Supporting Information

Tree height predicted tree death during a bark beetle outbreak better than distances to disturbances in a small catchment

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Regarding the references, please note that the numbering refers to the references list in the main manuscript, in accordance to the “Instructions to authors” (https://www.mdpi.com/journal/forests/instructions#coverletter): “Citations and References in Supplementary files are permitted provided that they also appear in the main text and in the reference list.” Since the references S1 and S2 cited here were not included in the main text, we added them at the end of this document.

Part A: Tree heights and tree deaths

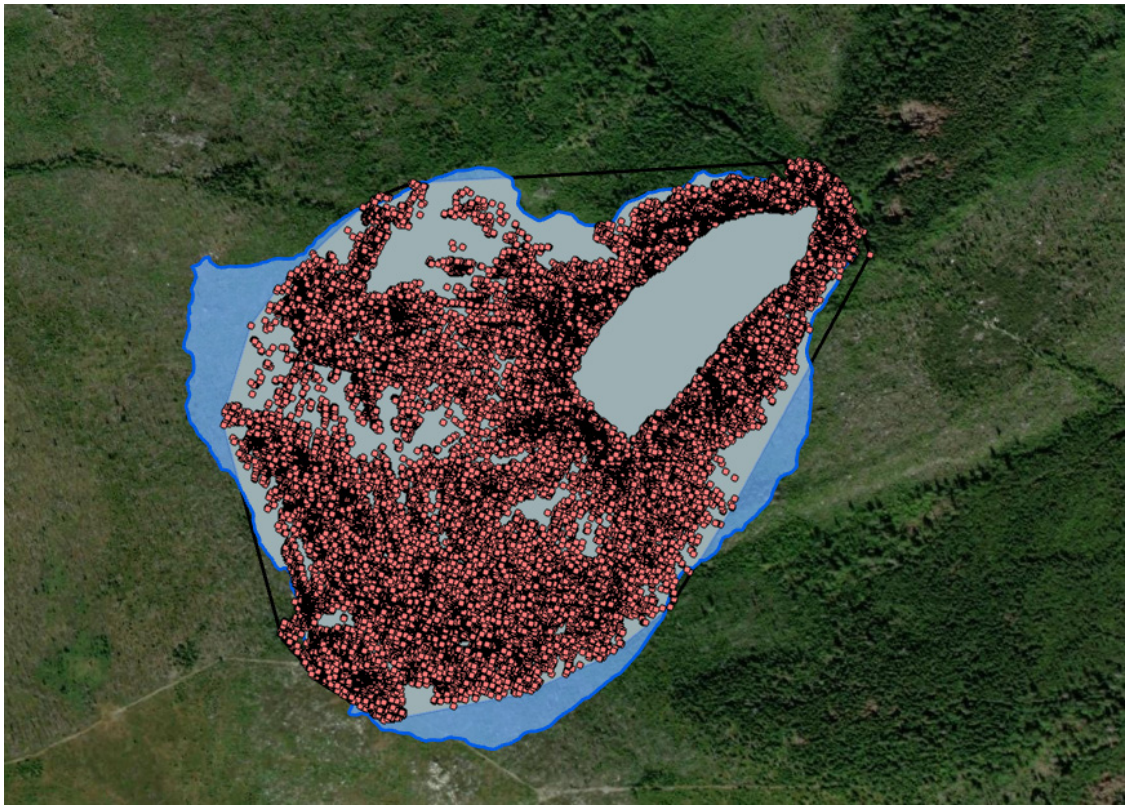


Figure S1: Terrain elevation derived from the two LiDAR campaigns (red dots) within the basin (darker blue). Encircling the LiDAR data with a minimum convex polygon (light blue), and relating this polygon to the catchment area yields that the coverage was about 90.1% of the catchment area.

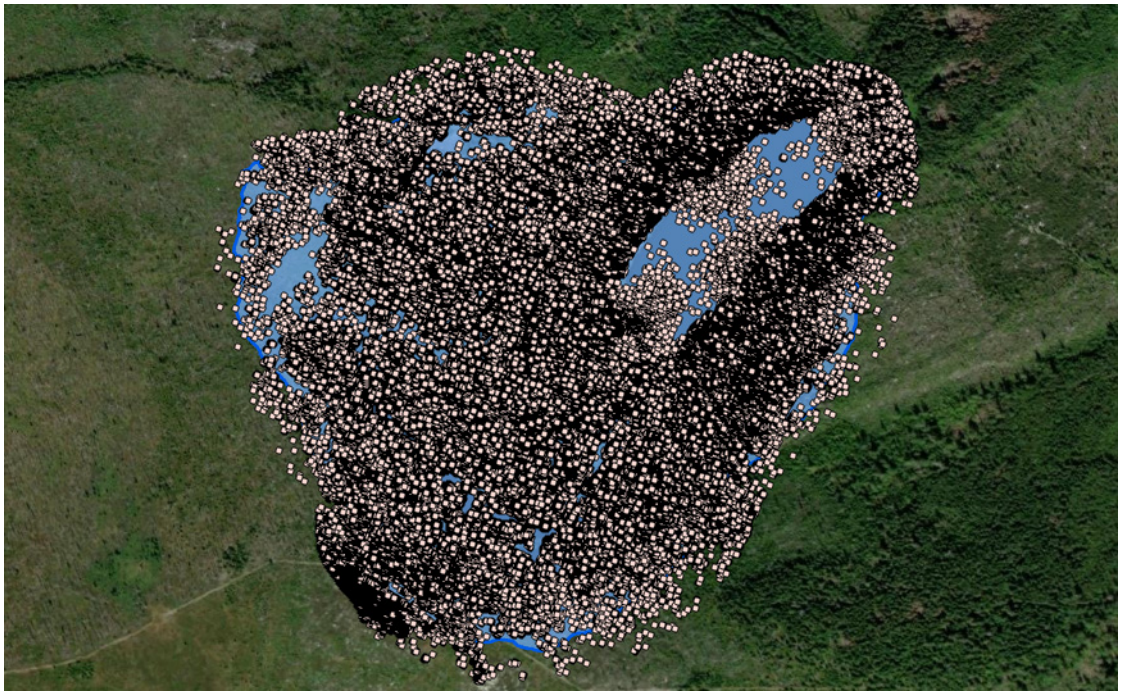


Figure S2: Tree height derived from the two LiDAR campaigns (white dots) within the basin (blue). The original source points for vegetation (defined as a reflection other than ground) cover a larger area than the terrain elevation (Figure S1), and they cover almost the whole basin area.

Table S1: Number of trees per category present in the basin in the observed time segments according to their health and height conditions. Reproduced with the authors' permission from Table 1 [20].

Category/Year	2000	2003	2005	2007	2008	2009	2010	2011	2013	2015
Adult healthy	16148	14841	11025	6089	4851	2513	2383	2133	2103	2065
Adult dead	1178	2436	5600	8724	8793	9890	8732	7293	3863	1688
Young healthy	3227	3217	3129	2952	2845	2722	2766	3698	4375	5596
Young dead	14	24	109	262	314	441	385	437	352	141
Stump	13	62	717	2560	3786	5050	6413	8151	11699	14198
Sapling	774	1180	2631	3596	4282	4938	6981	9275	18237	37646
Total (without saplings)	20580	20580	20580	20587	20589	20616	20679	21712	22392	23688
Total	21354	21760	23211	24183	24871	25554	27660	30987	40629	61334

Table S2: Number of trees that had been classified as "dead" (either "dead standing", "dead lying", or "stump"; compare Table 1) for the first time in a year.

2000	2003	2005	2008	2009	2010	2011	2013	2015	alive at the end of the observations
1241	1370	3886	1386	2658	158	369	34	0	47838

Table S3: Since the number of dead trees given for a year in Table S2 refer to irregular time spans, here, the yearly rate was estimated by dividing the number of dead trees per period by the number of years this period lasted, starting with 2003 because the deaths having been observed in the year 2000 are cumulative.

2003	2005	2007	2008	2009	2010	2011	2013	2015
456	1943	2618	1386	2658	158	369	17	0

Part B.1: Derivation of the tree data bases

Further to the short explanation of this part of the method section in the main paper, we provide the full methodology here.

Tree heights were extracted from LiDAR data for all trees (except for saplings) using the method of local maxima for height estimation. The terrestrial LiDAR surface data were taken in 2010 and 2011 by GEOREAL spol. s r.o.. In 2010, the data were taken from the lake dam and in 2011, from the trail leading to the ridge. The range of the data is shown in Figures S1 and S2 in the Supplementary Information. The LiDAR appraisal was carried out with an imaging density of 2 points per meter, pixel size 20 cm, with the pixel value corresponding to the local maximum of the points within a given pixel. The final DEM thus had a spatial resolution of 0.2 m. We considered the difference in tree height between the two years negligible. The main steps of the procedure are show in Figure 2.

Visual correction of the calculated DEM was performed by using digital aerial images from Argus GeoSystem Ltd. (Hradec Králové, Czech Republic) on the scale of 1:7000 and with the same spatial resolution of 0.2 m. Tree heights were derived from the first return of the LiDAR point as an elevation (height) for the top of a tree. An automatic separation of the individual tree and an automatic attribution of the respective height were not achieved due to gaps in the LiDAR data. Therefore, circular crown projections were manually derived for each individual surviving tree from the local maximum raster (see below for more details). LiDAR data were combined with a visual interpretation of the aerial images to allow the highest accuracy of individual tree delineation.

In detail, centroids of the crown projections were converted to a point layer (layer “tree height”) with local maximum height values [44]. Trees from the LiDAR layer “tree height” were matched to the closest trees in the layer “tree stand” (see above) and the height from LiDAR was added to each tree point in the “tree stand” layer. This resulted in 11,711 tree heights matched. This approach thus used the transition parameter crown projection to find the corresponding points from the tree layer (i.e. orthophoto digitization) and from the elevation layer (derived from LiDAR). Healthy young and dead young tree which were between 7 and 25 m were used to derive two raster layers of interpolated tree height, one raster layer for young (2,419 individuals), and one raster layer for adult (9,292 individuals) trees. For both subsets we interpolated individual natural neighbourhood rasters (adult tree raster, young tree raster) with 10 m spatial resolution and subsequently filtered to derive a mean height value per hectare.

Height values for all trees which had not been assigned a height from the layer “tree height” due to gaps in LiDAR data, were derived from an interpolated pixel value from these newly created rasters (high trees and stumps from the adult tree raster, young trees from the young tree raster). These interpolated rasters were derived from all trees within a given category with already assigned tree height („tree heights interpolated raster“).

Trees were further distinguished into deciduous or coniferous trees, based on the crown appearance in the aerial image. For saplings, this distinction could not be made.

The resulting geodatabase was used for further calculations, except for trees in class 0 because they were saplings in later years only, and these otherwise empty locations were deemed unimportant for survival of small and tall trees. The sum of newly dead trees in each aerial image is noted in Table S1 and S2.

Six sub-catchments were geostatistically calculated in the Plešné catchment and were considered to be potential predictors on the stand scale (see Table 2 in the main paper).

We first subset the complete data base to the respective time period datasets up until the year named (i.e. data set 2000 comprised trees present in 2000 to represent the period until and including 2000; data set 2003 comprised trees present in 2001-2003 etc.). In other words, for each such period, we excluded trees of category 0 (Table 1), which would only appear in later years (i.e. future sapling), and we excluded for each year those trees that were already marked dead for previous years in the "Death" column, because we wanted to predict the death in a particular year (or period), and not whether a tree had died already many years ago. This resulted in datasets of 14,214 trees for the year 2011, when the most old trees were already dead but not much regrowth had happened yet, up to 47,838 trees, mainly saplings, in 2015 ([20]; Table S1).

For the raster cells in the stand scale, we chose cell sizes of 50 and 100 m. Kernel densities were then calculated separately for healthy trees, combining healthy tall and healthy small trees from the Fluksová et al. [20] data base. The respective column names in the "tree stand" shapefile geodatabase contain the cell size (e.g. 30 for 30 meters), followed by two digits for the year (e.g. 07 for 2007). This column name is preceded by "h_" for healthy trees, and "d_" for dead trees. Here, "dead trees" comprised "dead tall" and "dead small" trees from the Fluksová et al. [20] data base. The letter "f_" at the first position of this column name indicated newly dead, i.e. dead for the first time in the respective year.

For each tree of the Fluksová et al. [20] data base, we calculated the smallest distance to the nearest polygon of damage in the respective year, using the command st_distance() from the R package sf [48,49], assuming that each polygon included not only fresh disturbances, but also legacy disturbances for the respective year. The respective columns in the "tree stand" shapefile geodatabase are called "d_ls_" year, and are only available from the year 2006 onwards.

Part B.2: Methods: FII, cFII, and delineating period of damage

The cFII index was based on the FII (Forest infrared index) of the Forest Management Institute of the Ministry of Agriculture of the Czech Republic (Ústav pro hospodářskou úpravu lesů, UHUL; http://geoportal.uhul.cz/mapy/mapyzsl.html). The FII was constructed using radiance and reflectance of infrared light of Landsat-6, -7, and -8 multispectral satellite scenes (with high spatial resolution of 30 × 30 m), retrieved for August of the respective years. The FII was calculated by normalizing the ratio of forest reflectance in the infrared bands of the SWIR (short wave infrared) and NIR (near-infrared) spectra (available at http://geoportal.uhul.cz/mapy/MapyZsl_Info.html). The reflectance of the forest stand in the near infrared band of NIR radiation contains information about the state of the cell assimilation apparatus. The reflectance of the forest stand in the middle infrared band of SWIR radiation contains information about the water content in the assimilation apparatus. Note that the FII is most reliable for trees older than 20 years and with a density of over 70% area covered by canopies. In other cases, the raster cell is classified as not being covered by forest. When recognizing clouds, fog or smog, the evaluation is not performed [S1]. The FII at the catchment scale (cFII) was calculated by averaging the weighted factors of forest damage

in the catchment area and its linear normalization in the range from 0 (no disturbance) to 1 (complete damage, i.e. tree death). This classification is in line with Šumava National Park rangers having reported (pers. comm.) that the bark beetle attack had started in 2004 in the northwest. Likely the Trojmezná area northwest of Plešné which was reportedly badly affected [S2], was the source.

The categories of the cFII are not directly comparable to the categories in the database used here. Saplings and trees smaller than 30 m will be missed by the FII. Based on the cFII [45] in connection with the tree counts from [20] we divided the observed time span into three phases (Figure S3).

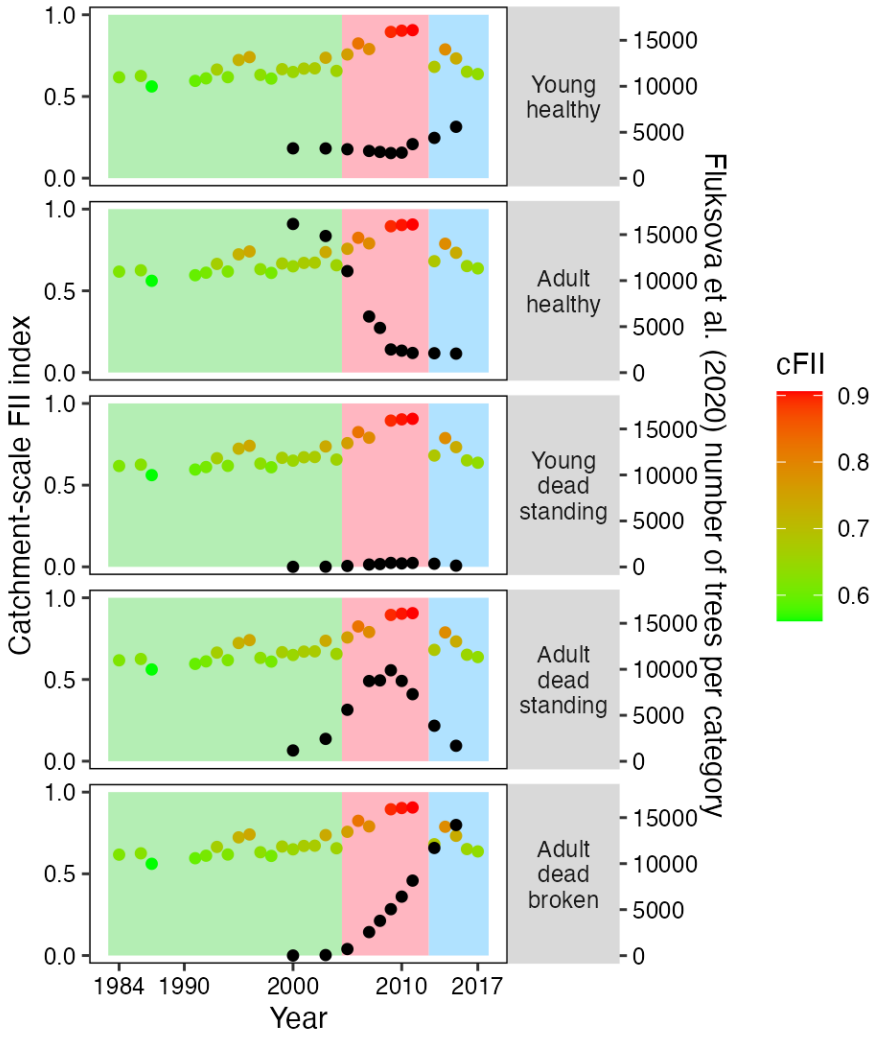


Figure S3: Catchment scale Forest Infrared index of damage, cFII ([45]; coloured dots; repeated in each line), in connection with the different tree counts from the Fluksová data base (black dots). Based on these two measures, we divided the observed time span into a pre-damage phase (green shadow), a damage phase (red shadow), and recovery phase (blue shadow).

The Moran's I statistic shows (Table S4) highly significant ($p < 0.05$) spatial autocorrelation ("Observed" larger than "expected" means positive autocorrelation) in each tree category, in both the reference and the impact phases.

Table S4: Moran's I spatial pattern test on the distribution of tall dead trees (upper half) and small dead trees (lower half) versus all other tree types.

			Moran's I			
End point	**Phase**	**Year**	**Observed**	**Expected**	**sd**	**p**
Tall dead or not	Reference phase	2000	0.013	-6.12E-05	0.000	0
		2003	0.031	-6.12E-05	0.000	0
	Impact phase	2005	0.100	-6.12E-05	0.000	0
		2007	0.067	-6.12E-05	0.000	0
		2008	0.069	-6.12E-05	0.000	0
		2009	0.100	-6.12E-05	0.000	0
		2010	0.098	-6.12E-05	0.000	0
		2011	0.091	-6.12E-05	0.000	0
	Post-impact phase	2013	0.072	-6.12E-05	0.000	0
		2015	0.050	-6.12E-05	0.000	0
Small dead or not	Reference phase	2000	0.002	-6.12E-05	0.000	0
		2003	0.003	-6.12E-05	0.000	0
	Impact phase	2005	0.013	-6.12E-05	0.000	0
		2007	0.023	-6.12E-05	0.000	0
		2008	0.020	-6.12E-05	0.000	0
		2009	0.019	-6.12E-05	0.000	0
		2010	0.016	-6.12E-05	0.000	0
		2011	0.016	-6.12E-05	0.000	0
	Post-impact phase	2013	0.017	-6.12E-05	0.000	0
		2015	0.013	-6.12E-05	0.000	0

Part B.3: Methods: Overview over the Fluksová et al. tree data base [20] together with the Czech forest state geodatabase and the Senf et al. (2021) [46,47] raster data on forest state

Complementing the Czech database with just the Senf's data for the missing areas is not directly possible because the Senf's data are in raster format and the Czech data are in shapes and thus, on a different resolution – a transformation from one format to the other would have been possible but would not have been directly comparable. The European forest damage map [46,47] is given on a spatial grain of 30 m. Each raster cell contains a year of (first) damage, on a continuous scale. Since a damaged tree might only become a home for bark beetle with a delay of a couple of years, we combined in the following step the damages of the previous 5 years of this raster. And we used only those years for which there was tree counting in [20]. E.g. trees were counted for the 2003 and 2005 aerial image [20]. Therefore, we combined the yearly damages from the Senf's database [46,47] from the years 2004 and 2005 to obtain this damage in 2005, and related this image to the 2005 counts in [20]. We used this summed damage to calculate the central points of each damage raster cell.

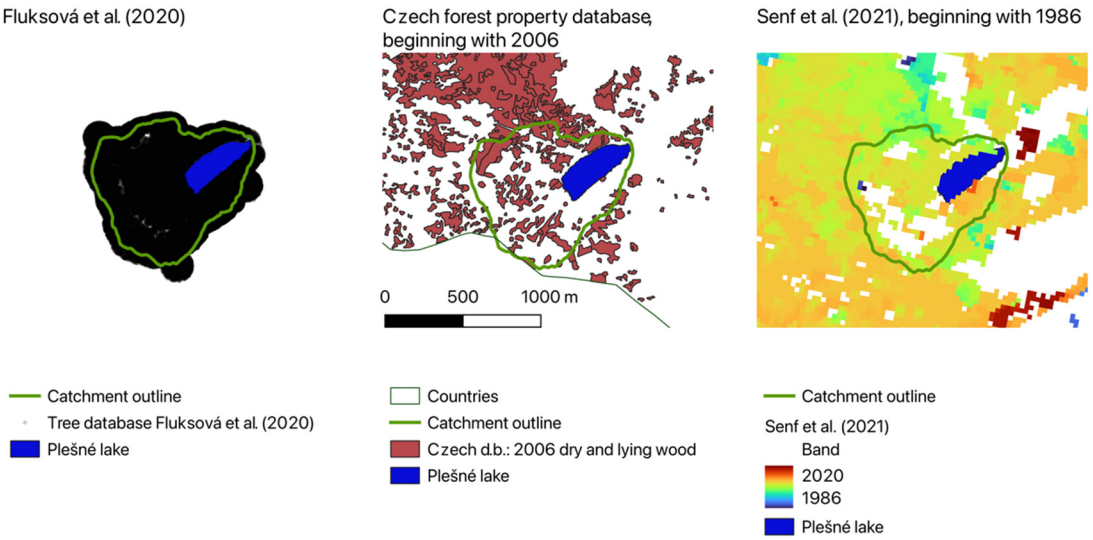


Figure S4: Overview over the [20] tree data base together with the Czech forest state geodatabase (Šumava National Park administration, pers. comm.) and the [46,47] raster data on forest state.

The distances from trees to damages mostly showed a similar trend with the two damage data sets, but varied widely in the years 2010, 2014, and 2015, with sometimes the Czech geodatabase showing the smaller distances to damage, sometimes the Senf & Seidl [46,47] data base (Figure S5). The distance to damage already decreased markedly in the year 2005, i.e. two years prior to the storm Kyrill which was known to produce many windthrows. According to the Senf & Seidl [46,47] data base, the distance to the closest disturbance was only in the year 2015 slightly higher than before the known damages, in the years 2000 and 2005, while the Czech geodatabase indicated large distances to disturbances in the year 2014, but in the year 2015, damages were as close as they were in 2011. For a subset of data covering the years when values from both data sets were available, the difference between the distances computed from the two data sets was statistically highly significant (F value = 4063, $p < 2*10^{-16}$).

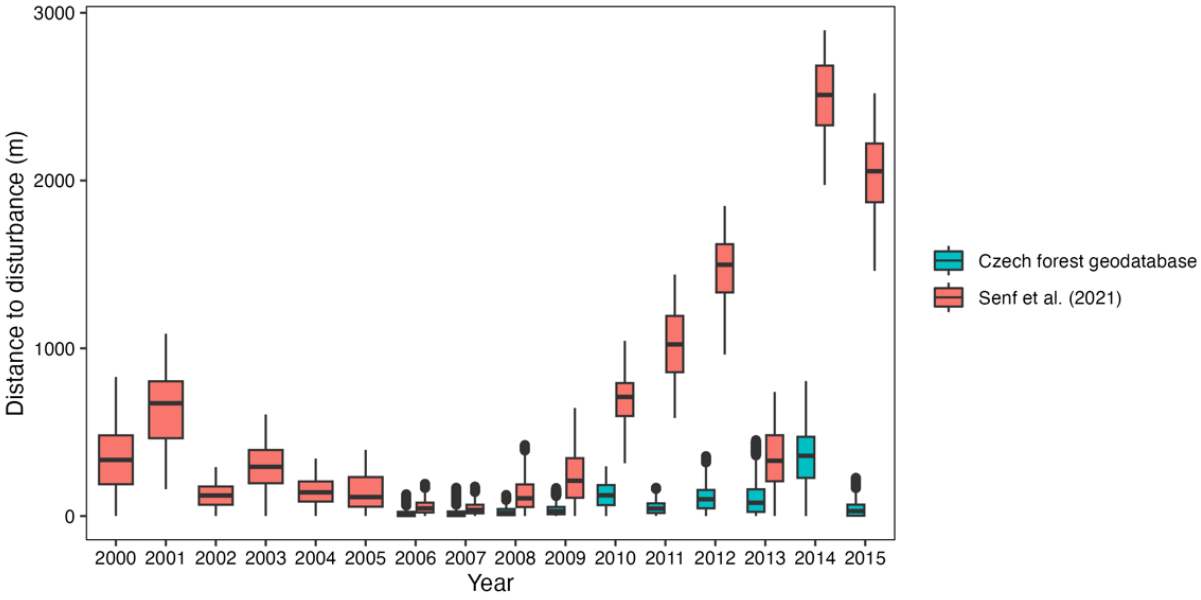


Figure S5: Boxplots of distances to disturbance per year, separated into the Czech forest state geodatabase provided by Šumava National Park administration, which was only available from the year 2006 onwards, and the Senf & Seidl [46,47] raster of damage.

Part B.4: Coniferous versus deciduous survivors in the Plešné catchment, compared with dead conifers

The surviving coniferous and deciduous trees were scattered across the catchment. Only in the northwest and south catchment borders, as well as south of the lake there were no trees surviving in 2015. Trees survived predominantly along the former iron curtain and southwest of the lake.

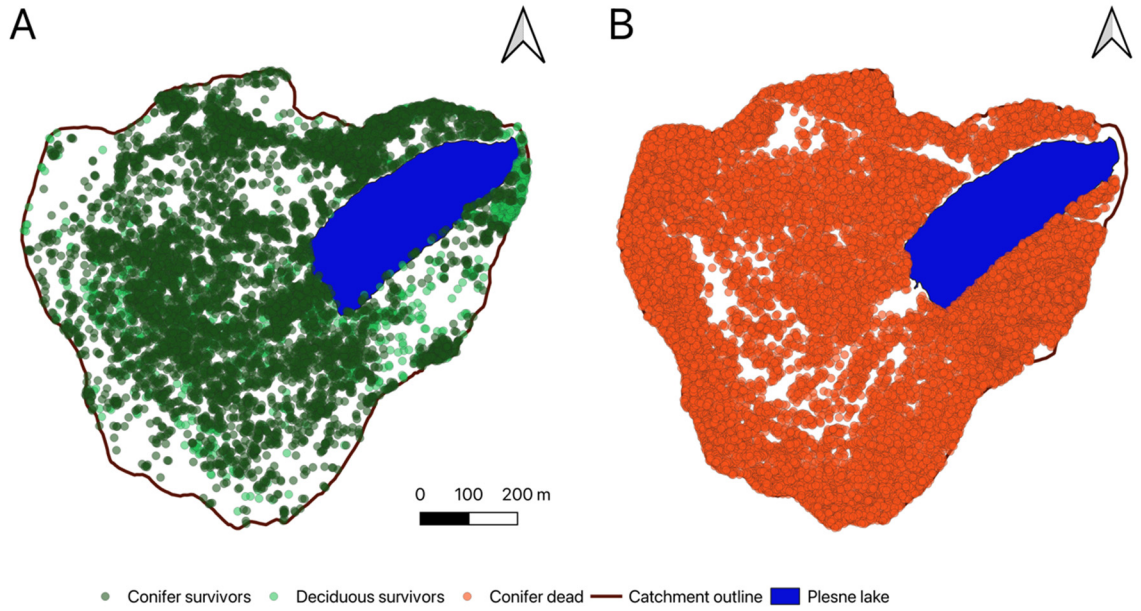


Figure S6: Coniferous versus deciduous survivors in 2015 in the Plešné catchment (left), compared with the dead conifers (right). Krovak projection EPSG 5514.

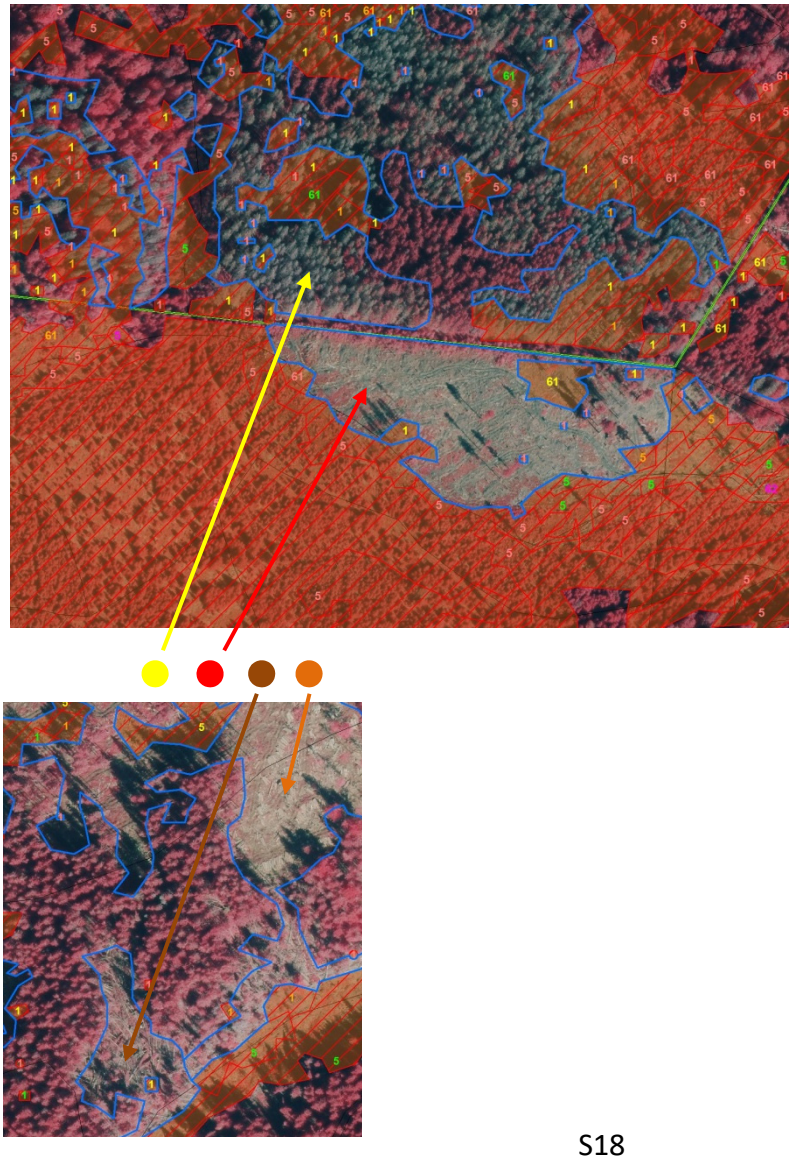
Part C: Explanation of the tree health geodatabase from the Šumava National Park administration

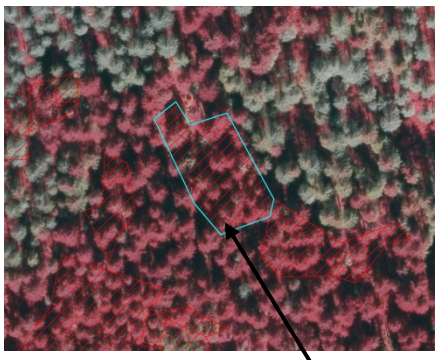
1. Vectorized layer

- Polygon layer with character attributes for individual year
- Coordinate system EPSG: 5514 (S-JTSK Krovak East-North).

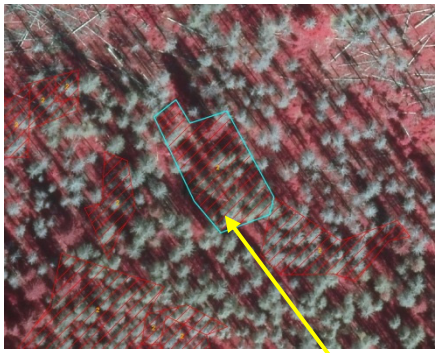
2. Sites character (attributes for polygons)

0	No change	
1	Sites with dry or drying standing trees	Forest with 91 – 100% dry (drying) trees mostly standing (more than ½ dry standing trees)
2	Sites with dry lying trees	Stand with 91 - 100% dry (drying) trees mostly lying (more than ½ dry trees are lying)
5	Sites after incidental mining	with the removal of most of the wood
61		leaving most or all of the wood mass to decay (sanitized areas)
62	breaks and upheavals not resolved	area with untreated and mechanically non-remediated wood mass





r. 2012 – healthy forest



r. 2015 – new dead tree

r. 2019 – lying dead tree

Attributes

char_yyyy (Incremental attribute)	• yyyy represents relevant year (2006 - current year) when the forest condition assessment was performed (eg char_2019 acquires values from the end of summer 2018 to the end of summer 2019, when a new aerial survey and assessment was performed). • value> 0 always corresponds to the change in the given year compared to the previous period. It does not always necessarily indicate deforestation, but only a change in the character of the area - eg one year is recorded in the field, the next year after remediation of the field is recorded eg cleared area (deforestation took place in 1 year, 2nd year state has changed). If no change has occurred each year, it is filled with the value 0. • Possible values 0, 1, 2, 5, 61, 62
char_xx_akt (Cumulative attribute)	• xx is the last two digits of the year (06 - current year) to which the current state of the area relates • The difference between the char_yyyy and char_xx_akt attributes is that char_xx_akt does not contain changes only given year. If change did not take place this year, the value is not 0, but contains the last change (eg in 07 the field is recorded, in 08 the field is rehabilitated and the mass is left, and in 2013 the whole area is cleared, then "char_21_akt" = 5). • Possible values 1, 2, 5, 61, 62
odles_xx (Incremental attribute)	• xx is the last two digits of the year (06 - current year), when forest stand was assessed • value> 0 always corresponds to the change which means new deforestation in the given year (in the previous period there was still a green forest on the area). E.g. one year is recorded windbreak,, the next year after the remediation of the field is cleared area (deforestation took place for the 1st year, the 2nd year there was only a change in the state of the deforested area and this change in the 2nd year is not recorded in this attribute) . If no change has occurred in recorder year or this change has not led to new deforestation, it is filled with the value 0. • Possible values 0, 1, 5, 61, 62
odles_jak (Cumulative attribute)	• the way deforestation has taken place (not the following changes), whatever the year • Possible values 1, 5, 61, 62
odles_kdy (Cumulative attribute)	• year in which deforestation was recorded (not the following changes) • Possible values 2006, 2007, …., recent year

Of the possible categories 0, 1, 2, 5, 61, 62, 0 was not considered because there was no change in category 0, thus no dead trees that could be a source for bark beetle. Category 5 was also not considered because those trees were removed and thus, not a source for bark beetle. Categories 1, 2, 61, 63 could be considered potential sources for bark beetle.

Over the years 2006 until 2015 which is the last year of [20], the damages are shown in Figure S7.

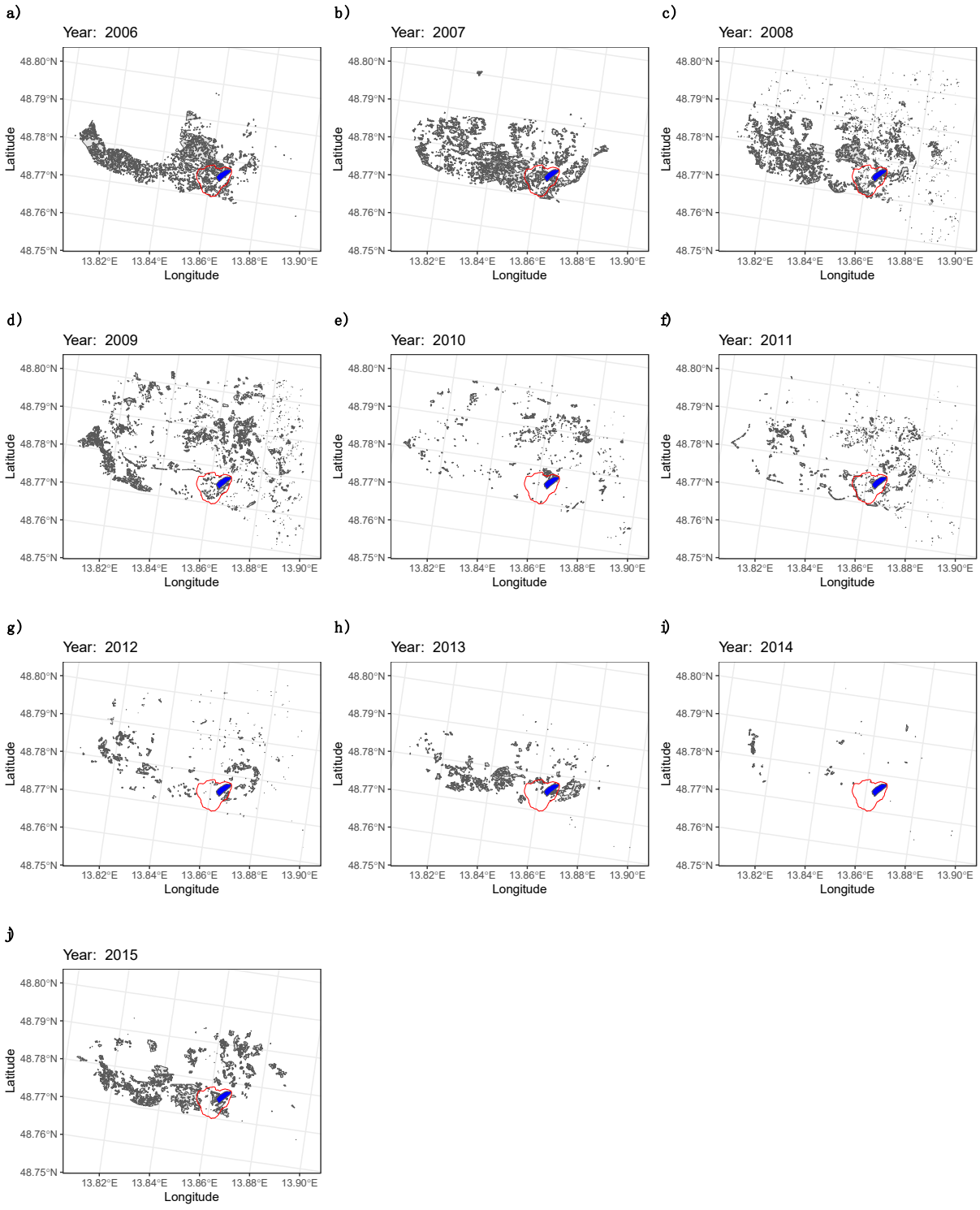


Figure S7: Damages from the geodatabase "ZjistovaniStavLesa" of the Šumava National Park administration (pers. comm.), from the years 2006 until 2015 (last year in the Fluksová database).

We compared the area of the polygons showing damage (categories 1, 2, 61, 62, see above) from the whole geodata base to those within Plešné in Figure S8.

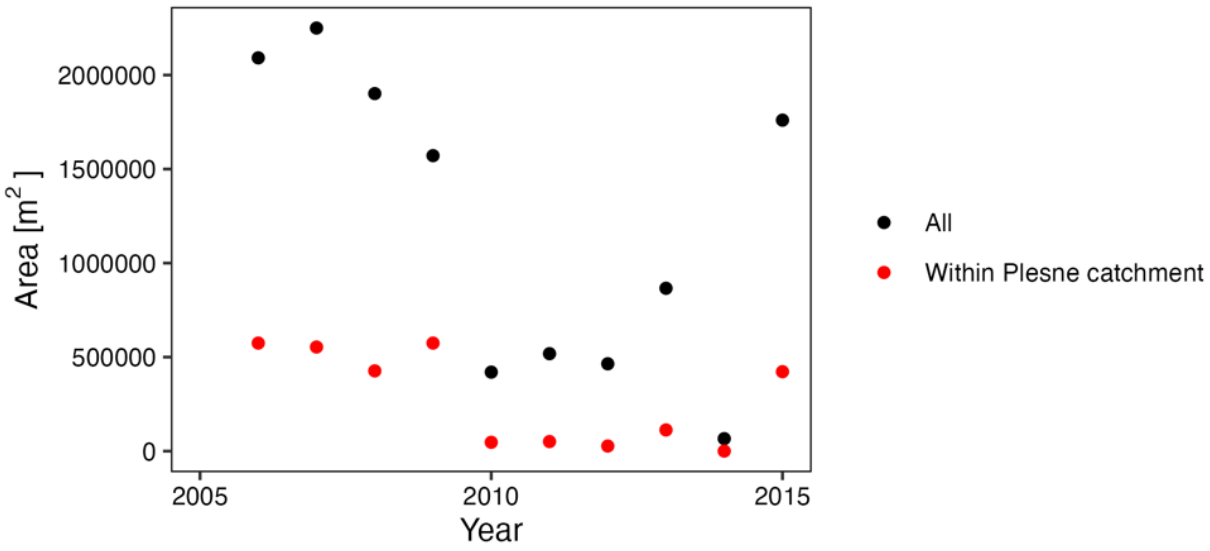


Figure S8: Area of windthrows and dead wood (categories 1, 2, 61, 62 in the whole area covered by the geodatabase "ZjistovaniStavLesa" of the Šumava National Park administration; pers. comm.)(black dots), compared to damages just within the Plešné catchment (red dots).

Distances from each coniferous dead tree to the closest disturbance was calculated as shown in Figure S9.

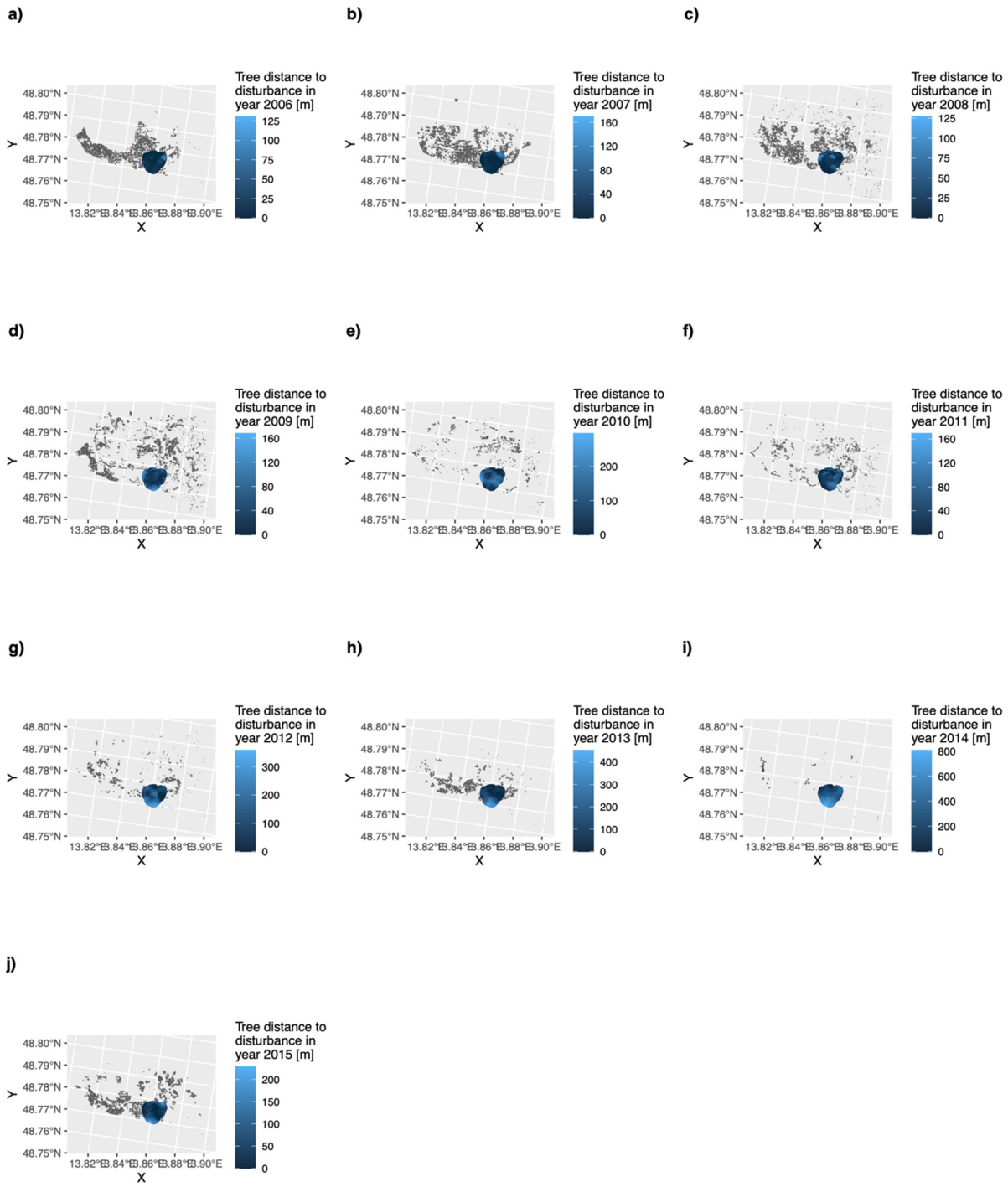


Figure S9: Distances from the yearly dead trees in the Fluksová data base to the yearly damages as outlined in Figure S7. The distances from all trees to the closest damage are indicated by increasingly light blue.

Part D: GBM of predictors for tree death in each year for which the tree data base was available

Results for the yearly variable influences from the GBM on the individual trees are shown in the SI, Figures S10 to S18. Each yearly figure includes a barplot showing the influences of the 10 most influential variables, and three scatter plots of the predicted outcome (dead or alive) along the increase of three most important variables. The variables' influence varied widely. In order to check the ca. 10 most influential variables for GAMs, we chose a cut-off of 4% influence. The variables that had at least in one year at least 4% influence, over the observation period, were "c2_3m_j" , "c2_5m_j" , "c2_10m_j"," "c2_30m_j", "c4_3m_j", , "c5_10m_j", "c5_30m_j", "plec_4g" = elevation, "Tre_hgh", "dm_2003", i.e. distance from the Send & Seidl (2021) damage, and the "X" and the "Y" coordinate. For explanations refer to Table 1. The full table is given in Table S5 (external Table; not within this file).

There is no figure for the year 2015 because no trees were recorded freshly dead in 2015 and thus, there were no predictions to be made. Where the estimated likelihood of a tree to be dead or alive was above 0, also interaction plots between the most important and the second and third most important variable were drawn. Likelihoods below 0 are statistical artefacts and a sign for the explanatory power of the variable to be low.

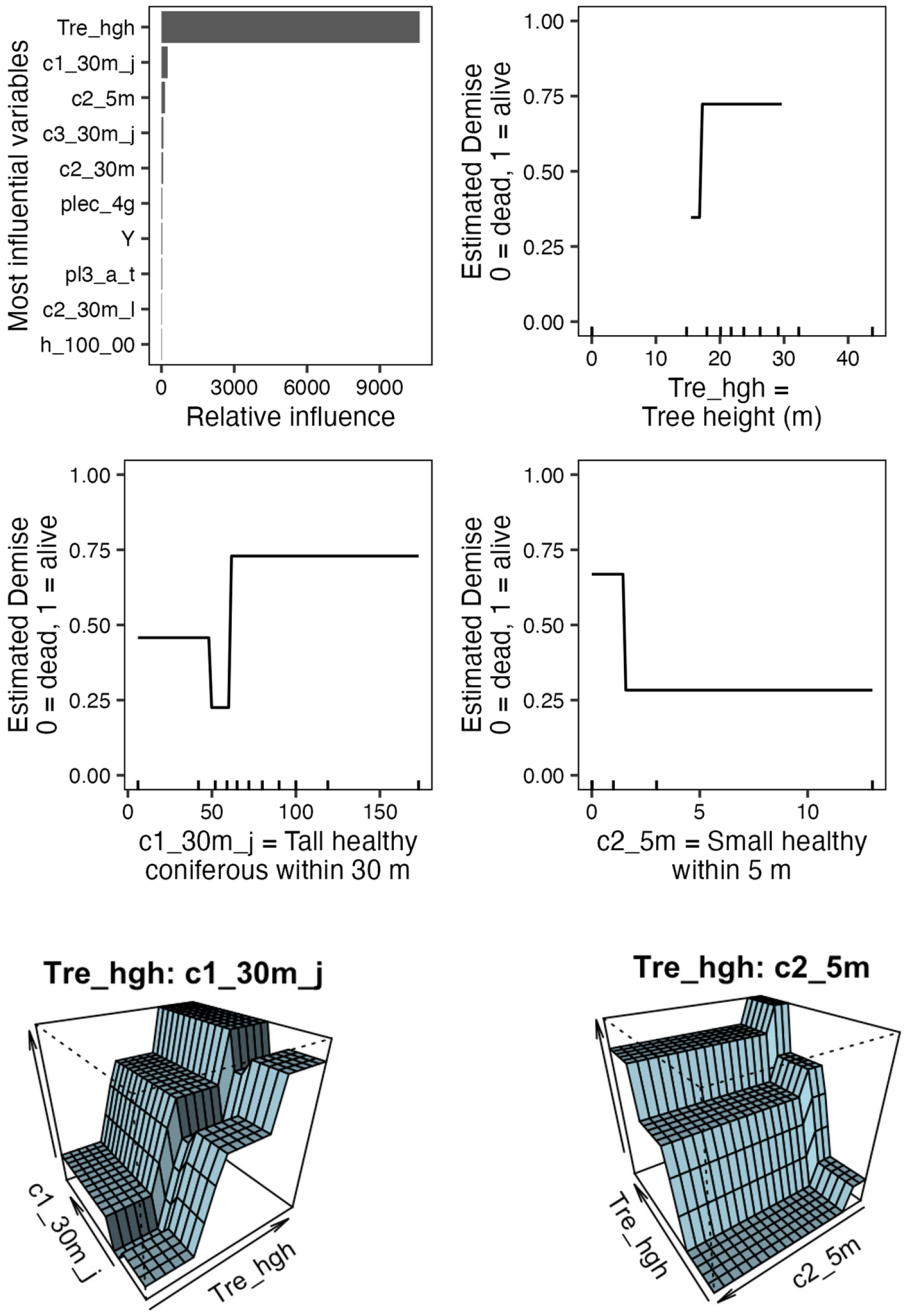


Figure S10: Most influential partial influences for the year 2000. Top left: relative influence of the ten most influential variables in decreasing order. Top right: Partial influence of Tree height which was found to the be the variable with the highest influence on the patterns (compare top left graph). Middle left: Partial influence of the variable with the second highest influence on the patterns (compare top left graph). Middle right: Partial influence of the variable with the third highest influence on the patterns (compare top left graph). For explanations of the abbreviations refer to Table 2 in the main text. For explanations of the abbreviations refer to Table 2 in the main text. Bottom left: Interaction plot between the most important variable tree height ("Tre_hgh") and the second most important variable tall healthy coniferous trees within 30 m ("c1_30m_j"). Bottom right: Interaction plot between the most important variable tree height ("Tre_hgh") and the third most important variable small healthy trees within 5 m ("c2_5m").

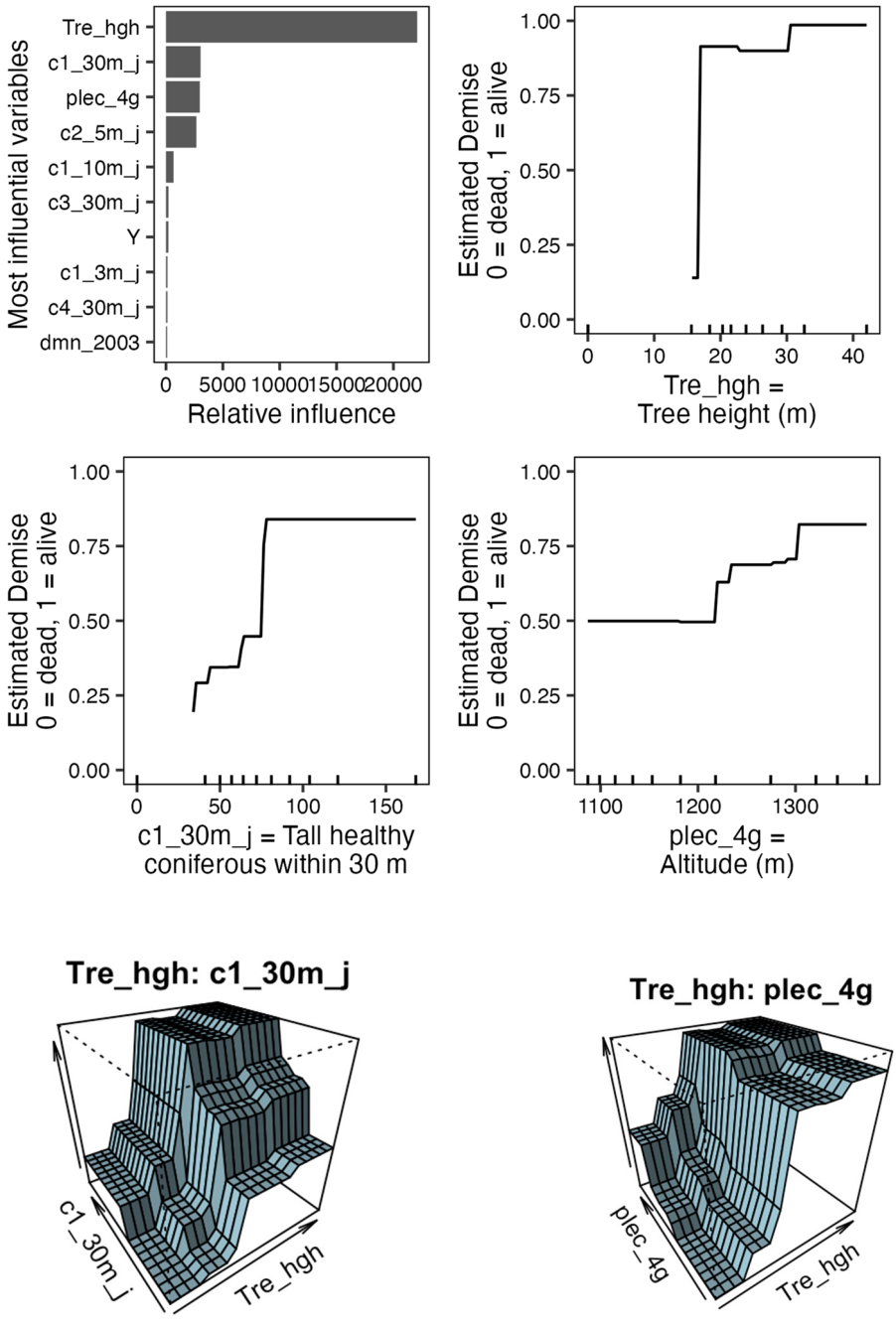


Figure S11: Most influential partial influences for the year 2003. Top left: relative influence of the ten most influential variables in decreasing order. Top right: Partial influence of Tree height which was found to the be the variable with the highest influence on the patterns (compare top left graph). Middle left: Partial influence of the variable with the second highest influence on the patterns (compare top left graph). Middle right: Partial influence of the variable with the third highest influence on the patterns (compare top left graph). For explanations of the abbreviations refer to Table 2 in the main text. Bottom left: Interaction plot between the most important variable tree height ("Tre_hgh") and the second most important variable tall healthy coniferous trees within 30 m ("c1_30m_j"). Bottom right: Interaction plot between the most important variable tree height ("Tre_hgh") and the third most important variable altitude ("plec_4g").

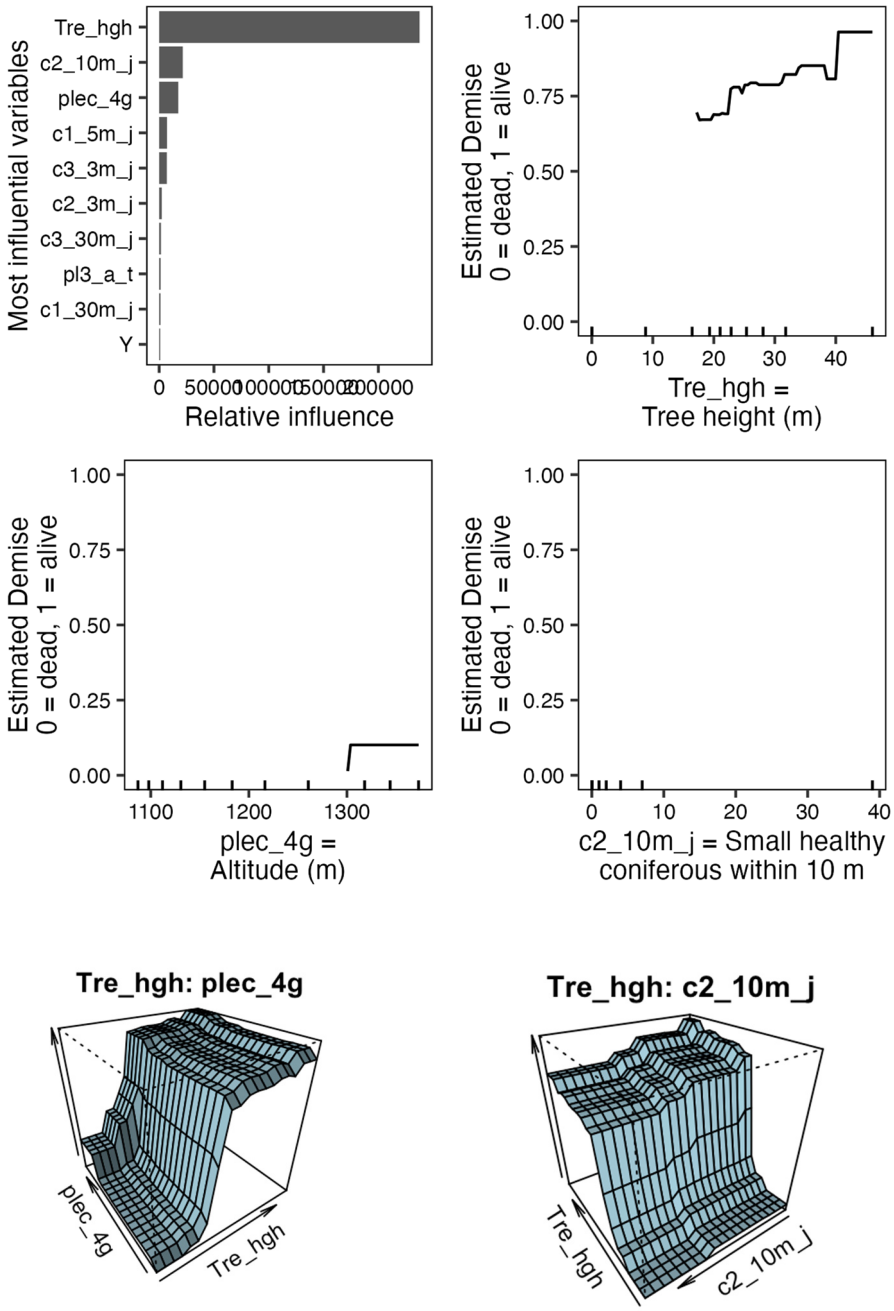


Figure S12: Most influential partial influences for the year 2005. Top left: relative influence of the ten most influential variables in decreasing order. Top right: Partial influence of Tree height which was found to the be the variable with the highest influence on the patterns (compare top left graph). Middle left: Partial influence of the variable with the second highest influence on the patterns (compare top left graph). Middle right: Partial influence of the variable with the third highest influence on the patterns (compare top left graph). For explanations of the abbreviations refer to Table 2 in the main text. Bottom left: Interaction plot between the most important variable tree height ("Tre_hgh") and the second most important variable altitude above sea level ("plec_4g"). Bottom right: Interaction plot between the most important variable tree height ("Tre_hgh") and the third most important variable small healthy coniferous trees within 10 m ("c2_10m_j").

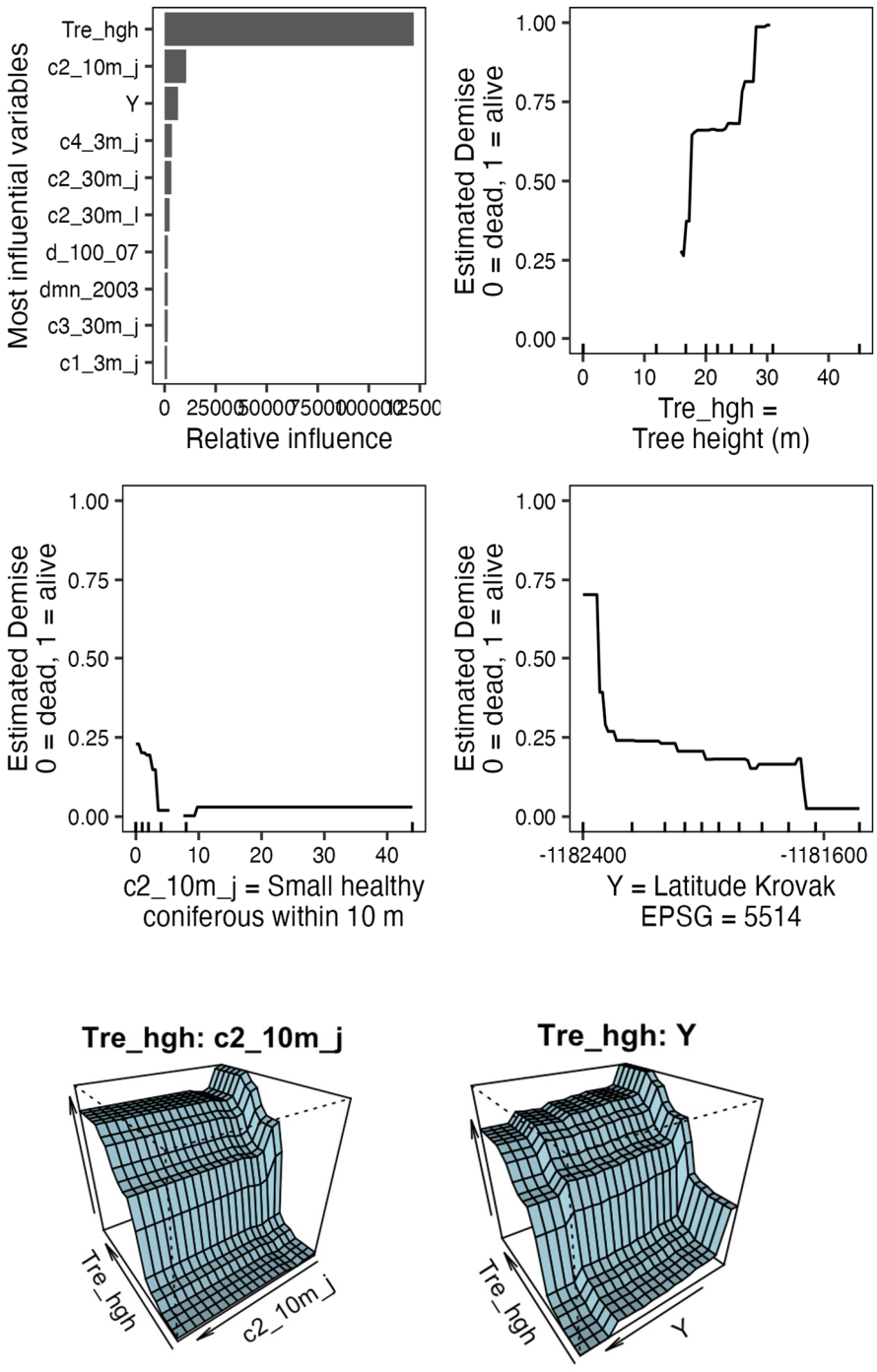


Figure S13: Most influential partial influences for the year 2007. Top left: relative influence of the ten most influential variables in decreasing order. Top right: Partial influence of Tree height which was found to the be the variable with the highest influence on the patterns (compare top left graph). Middle left: Partial influence of the variable with the second highest influence on the patterns (compare top left graph). Middle right: Partial influence of the variable with the third highest influence on the patterns (compare top left graph). For explanations of the abbreviations refer to Table 2 in the main text. Bottom left: Interaction plot between the most important variable tree height ("Tre_hgh") and the second most important variable small healthy coniferous trees within 10 m ("c2_10m_j"). Bottom right: Interaction plot between the most important variable tree height ("Tre_hgh") and the third most important variable Y coordinate, i.e. latitude.

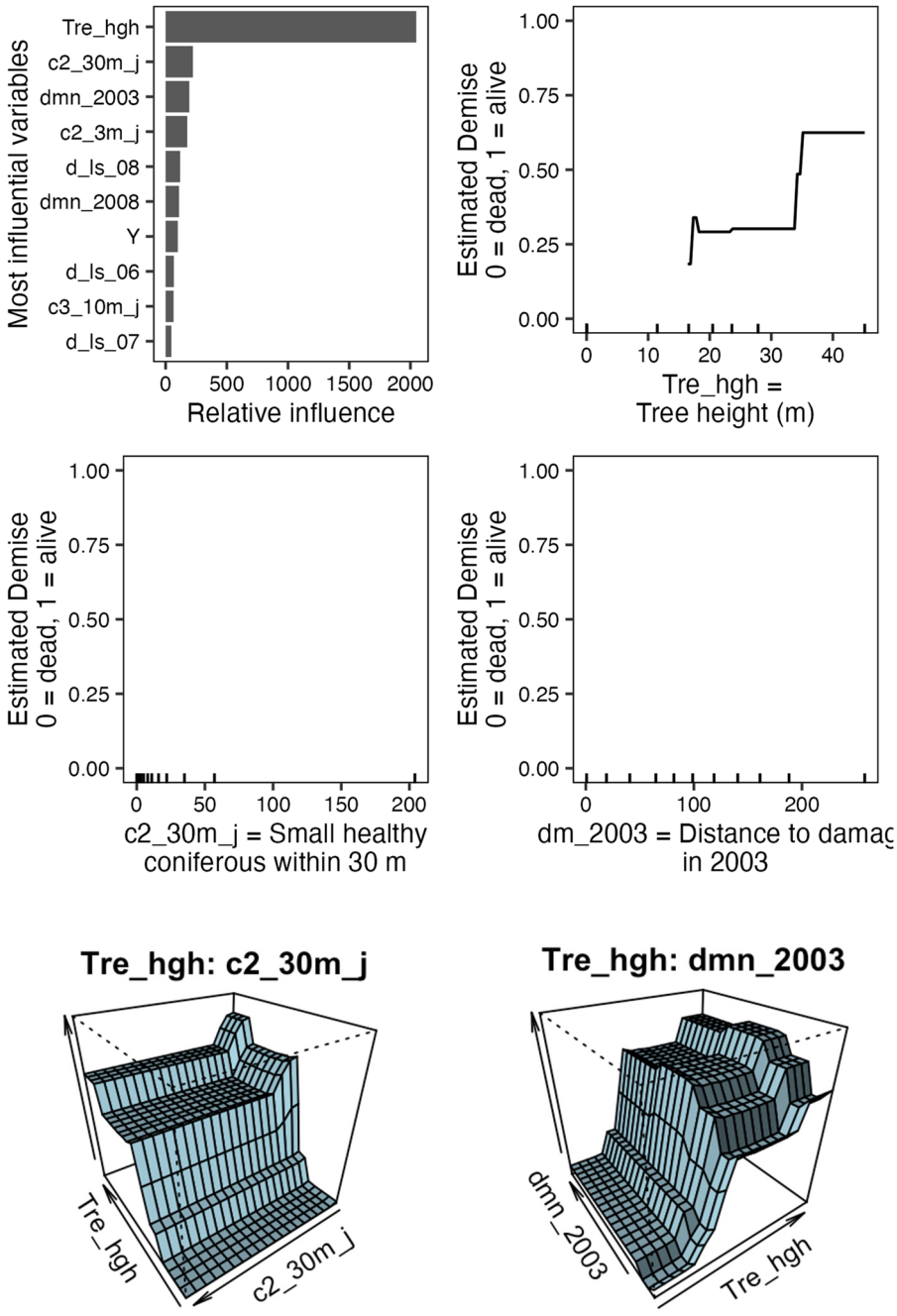


Figure S14: Most influential partial influences for the year 2008. Top left: relative influence of the ten most influential variables in decreasing order. Top right: Partial influence of Tree height which was found to the be the variable with the highest influence on the patterns (compare top left graph). Middle left: Partial influence of the variable with the second highest influence on the patterns (compare top left graph). Middle right: Partial influence of the variable with the third highest influence on the patterns (compare top left graph). For explanations of the abbreviations refer to Table 2 in the main text. Bottom left: Interaction plot between the most important variable tree height ("Tre_hgh") and the second most important variable small healthy coniferous trees within 30 m ("c2_30m_j")). Bottom right: Interaction plot between the most important variable tree height ("Tre_hgh") and the third most important variable distance to damage in the year 2003 in the Senf & Seidl (2001) database ("dm_2003").

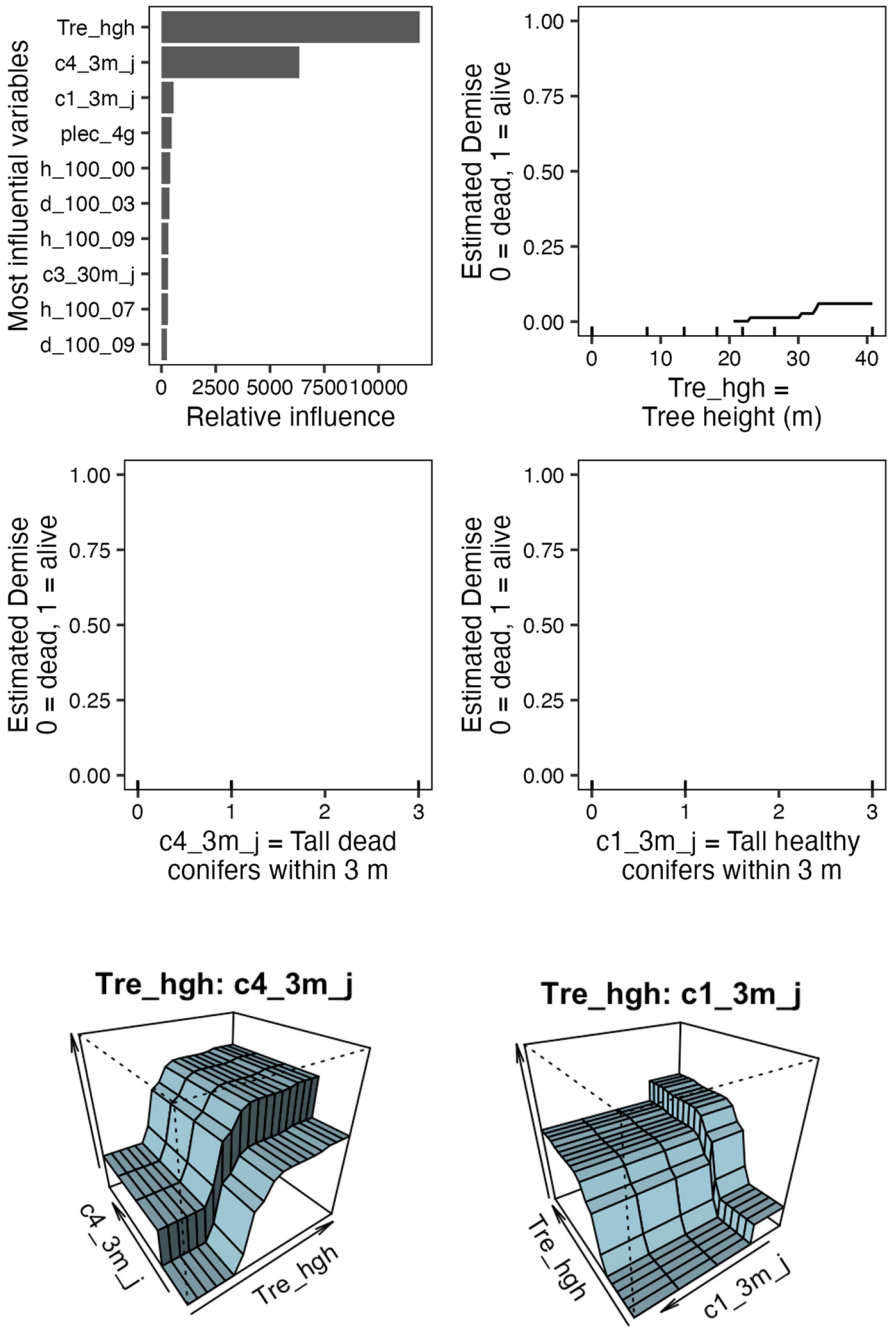


Figure S15: Most influential partial influences for the year 2009. Top left: relative influence of the ten most influential variables in decreasing order. Top right: Partial influence of Tree height which was found to the be the variable with the highest influence on the patterns (compare top left graph). Middle left: Partial influence of the variable with the second highest influence on the patterns (compare top left graph). Middle right: Partial influence of the variable with the third highest influence on the patterns (compare top left graph). For explanations of the abbreviations refer to Table 2 in the main text. Bottom left: Interaction plot between the most important variable tree height ("Tre_hgh") and the second most important variable Tall dead coniferous trees within 3 m ("c4_3m_j"). Bottom right: Interaction plot between the most important variable tree height ("Tre_hgh") and the third most important variable tall healthy coniferous trees within 3 m ("c1_3m_j").

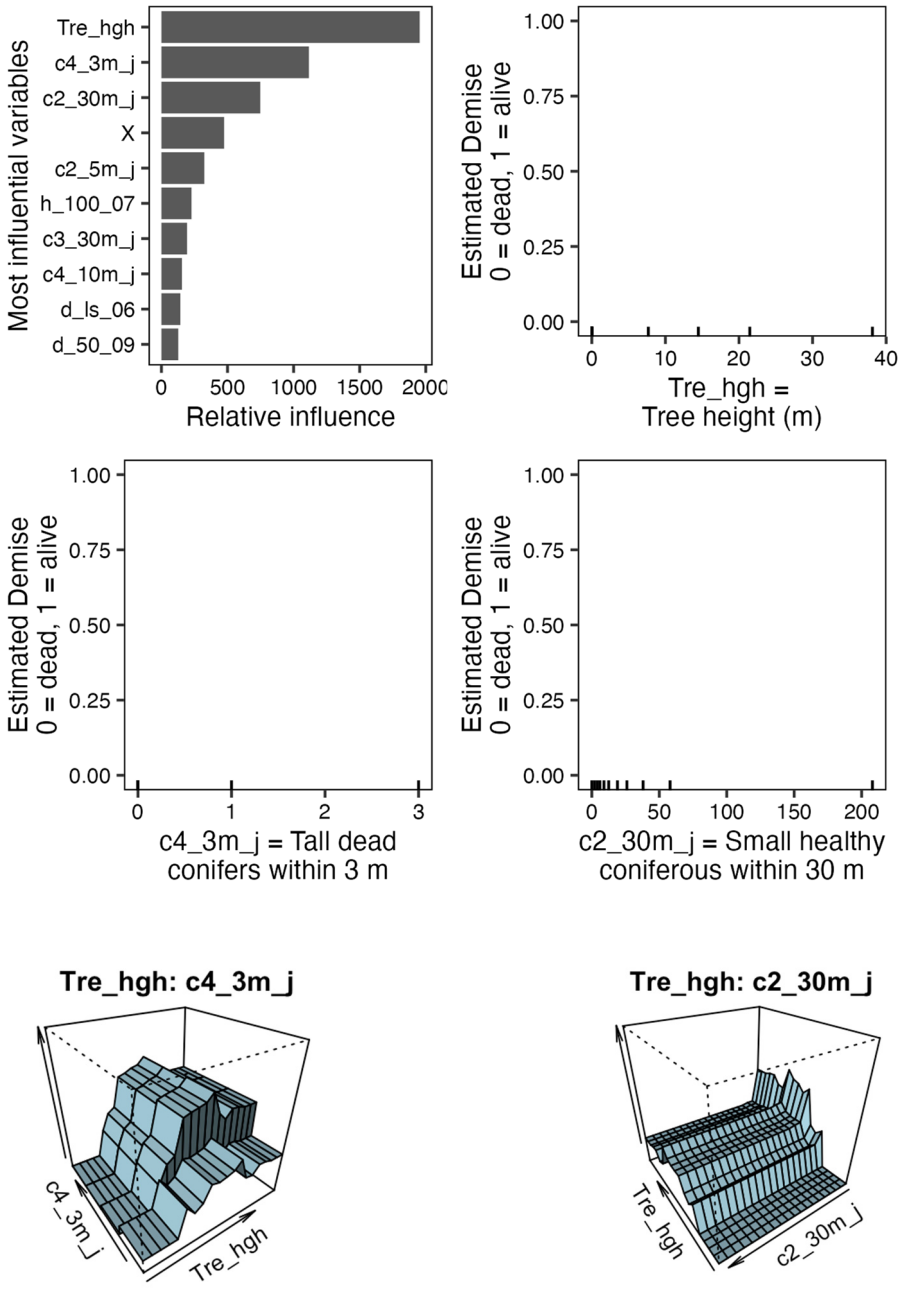


Figure S16: Most influential partial influences for the year 2010. Top left: relative influence of the ten most influential variables in decreasing order. Top right: Partial influence of Tree height which was found to the be the variable with the highest influence on the patterns (compare top left graph). Middle left: Partial influence of the variable with the second highest influence on the patterns (compare top left graph). Middle right: Partial influence of the variable with the third highest influence on the patterns (compare top left graph). For explanations of the abbreviations refer to Table 2 in the main text. Bottom left: Interaction plot between the most important variable tree height ("Tre_hgh") and the second most important variable altitude above sea level ("plec_4g"). Bottom right: Interaction plot between the most important variable tree height ("Tre_hgh") and the third most important variable small healthy coniferous trees within 10 m ("c2_10m_j").

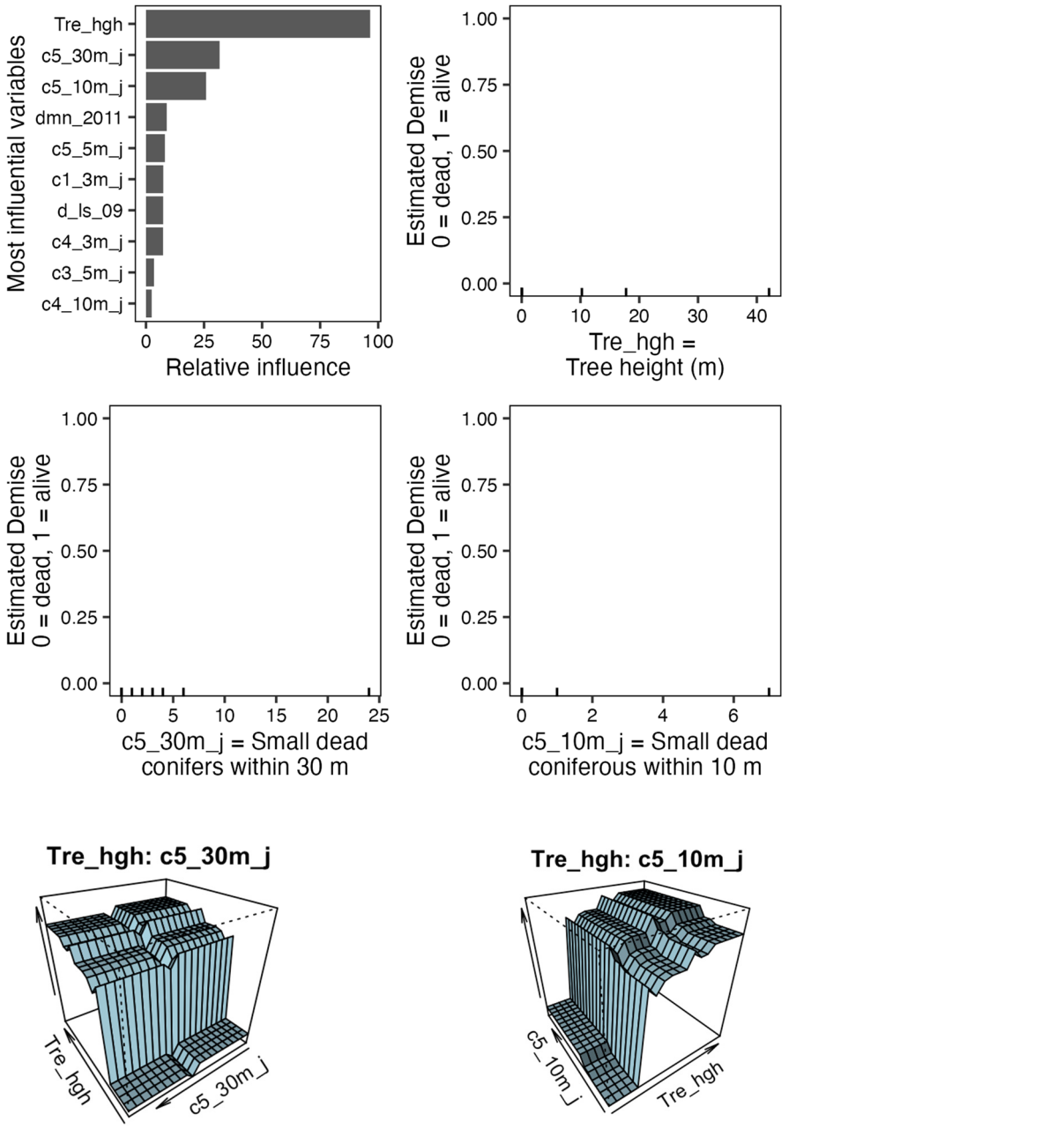


Figure S17: Most influential partial influences for the year 2011. Top left: relative influence of the ten most influential variables in decreasing order. Top right: Partial influence of Tree height which was found to the be the variable with the highest influence on the patterns (compare top left graph). Middle left: Partial influence of the variable with the second highest influence on the patterns (compare top left graph). Middle right: Partial influence of the variable with the third highest influence on the patterns (compare top left graph). For explanations of the abbreviations refer to Table 2 in the main text. Bottom left: Interaction plot between the most important variable tree height ("Tre_hgh") and the second most important variable small dead coniferous trees within 30 m ("c5_30m_j"). Bottom right: Interaction plot between the most important variable tree height ("Tre_hgh") and the third most important variable small dead coniferous trees within 10 m ("c5_10m_j").

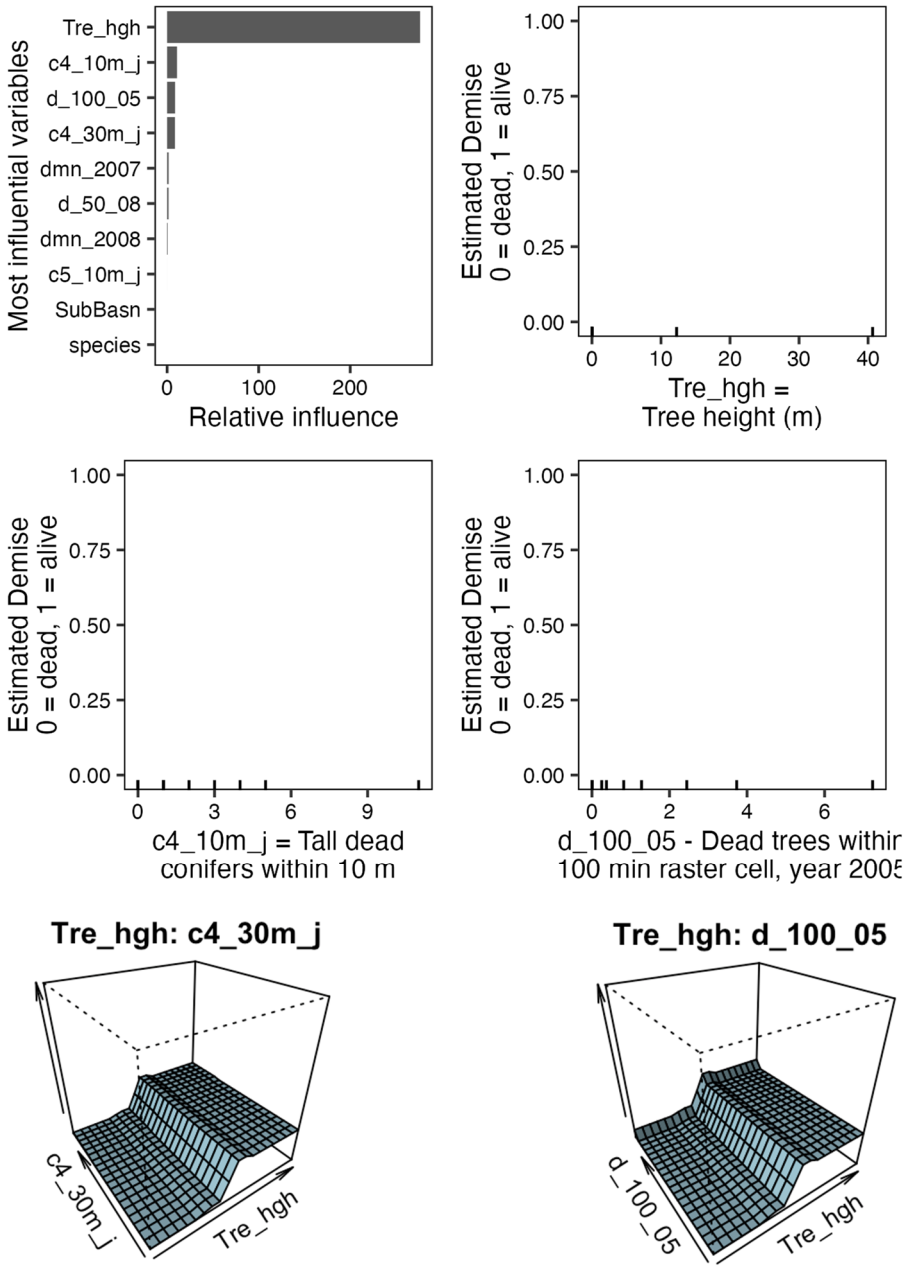


Figure S18: Most influential partial influences for the year 2013. Top left: relative influence of the ten most influential variables in decreasing order. Top right: Partial influence of Tree height which was found to the be the variable with the highest influence on the patterns (compare top left graph). Bottom left: Partial influence of the variable with the second highest influence on the patterns (compare top left graph). Bottom right: Partial influence of the variable with the third highest influence on the patterns (compare top left graph). For explanations of the abbreviations refer to Table 2 in the main text. Bottom left: Interaction plot between the most important variable tree height ("Tre_hgh") and the second most important variable altitude above sea level ("plec_4g"). Bottom right: Interaction plot between the most important variable tree height ("Tre_hgh") and the third most important variable small healthy coniferous trees within 10 m ("c2_10m_j").

Part E: Cross-checking results with random forests

Random Forest models are very commonly used, but have weaknesses. However, they may deal better with collinearities in variables and thus were used on the data set to check whether similar patterns would emerge. Here, we checked whether they reproduced the general patterns, if not the results, from GBM. Indeed, like for the GBM, tree height ("Tre_hgh") emerged as the by far most important variable for predicting tree death in all years (Figure S19 - Figure S27).

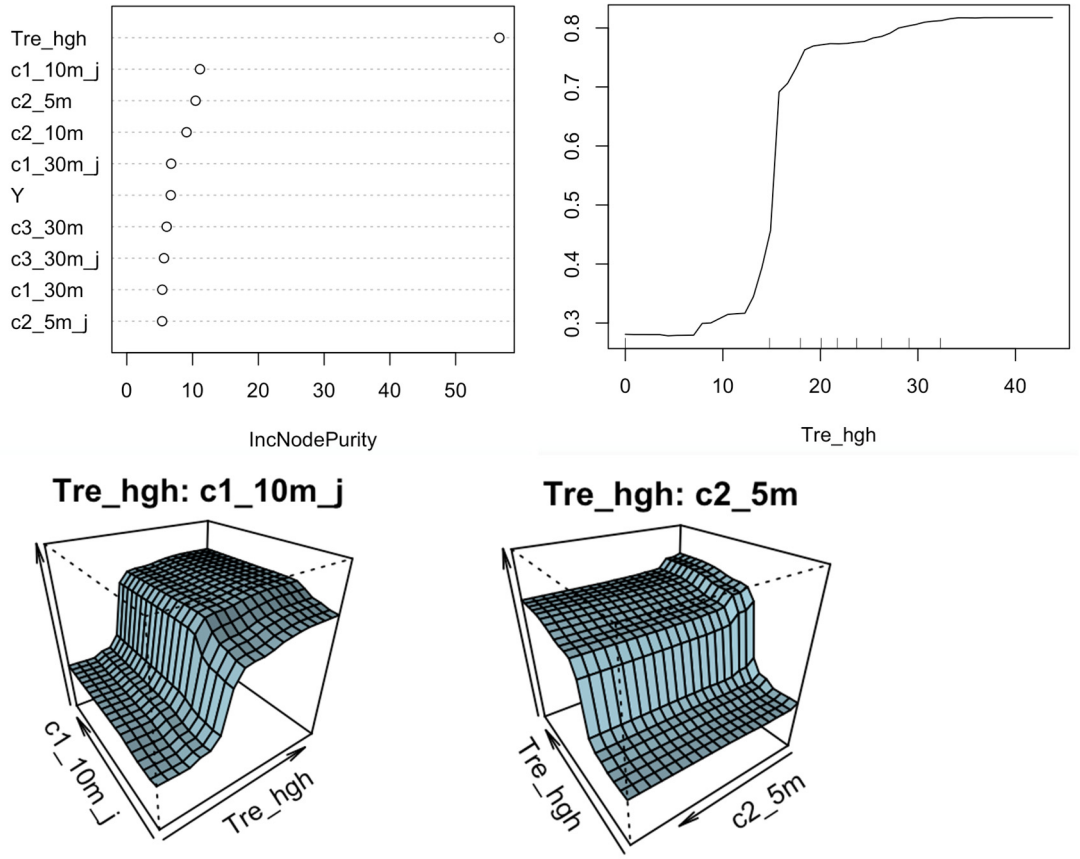


Figure S19: Cross-checking the GBM results with a random forest model for the year 2000. Top left: variance importance plot. Top right: Partial dependence of the likelihood for tree death (0 = unlikely, 1 = likely) on tree height. Bottom left: Interaction between the most important variable tree height ("Tre_hgh") and the second most important variable tall healthy coniferous trees within 10 m ("c1_10m_j"). Bottom right: Interaction between the most important variable tree height ("Tre_hgh") and the third most important variable small healthy trees within 5 m ("c2_5m").

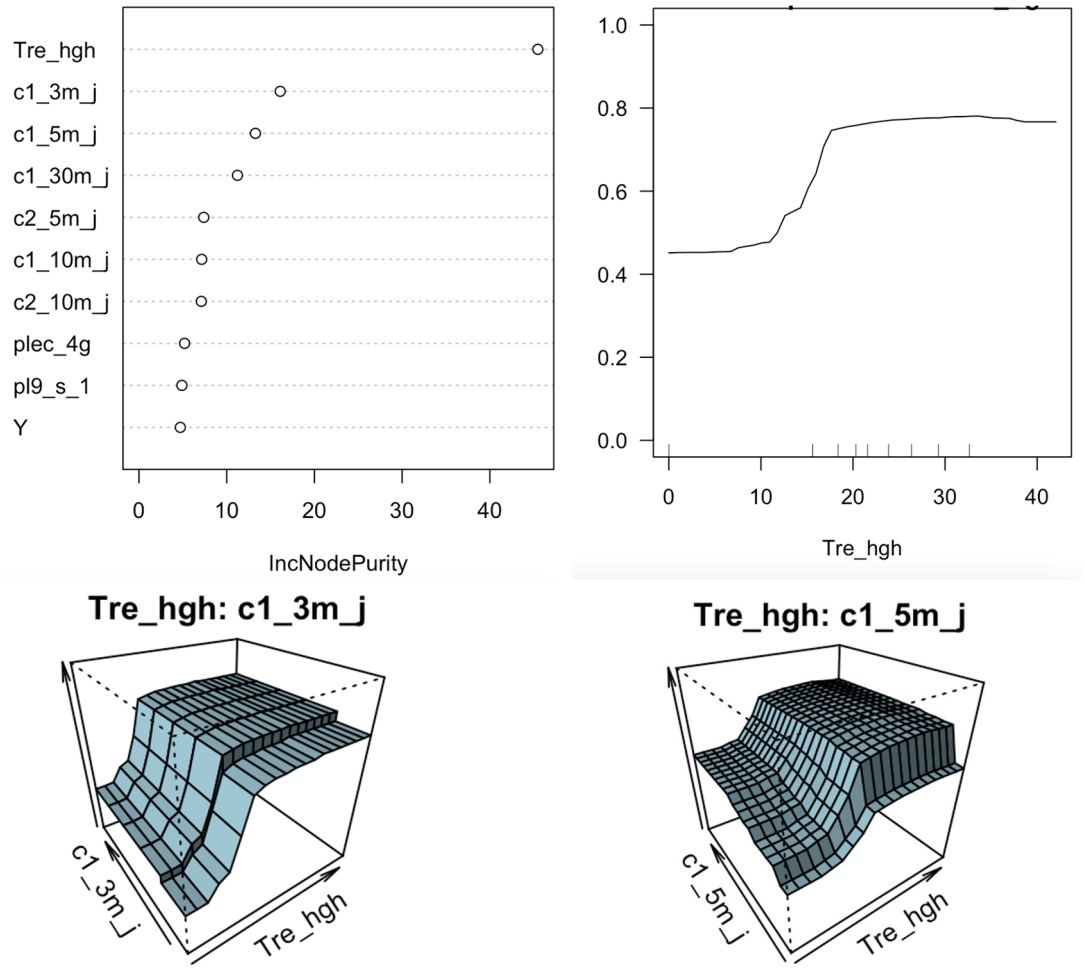


Figure S20: Cross-checking the GBM results with a random forest model for the year 2003. Top left: variance importance plot. Top right: Partial dependence of the likelihood for tree death (0 = unlikely, 1 = likely) on tree height. Bottom left: Interaction between the most important variable tree height ("Tre_hgh") and the second most important variable tall healthy coniferous trees within 3 m ("c1_3m_j"). Bottom right: Interaction between the most important variable tree height ("Tre_hgh") and the third most important variable small healthy coniferous trees within 5 m ("c2_3m_j").

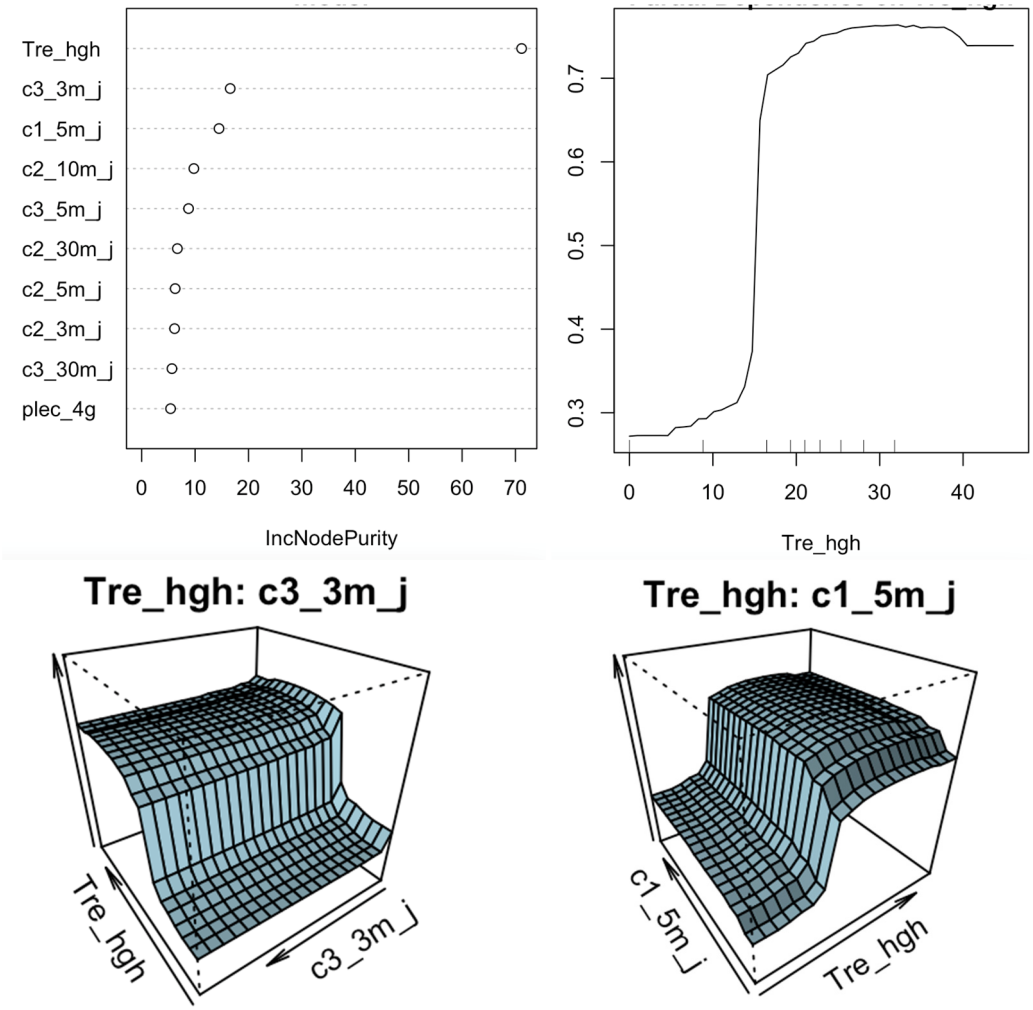


Figure S21: Cross-checking the GBM results with a random forest model for the year 2005. Top left: variance importance plot. Top right: Partial dependence of the likelihood for tree death (0 = unlikely, 1 = likely) on tree height. Bottom left: Interaction between the most important variable tree height ("Tre_hgh") and the second most important variable tall dead coniferous trees within 3 m ("c3_3m_j"). Bottom right: Interaction between the most important variable tree height ("Tre_hgh") and the third most important variable tall healthy coniferous trees within 5 m ("c1_5m_j").

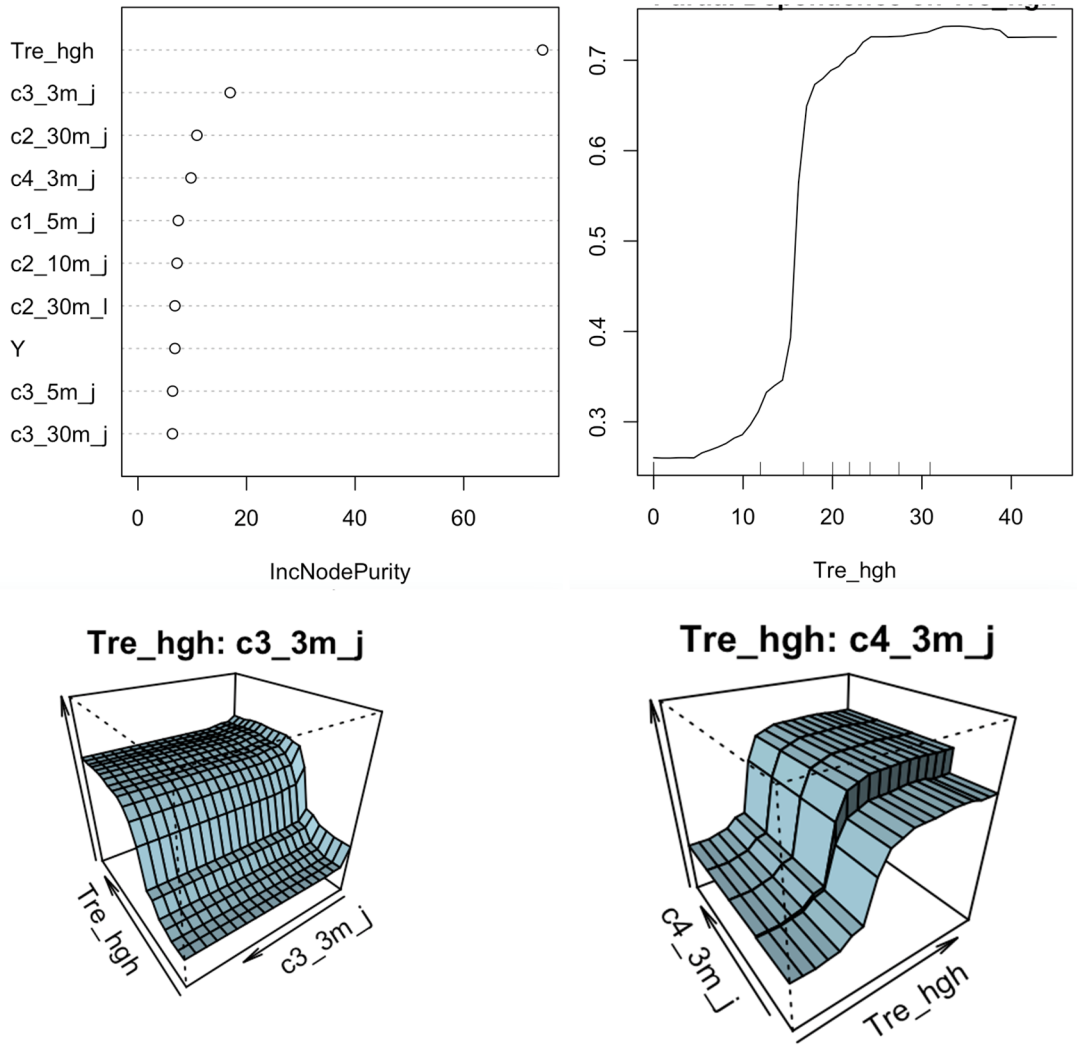


Figure S22: Cross-checking the GBM results with a random forest model for the year 2007. Top left: variance importance plot. Top right: Partial dependence of the likelihood for tree death (0 = unlikely, 1 = likely) on tree height. Bottom left: Interaction between the most important variable tree height ("Tre_hgh") and the second most important variable tall dead coniferous trees within 3 m ("c3_3m_j"). Bottom right: Interaction between the most important variable tree height ("Tre_hgh") and the third most important variable small healthy coniferous trees within 30 m ("c2_30m_j").

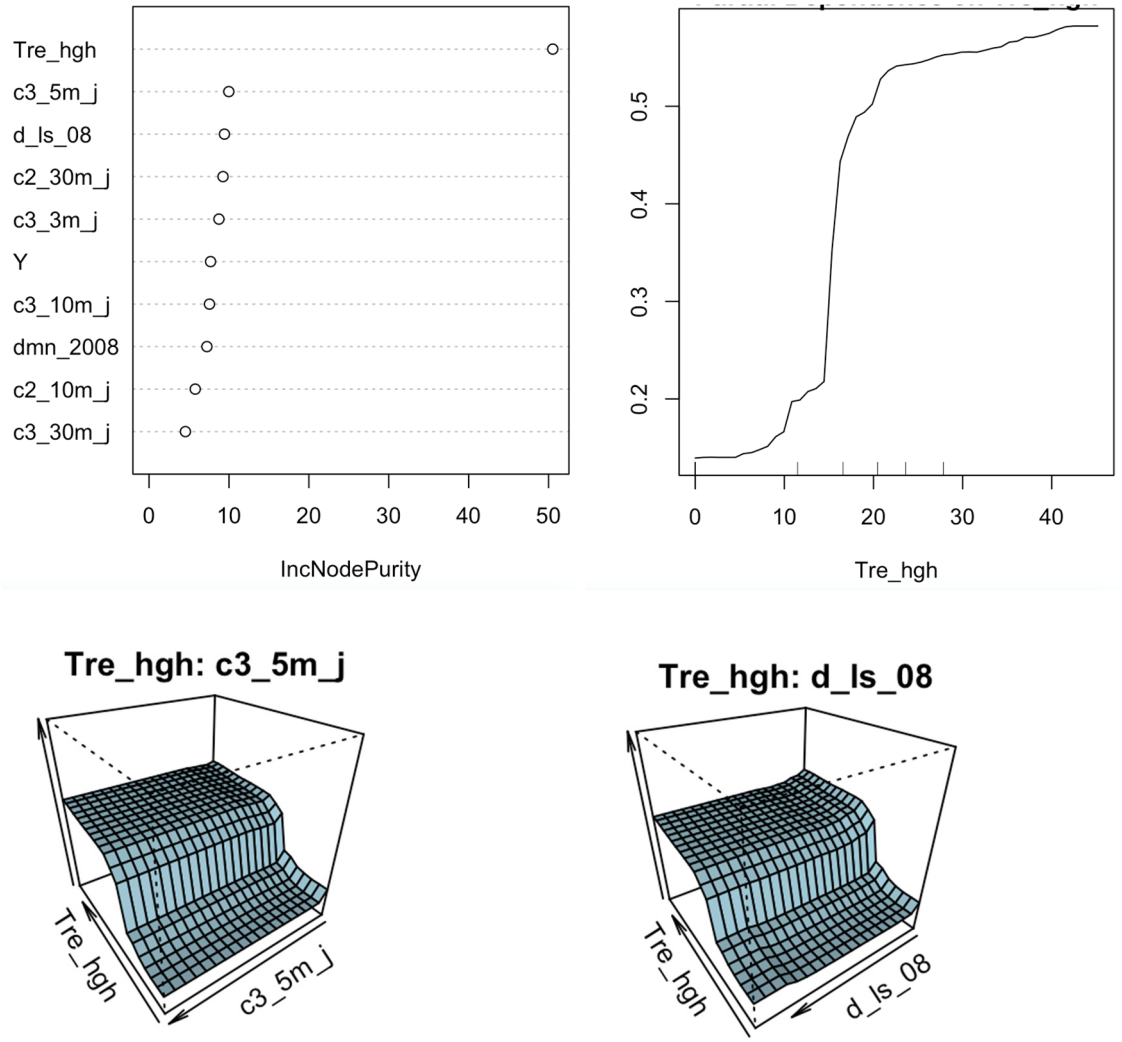


Figure S23: Cross-checking the GBM results with a random forest model for the year 2008. Top left: variance importance plot. Top right: Partial dependence of the likelihood for tree death (0 = unlikely, 1 = likely) on tree height. Bottom left: Interaction between the most important variable tree height ("Tre_hgh") and the second most important variable tall dead coniferous trees within 5 m ("c3_5m_j"). Bottom right: Interaction between the most important variable tree height ("Tre_hgh") and the third most important variable distance to disturbances in the year 2008 in the Czech disturbance database ("d_ls_08").

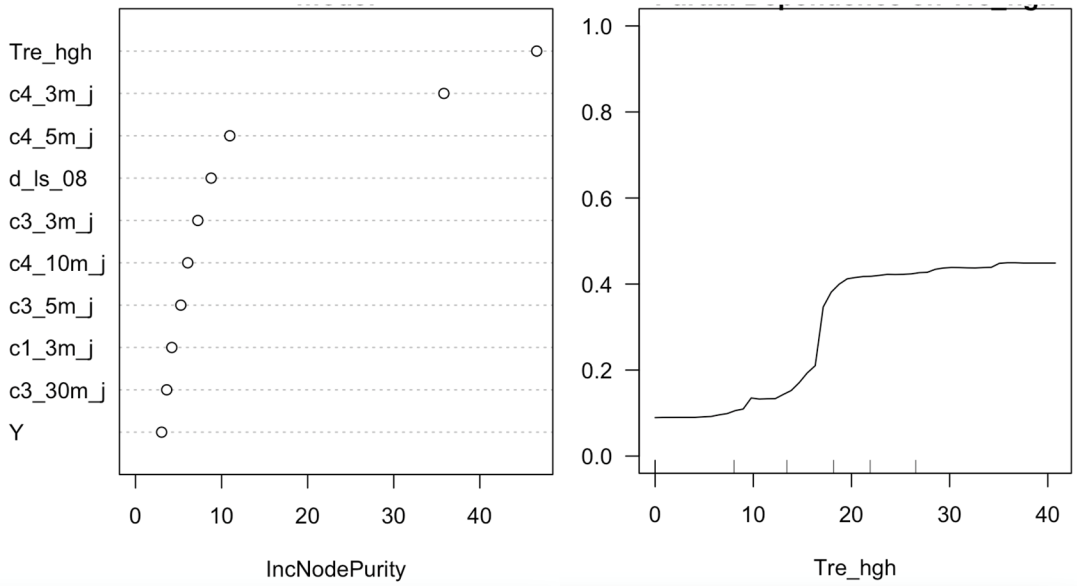


Figure S24: Cross-checking the GBM results with a random forest model for the year 2009. Top left: variance importance plot. Top right: Partial dependence of the likelihood for tree death (0 = unlikely, 1 = likely) on tree height. For this data set, no interaction plots could be calculated.

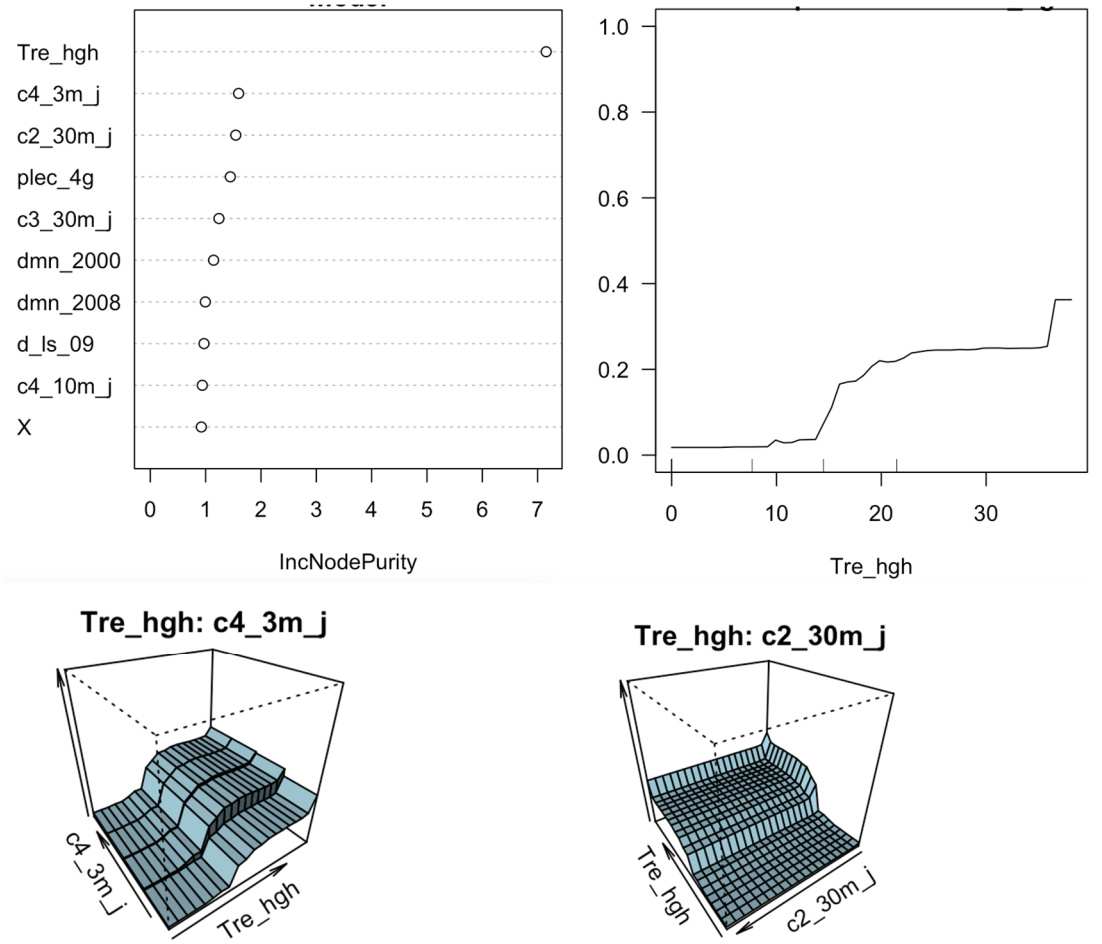


Figure S25: Cross-checking the GBM results with a random forest model for the year 2010. Top left: variance importance plot. Top right: Partial dependence of the likelihood for tree death (0 = unlikely, 1 = likely) on tree height. Bottom left: Interaction between the most important variable tree height ("Tre_hgh") and the second most important variable tall dead coniferous trees within 5 m ("c4_3m_j"). Bottom right: Interaction between the most important variable tree height ("Tre_hgh") and the third most important variable tall dead coniferous trees within 3 m ("c4_3m_j").

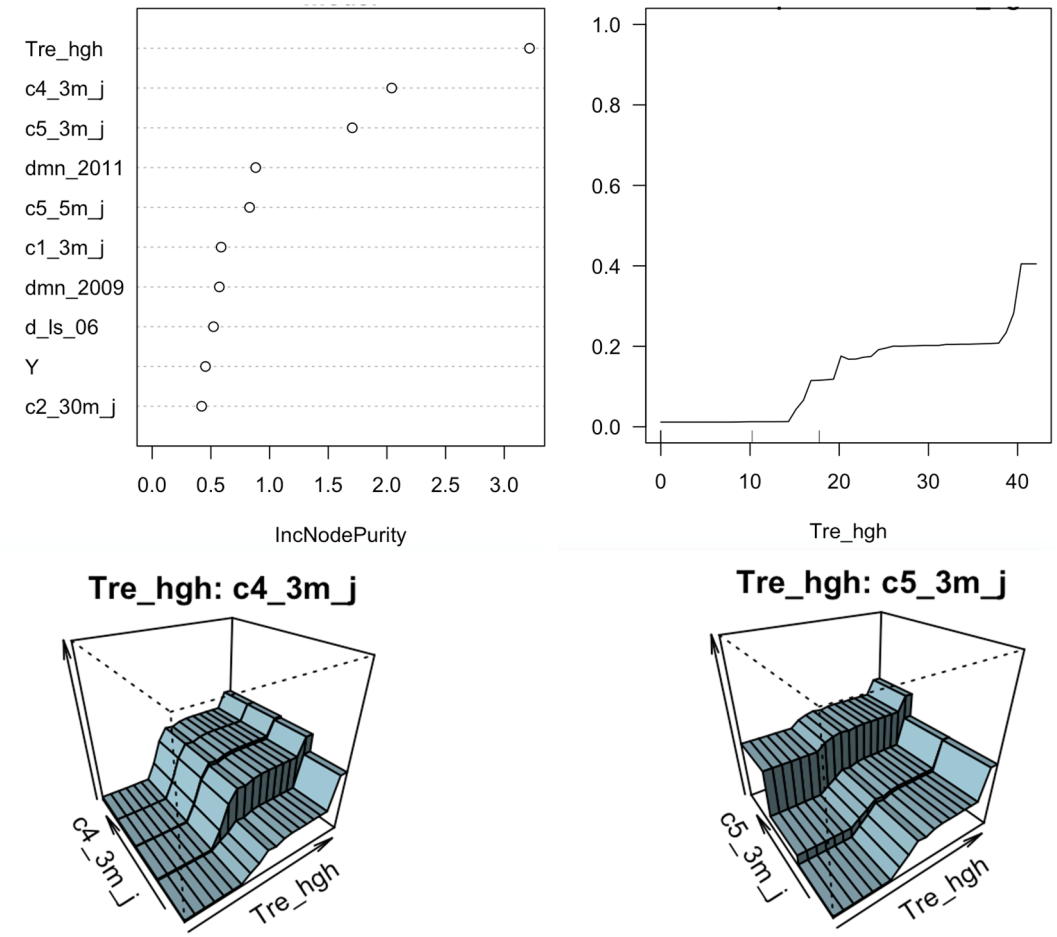


Figure S26: Cross-checking the GBM results with a random forest model for the year 2011. Top left: variance importance plot. Top right: Partial dependence of the likelihood for tree death (0 = unlikely, 1 = likely) on tree height. Bottom left: Interaction between the most important variable tree height ("Tre_hgh") and the second most important variable tall dead coniferous trees within 3 m ("c4_3m_j"). Bottom right: Interaction between the most important variable tree height ("Tre_hgh") and the third most important variable small dead coniferous trees within 3 m ("c5_3m_j").

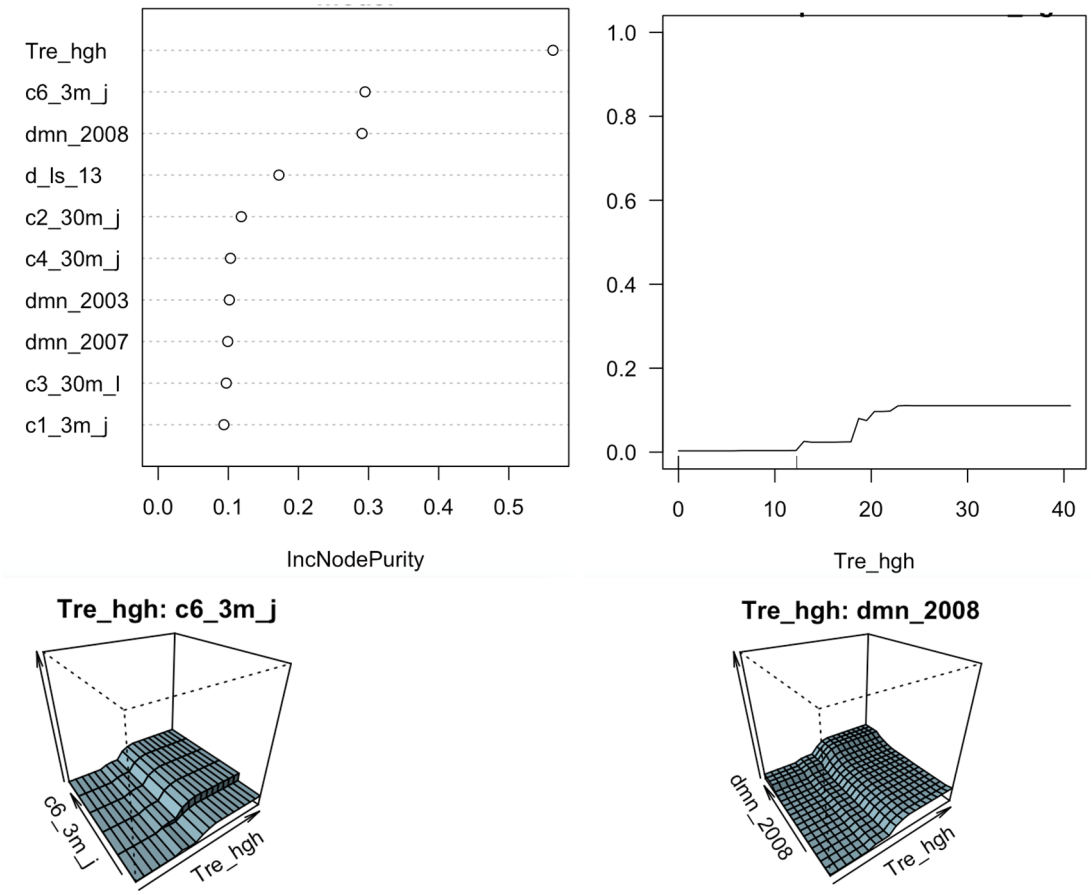


Figure S27: Cross-checking the GBM results with a random forest model for the year 2013. Top left: variance importance plot. Top right: Partial dependence of the likelihood for tree death (0 = unlikely, 1 = likely) on tree height. Bottom left: Interaction between the most important variable tree height ("Tre_hgh") and the second most important variable tree stumps within 3 m ("c6_3m_j"). Bottom right: Interaction between the most important variable tree height ("Tre_hgh") and the third most important variable distance to disturbances in the year 2008 in the Senf & Seidl database ("dm_08").

Part F: GAM of the predictors that had a variance importance of at least 4 in the GBM, for each year for which the tree data base was available

The figures S28 to S35 show General Additive Models (GAM) of the predictors that had a variance importance of at least 4 in the GBM, for predicting the percentage of trees within a 50 m raster cell for the years beginning with 2003. The figure for the year 2000 is included in the main paper as Figure 6. The percentage is the number of newly dead trees versus the sum of newly dead and healthy trees per grid cell. The latter two were estimated via kernel smoothing.

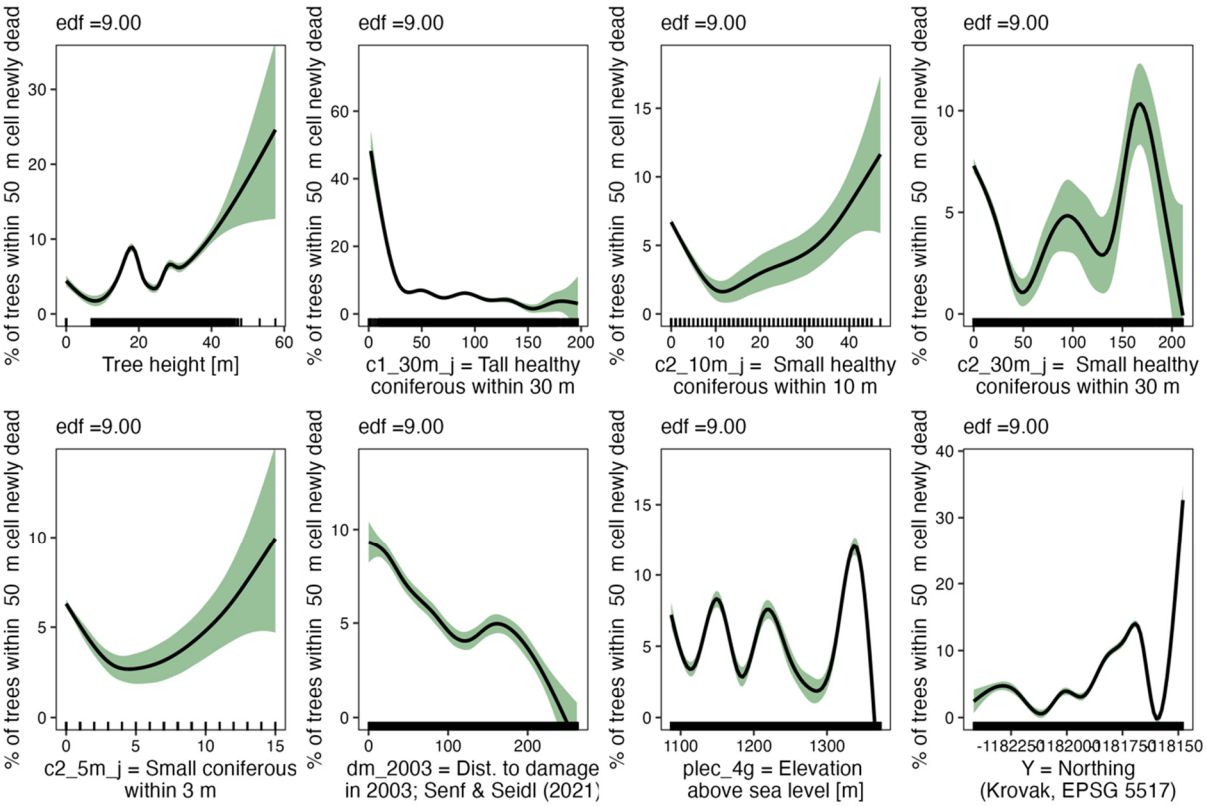


*Figure S28: General additive models (GAM) for predicting the percentage of trees within a 50 m raster cell, estimated via kernel smoothing, that were first dead in the year **2003**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m;; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; „Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

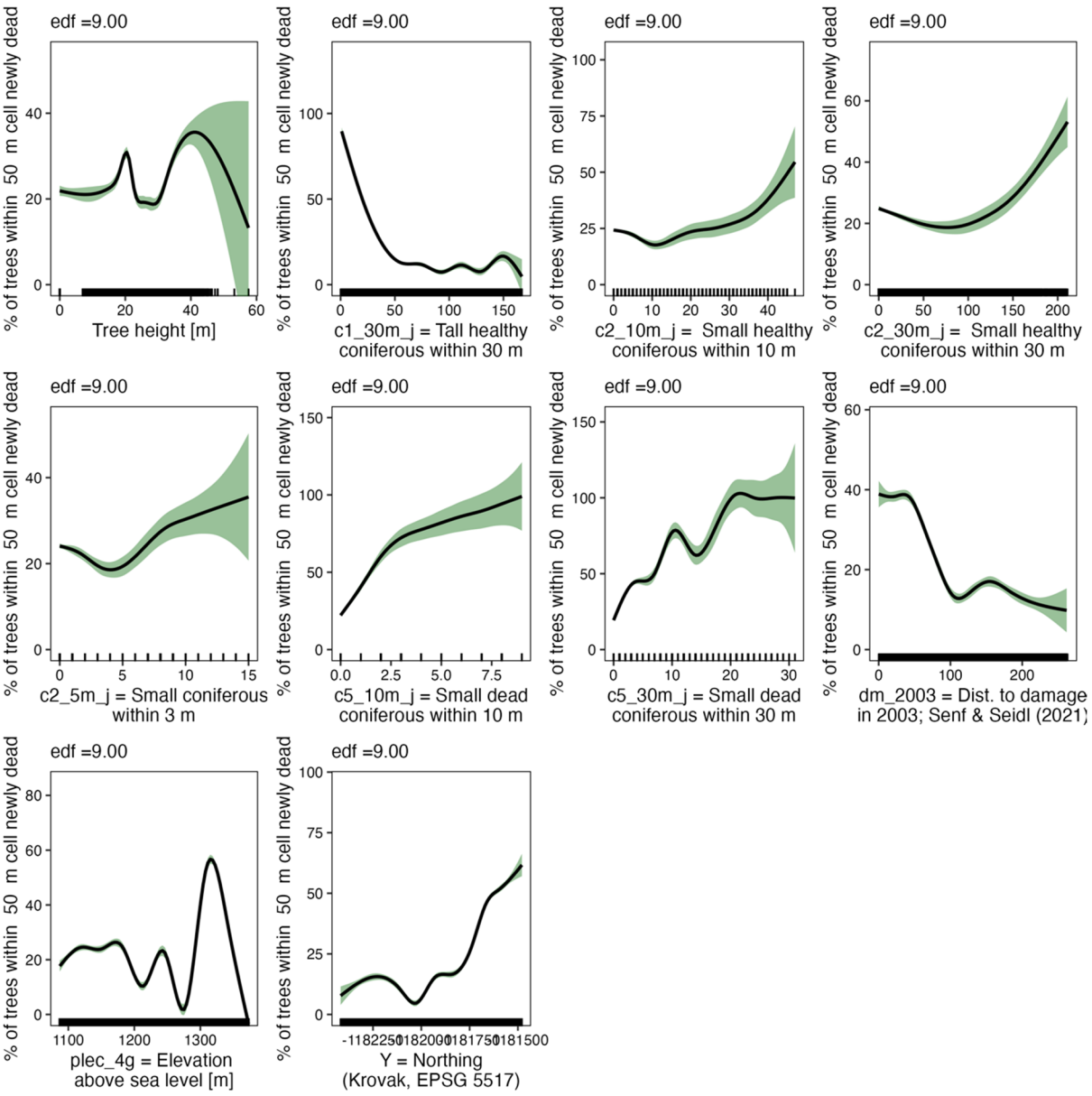


*Figure S29: General additive models (GAM) for predicting the percentage of trees within a 50 m raster cell, estimated via kernel smoothing, that were first dead in the year **2005**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

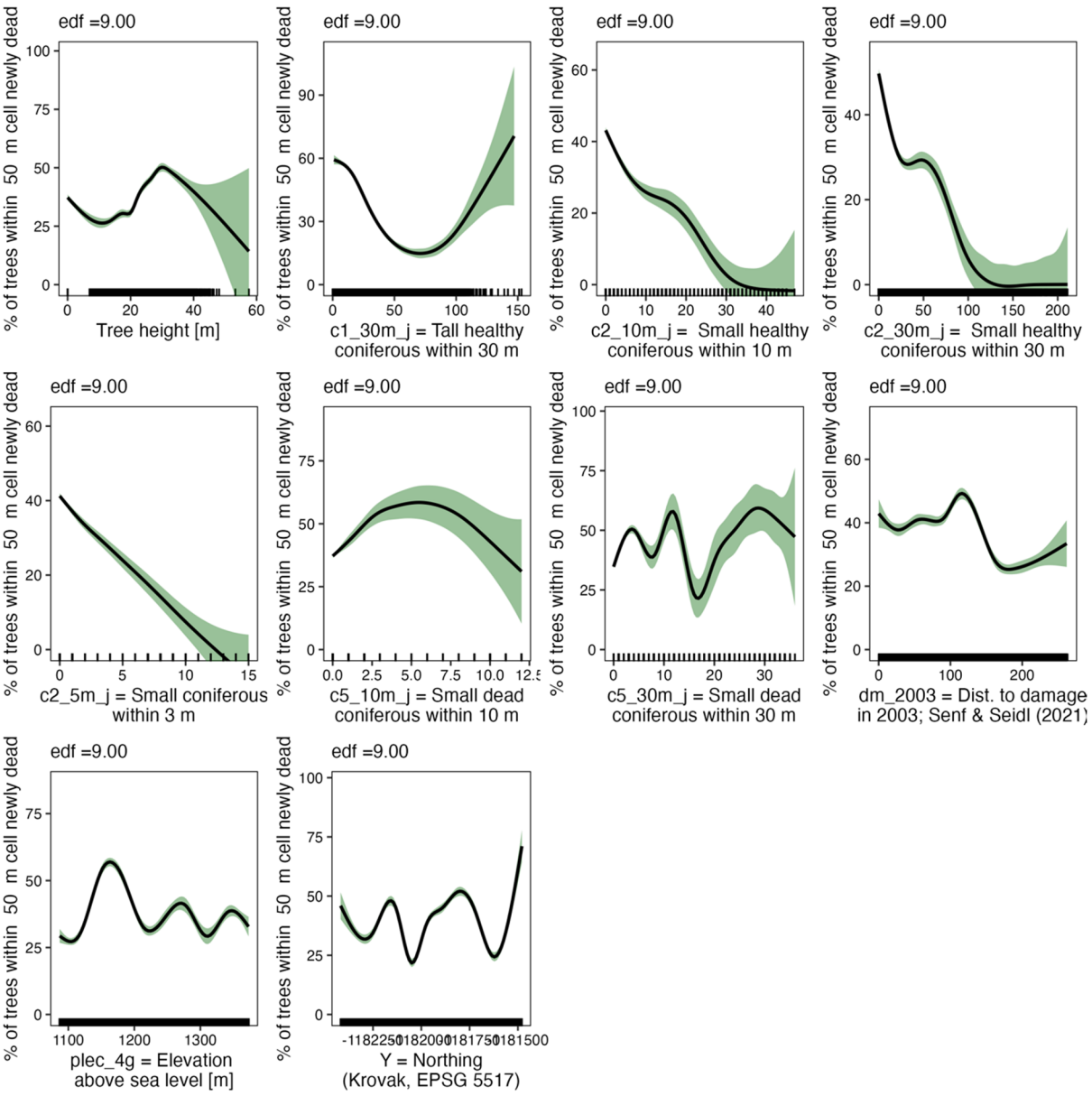


*Figure S30: General additive models (GAM) for predicting the percentage of trees within a 50 m raster cell, estimated via kernel smoothing, that were first dead in the year **2007**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

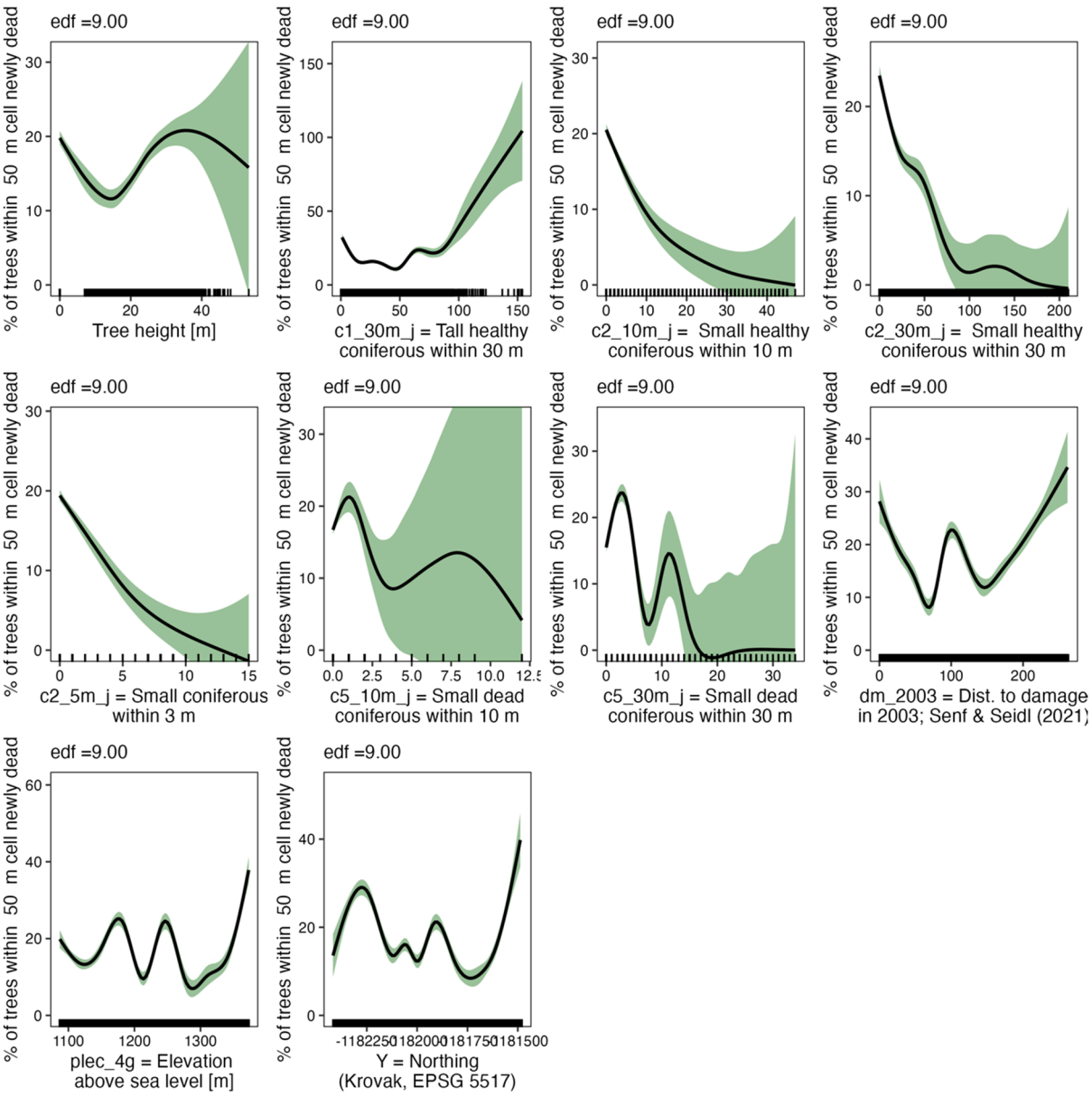


*Figure S31: General additive models (GAM) for predicting the percentage of trees within a 50 m raster cell, estimated via kernel smoothing, that were first dead in the year **2008**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

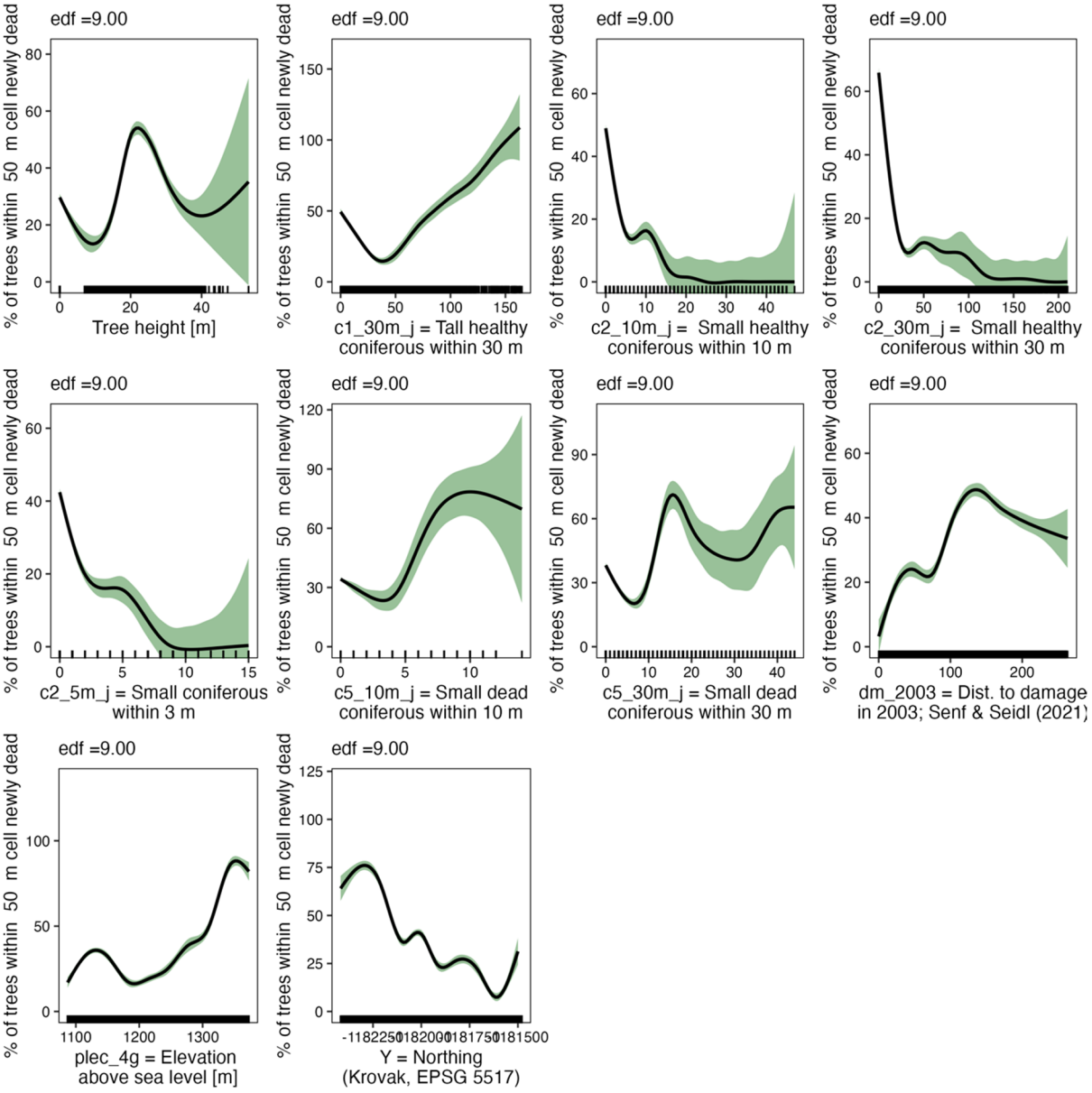


*Figure S32: General additive models (GAM) for predicting the percentage of trees within a 50 m raster cell, estimated via kernel smoothing, that were first dead in the year **2009**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

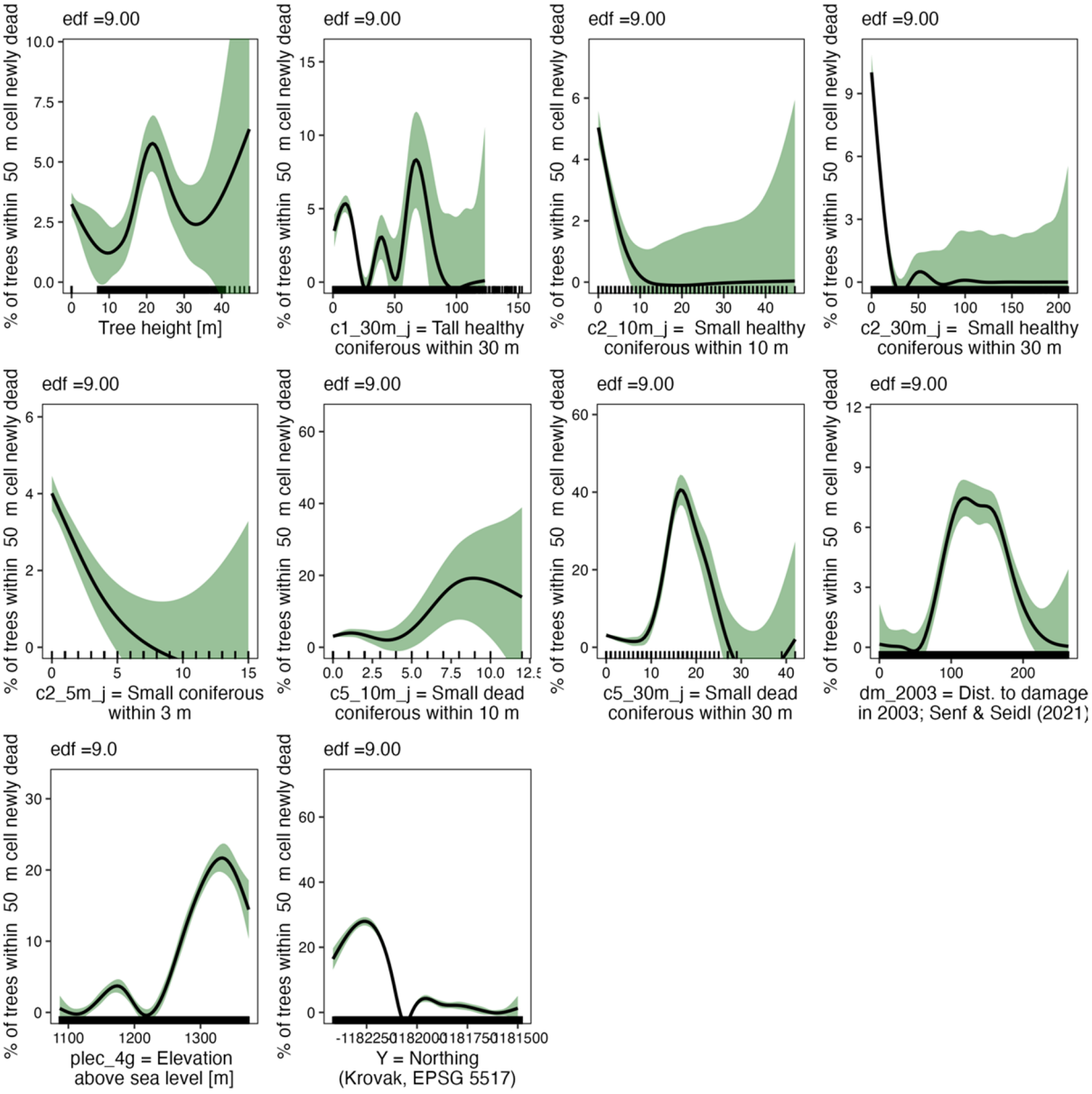


*Figure S33: General additive models (GAM) for predicting the percentage of trees within a 50 m raster cell, estimated via kernel smoothing, that were first dead in the year **2010**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

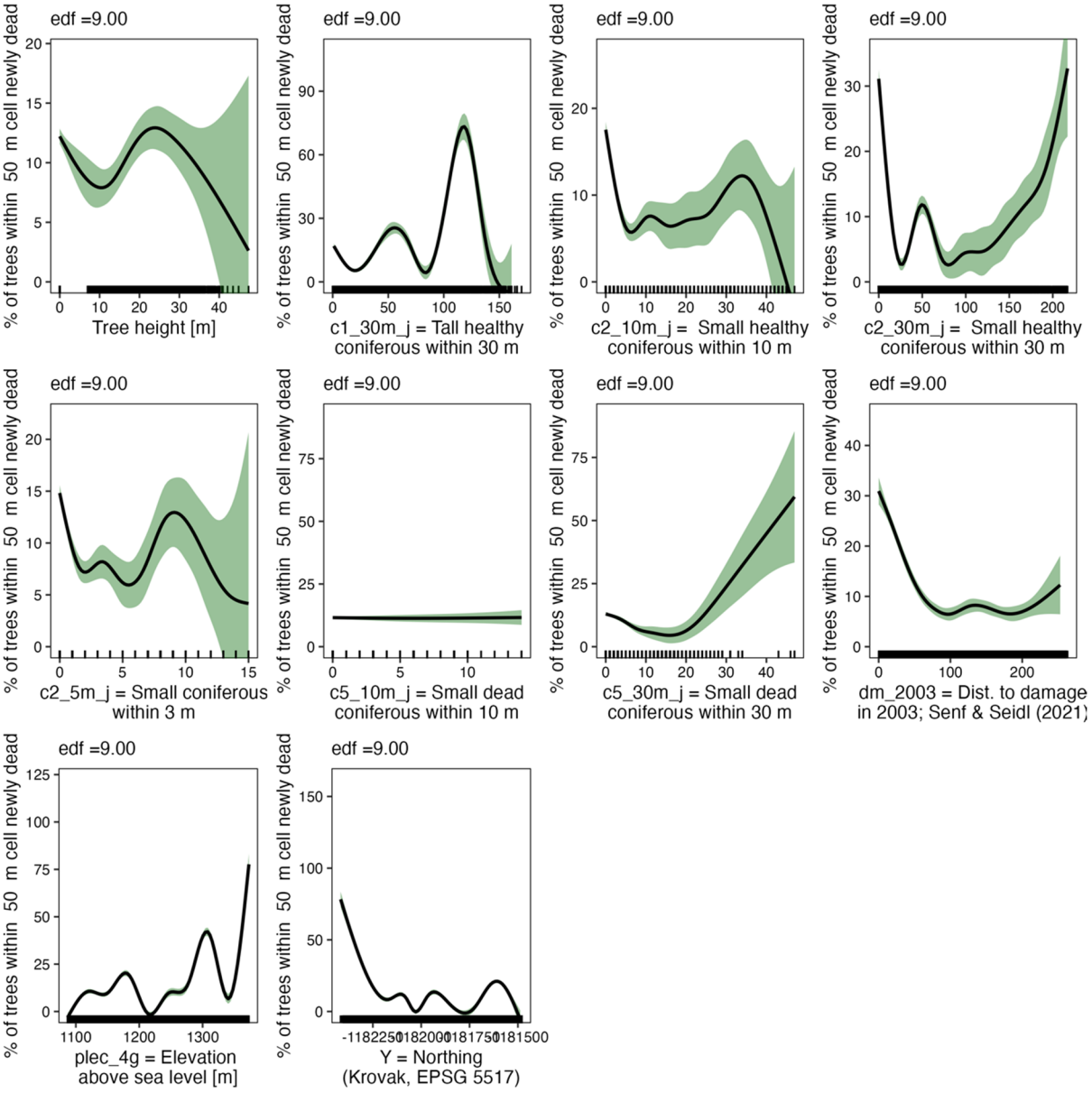


*Figure S34: General additive models (GAM) for predicting the percentage of trees within a 50 m raster cell, estimated via kernel smoothing, that were first dead in the year **2011**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

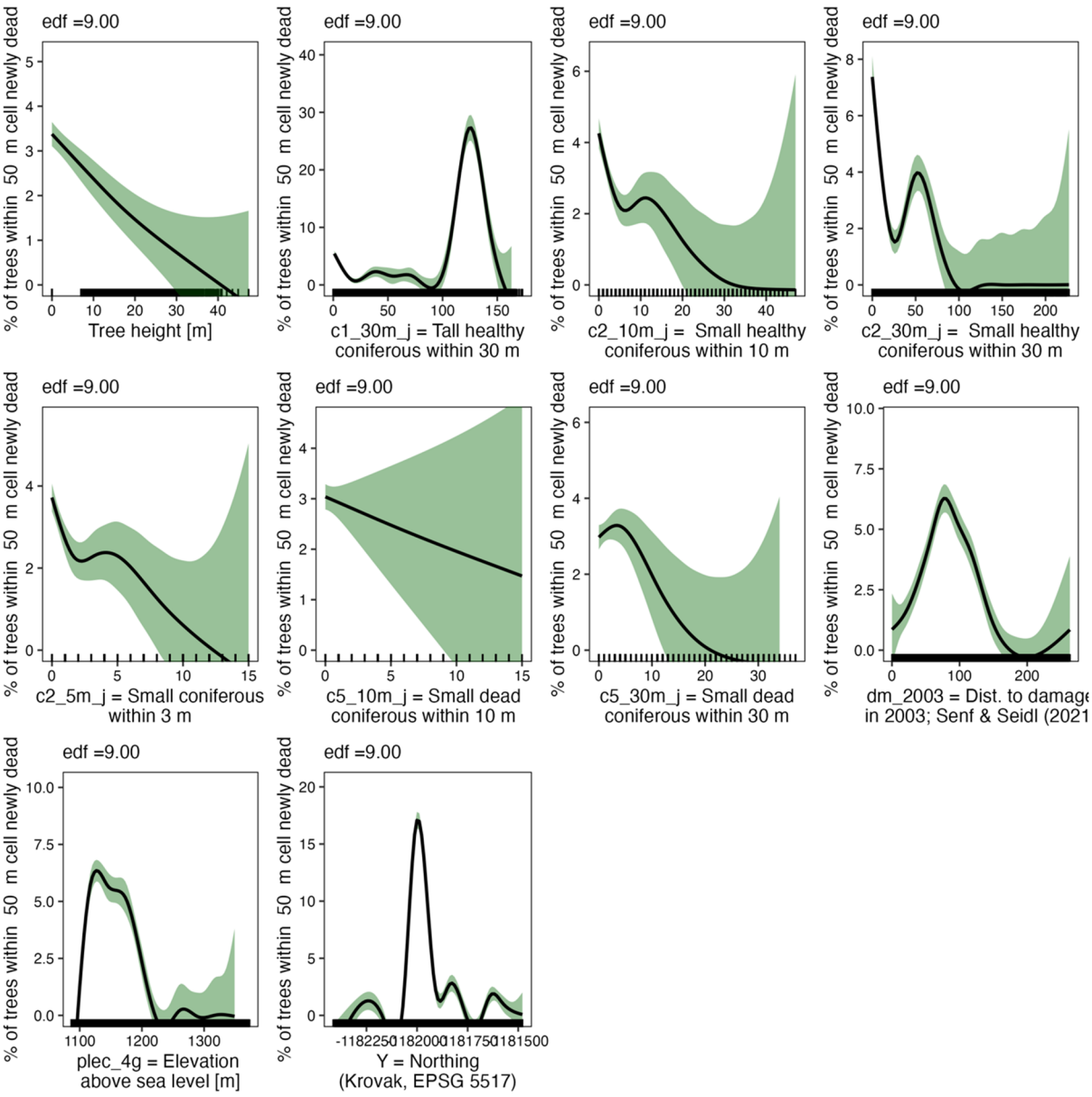


*Figure S35: General additive models (GAM) for predicting the percentage of trees within a 50 m raster cell, estimated via kernel smoothing, that were first dead in the year **2013**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

The Figures S36 to 44 show General Additive Models (GAM) for predicting the percentage of trees within a 100 m raster cell, analogously to Figure 6 in the main paper and Figures S28-35, but here based on 100 m raster cells instead of 50 m raster cells. The height of trees which had proven to be the variable with the highest influence on general boosting models (see above), at this raster scale, showed non-linear relationships with the proportion of newly dead trees. The behaviour of all other variables also depended on the year of observation.

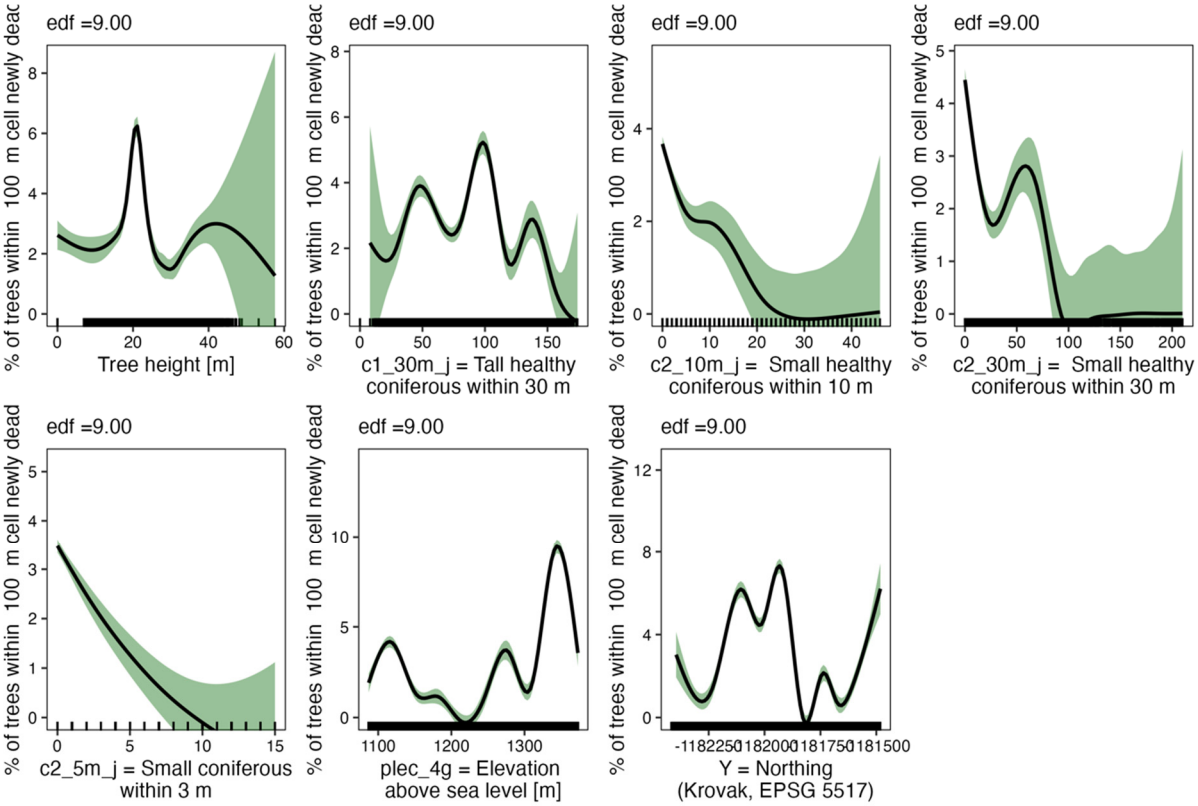


*Figure S36: General additive models (GAM) for predicting the percentage of trees within a 100 m raster cell, estimated via kernel smoothing, that were first dead in the year **2000**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

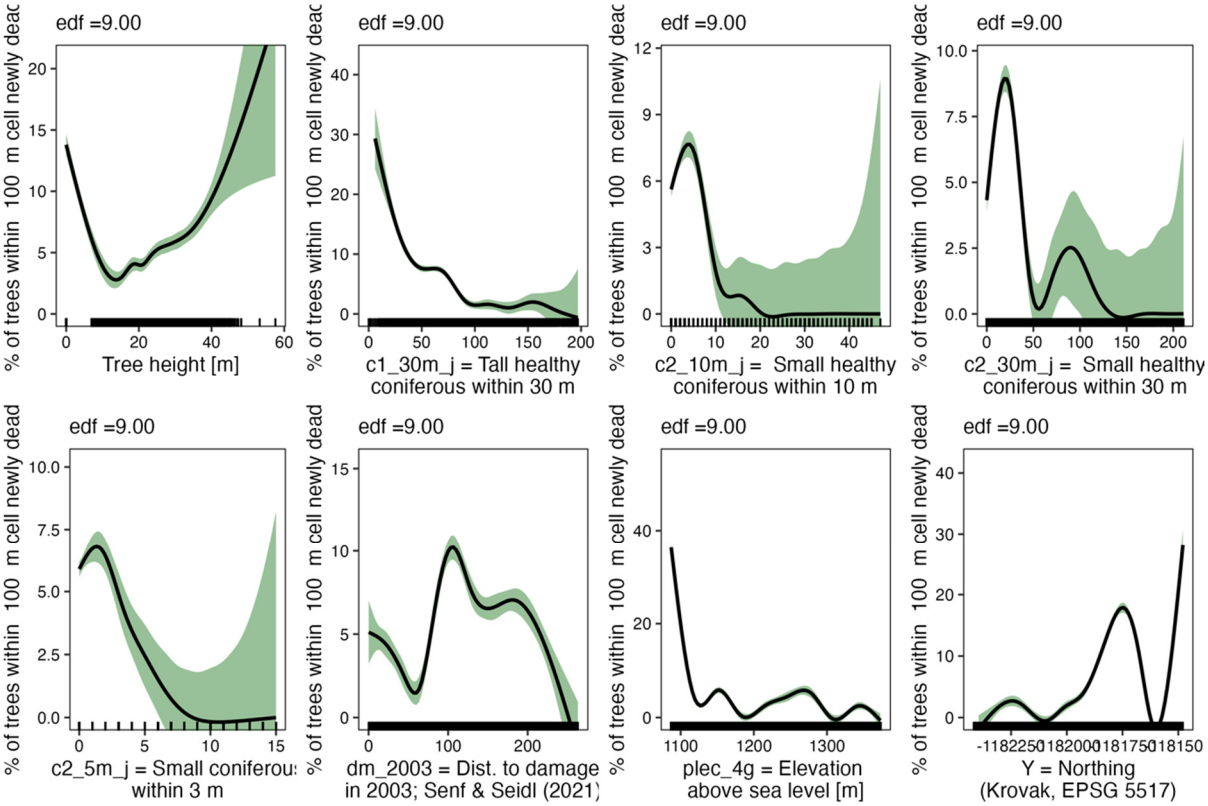


*Figure S37: General additive models (GAM) for predicting the percentage of trees within a 100 m raster cell, estimated via kernel smoothing, that were first dead in the year **2003**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

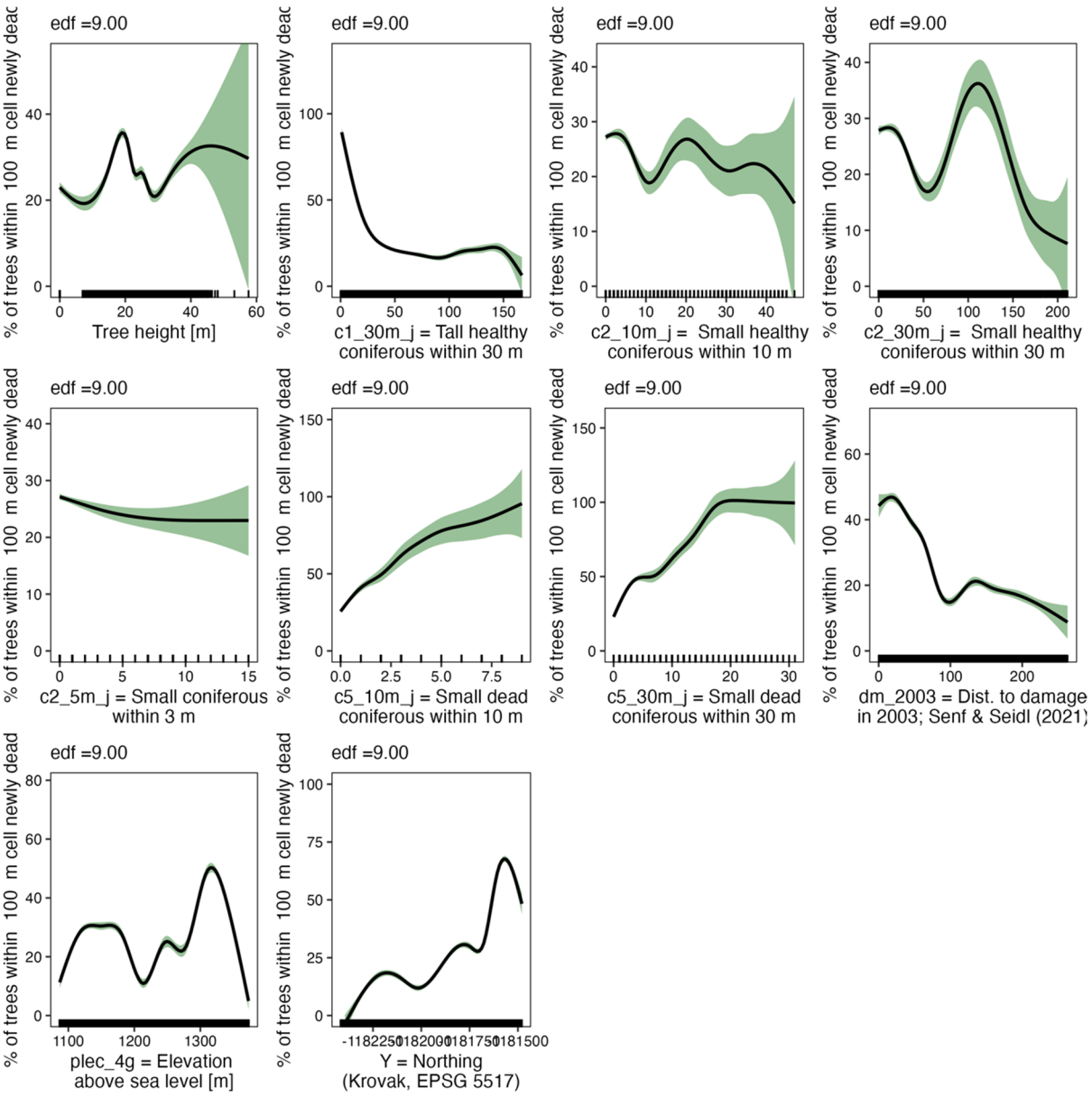


*Figure S38: General additive models (GAM) for predicting the percentage of trees within a 100 m raster cell, estimated via kernel smoothing, that were first dead in the year **2005**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

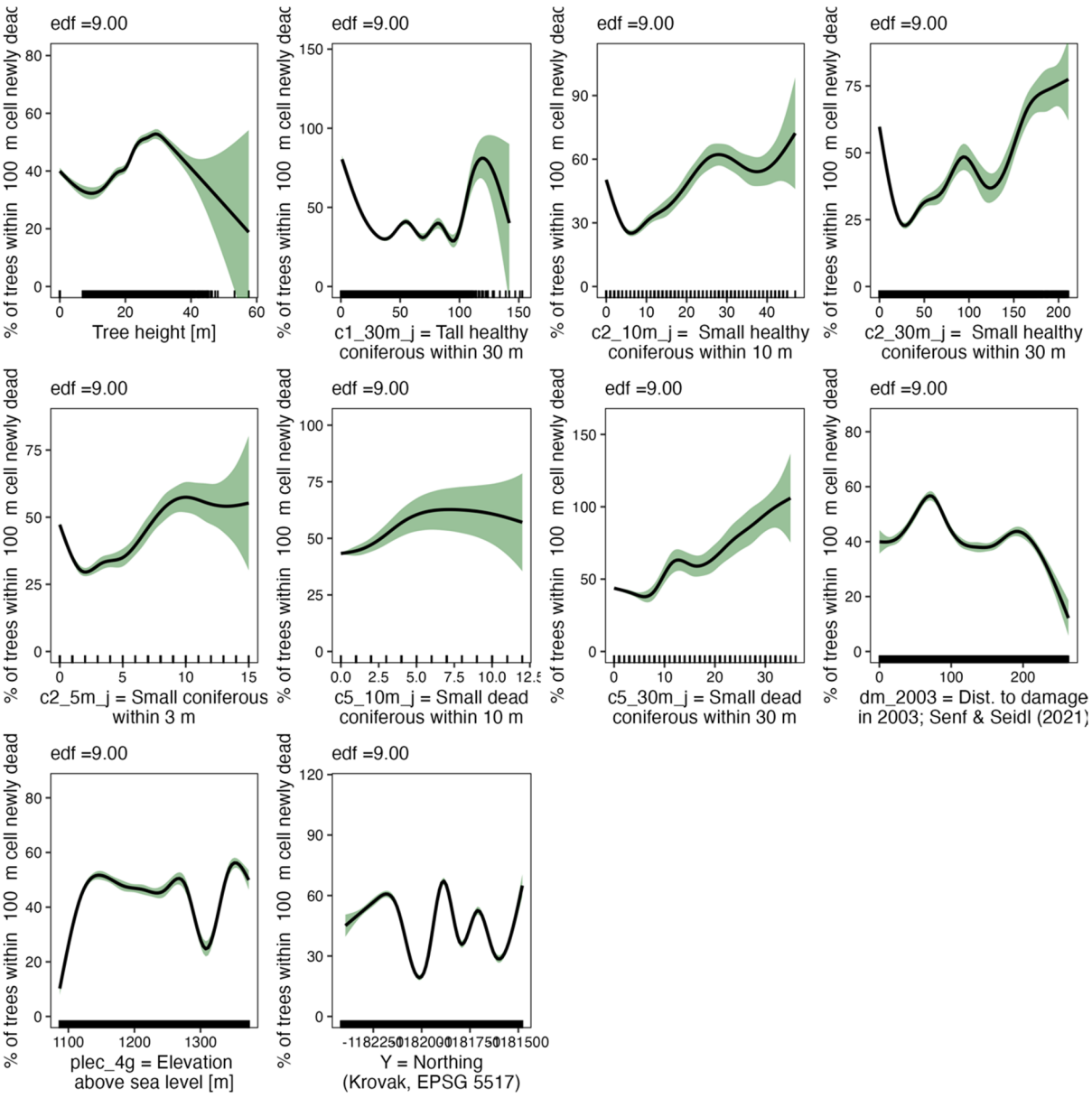


*Figure S39: General additive models (GAM) for predicting the percentage of trees within a 100 m raster cell, estimated via kernel smoothing, that were first dead in the year **2007**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

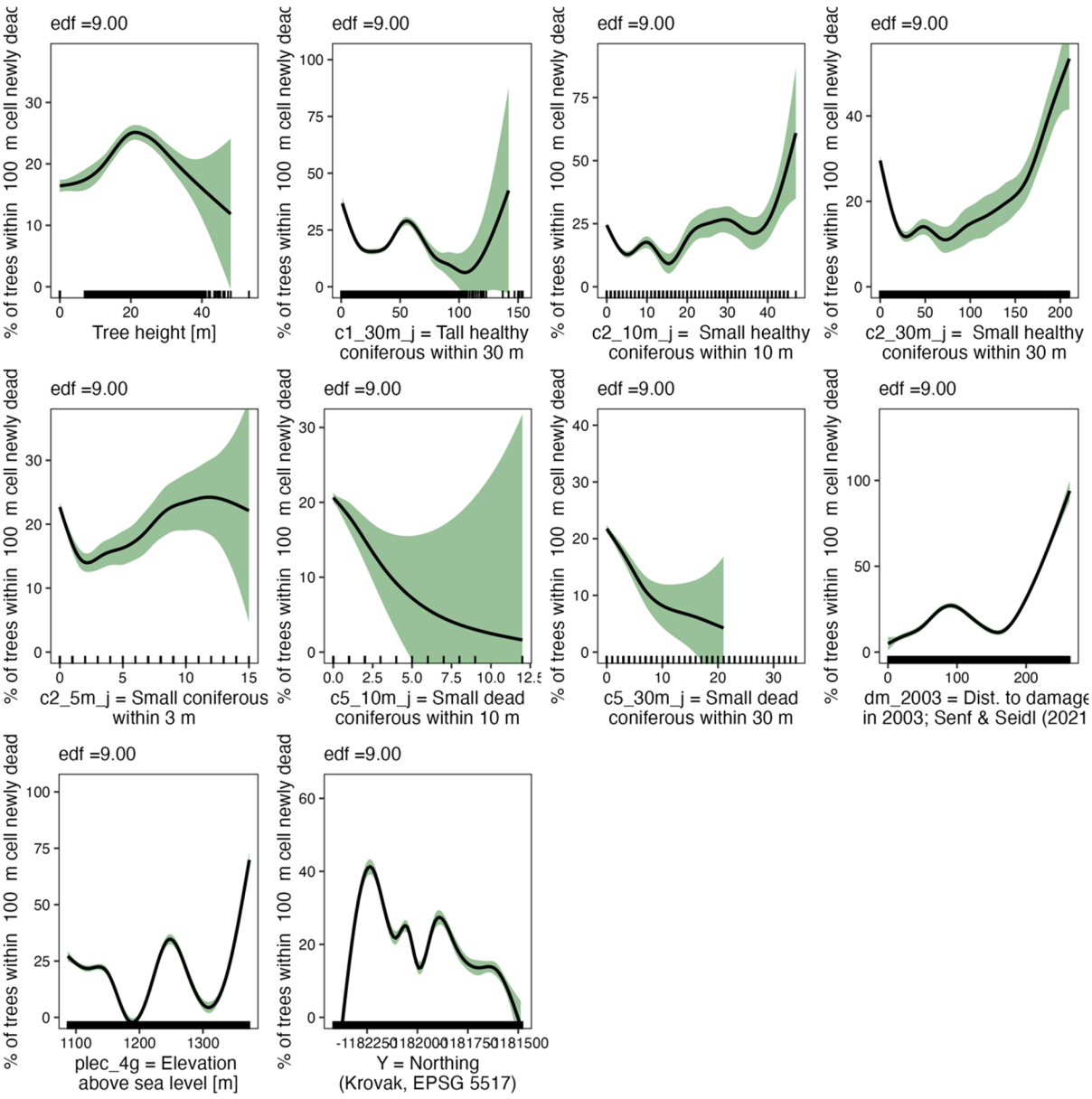


*Figure S40: General additive models (GAM) for predicting the percentage of trees within a 100 m raster cell, estimated via kernel smoothing, that were first dead in the year **2008**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

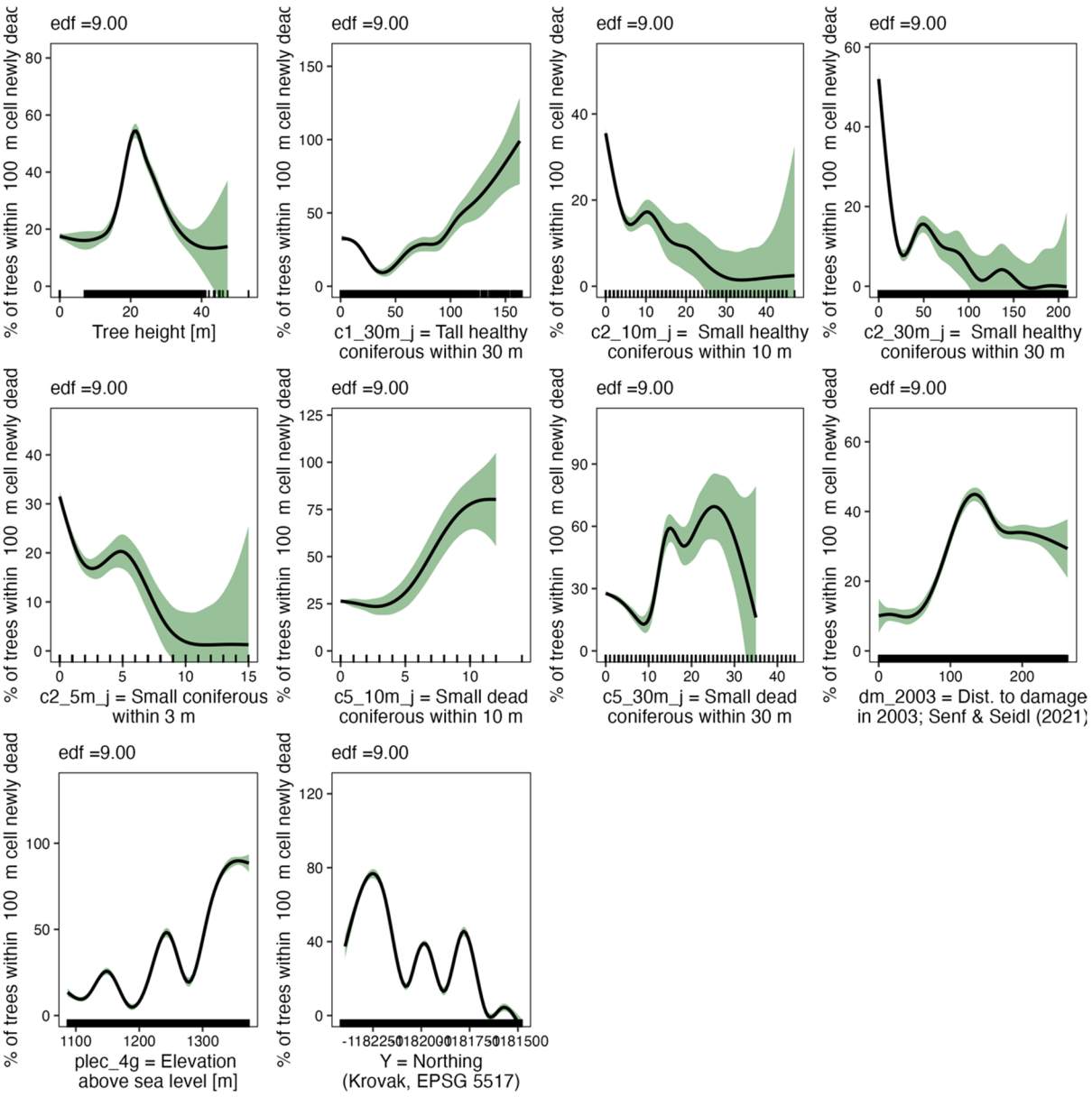


*Figure S41: General additive models (GAM) for predicting the percentage of trees within a 100 m raster cell, estimated via kernel smoothing, that were first dead in the year **2009**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

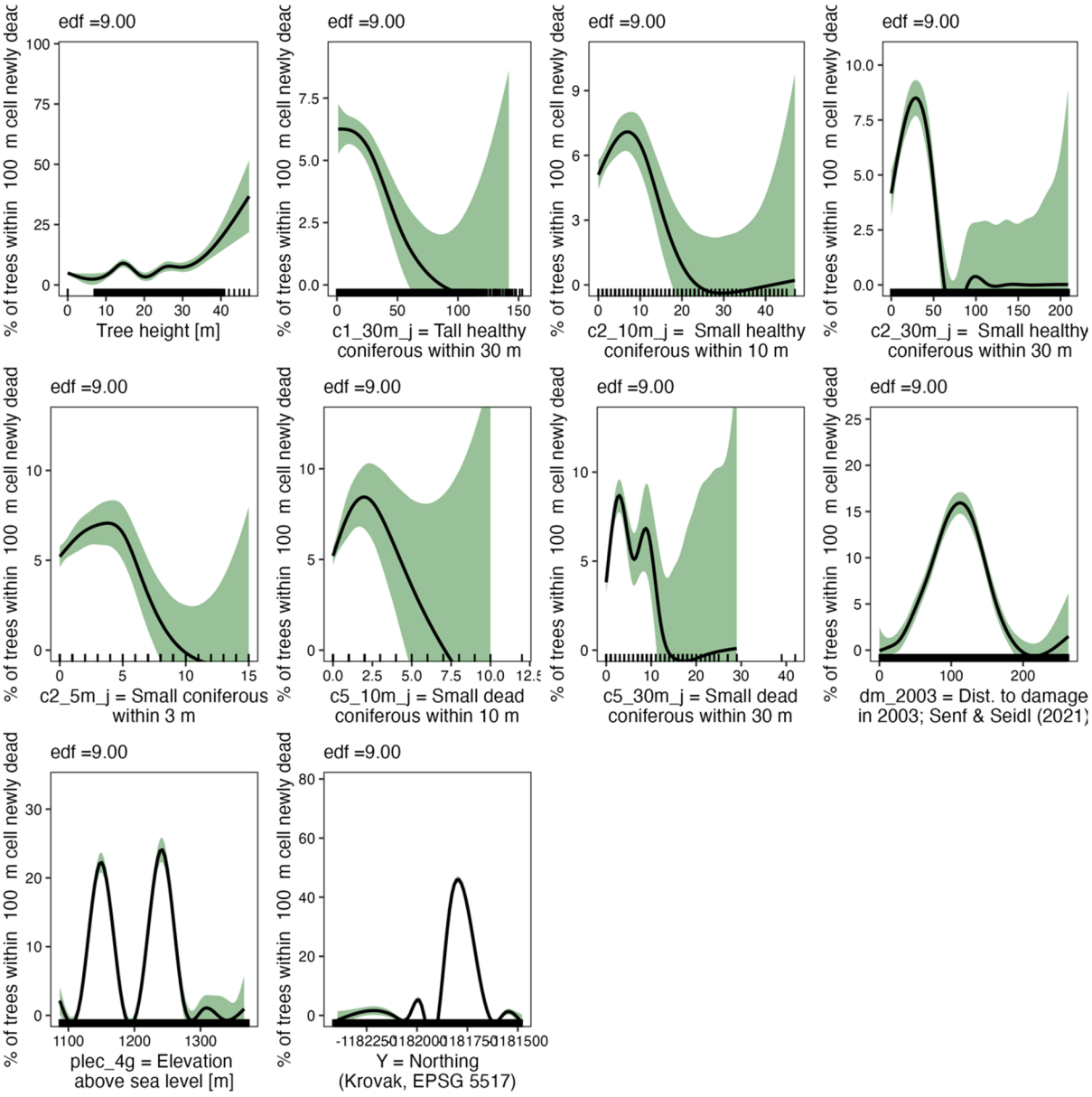


*Figure S42: General additive models (GAM) for predicting the percentage of trees within a 100 m raster cell, estimated via kernel smoothing, that were first dead in the year **2010**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

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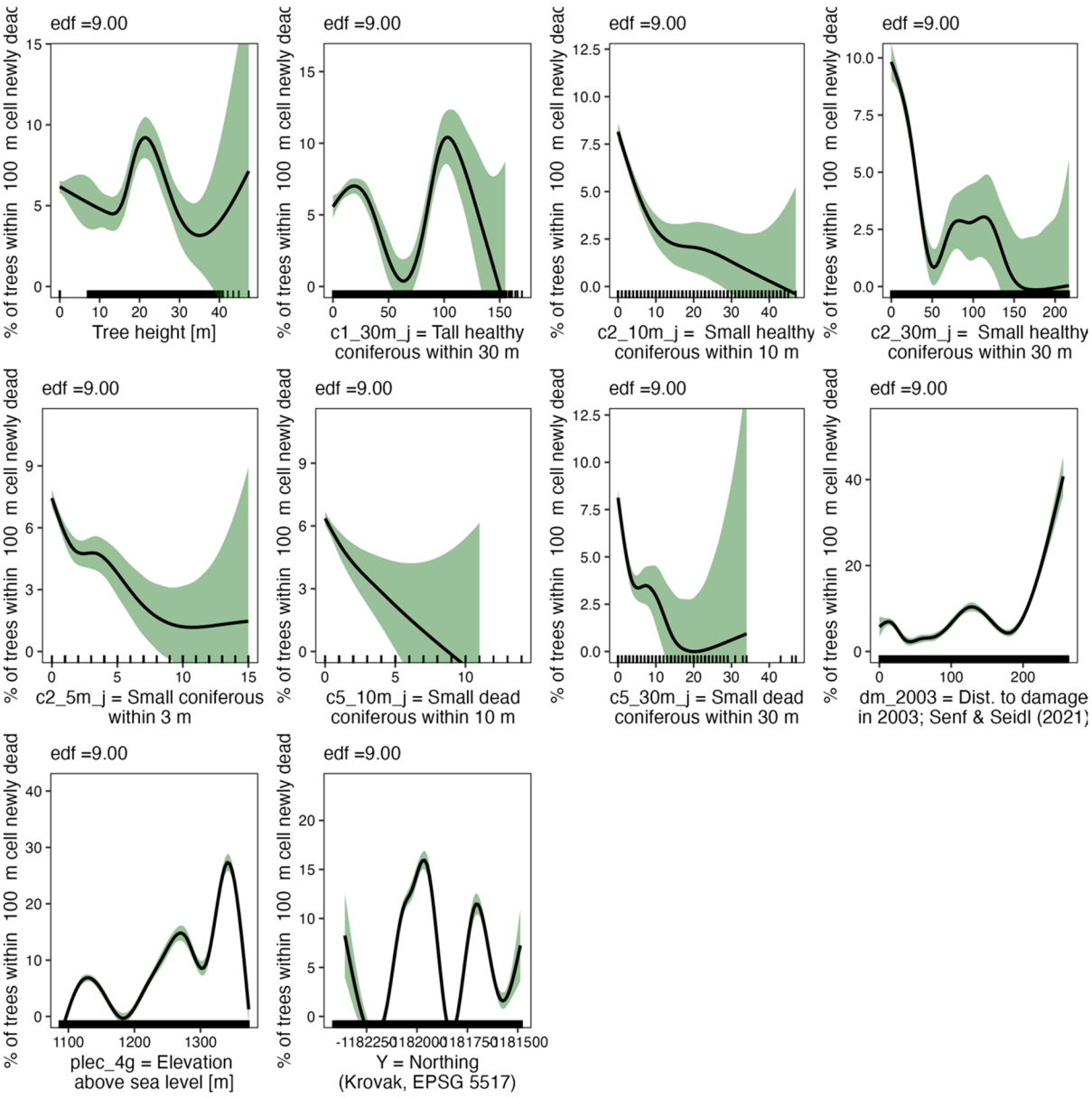

*Figure S43: General additive models (GAM) for predicting the percentage of trees within a 100 m raster cell, estimated via kernel smoothing, that were first dead in the year **2011**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

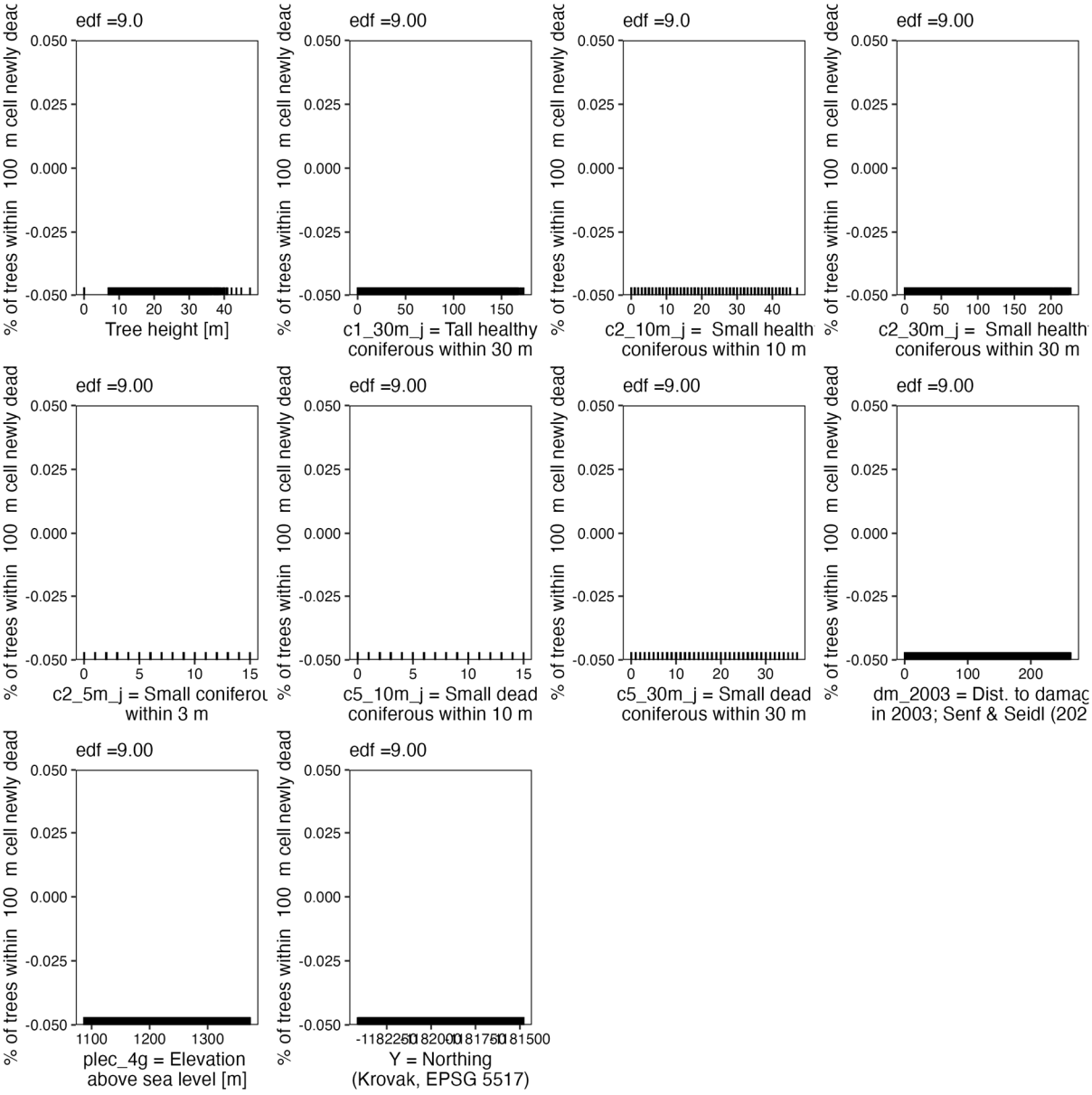

*Figure S44: General additive models (GAM) for predicting the percentage of trees within a 100 m raster cell, estimated via kernel smoothing, that were first dead in the year **2013**, of the up to 13 variables that proved the most influential in the GBM (General Boosting Models). In some cases, GAM could not be calculated. "Tre_hgh" = tree height (m); „c1_30m_j“ = Tall living coniferous trees within 30 m; „c2_3m_j“ = Small living coniferous trees within 3 m; „c2_5m_j“ = Small living coniferous trees within 5 m; „c2_10m_j“ = Small living coniferous trees within 10 m; „c2_30m_j“ = Small living coniferous trees within 30 m; "c4_3m_j" = Tall dead coniferous trees within 3 m; „c4_5m_j" = Tall dead coniferous trees within 5 m; "c3_3m_j"= Coniferous seedlings within 3 m; ; „c5_10m_j“ = Small dead coniferous trees within 10 m; „c5_30m_j“ = Small dead coniferous trees within 30 m; "plec_4g" = Elevation above sea level (m); "dm_2003" = Distance to damage as rasterized in Senf & Seidl (2021) in the year 2003; “Y” = Y coordinate = latitude. For explanations of the abbreviations refer to Table 2 in the main text.*

Part G: Relative variable importance per year; with decreasing influence, respectively

Table S5: Relative variable importance per year; with decreasing influence, respectively

Variable	2000		2003		2005		2007		2008		2009		2010		2011		2013
Tre_hgh	93.4	Tre_hgh	66.9	Tre_hgh	77.3	Tre_hgh	75.0	Tre_hgh	54.3	Tre_hgh	48.8	Tre_hgh	28.8	Tre_hgh	48.5	Tre_hgh	92.6
c1_30m_j	2.3	c1_30m_j	9.2	c2_10m_j	7.0	c2_10m_j	6.5	c2_30m_j	6.0	c4_3m_j	26.0	c4_3m_j	16.4	c5_30m_j	21.9	c4_10m_j	2.7
c2_5m	1.3	plec_4g	9.0	plec_4g	5.7	Y	4.1	dmn_2003	5.4	c1_3m_j	2.3	c2_30m_j	11.0	c5_10m_j	7.1	d_100_05	1.9
c3_30m_j	0.7	c2_5m_j	8.1	c1_5m_j	2.3	c4_3m_j	2.2	c2_3m_j	4.6	plec_4g	1.9	X	7.0	Y	6.5	c4_30m_j	1.9
c2_30m	0.6	c1_10m_j	2.0	c3_3m_j	2.3	c2_30m_j	2.1	dmn_2008	3.7	d_100_03	1.8	c2_5m_j	4.8	dmn_2011	2.5	dmn_2007	0.4
plec_4g	0.3	c3_30m_j	0.7	pl3_a_t	0.9	c2_30m_l	1.5	d_ls_08	3.3	h_100_00	1.8	h_100_07	3.3	c5_5m_j	2.3	d_50_08	0.3
Y	0.3	Y	0.7	c2_3m_j	0.8	dmn_2003	1.0	Y	2.6	h_100_07	1.4	c3_30m_j	2.9	d_ls_09	2.3	dmn_2008	0.1
pl3_a_t	0.3	c1_3m_j	0.4	c3_30m_j	0.6	d_100_07	1.0	d_ls_07	1.8	h_100_09	1.4	c4_10m_j	2.3	c1_3m_j	1.9	c5_10m_j	0.0
c2_30m_l	0.2	c4_30m_j	0.4	c1_30m_j	0.4	c3_30m_j	1.0	c3_10m_j	1.8	c3_30m_j	1.3	d_ls_06	2.1	c4_3m_j	1.9	species	0.0
h_100_00	0.2	dmn_2003	0.4	c2_30m_j	0.3	c1_3m_j	0.8	d_ls_06	1.8	d_100_07	1.2	d_50_09	1.9	c3_30m_j	1.0	SubBasn	0.0
c3_5m	0.1	c2_10m_j	0.3	Y	0.3	pl9_s_1	0.7	FII_05	1.3	d_100_08	1.1	d_50_05	1.8	c3_5m_j	0.9	FII_00	0.0
c2_30m_j	0.1	c3_10m_j	0.3	c4_30m_j	0.3	c2_3m_j	0.4	X	1.3	d_100_09	1.1	plec_4g	1.8	c4_10m_j	0.6	FII_03	0.0
c1_10m_j	0.1	pl9_s_1	0.2	c2_30m_l	0.2	c2_5m_j	0.3	c6_30m_j	1.2	h_100_03	1.1	c6_30m_j	1.2	FII_00	0.6	FII_05	0.0
dmn_2000	0.1	c2_30m_j	0.2	c4_10m_j	0.2	d_ls_06	0.3	pl3_a_t	1.1	h_100_05	1.0	pl3_a_t	0.9	c6_30m_j	0.4	FII_07	0.0
h_50_00	0.1	d_100_03	0.2	d_100_00	0.2	c1_30m_l	0.2	c1_3m_j	1.1	dmn_2008	0.9	d_ls_09	0.9	c3_3m_j	0.3	FII_08	0.0
species	0.0	X	0.2	dmn_2005	0.1	c4_30m_j	0.2	c3_30m_j	1.1	d_100_05	0.9	h_100_03	0.8	h_100_00	0.2	FII_09	0.0
SubBasn	0.0	c1_5m_j	0.2	dmn_2003	0.1	dmn_2005	0.2	plec_4g	1.1	d_50_00	0.9	dmn_2003	0.8	d_ls_06	0.2	FII_10	0.0
FII_00	0.0	FII_00	0.1	c3_5m_j	0.1	c5_10m_j	0.2	c4_3m_j	0.7	dmn_2000	0.7	c2_10m_j	0.8	d_ls_07	0.2	FII_11	0.0
c4_30m_j	0.0	c2_30m_l	0.1	X	0.1	dmn_2000	0.2	c4_30m_j	0.7	c2_30m_j	0.6	dmn_2010	0.7	c2_30m_j	0.2	FII_13	0.0
c5_30m_j	0.0	h_50_00	0.1	d_100_05	0.1	h_50_03	0.2	dmn_2007	0.5	d_100_00	0.6	d_50_10	0.7	pl9_s_1	0.1	c1_30m_j	0.0
c1_30m_l	0.0	c1_10m_l	0.1	c6_100m_j	0.1	c5_5m_j	0.1	d_100_05	0.4	d_ls_08	0.6	h_50_00	0.7	c2_10m_j	0.1	c2_30m_j	0.0
c3_30m_l	0.0	d_50_00	0.1	c4_3m_j	0.1	c1_10m_j	0.1	d_50_05	0.4	c5_5m_j	0.5	FII_00	0.6	c4_30m_l	0.1	c3_30m_j	0.0
c1_30m	0.0	c4_3m_j	0.0	c1_30m_l	0.1	d_100_03	0.1	d_100_08	0.3	h_100_08	0.5	d_50_03	0.6	pl3_a_t	0.1	c5_30m_j	0.0
c3_30m	0.0	c6_100m_j	0.0	pl9_s_1	0.1	X	0.1	c1_30m_j	0.3	c4_10m_j	0.3	h_100_08	0.5	species	0.0	c1_30m_l	0.0
c4_30m	0.0	h_100_03	0.0	dmn_2000	0.1	h_50_05	0.1	c6_10m_j	0.3	c2_10m_j	0.2	c4_5m_j	0.5	SubBasn	0.0	c2_30m_l	0.0
c5_30m	0.0	c1_5m_l	0.0	d_50_00	0.1	pl3_a_t	0.1	d_50_07	0.3	c4_5m_j	0.2	dmn_2007	0.5	FII_03	0.0	c3_30m_l	0.0
c2_10m_j	0.0	c5_30m_j	0.0	c2_5m_j	0.1	h_50_00	0.1	c4_10m_j	0.3	c5_3m_j	0.2	dmn_2000	0.4	FII_05	0.0	c4_30m_l	0.0
c3_10m_j	0.0	h_50_03	0.0	FII_00	0.0	FII_05	0.1	d_50_03	0.3	Y	0.1	h_100_09	0.4	FII_07	0.0	c5_30m_l	0.0
c4_10m_j	0.0	species	0.0	h_50_03	0.0	c4_5m_j	0.1	c2_10m_j	0.2	h_50_00	0.1	c5_30m_j	0.4	FII_08	0.0	c1_10m_j	0.0
c5_10m_j	0.0	SubBasn	0.0	c1_10m_j	0.0	c6_30m_j	0.1	d_50_00	0.2	h_50_08	0.1	d_ls_08	0.3	FII_09	0.0	c2_10m_j	0.0
c1_10m_l	0.0	FII_03	0.0	c6_50m_j	0.0	c1_30m_j	0.1	c1_10m_j	0.2	c2_3m_j	0.1	d_ls_07	0.3	FII_10	0.0	c3_10m_j	0.0
c2_10m_l	0.0	c1_30m_l	0.0	c3_10m_j	0.0	dmn_2007	0.1	h_50_03	0.2	c1_10m_l	0.1	pl9_s_1	0.3	FII_11	0.0	c1_10m_l	0.0
c3_10m_l	0.0	c3_30m_l	0.0	c1_3m_j	0.0	h_100_05	0.1	FII_00	0.2	c2_5m_j	0.1	FII_08	0.2	c1_30m_j	0.0	c2_10m_l	0.0
c1_10m	0.0	c4_30m_l	0.0	d_50_05	0.0	d_50_07	0.1	c5_5m_j	0.2	c5_30m_j	0.0	h_50_10	0.2	c4_30m_j	0.0	c3_10m_l	0.0
c2_10m	0.0	c4_10m_j	0.0	h_50_00	0.0	c3_3m_j	0.1	c2_5m_j	0.2	c3_30m_l	0.0	c4_30m_j	0.2	c1_30m_l	0.0	c4_10m_l	0.0
c3_10m	0.0	c5_10m_j	0.0	d_50_03	0.0	h_50_07	0.0	dmn_2000	0.2	c1_30m_j	0.0	d_50_07	0.2	c2_30m_l	0.0	c5_10m_l	0.0
c4_10m	0.0	c2_10m_l	0.0	h_50_05	0.0	plec_4g	0.0	h_100_00	0.2	species	0.0	c1_30m_j	0.2	c3_30m_l	0.0	c1_5m_j	0.0
c5_10m	0.0	c3_10m_l	0.0	h_100_00	0.0	FII_00	0.0	h_100_08	0.1	SubBasn	0.0	d_ls_10	0.2	c5_30m_l	0.0	c2_5m_j	0.0
c1_5m_j	0.0	c4_10m_l	0.0	c1_5m_l	0.0	h_100_07	0.0	h_50_05	0.1	FII_00	0.0	c6_5m_j	0.2	c1_10m_j	0.0	c3_5m_j	0.0
c2_5m_j	0.0	c3_5m_j	0.0	SubBasn	0.0	h_100_03	0.0	pl9_s_1	0.1	FII_03	0.0	dmn_2008	0.2	c3_10m_j	0.0	c4_5m_j	0.0
c3_5m_j	0.0	c4_5m_j	0.0	c3_30m_l	0.0	c4_10m_j	0.0	species	0.0	FII_05	0.0	d_50_00	0.2	c1_10m_l	0.0	c5_5m_j	0.0
c4_5m_j	0.0	c5_5m_j	0.0	FII_03	0.0	FII_07	0.0	SubBasn	0.0	FII_07	0.0	dmn_2005	0.1	c2_10m_l	0.0	c1_5m_l	0.0
c5_5m_j	0.0	c2_5m_l	0.0	c2_10m_l	0.0	d_50_05	0.0	FII_03	0.0	FII_08	0.0	Y	0.1	c3_10m_l	0.0	c2_5m_l	0.0
c1_5m_l	0.0	c3_5m_l	0.0	d_100_03	0.0	d_ls_07	0.0	FII_07	0.0	FII_09	0.0	h_100_10	0.1	c4_10m_l	0.0	c3_5m_l	0.0
c2_5m_l	0.0	c4_5m_l	0.0	c6_30m_j	0.0	c5_30m_j	0.0	FII_08	0.0	c4_30m_j	0.0	dmn_2009	0.1	c5_10m_l	0.0	c4_5m_l	0.0
c3_5m_l	0.0	c2_3m_j	0.0	h_100_03	0.0	h_100_00	0.0	c5_30m_j	0.0	c1_30m_l	0.0	FII_03	0.1	c1_5m_j	0.0	c1_3m_j	0.0
c1_5m	0.0	c3_3m_j	0.0	c5_30m_j	0.0	c1_5m_j	0.0	c1_30m_l	0.0	c2_30m_l	0.0	h_50_07	0.1	c2_5m_j	0.0	c2_3m_j	0.0
c4_5m	0.0	c5_3m_j	0.0	c6_5m_j	0.0	d_100_05	0.0	c2_30m_l	0.0	c4_30m_l	0.0	d_50_08	0.1	c4_5m_j	0.0	c3_3m_j	0.0
c5_5m	0.0	c1_3m_l	0.0	c1_10m_l	0.0	c3_10m_j	0.0	c3_30m_l	0.0	c5_30m_l	0.0	d_100_10	0.1	c1_5m_l	0.0	c4_3m_j	0.0
pl9_s_1	0.0	c2_3m_l	0.0	FII_05	0.0	d_50_03	0.0	c4_30m_l	0.0	c1_10m_j	0.0	c1_10m_l	0.1	c2_5m_l	0.0	c5_3m_j	0.0
X	0.0	c3_3m_l	0.0	h_100_05	0.0	SubBasn	0.0	c5_30m_l	0.0	c3_10m_j	0.0	d_100_09	0.1	c3_5m_l	0.0	c1_3m_l	0.0
d_50_00	0.0	c4_3m_l	0.0	species	0.0	FII_03	0.0	c5_10m_j	0.0	c5_10m_j	0.0	c3_10m_j	0.1	c4_5m_l	0.0	c2_3m_l	0.0
d_100_00	0.0	pl3_a_t	0.0	c4_30m_l	0.0	d_100_00	0.0	c1_10m_l	0.0	c2_10m_l	0.0	c1_5m_j	0.1	c2_3m_j	0.0	c3_3m_l	0.0
c2_3m_j	0.0	c6_3m_j	0.0	c5_30m_l	0.0	c3_5m_j	0.0	c2_10m_l	0.0	c3_10m_l	0.0	FII_05	0.1	c5_3m_j	0.0	c4_3m_l	0.0
		c6_5m_j	0.0	c5_10m_j	0.0	c3_30m_l	0.0	c3_10m_l	0.0	c4_10m_l	0.0	FII_07	0.0	c1_3m_l	0.0	pl9_s_1	0.0
		c6_10m_j	0.0	c3_10m_l	0.0	species	0.0	c4_10m_l	0.0	c5_10m_l	0.0	c1_10m_j	0.0	c2_3m_l	0.0	plec_4g	0.0
		c6_30m_j	0.0	c4_10m_l	0.0	d_50_00	0.0	c5_10m_l	0.0	c1_5m_j	0.0	d_100_05	0.0	c3_3m_l	0.0	X	0.0
		c6_50m_j	0.0	c5_10m_l	0.0	c6_5m_j	0.0	c1_5m_j	0.0	c3_5m_j	0.0	c6_10m_j	0.0	c4_3m_l	0.0	Y	0.0
		dmn_2000	0.0	c4_5m_j	0.0	c1_10m_l	0.0	c3_5m_j	0.0	c1_5m_l	0.0	FII_10	0.0	plec_4g	0.0	pl3_a_t	0.0
		d_50_03	0.0	c5_5m_j	0.0	c4_30m_l	0.0	c4_5m_j	0.0	c2_5m_l	0.0	d_100_08	0.0	X	0.0	d_ls_14	0.0
		d_100_00	0.0	c2_5m_l	0.0	c5_30m_l	0.0	c1_5m_l	0.0	c3_5m_l	0.0	c2_3m_j	0.0	d_ls_11	0.0	d_ls_13	0.0
		h_100_00	0.0	c3_5m_l	0.0	c2_10m_l	0.0	c2_5m_l	0.0	c4_5m_l	0.0	c1_3m_j	0.0	d_ls_10	0.0	d_ls_12	0.0
				c4_5m_l	0.0	c3_10m_l	0.0	c3_5m_l	0.0	c3_3m_j	0.0	c3_5m_j	0.0	d_ls_08	0.0	d_ls_11	0.0
				c5_3m_j	0.0	c4_10m_l	0.0	c4_5m_l	0.0	c1_3m_l	0.0	c4_30m_l	0.0	c6_3m_j	0.0	d_ls_10	0.0
				c1_3m_l	0.0	c5_10m_l	0.0	c3_3m_j	0.0	c2_3m_l	0.0	c3_3m_j	0.0	c6_5m_j	0.0	d_ls_09	0.0
				c2_3m_l	0.0	c1_5m_l	0.0	c5_3m_j	0.0	c3_3m_l	0.0	h_50_09	0.0	c6_10m_j	0.0	d_ls_08	0.0
				c3_3m_l	0.0	c2_5m_l	0.0	c1_3m_l	0.0	c4_3m_l	0.0	species	0.0	dmn_2010	0.0	d_ls_07	0.0
				c6_3m_j	0.0	c3_5m_l	0.0	c2_3m_l	0.0	pl9_s_1	0.0	SubBasn	0.0	dmn_2009	0.0	d_ls_06	0.0
				c6_10m_j	0.0	c4_5m_l	0.0	c3_3m_l	0.0	X	0.0	FII_09	0.0	dmn_2008	0.0	c6_3m_j	0.0
				d_100_05	0.0	c5_3m_j	0.0	c6_3m_j	0.0	pl3_a_t	0.0	c1_30m_l	0.0	dmn_2007	0.0	c6_5m_j	0.0
						c1_3m_l	0.0	c6_5m_j	0.0	d_ls_09	0.0	c2_30m_l	0.0	dmn_2005	0.0	c6_10m_j	0.0
						c2_3m_l	0.0	dmn_2005	0.0	d_ls_07	0.0	c3_30m_l	0.0	dmn_2003	0.0	c6_30m_j	0.0
						c3_3m_l	0.0	d_50_08	0.0	d_ls_06	0.0	c5_30m_l	0.0	dmn_2000	0.0	dmn_2013	0.0
						c6_3m_j	0.0	h_50_00	0.0	c6_3m_j	0.0	c5_10m_j	0.0	d_50_00	0.0	dmn_2011	0.0
						c6_10m_j	0.0	h_50_07	0.0	c6_5m_j	0.0	c2_10m_l	0.0	d_50_03	0.0	dmn_2010	0.0
						h_100_03	0.0	h_50_08	0.0	c6_10m_j	0.0	c3_10m_l	0.0	d_50_05	0.0	dmn_2009	0.0
								d_100_00	0.0	c6_30m_j	0.0	c4_10m_l	0.0	d_50_07	0.0	dmn_2005	0.0
								d_100_03	0.0	dmn_2009	0.0	c5_10m_l	0.0	d_50_08	0.0	dmn_2003	0.0
								h_100_03	0.0	dmn_2007	0.0	c5_5m_j	0.0	d_50_09	0.0	dmn_2000	0.0
								h_100_05	0.0	dmn_2005	0.0	c1_5m_l	0.0	d_50_10	0.0	d_50_00	0.0
								d_100_07	0.0	dmn_2003	0.0	c2_5m_l	0.0	d_50_11	0.0	d_50_03	0.0
								h_100_07	0.0	d_50_03	0.0	c3_5m_l	0.0	h_50_00	0.0	d_50_05	0.0
								h_100_08	0.0	d_50_05	0.0	c4_5m_l	0.0	h_50_03	0.0	d_50_07	0.0
										d_50_07	0.0	c5_3m_j	0.0	h_50_05	0.0	d_50_09	0.0
										d_50_08	0.0	c1_3m_l	0.0	h_50_07	0.0	d_50_10	0.0
										d_50_09	0.0	c2_3m_l	0.0	h_50_08	0.0	d_50_11	0.0
										h_50_03	0.0	c3_3m_l	0.0	h_50_09	0.0	h_50_00	0.0
										h_50_05	0.0	c4_3m_l	0.0	h_50_10	0.0	h_50_03	0.0
										h_50_07	0.0	c6_3m_j	0.0	h_50_11	0.0	h_50_05	0.0
										h_50_09	0.0	h_50_03	0.0	d_100_00	0.0	h_50_07	0.0
										h_100_08	0.0	h_50_05	0.0	d_100_03	0.0	h_50_08	0.0
												h_50_08	0.0	h_100_03	0.0	h_50_09	0.0
												d_100_00	0.0	d_100_05	0.0	h_50_10	0.0
												h_100_00	0.0	h_100_05	0.0	h_50_11	0.0
												d_100_03	0.0	d_100_07	0.0	d_100_00	0.0
												h_100_05	0.0	h_100_07	0.0	h_100_00	0.0
												d_100_07	0.0	d_100_08	0.0	d_100_03	0.0
														h_100_08	0.0	h_100_03	0.0
														d_100_09	0.0	h_100_05	0.0
														h_100_09	0.0	d_100_07	0.0
														d_100_10	0.0	h_100_07	0.0
														h_100_10	0.0	d_100_08	0.0
														d_100_11	0.0	h_100_08	0.0
														h_100_11	0.0	d_100_09	0.0
																h_100_09	0.0
																d_100_10	0.0
																h_100_10	0.0
																d_100_11	0.0
																h_100_11	0.0
																d_100_13	0.0
																h_100_13	0.0

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