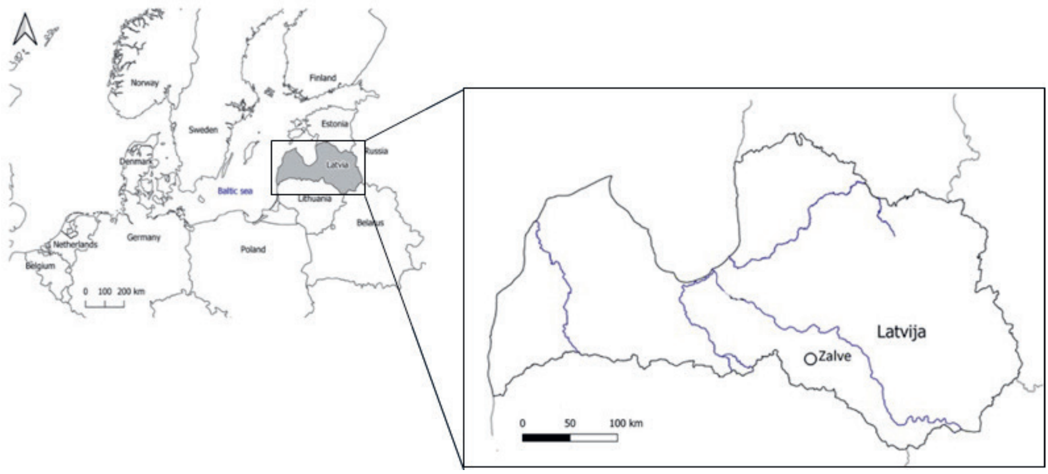

Figure 1. The location of the research area.

an admixture of deciduous trees, mainly on mesotrophic mineral soils. The dominating tree species are *Picea abies* (L.) H. Karst., *Pinus sylvestris* L., *Betula pendula* Roth and *Betula pubescens* Ehrh. Part of the studied area has been drained for forestry in the second half of the 20th century. The stands are growing in lowland conditions (30–100 m a.s.l.). The mean annual temperature in the study area during the study period (2016–2020) was +8.3 °C (slightly higher than the mean value in Latvia) and the mean annual precipitation was 638 mm (slightly lower than the mean value in Latvia) (local meteorological station data, compared to the Latvian Environment, Geology and Meteorology Centre (2023) data).

Data collection

In 2016, vegetation monitoring plots were established along four forest ditch edges with a different management history. Plant species were inventoried along two recently reconstructed forest ditches (reconstruction year 2015) and two unmanaged forest ditches (left unattended for at least 20 years). At each site, a vegetation survey was performed along a 1-km-long section of the ditch, with ten 3 m x 10 m plots positioned with the long side perpendicular to the ditch on the left and right sides of the ditch, 100 m plots were located immediately adjacent to the ditch (Matisone *et al.*, 2018). In total, 80 plots (4 transects x 20 plots) were established. In each plot, the cover of each vascular plant species and bryophyte species was recorded according to a 5-point scale (Braun-Blanquet, 1964). The tree and shrub species with a height of up to 1 m were also recorded and their cover estimated. The nomenclature of Gavrilova & Šulcs (1999) was followed for vascular plants and by Bambe *et al.* (2023) for bryophytes. The first vegetation survey was conducted from June to July 2016 and the repeated assessment during the same months in 2020. Insect-pollinated plants were identified combining all vascular plant species that are pollinated by different taxonomic groups of insects and/or those plant species with insects as one of pollen vectors. The values were extracted from the BiolFlor Database (2023).

Data analysis

Ellenberg indicator values (nitrogen, moisture, light, soil reaction) were used to describe the environmental conditions of each studied plot (Simmel *et al.*, 2021; Tichý *et al.*, 2023; Düll, 2001). Community-weighted means (by species cover) were calculated for Ellenberg values within a plot.

Generalized linear mixed-effects models were used to assess the differences between survey years, the effects of the object type (managed or unmanaged) and of Ellenberg variables on species richness. The residuals were adjusted according to the Poisson distribution (log link function). The predictors were checked for co-linearity using the variance inflation factor; variables showing values >5 were discarded.

The plant species composition was analyzed using the detrended correspondence analysis (DCA) based on species cover data. The relationship between two canonical axes and species community characteristics (total species richness, richness of insect-pollinated flowers, species diversity index (H')) and Ellenberg variables were calculated with Pearson's correlation analysis. Canonical axes were rescaled and rare species were downweighed. Successional vectors were drawn to assess changes in plant species communities between the studied ditches according to the survey year. Data analysis was conducted in *R v. 4.2.0* (R Core Team, 2020), using the libraries *"lme4"* (Bates *et al.*, 2015). Ordination was conducted in PC-ORD 6 package (Peck, 2010).

Results and Discussion

In total, 254 plant taxa were recorded along the studied ditches: 34 bryophytes and 220 vascular plants – some individuals could be identified only down to genera. The species community represented the local pool of common species. The most common vascular plant species were *Athyrium filix-femina* (L.) Roth, *Calamagrostis canescens* (Weber) Roth, *Cirsium oleraceum* (L.) Scop., *Dryopteris carthusiana* (Vill.) H.P. Fuchs, *Lysimachia vulgaris* L., *Rubus idaeus* L. and *Urtica dioica* L. and the most common bryophytes were *Brachythecium rutabulum* (Hedw.) Schimp., *Plagiomnium ellipticum* (Brid.) T.J. Kop., *Calliergonella cuspidata* (Hedw.) Loeske (Appendix 1). For the second survey in 2020, 44 new taxa had emerged and 43 taxa had disappeared (Appendix 1). In the studied plots one protected orchid species *Platanthera bifolia* (L.) Rich. (Cabinet Regulation No. 396, 2000) was found once in the studied time period, but this species is rather common along

Table 1. Strength (χ^2-value) and significance (p-value) of effects of year, object and Ellenberg light and nitrogen on species total richness and richness of insect-pollinated plant species. Similar letters indicate a lack of significant differences at α=0.05.

		Richness of species				Insect-pollinated plant species			
Effects	Variable	Chi-Square (χ^2)	p-value	Mean	Group	Chi-Square (χ^2)	p-value	Mean	Group
Year	2016	16.77	<0.001	38 ± 7.5	a	14.35	<0.001	22 ± 6.2	a
	2020			43 ± 8.2	b			25 ± 5.3	b
Object	Reconstructed (A)	31.77	<0.001	47 ± 7.7	a	41.07	<0.001	27 ± 5.1	a
	Reconstructed (B)			43 ± 6.9	ab			27 ± 5.4	a
	Old (C)			34 ± 6.8	c			19 ± 5	b
	Old (D)			39 ± 6.2	b			22 ± 4.1	b
Light		3.81	0.05			0.17	0.68		
Nitrogen		4.8	0.03			1.09	0.3		

forest edges. The majority of the species were forbs and graminoids. More than half of all identified species were insect-pollinated flowering plant species (135 species) and made up around 60% of all recorded vascular plant species (Appendix 1).

The results showed that during the 4-year-period the richness of insect-pollinated plant species and the richness of total species had significantly increased, from 22 to 25 species and from 38 to 43 species per studied plot, respectively (Table 1). According to glmer models, the object type was the main predictor of the insect-pollinated plant species richness and total species richness as indicated by the highest χ^2 values (Table 1). The highest insect-pollinated flower species richness was associated with managed ditches, and it was significantly higher than along unmanaged ditches (Table 1). The highest total species richness was identified along both reconstructed ditches, and the differences were significant for the strongest contrasts (compared to unmanaged ditch C) (Table 1). This confirms previously drawn conclusions that ditches as anthropogenic structures impact the plant species biodiversity in a managed forest landscape by increasing floristic richness (Zielińska *et al.*, 2013; Zielińska *et al.*, 2017). They do not, however, support endangered plant species. The explained factors for higher species richness were associated with higher Ellenberg light and nitrogen values (Table 1) that generally increase after the forest infrastructure reconstruction (Godefroid & Koedam, 2004). Our results showed that Ellenberg light values were significantly higher on the studied managed ditches (Appendix 2), indicating that management was improving the light conditions, while Ellenberg nitrogen values showed significantly strongest contrasts only between both managed ditches (Appendix 2).

According to our results, especially reconstructed diches provide important habitats for insect-pollinated plant species and thus could be favorable for groups of pollinators. Our results did not show the Ellenberg nutrient value as a significant factor for higher insect-pollinated species richness. According to the literature, it is possible that nitrogen enrichment benefits the growth of grasses more than that of forbs (Bråthen *et al.*, 2021). While light availability could be a limiting factor for flowering plant species, our results did not show Ellenberg light values as a significant factor for higher insect-pollinator species richness as well. We hypothesize that pollinator species richness could be affected also by other factors, such as microtopography, features of soil and forest type and management in the studied area (Zielińska *et al.*, 2017), which were not analyzed in this study.

The DCA ordination of the studied plots indicated an influence of management on the species composition. The higher number of insect-pollinated plants were more strongly associated with plots on reconstructed ditches (located on the left part of the DCA ordination) (Figure 2). Richness of insect-pollinated flowers were related to the first gradient (r=0.672), which accounted for 35% of the total variation (eigenvalue=0.348). According to the results, the species composition of managed forest ditches was associated with higher Ellenberg light values (the Pearson's correlation coefficient between Ellenberg light and the first axis was 0.672 and second axis – 0.478, respectively) (Figure 2). Our results indicate that light could be related to higher richness of flowering plants.

The studied old ditches were characterized by lower light availability (Figure 2). The second gradient that accounted for 17% of the total variation (eigenvalue=0.165) and was explained by moisture, was most likely related to local specific conditions (Figure 2). The results confirm earlier findings that ditches could provide higher variability of microsite conditions resulting in high species richness (Bergès *et al.*, 2013; Zielińska *et al.*, 2013; Staniaszek-Kik *et al.*, 2016). Several previous studies, e.g. Smith *et al.* (2007) and

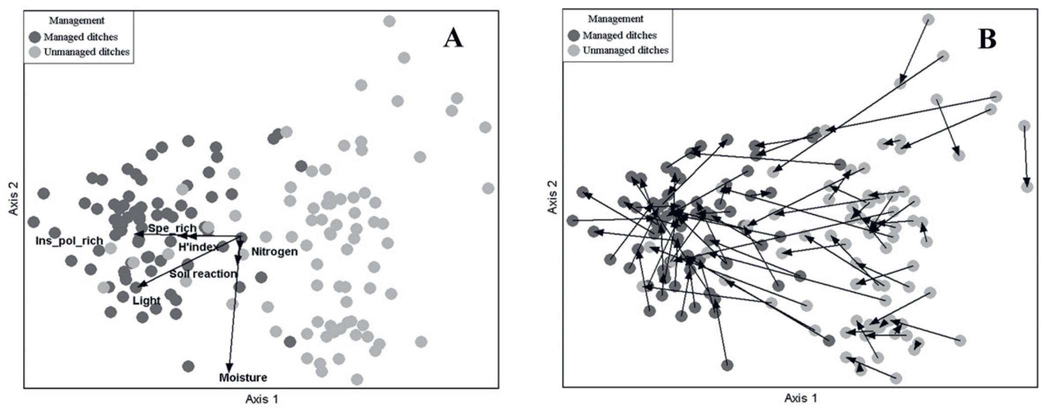

Figure 2. DCA ordination of studied plots in survey years 2016 and 2020. The first two canonical axes are shown. (A) shows plot ordination according to management intensity. The vectors show correlation between calculated Ellenberg indicator values (light, soil reaction, moisture, nitrogen) and between species communities metrics. Abbreviations: Spe_rich – species richness, Ins_pol_rich – insect-pollinated species richness. (B) shows species ordination with successional changes on studied plots. The successional changes in the species composition among the observations in 2016 and 2020 are indicated with black vectors.

Baltzinger *et al.* (2011), mention especially roadsides with ditches as one of the most species-rich habitats in managed forests. The preliminary results obtained after the first survey in 2016 demonstrated that the species composition and species richness significantly differed between managed and unmanaged ditches, with Ellenberg nitrogen values as the main predictor of the differences (Matisone *et al.*, 2018). Four years later, the differences were still significant, but the importance of nitrogen had decreased. After the second survey, light was the main environmental factor impacting the species composition.

The DCA ordination indicated also successional changes in species communities over a 4-year period (Figure 2). The changes in species composition were specific to the studied plot and most explicit according to the first gradient. According to the main gradient, successional changes on the unmanaged ditches were small as indicated by the relative length of successional vectors. The changes in species communities could be related to light conditions, showing that successional changes along reconstructed ditches were expressed as an increase in species richness, including insect-pollinated species richness and diversity. Successional changes on the unmanaged ditches were less pronounced, except for some individual plots where the increase in species richness was high (Figure 2). Such changes could be explained by management of forest stands along the studied old ditches promoting better light availability and resulting in higher species richness in the second assessment.

Conclusions

Our research confirms that intensive forest management (ditch reconstruction) promotes higher plant species richness along ditch edges in comparison with unmanaged forest ditches. Ditch reconstruction changes species composition, promoting more light and nitrogen demanding species, including flowering plants important for pollinators, thus providing nutrition sources for pollinator communities. Anthropogenically created or altered ecosystems should be evaluated in a complex way, considering both the ecosystem services and disservices they deliver.

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References

Avon, C., Dumas, Y., Bergès, L. 2013. Management practices increase the impact of roads on plant communities in forests. – Biological Conservation, 159, 24–31. https://doi.org/10.1016/j.biocon.2012.10.008.

Baltzinger, M., Archaux, F., Gosselin, M., Chevalier, R. 2011. Contribution of forest management artefacts to plant diversity at a forest scale. – Annals of Forest Science, 68, 395–406. https://doi.org/10.1007/s13595-011-0026-x.

Bambe, B., Gerra-Inohosa, L., Kluša, J., Kukāre, I., Ķeire, L., Leimanis, I., Liepiņa, L., Longs, D., Mežaka, A., Olenhoviča, E., Opmanis, A., Pošiva-Bunkovska, A., Strazdiņa, L., Suško, U., Fonteina-Kazeka, M., Volskis, G.J., Zvejniece, E. 2023. Checklist of Latvian Bryophytes. (Latvijas sūnu taksonu saraksts). Daugavpils, Latvia, Daugavpils University Press Saule. 48 pp. (In Latvian with English summary).

Bates, D., Mächler, M., Bolker, B., Walker, S. 2015. Fitting linear mixed-effects models using lme4. – Journal of Statistical Software, 67(1), 1–48. https://doi.org/10.18637/jss.v067.i01.

Bergès, L., Chevalier, R., Avon, C. 2013. Influence of forest road, road-surfacing material and stand age on floristic diversity and composition in a nutrient-poor environment. – Applied Vegetation Science, 16(3), 470–479. https://doi.org/10.1111/avsc.12019.

BiolFlor Database. 2023. [WWW document]. – URL www.biolflor.de. [Accessed 10 September 2023].

Braun-Blanquet, J. 1964. Plant sociology. Basic principles of vegetation science. (Pflanzensoziologie. Grundzüge der Vegetationskunde). Wien, New York, Springer Verlag. 865 pp. (In German).

Bråthen, K.A., Pugnaire, F.I., Bardgett, R.D. 2021. The paradox of forbs in grasslands and legacy of the mammoth steppe. – Frontiers in Ecology and the Environment, 19(10), 584–592.

Cabinet Regulation No. 396. 2000. Regulations on the list of specially protected species and restricted uses of specially protected species. [WWW document]. – URL https://likumi.lv/doc.php?id=12821. [Accessed 1 November 2023].

Düll, R. 2001. Indicator values of mosses and liverworts. (Zeigerwerte von Laub- und Lebermoosen). – Ellenberg, H., Weber, H.E., Düll, R., Wirth, V., Werner, W. (eds.). Indicator values of plants in Central Europe. (Zeigerwerte von Pflanzen in Mitteleuropa). Göttingen, Erich Goltze Verlag, 175–220. (In German).

Favre-Bac, L., Mony, C., Ernoult, A., Burel, F., Arnaud, J.-F. 2016. Ditch network sustains functional connectivity and influences patterns of gene flow in an intensive agricultural landscape. – Heredity, 116(2), 200–212.

Flory, S.L., Clay, K. 2009. Effects of roads and forest successional age on experimental plant invasions. – Biological Conservation, 142(11), 2531–2537. https://doi.org/10.1016/j.biocon.2009.05.024.

Gavrilova, Ģ., Šulcs, V. 1999. Flora of vascular plants of Latvia: List of taxa. (Latvijas vaskulāro augu flora: Taksonu saraksts). Rīga, Latvijas Akadēmiskā bibliotēka. 136 pp. (In Latvian).

Godefroid, S., Koedam, N. 2004. The impact of forest paths upon adjacent vegetation: effects of the path surfacing material on the species composition and soil compaction. – Biological Conservation, 119(3), 405–419. https://doi.org/10.1016/j.biocon.2004.01.003.

Goudie, A.S. 2018. Human Impact on the Natural Environment. Chichester, John Wiley & Sons. 480 pp.

Hanula, J.L., Ulyshen, M.D., Horn, S. 2016. Conserving pollinators in North American forests: A review. – Natural Areas Journal, 36(4), 427–439. https://doi.org/10.3375/043.036.0409.

Jackson, A.R.W., Jackson, J.M. 2000. Environmental Science. The Natural Environment and Human Impact. 2nd Edition. London, Pearson Education. 405 pp.

Jackson, L., Rosenstock, T., Thomas, M., Wright, J., Symstad, A. 2009. Managed ecosystems: biodiversity and ecosystem functions in landscapes modified by human use. – Naeem, S., Bunker, D.E., Hector, A., Loreau, M., Perrings, C. (eds.). Biodiversity, Ecosystem Functioning, and Human Wellbeing: An Ecological and Economic Perspective. Oxford, Oxford University Press, 178–194. https://doi.org/10.1093/acprof:oso/9780199547951.001.0001.

Karim, M.N., Mallik, A.U. 2008. Roadside revegetation by native plants: I. Roadside microhabitats, floristic zonation and species traits. – Ecological Engineering, 32(3), 222–237. https://doi.org/10.1016/j.ecoleng.2007.11.003.

Latvian Environment, Geology and Meteorology Centre. 2023. [WWW document]. – URL https://videscentrs.lvgmc.lv/. [Accessed 10 November 2023].

Liss, K.N., Mitchell, M.G.E., MacDonald, G.K., Mahajan, S.L., Méthot, J., Jacob, A.L., Maguire, D.Y., Metson, G.S., Ziter, C., Dancose, K., Martins, K., Terrado, M., Bennett E.M. 2013. Variability in ecosystem service measurement: a pollination service case study. – Frontiers in Ecology and the Environment, 11(8), 414–422. https://doi.org/10.1890/120189.

Lõhmus, A., Remm, L., Rannap, R. 2015. Just a ditch in forest? Reconsidering draining in the context of sustainable forest management. – BioScience, 65(11), 1066–1076. https://doi.org/10.1093/biosci/biv136.

Marsh, G.P. 2003. Man and Nature. Seattle, WA, University of Washington Press. 512 pp.

Matisone, I., Zumberga, A., Lībiete, Z., Gerra-Inohosa, L., Jansons, J. 2018. The impact of forest infrastructure reconstruction on expansion of potentially invasive plant species: First results from a study in Latvia. – Journal of Forest Science, 64(8), 353–357. https://doi.org/10.17221/28/2018-JFS.

Paavilainen, E., Päivänen, J. 1995. Peatland Forestry: Ecology and Principles. Berlin, Heidelberg, Springer Verlag. 248 pp.

Päivänen, J., Hånell, B. 2012. Peatland ecology and forestry – a sound approach. Helsinki, Helsingin Yliopiston Metsätieteiden Laitos. 267 pp.

Peck, J.E. 2010. Multivariate Analysis for Community Ecologists: Step-by-Step using PC-ORD. Gleneden Beach, Oregon, MjM Software Design. 162 pp.

Phillips, B.B., Wallace, C., Roberts, B.R., Whitehouse, A.T., Gaston, K.J., Bullock, J.M., Dicks, L.V., Osborne, J.L. 2020. Enhancing road verges to aid pollinator conservation: A review. – Biological Conservation, 250, 108687. https://doi.org/10.1016/j.biocon.2020.108687.

Porto, R.G., Fernandes de Almeida, R., Cruz-Neto, O., Tabarelli, M., Viana, B.F., Peres, C.A., Lopes, A.V. 2020. Pollination ecosystem services: A comprehensive review of economic values, research funding and policy actions. – Food Security, 12, 1425–1442. https://doi.org/10.1007/s12571-020-01043-w.

Rasran, L., Vogt, K. 2018. Ditches as species-rich secondary habitats and refuge for meadow species in agricultural marsh grasslands. – Applied Vegetation Science, 21(1), 21–32. https://doi.org/10.1111/avsc.12337.

R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. [WWW document]. – URL http://www.R-project.org. [Accessed 21 August 2023].

Rydin, H., Jeglum, J.K. 2006. The Biology of Peatlands. Oxford, Oxford University Press. 343 pp.

Simmel, J., Ahrens, M., Poschlod, P. 2021. Ellenberg *N* values of bryophytes in Central Europe. – Journal of Vegetation Science, 32(1), e12957. https://doi.org/10.1111/jvs.12957.

Smart, S.M., Thompson, K., Marrs, R.H., Le Duc, M.G., Maskell, L.C., Firbank, L.G. 2006. Biotic homogenization and changes in species diversity across human-modified ecosystems. – Proceedings of the Royal Society B: Biological Sciences, 273(1601), 2659–2665.

Smith, G.F., Iremonger, S., Kelly, D.L., O'Donoghue, S., Mitchell, F.J.G. 2007. Enhancing vegetation diversity in glades, rides and roads in plantation forests. – Biological Conservation, 136(2), 283–294. https://doi.org/10.1016/j.biocon.2006.12.001.

Staniaszek-Kik, M., Zielińska, K.M., Misztal, M. 2016. How do ditches contribute to bryophyte diversity in managed forests in East-Central Europe? – European Journal of Forest Research, 135, 621–632. https://doi.org/10.1007/s10342-016-0959-6.

Tichý, L., Axmanová, I., Dengler, J., Guarino, R., Jansen, F., Midolo, G., Nobis, M.P., Van Meerbeek, K., Aćić, S., Attorre, F., Bergmeier, E., Biurrun, I., Bonari, G., Bruelheide, H., Campos, J.A., Čarni, A., Chiarucci, A., Ćuk, M., Ćušterevska, R., Didukh, Y., Dítě, D., Dítě, Z., Dziuba, T., Fanelli, G., Fernández-Pascual, E., Garbolino, E., Gavilán, R.G., Gégout, J.-C., Graf, U., Güler, B., Hájek, M., Hennekens, S.M. Jandt, U., Jašková, A., Jiménez-Alfaro, B., Julve, P., Kambach, S., Karger, D.N., Karrer, G., Kavgacı, A., Knollová, I., Kuzemko, A., Küzmič, F., Landucci, F., Lengyel, A., Lenoir, J., Marcenò, C., Moeslund, J.E., Novák, P., Pérez-Haase, A., Peterka, T., Pielech, R., Pignatti, A., Rašomavičius, V., Rūsiņa, S., Saatkamp, A., Šilc, U., Škvorc, Ž., Theurillat, J.-P., Wohlgemuth, T., Chytrý, M. 2023. Ellenberg-type indicator values for European vascular plant species. – Journal of Vegetation Science, 34(1), e13168. https://doi.org/10.1111/jvs.13168.

Wratten, S.D., Gillespie, M., Decourtye, A., Mader, E., Desneux, N. 2012. Pollinator habitat enhancement: Benefits to other ecosystem services. – Agriculture, Ecosystems & Environment, 159, 112–122. https://doi.org/10.1016/j.agee.2012.06.020.

Zielińska, K. 2007. The influence of roads on the species diversity of forest vascular flora in Central Poland. – Biodiversity: Research and Conservation, 5–8, 71–80.

Zielińska, K.M., Misztal, M., Zielińska, A., Żywiec, M. 2013. Influence of ditches on plant species diversity in the managed forests of central Poland. – Baltic Forestry, 19(2), 270–279.

Zielińska, K.M., Staniaszek-Kik, M., Misztal, M. 2017. Vascular plants and bryophytes in managed forests – analysis of the impact of the old ditches on the species diversity (Central European plain). – Applied Ecology and Environmental Research, 15(3), 1375–1392.

Appendix 1. The list of recorded vascular plant and bryophyte taxa along the studied ditches (in 2016 and 2020). The number of plots (n=40) where each species was recorded are shown. Insect-pollinated plant species are marked with *.

	Managed ditches		Unmanaged ditches	
Species	2016	2020	2016	2020
Acer platanoides L.*	0	1	0	0
Aegopodium podagraria L.*	4	3	0	1
Agrostis stolonifera L.	1	0	0	1
Agrostis tenuis Sibth.	7	6	0	1
Alisma plantago-aquatica L.*	15	20	4	8
Alnus glutinosa (L.) Gaertn.	9	25	9	19
Alnus incana (L.) Moench	6	0	0	1
Alopecurus aequalis Sobol.	26	11	0	0
Anemone nemorosa L.*	1	0	1	0
Angelica sylvestris L.*	17	26	24	23
Anthriscus sylvestris (L.) Hoffm.*	2	0	0	1
Artemisia vulgaris L.	7	11	0	0
*Athyrium filix-femin*a (L.) Roth	29	32	36	34
Betula pendula Roth	5	26	0	5
Betula pubescens Ehrh.	12	0	7	3
*Bidens tripartit*a L.*	2	2	0	2
Brachypodium pinnatum (L.) P.Beauv.	6	0	0	0
*Bromus arvensi*s L.	1	0	0	0
Calamagrostis arundinacea (L.) Roth	3	2	5	5
Calamagrostis canescens (Weber) Roth	32	38	24	31
Calamagrostis epigeios (L.) Roth	6	16	2	3
Calla palustris L.*	0	0	11	13
Caltha palustris L.*	3	1	14	15
Campanula patula L*	0	1	0	0
Cardamine spp.*	0	6	0	4
Carex acuta L.	0	4	0	0
Carex appropinquata Schumach.	3	2	2	0
Carex cinerea Pollich	1	1	0	5
Carex digitata L.	0	2	0	0
*Carex echinat*a Murray	0	0	0	1
Carex elongata L.	2	3	26	32
Carex flacca Schreb.	0	0	2	0
Carex flava L. s.str.	1	6	0	0

Species	Managed ditches		Unmanaged ditches	
	2016	2020	2016	2020
Carex hirta L.	0	2	0	0
Carex leporina L.	1	3	0	1
Carex nigra (L.) Reichard	5	2	0	1
Carex pseudocyperus L.	4	19	5	19
Carex remota L.	0	0	3	4
Carex rostrata Stokes	16	6	6	0
Carex spp.	1	18	0	5
Carex sylvatica Huds.	0	0	2	0
Carex vaginata Tausch	0	1	0	0
Carex vesicaria L.	10	11	0	4
Cerastium arvense L.*	1	0	0	0
Cerastium holosteoides Fr.*	1	3	0	0
Cerastium spp.*	0	7	0	0
Ceratophyllum demersum L.	5	5	0	2
Chamaenerion angustifolium (L.) Scop.*	2	4	0	0
Chenopodium album L.	2	0	0	0
Chrysosplenium alternifolium L.*	12	16	21	22
Cicuta virosa L.*	16	21	15	16
Circaea alpina L.*	3	5	12	19
Cirsium arvense (L.) Scop.*	21	24	0	5
Cirsium heterophyllum (L.) Hill*	0	1	0	0
Cirsium oleraceum (L.) Scop.*	28	30	22	30
Cirsium palustre (L.) Scop.*	12	18	3	3
Cirsium vulgare (Savi) Ten.*	2	3	0	1
Comarum palustre L.*	1	2	4	3
Convolvulus arvensis L.*	2	0	0	0
Crepis paludosa (L.) Moench*	1	0	12	9
Dactylis glomerata L.	4	0	0	0
Daphne mezereum L.*	1	0	0	0
Deschampsia caespitosa (L.) P.Beauv.	33	31	11	5
Dryopteris carthusiana (Vill.) H.P.Fuchs	19	28	34	35
Dryopteris filix-mas (L.) Schott	4	0	0	0
Elymus caninus (L.) L.	0	11	0	0
Elytrigia repens (L.) Nevski	0	3	0	0
Epilobium spp.*	27	35	5	11
Equisetum arvense L.	13	17	0	0
Equisetum fluviatile L.	1	6	8	6
Equisetum hyemale L.	0	0	1	0

	Managed ditches		Unmanaged ditches	
Species	2016	2020	2016	2020
Equisetum palustre L.	0	5	0	5
Equisetum pratense Ehrh.	17	11	6	0
Equisetum sylvaticum L.	17	17	10	13
Erigeron annuus (L.) Pers.*	1	4	0	0
Erigeron canadensis L.*	3	12	0	2
Euonymus europaea L.*	1	2	0	0
Eupatorium cannabinum L.*	1	0	2	2
Fagopyrum esculentum Moench*	0	1	0	0
Festuca gigantea (L.) Vill.	0	2	0	0
Festuca rubra L. s.l.	0	3	0	0
Festuca spp.	0	3	0	0
Filipendula ulmaria (L.) Maxim.*	32	31	13	10
Fragaria moschata Duchesne*	6	0	1	0
Fragaria vesca L.*	5	8	0	1
Frangula alnus Mill.*	19	27	14	19
Galeobdolon luteum Huds.*	5	4	6	9
Galeopsis spp.*	16	17	0	5
Galium album Mill.*	1	3	0	1
Galium aparine L.*	32	2	26	12
Galium elongatum C.Presl*	1	36	0	18
Galium palustre L.*	15	26	22	31
Galium uliginosum L.*	1	0	0	1
Geranium robertianum L.*	2	6	0	2
Geum rivale L.*	16	16	17	16
Glyceria fluitans (L.) R.Br.	32	34	8	16
Gnaphalium uliginosum L.*	2	4	0	0
Gymnocarpium dryopteris(L.) Newman	10	8	14	9
Hepatica nobilis Mill.*	0	0	1	0
Hieracium spp.*	0	0	0	1
*Hottonia palustri*s L.	0	0	0	1
Hypericum maculatum Crantz*	10	13	0	0
*Impatiens noli-tanger*e L.*	9	8	22	21
Impatiens parviflora DC.*	13	7	0	3
*Iris pseudacoru*s L.*	20	11	4	4
Juncus alpino-articulatus Chaix	4	0	0	0
Juncus articulatus L.	6	17	0	0
Juncus compressus Jacq.	0	1	0	0
Juncus filiformis L.	34	38	3	13

	Managed ditches		Unmanaged ditches	
Species	2016	2020	2016	2020
Lathyrus pratensis L.*	1	1	0	0
Lathyrus vernus (L.) Bernh.*	0	0	1	0
*Lemna mino*r L.	2	11	0	5
Chamomilla suaveolens (Pursh) Rydb.*	1	0	0	0
Leucanthemum vulgare Lam.*	1	0	0	0
Lolium multiflorum Lam.	2	0	0	0
Lolium perenne L.	0	1	0	0
*Lupinus polyphyll*us Lindl.*	0	1	0	0
Luzula multiflora (Ehrh.) Lej.	0	4	0	0
Luzula pilosa (L.) Willd.	11	12	17	17
Coronaria flos-cuculi (L.) A.Braun*	23	27	3	4
Lycopus europaeus L.*	18	30	18	34
Lysimachia nummularia L.*	1	2	0	0
Lysimachia vulgaris L.*	33	27	30	32
Lythrum salicaria L.*	0	2	0	0
Maianthemum bifolium (L.) F.W.Schmidt*	19	20	29	29
Mentha arvensis L.*	15	23	1	8
Mercurialis perennis L.	2	2	1	1
Milium effusum L.	2	9	6	7
Moehringia trinervia (L.) Clairv.*	17	20	4	2
*Mycelis murali*s (L.) Dumort.*	12	15	6	6
Myosostis arvensis (L.) Hill*	1	0	0	2
Myosotis palustris (L.) L.*	25	10	12	22
Myosotis sylvatica Ehrh. ex Hoffm.*	12	1	0	0
Myosoton aquaticum (L.) Moench *	22	0	1	0
Naumburgia thyrsiflora (L.) Rchb.*	3	5	3	18
Oenothera biennis L.*	0	0	1	0
Orthilia secunda (L.) House*	1	0	1	4
Oxalis acetosella L.*	18	15	33	33
Padus avium Mill.*	1	1	1	1
Paris quadrifolia L.*	12	10	14	17
Polygonum hydropiper L.*	0	3	0	2
Peucedanum palustre (L.) Moench*	8	8	21	15
Phegopteris connectilis (Michx.) Watt	1	1	0	0
Phragmites australis (Cav.) Trin. ex Steud.	11	15	3	4
Picea abies (L.) H.Karst.	16	24	20	27
Pimpinella saxifraga L.*	1	0	0	0
Pinus sylvestris L.	2	3	1	1

	Managed ditches		Unmanaged ditches	
Species	2016	2020	2016	2020
Plantago major L.*	5	1	0	0
Platanthera bifolia (L.) Rich.*	1	0	0	0
Poa compressa L.	1	1	0	0
Poa nemoralis L.	0	3	0	0
Poa palustris L.	17	22	12	22
Poa pratensis L.	4	5	0	1
Poa spp.	0	8	0	3
Polygonum hydropiper L.*	18	16	2	15
Populus tremula L.	7	5	0	0
Potentilla erecta (L.) Raeusch.*	1	1	0	1
Prunella vulgaris L.*	0	1	0	0
Pyrola minor L.*	1	0	3	0
Quercus robur L.	0	0	0	1
Ranunculus acris L.*	5	2	3	0
Ranunculus flammula L.*	11	9	0	1
Ranunculus lingua L.*	2	7	0	0
Ranunculus polyanthemos L.*	17	0	11	2
Ranunculus repens L.*	22	33	13	25
Ribes alpinum L.*	1	0	0	0
Ribes nigrum L.*	0	2	1	2
Rorippa sylvestris (L.) Besser*	2	0	0	0
Rubus idaeus L.*	35	37	20	24
Rubus saxatilis L.*	15	14	15	16
Rumex acetosa L.	0	1	0	0
Rumex acetosella L.	4	1	0	4
Rumex aquaticus L.	0	1	0	0
*Rumex confertu*s Willd.	4	0	4	0
Rumex obtusifolius L.	0	3	0	5
Rumex sp.	0	0	0	2
Sagina procumbens L.*	4	0	0	0
Salix spp.*	19	32	3	4
*Scirpus sylvaticu*s L.	17	28	11	11
Scleranthus perennis L.*	1	0	0	0
Scrophularia nodosa L.*	1	3	0	0
Scutellaria galericulata L.*	28	22	23	31
Senecio spp.*	0	1	0	1
*Senecio sylvaticu*s L.*	0	0	0	1
Senecio vulgaris L.*	5	0	1	0

	Managed ditches		Unmanaged ditches	
Species	2016	2020	2016	2020
Solanum dulcamara L.*	19	6	28	28
Solidago canadensis L. s.l. *	4	2	0	0
Solidago virgaurea L.*	3	7	6	3
Sonchus arvensis L.*	2	1	0	2
Sonchus oleraceus L.*	9	14	0	2
Sorbus aucuparia L.*	5	5	7	7
Spergularia rubra (L.) J. et C.Presl*	1	0	0	0
Stellaria graminea L.*	0	4	0	1
Stellaria holostea L.*	4	9	0	3
Stellaria longifolia Muhl. ex Willd.*	1	0	0	0
Stellaria media (L.) Vill.*	1	2	0	1
Stellaria nemorum L.*	0	20	23	18
Stellaria palustris Retz.*	4	1	3	4
Stellaria spp.*	0	0	0	3
Stellaria uliginosa Murray*	1	0	0	0
Taraxacum officinale F.H.Wigg. s.l.*	25	25	0	3
Thelypteris palustris Schott	15	9	16	20
Tilia cordata Mill.*	3	2	0	0
Trientalis europaea L.*	2	4	10	12
Trifolium repens L.*	3	0	0	0
Tussilago farfara L.*	21	29	0	0
Typha latifolia L.	0	4	0	4
Typha sp.	0	0	2	0
Urtica dioica L.*	32	33	31	33
Vaccinium myrtillus L.*	1	2	14	11
Vaccinium vitis-idaea L.*	0	0	3	4
Valeriana officinalis L.*	0	4	4	1
Veronica beccabunga L.*	0	0	1	0
Veronica chamaedrys L.*	16	25	4	3
Veronica officinalis L.*	1	5	0	0
Veronica serpyllifolia L.*	2	0	0	0
Veronica spp.*	0	2	0	4
Viburnum opulus L.*	2	1	0	0
Vicia cracca L.*	1	0	0	0
Viola spp.*	27	25	27	35
Atrichum undulatum (Hedw.) P.Beauv.	8	9	1	3
Aulacomnium palustre (Hedw.) Schwägr.	0	0	0	1
Brachythecium rutabulum (Hedw.) Schimp.	8	19	34	22

	Managed ditches		Unmanaged ditches	
Species	2016	2020	2016	2020
Calliergon cordifolium (Hedw.) Kindb.	1	7	30	23
Calliergonella cuspidata (Hedw.) Loeske	7	6	32	20
Ceratodon purpureus (Hedw.) Brid.	0	5	0	0
Climacium dendroides (Hedw.) F.Weber & D.Mohr	4	2	31	21
Conocephalum conicum (L.) Dumort	2	0	4	0
Dicranum polysetum Sw. ex anon.	6	2	9	5
Dicranum scoparium Hedw.	1	3	21	11
Plagiochila asplenoides (L.) Dumort.	0	0	1	1
Plagiomnium affine (Blandow ex Funck) T.J.Kop.	3	15	20	21
Plagiomnium cuspidatum (Hedw.) T.J.Kop.	13	10	12	17
Plagiomnium ellipticum (Brid.) T.J.Kop.	9	5	28	19
Plagiomnium undulatum (Hedw.) T.J.Kop.	1	1	1	2
Plagiothecium spp.	0	0	8	0
Eurhynchium angustirete T.Koponen	8	1	13	3
Oxyrrhynchium hians (Hedw.) Loeske	16	3	7	0
Fissidens taxifolius Hedw.	1	0	2	1
Funaria hygrometrica Hedw.	14	2	0	0
Hylocomium splendens (Hedw.) Schimp.	5	5	17	16
Marchantia polymoropha L.	4	26	0	2
Pleurozium schreberi (Willd. ex Brid.) Mitt.	9	4	22	17
Pohlia nutans (Hedw.) Lindb.	0	1	0	0
Polytrichum commune Hedw.	0	2	0	3
Polytrichum juniperinum Hedw.	0	2	14	0
Ptilium crista-castrensis (Hedw.) De Not.	1	0	0	0
Sphagnum angustifolium (Russow) C.E.O.Jensen	0	0	3	1
Sphagnum girgensonii Russow	0	0	0	3
Sphagnum squarrosum Crome	0	0	11	7
Thuidium tamariscinum (Hedw.) Bruch, Schimp. & W.Guembel	0	0	2	0
Rhodobryum roseum (Hedw.) Limpr.	2	0	8	0
Rhytidiadelphus squarrosus (Hedw.) Warnst.	0	1	2	2
Rhytidiadelphus triquetrus (Hedw.) Ochyra &	5	4	14	13

Appendix 2. Mean values of Ellenberg light and nitrogen for the studied objects. Similar letters indicate a lack of significant differences at α=0.05.

	Light				Nitrogen			
Objects	Mean	lower.CL	upper.CL	Group	Mean	lower.CL	upper.CL	Group
Managed (A)	5.73	5.51	5.94	a	4.11	3.96	4.25	a
Managed (B)	5.86	5.65	6.07	a	4.40	4.26	4.54	b
Unmanaged (C)	4.83	4.61	5.04	b	4.36	4.22	4.51	ab
Unmanaged (D)	5.16	4.95	5.37	b	4.36	4.22	4.51	ab