Natural disturbance impacts on trade-offs and co-benefits of forest biodiversity and carbon

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Electronic Supplementary Material
**Supplementary methods**

*Biodiversity potential index construction*

Biodiversity index construction followed the rules of McElhinny et al. (2005). We selected a comprehensive set of five basic structural attributes (living trees dimensional diversity highlighting old and large diameter trees, standing deadwood and its dimensional and decay diversity, lying deadwood and its dimensional and decay diversity, diversity of understory vegetation, understory light availability and its variability), which were demonstrated as strong predictors of some element of biodiversity by several studies (Gao et al. 2015). Biodiversity index was calculated on the basis of the sum (for cumulative index) of the individual basic attributes (Fig. S 1). Cumulative biodiversity index assumes that each biodiversity attribute can partially compensate for each other. Values of the basic attributes were determined by the sum of the basic components. All five basic attributes and all components were scaled below 1 (divided by max) to achieve the same weight for all attributes. All five attributes therefore have the same weight in the summary index. 20% of the weight is formed by standing dead trees (wood volume and diversity). This structural aspect represents, for example, species-rich groups of saproxylic beetles (Jonsell & Weslien 2003). A further 20% is formed by the lying logs representing saproxylic fungi (Pouska et al., 2011). A third 20% is formed by thick and old trees are typically associated with lichens and mosses (Zemanová et al., 2017). Another 20% represents direct diversity of understory vascular plants (Halpern & Spies 1995). And finally, the last fifth is formed by light demanding species representing e.g. true bugs (Muller et al., 2008). The commonly used attribute of tree species diversity was not used because the research was done in naturally monospecific forests. The availability and variability of light in the understorey was analysed using the WinSCANOPY software (Regent Instruments) using the ‘openness’ variable. The
mean and standard deviation were calculated and used as response variables to detect mean and variability of light distribution in understory within plot.

**Figure S1.** Structure-based biodiversity index construction. Primary values of components and attributes were scaled to a maximum of 1 to achieve that all the components and attributes have the same weight in the attributes and final indexes.

**Fig. S2.** Stands with low biodiversity potential (left) and high biodiversity potential (right).
Testing the index of biodiversity potential

In order to test the biodiversity potential index, we selected 58 plots in 10 primary forest stands and collected data on lichens and wood-inhabiting fungi. In the above mentioned 10 stands, 145 plots were established as a part of an international primary forest research project (www remoteforests org), using a stratified-random design (Svoboda et al. 2014). Dendrochronological disturbance history data were previously published in Janda et al. (2017).

For lichens and wood-inhabiting fungi sampling, we selected 58 plots (six plots per stand with the exception of one stand in the Tatra Mts. containing only four plots). In each stand, study plots were selected to cover the whole gradient of disturbance severities and timing over the last 250 years. For this purpose, we split plots from Janda et al. (2017) according to disturbance event timing into three equally large classes. We then selected two plots within each class on every stand, with differing severity if available. At the same time, we avoided locating any additional plots within 150 m around a given plot. Average distance among plots within the stands was 1.2 km.

Wood-inhabiting fungi: The occurrence of wood-inhabiting fungi (sporocarps) was surveyed in a time per effort standardised way: for 1.25 hours, two mycologists recorded sporocarps of all macrofungi (i.e., ascomycetes and basidiomycetes) on all available types of wood objects (standing/lying trunks or trunk parts, branches, twigs) in all available decay stages in a plot; the smallest wood piece sampled was 2 cm. Each piece of wood was considered a separate object. A dominant object type was sampled for approximately half of the time, and all other types are included in a balanced way.

Lichens: On each plot, relative abundance of all epiphytic and epixylic lichens on selected objects were recorded by an experienced lichenologist up to a height of 2 m. We selected up to nine objects stratified by tree species and substrate type (living tree, standing dead tree, snags of different decay stages, logs of different decay stages). We selected only one object per tree
species and substrate type, or three similar objects if the plot contained only homogeneous substrates. Lichens growing on the ground, rocks, or fallen twigs were not recorded. Each plot was visited once between August and October.

Collected data are available in our published database (Mikoláš et al. 2021).

References:

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Forrester DI *et al*. 2017 Generalized biomass and leaf area allometric equations for European tree species incorporating stand structure, tree age and climate. *For. Ecol. Manag.* **396**, 160–175. (doi: 10.1016/j.foreco.2017.04.011)
Table S1. Allometric equations used to calculate aboveground C stocks in tree biomass using species-specific equations [Forrester et al. 2017]. Aboveground live tree biomass = branch mass + foliage mass + stem mass.

| Species                | Branch mass (kg)          |
|------------------------|---------------------------|
| *Pinus cembra*         | $\exp(-3.6641 + 2.1601 \ln(dbh\_cm \times 0.1))$ |
| *Pinus sylvestris*     | $\exp(-3.6641 + 2.1601 \ln(dbh\_cm \times 0.1))$ |
| *Populus tremula*      | $\exp(-3.7241 + 2.4069 \ln(dbh\_cm \times 0.1))$ |
| *Larix decidua*        | $\exp(-3.2409 + 2.1412 \ln(dbh\_cm \times 0.1))$ |
| *Picea abies*          | $\exp(-3.3163 + 2.1983 \ln(dbh\_cm \times 0.1))$ |
| *Ulmus glabra*         | $\exp(-3.7241 + 2.4069 \ln(dbh\_cm \times 0.1))$ |
| *Sorbus aucuparia*     | $\exp(-3.7241 + 2.4069 \ln(dbh\_cm \times 0.1))$ |
| *Abies alba*           | $\exp(-3.3163 + 2.1983 \ln(dbh\_cm \times 0.1))$ |
| *Acer pseudoplatanus*  | $\exp(-3.7241 + 2.4069 \ln(dbh\_cm \times 0.1))$ |
| *Betula sp.*           | $\exp(-3.7241 + 2.4069 \ln(dbh\_cm \times 0.1))$ |
| *Fagus sylvatica*      | $\exp(-3.7694 + 2.8003 \ln(dbh\_cm \times 0.1) + (-0.0247 \times ba\_m^2ha^{-1}))$ |
| *Salix sp.*            | $\exp(-3.7241 + 2.4069 \ln(dbh\_cm \times 0.1))$ |
| *Corylus avellana*     | $\exp(-3.7241 + 2.4069 \ln(dbh\_cm \times 0.1))$ |
| *Alnus viridis*        | $\exp(-3.7241 + 2.4069 \ln(dbh\_cm \times 0.1))$ |

| Species                | Foliage_mass (kg)          |
|------------------------|----------------------------|
| *Pinus cembra*         | $\exp(-2.4122 + 1.8683 \ln(dbh\_cm \times 0.1) + (-0.0537 \times ba\_m^2ha^{-1}))$ |
| *Pinus sylvestris*     | $\exp(-2.4122 + 1.8683 \ln(dbh\_cm \times 0.1) + (-0.0537 \times ba\_m^2ha^{-1}))$ |
| *Populus tremula*      | $\exp(-4.2286 + 1.8625 \ln(dbh\_cm \times 0.1))$ |
| *Larix decidua*        | $\exp(-3.8849 + 1.7502 \ln(dbh\_cm \times 0.1))$ |
| *Picea abies*          | $\exp(-2.1305 + 2.0087 \ln(dbh\_cm \times 0.1) + (-0.0324 \times ba\_m^2ha^{-1}))$ |
| *Ulmus glabra*         | $\exp(-4.2286 + 1.8625 \ln(dbh\_cm \times 0.1))$ |
| *Sorbus aucuparia*     | $\exp(-4.2286 + 1.8625 \ln(dbh\_cm \times 0.1))$ |
| *Abies alba*           | $\exp(-2.1305 + 2.0087 \ln(dbh\_cm \times 0.1) + (-0.0324 \times ba\_m^2ha^{-1}))$ |
| *Acer pseudoplatanus*  | $\exp(-4.0625 + 2.0662 \ln(dbh\_cm \times 0.1))$ |
| *Betula sp.*           | $\exp(-4.2286 + 1.8625 \ln(dbh\_cm \times 0.1))$ |
| *Fagus sylvatica*      | $\exp(-4.4813 + 1.9073 \ln(dbh\_cm \times 0.1))$ |
| *Salix sp.*            | $\exp(-4.2286 + 1.8625 \ln(dbh\_cm \times 0.1))$ |
| *Corylus avellana*     | $\exp(-4.2286 + 1.8625 \ln(dbh\_cm \times 0.1))$ |
| *Alnus viridis*        | $\exp(-4.2286 + 1.8625 \ln(dbh\_cm \times 0.1))$ |

| Species                | Stem_mass (kg)             |
|------------------------|----------------------------|
| *Pinus cembra*         | $\exp(-2.3583 + 2.308 \ln(dbh\_cm \times 0.1))$ |
| *Pinus sylvestris*     | $\exp(-2.3583 + 2.308 \ln(dbh\_cm \times 0.1))$ |
| *Populus tremula*      | $\exp(-2.4521 + 2.4115 \ln(dbh\_cm \times 0.1))$ |
| *Larix decidua*        | $\exp(-2.4105 + 2.424 \ln(dbh\_cm \times 0.1))$ |
| *Picea abies*          | $\exp(-2.5027 + 2.3404 \ln(dbh\_cm \times 0.1))$ |
| *Ulmus glabra*         | $\exp(-2.4521 + 2.4115 \ln(dbh\_cm \times 0.1))$ |
| *Sorbus aucuparia*     | $\exp(-2.4521 + 2.4115 \ln(dbh\_cm \times 0.1))$ |
| *Abies alba*           | $\exp(-3.2683 + 2.5768 \ln(dbh\_cm \times 0.1))$ |
| *Acer pseudoplatanus*  | $\exp(-2.4521 + 2.4115 \ln(dbh\_cm \times 0.1))$ |
| Species                  | Formula                                                                 |
|-------------------------|-------------------------------------------------------------------------|
| *Betula sp.*            | $\exp(-2.4521 + 2.4115 \times \ln(\text{dbh}_{cm} \times 0.1))$         |
| *Fagus sylvatica*       | $\exp(-1.4487 + 2.1661 \times \ln(\text{dbh}_{cm} \times 0.1))$         |
| *Salix sp.*             | $\exp(-2.4521 + 2.4115 \times \ln(\text{dbh}_{cm} \times 0.1))$         |
| *Corylus avellana*      | $\exp(-2.4521 + 2.4115 \times \ln(\text{dbh}_{cm} \times 0.1))$         |
| *Alnus viridis*         | $\exp(-2.4521 + 2.4115 \times \ln(\text{dbh}_{cm} \times 0.1))$         |
Fig. S3 Contour plots showing expected probability of capercaillie occurrence as well as carbon stock, carbon sequestration and biodiversity potential based on GAMMs with maximum disturbance severity and time since that event as predictors. The blue plus signs assign stand-specific conditions with highest expected response (predictions involving random effect variation).
Fig. S4 Relationships between carbon stock, biodiversity potential (left) and probability of capercaillie occurrence (right). GAMM-based estimates (lines) are shown along with 95% confidence intervals (grey bands) and observed values (dots). Statistical details of displayed models are as follows: edf = 0.85, F = 3.7, p = 0.0104 (left), edf < 0.01, $\chi^2 < 0.1$, p = 0.563 (right).