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Phytodiversity in Christmas-tree plantations under different management regimes

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Abstract

Christmas trees are increasingly being cultivated throughout Europe. Christmas-tree plantations (CTP) are characterised by intensive vegetation management, which is essential for ensuring tree quality. Within conventional CTP, herbicides are applied extensively, whereas in organic plantations, alternative methods for vegetation management, such as grazing, are implemented. A further characteristic of organic CTP is the application of organic fertiliser. We compared soil conditions, habitat structure and phytodiversity of differently managed CTP for deriving management recommendations for promoting plant species diversity in CTP. We focused on four different plantation types, representing a gradient of land-use intensity: conventional CTP in open landscapes (CTP-OPEN) and on former windthrows (CTP-WIND), organic CTP (CTP-ORG) and fir-greenery plantations (FIR) as a baseline for lowest land-use intensity. Our study discovered clear differences in soil characteristics, habitat structure and phytodiversity among the different plantation types. However, former land use had only little impact, as the differences between the two conventional CTP (CTP-OPEN/-WIND) were small. Soil conditions were similar among the three types of CTP compared to FIR. In contrast, habitat structure and phytodiversity differed between the two conventional CTP and the less intensively managed CTP-ORG and FIR. Conventional CTP were characterised by open vegetation with relatively low plant species richness and a low number of stress-tolerant species, but some neophytes. In contrast, CTP-ORG and FIR had a high cover of grasses, the highest overall species richness and the highest number of stress-tolerant species. For promoting plant species diversity in CTP, we recommend a reduction in management intensity, especially herbicide application.

KEYWORDS
biodiversity conservation, grazing, land-use change, organic farming, perennial crop, species richness

1 | INTRODUCTION

Biodiversity in agricultural ecosystems is strongly determined by land-use intensity. In Europe, agricultural ecosystems managed by traditional low-intensity farming are of special importance for biodiversity conservation (Halada et al., 2011). These ecosystems are characterised by low disturbance and nutrient-poor conditions due to low pesticide inputs and reduced fertilisation in comparison to conventional systems. Many species benefit from such conditions; therefore, agroecosystems managed by low-intensity farming practices are among the most species-rich habitats throughout Europe (Veen et al., 2009). This holds especially true for semi-natural grassland ecosystems, which have declined dramatically throughout Europe since the onset of agricultural intensification in the 20th century (Veen et al., 2009). In arable fields, farmland biodiversity has also declined during the past decades due to agricultural industrialisation (Richner et al., 2015). Consequently, farmland biodiversity is threatened (Storkey et al., 2012). Populations of arable plants have undergone an especially marked decline (Meyer et al., 2013). In agroecosystems, a high diversity and abundance of plants is essential for promoting farmland biodiversity; for example, granivorous bird species are dependent on several herb species as a food resource, and insect diversity is correlated with plant species diversity (Marshall et al., 2003).

For conserving farmland biodiversity, the establishment of low-intensity farming systems represents one of the most important strategies in Europe (Albrecht et al., 2016). However, further research on the effects of land-use intensity and different farming systems on biodiversity is indispensable for developing specific management recommendations for the conservation of flora and fauna.

With respect to arable cropping, several studies have documented a positive effect of low-intensity farming systems, such as organic farming, on biodiversity compared to conventional management (e.g. Chamorro et al., 2016; Happe et al., 2018). Due to reduced land-use intensity, lower fertilisation rates and/or the abandonment of agrochemicals, species richness is typically higher within organic farming systems. Positive effects were found for a great variety of different taxa, such as butterflies (Rundlöf et al., 2008). As shown by meta-analyses, plants, herbivores and pollinators generally benefit from organic farming, while the species richness of predators is often reduced under organic farming (Birkhofer et al., 2014; Tuck et al., 2014).

So far, most studies comparing different farming systems have focused on cereal fields (e.g. Happe et al., 2018) or traditional perennial cropping systems, such as vineyards (e.g. Puig-Montserrat et al., 2017). In contrast, novel agricultural systems have rarely been studied. One example of a novel agroecosystem is Christmas-tree plantations (CTP; Fartmann et al., 2018), which have been increasingly established in Central Europe, especially in Germany since the 1980s (Maurmann, 2013).

Biodiversity studies on CTP are still rare and limited to birds, few arthropod taxa and plants (Fartmann et al., 2018; Gailly et al., 2017; Hagge et al., 2019). Streitberger and Fartmann (2020) were the first to analyse phytodiversity within conventionally managed CTP, where vegetation management is typically carried out by herbicide application. They compared vegetation composition of conventional CTP with other land-use types such as intensively managed non-native spruce (*Picea abies* [L.] Karsten) forests. Vegetation management in CTP is essential for the farmers to avoid negative effects of competition by plants on tree survival and quality (Saha et al., 2020). As a consequence of chemical vegetation management, conventional CTP are characterised by a unique plant species community composed of ruderal species and an intermediate species diversity compared to other habitat types, such as spruce forests or improved grasslands (Streitberger and Fartmann, 2020). Due to their characteristic vegetation structure with a high percentage of bare ground as a result of intensive vegetation management, CTP function as important habitats for ground-nesting and ground-feeding bird species (Fartmann et al., 2018). In contrast to conventional CTP, vegetation management in organically managed CTP is less intensive and achieved by alternative methods, such as grazing (Maurer, 2014). Further examples for non-chemical vegetation management practices in CTP are mowing or cultivation of cover crops (Saha et al., 2020). Besides non-chemical vegetation management, the application of organic fertiliser is a further characteristic of organic CTP (G. Kaiser pers. comm.).

Due to the low management intensity, organic CTP differ from conventional CTP in vegetation structure. Bagge et al. (2012) showed that conventional CTP promote a higher density of carabid beetles due to the greater availability of bare ground compared to organic CTP. However, despite the continuous increase of CTP in Europe, further studies on the effects of different land-use intensities on biodiversity within this agroecosystem are still unavailable.

As a follow-up to the study of Streitberger and Fartmann (2020), which compared phytodiversity in conventionally managed CTP to other land-use types, the present study analysed the role of different management regimes in CTP for promoting plant species diversity. The study was carried out in central Germany, within one of the most important areas for Christmas-tree production in Europe (German Association for Forest Protection, 2019). We created a gradient of management intensity by considering different types of CTP. For this purpose, we distinguished between conventional CTP, representing the most intensively managed CTP, and organic CTP with lower land-use intensity. As a baseline for the lowest land-use intensity within CTP, we included fir-greenery plantations, which are managed with low fertiliser inputs and low-intensive vegetation management. The study addressed the following questions:

- How do the different plantation types differ in terms of soil and habitat-structure characteristics and phytodiversity?
- How is phytodiversity in CTP influenced by land-use intensity?
- Are soil and vegetation characteristics in conventional CTP influenced by former land use? For this question, we differentiated between conventional CTP in open agriculturally used landscapes and conventional CTP on former windthrows of spruce forests.
- What management recommendations can be derived from the findings for promoting phytodiversity in CTP?

2 | MATERIALS AND METHODS

2.1 | Study area and sites

The study was carried out in the 'Sauerland' (51°6′N/8°5′ and 51°22′N/8°33′E, 250–550 m above sea level), which is located in the southeast of the German Federal State of North Rhine-Westphalia and has a size of 541 km^2. The climate is rather cool and wet (mean annual temperature: 7.5°C; mean annual precipitation: 1,184 mm; meteorological station Eslohe [351 m above sea level]; period: 1961–1990; German Weather Service, 2017). Nutrient-poor cambisols on acidic bedrock are the most dominant soils (Geologisches Landesamt NRW, 1998). The most widespread habitat types are non-native spruce forests and improved grasslands (Fartmann et al., 2018). Additionally, CTP are frequent habitats, covering 7% of the study area. During the early 1980s, many grasslands were converted to CTP due to agricultural overproduction (Rüther, 1990). Also, after the European storm 'Kyrill' in 2007, Christmas-tree cultivation expanded extensively in the study area (Fartmann et al., 2018). Most CTP in the study area are managed conventionally; this includes regular herbicide treatment and rotation cycles of about 8–12 years (Fartmann et al., 2018). Herbicide treatment is carried out at least during the first 3–4 years after the trees are planted. Herbicides are applied prior to and after planting, two times a year in spring and in autumn after lignification of the tree shoots (Körner, 1988). In spring, usually soil-acting herbicides are applied, whereas in autumn, foliar-applied herbicides are used relative to the abundance of competitive plants. Within the study area, glyphosate is the most frequently used foliar herbicide, and flazasulfuron is typically used as a soil-acting agent. Usually, the herbicides are applied extensively within CTP among the interspaces between the trees. In contrast to conventional CTP, herbicide application is banned within organic CTP, which are less frequent within the study area. Most organic CTP are grazed by sheep for vegetation management and cultivated on smaller parcels with a size of 0.8 to 1.2 ha. For manuring and insect control, organic substances are used (e.g. organic fertiliser pellets for fertilisation and pyrethrin for insect control, which is rarely necessary; G. Kaiser pers. comm.). In the study area, Nordmann fir (*Abies nordmanniana* Stev.) is the most frequent tree species cultivated within conventional and organic CTP (Maurmann, 2013; Streitberger and Fartmann, 2020).

Besides CTP, plantations for producing decorative greenery are frequently found within the study area and are often interspersed within large-scale conventional CTP. Here, Noble fir (*Abies procera* Rehder) is typically cultivated for greenery production. For the establishment of greenery plantations, the trees are often planted in mixture with Christmas trees (C. Köhler pers. comm.). Until the harvest of Christmas trees, the plantations are managed intensively like conventional CTP. After about 8–9 years, when the Christmas trees are harvested, the branches of the remaining trees are cut regularly for greenery production. During this time, the plantations are generally characterised by low-intensive management with low fertilisation and vegetation management, which is mainly carried out by mulching of vegetation; herbicide treatment only occurs in exceptional cases (e.g. in cases of high covers of *Rubus* species; C. Köhler pers. comm.). For the study, we selected only pure greenery plantations without Christmas trees where vegetation management was carried out only infrequently.

For vegetation and soil sampling, we distinguished between the four following plantation types: conventionally managed CTP within open landscapes (CTP-OPEN), conventionally managed CTP on windthrows created by the storm 'Kyrill' (CTP-WIND), organically managed CTP (CTP-ORG) and fir-greenery plantations (FIR).

2.2 | Vegetation and soil sampling

Sampling took place during July 2017 and August 2017. For every plantation type, six sites were randomly selected for vegetation sampling. All selected CTP were mid- to late-rotation stands (age 4–10 years). For conventional CTP (CTP-OPEN, CTP-WIND), we selected plantations where herbicides (glyphosate alone or in combination with a soil-acting herbicide [flazasulfuron]) were applied regularly at least once a year and where the last herbicide treatment occurred at least four months prior to the time of vegetation sampling. In contrast, all organically managed CTP selected for analysis were grazed by sheep during summer. On every site, three vegetation plots were randomly placed with a minimum distance of 5 m to the edge of the site ($N = 18$ per plantation type). The plots had a size of 5 m × 5 m, and the cover of all plant species was estimated by using the Wilmanns scale (Wilmanns, 1998). For statistics, the categories were transformed into the following percentage cover values: $r = 0.1\%$, $+ = 0.5\%$, $1 = 1\%$, $2m = 2.5\%$, $2a = 10\%$, $2b = 20.5\%$, $3 = 38\%$, $4 = 63\%$ and $5 = 88\%$ (Streitberger and Fartmann, 2020). The scientific nomenclature followed Wisskirchen and Haeupler (1998). In addition, we analysed soil and habitat-structure parameters on each plot. In every plot, soil samples were taken to a depth of 10 cm at three randomly selected locations and subsequently mixed. After air-drying and sieving, the samples were analysed for soil reaction (CaCl$_2$, WTW Multi 3,430, pH electrode SenTrix 940-3), calcium-acetate-lactate-soluble phosphate (spectrophotometer, Biochrom Libra S11), potassium (flame photometer, BWB Technologies BWB XP), mineralised nitrogen (ion chromatography, Metrohm 761 Compact IC) and total carbon (Elementar Vario EL III).

Habitat structure was analysed by estimating the cover of the following vegetation layers: Christmas/greenery trees, tree layer (woody species with heights >6 m, including Christmas/greenery trees), shrub layer (shrubs and woody species with heights between 0.5 and 6 m, including Christmas/greenery trees), herb layer (total cover of herbs and grasses), herbs, grasses and cryptogams. Moreover, we estimated the cover of litter, bare ground and stones/gravel. Estimation of all parameters was undertaken with an accuracy of 5%. Maximum herb layer and Christmas-tree heights were measured at five randomly selected locations within the plot for each layer. For analysis, the mean of the values was used.

2.3 | Phytodiversity and vegetation composition

For characterising phytodiversity, we calculated the total number of species and number of threatened species according to the regional red list (LANUV NRW, 2010) per plot. For describing vegetation composition, we determined the number of neophytes (including the tree species *Larix decidua* Mill. and *P. abies*, which are non-native to the study area) according to Haeupler et al. (2003) and NetPhyD and BfN (2013). We focused on the number of neophytes as a proxy for man-made disturbance (cf. Fanfarillo et al., 2019). We used the BIOLFLOR trait database (Klotz et al., 2002) for detecting the number of stress-tolerant plant species (including stress-tolerators, stress-tolerant ruderals, stress-tolerant competitors; cf. Grime, 2001) for every plot as an indicator of stress intensity. Stress-tolerators are characterised by low productivity and are tolerant towards stress such as nutrient limitations due to physical adaptations. Stress-tolerant competitors and stress-tolerant ruderals occur in habitats with moderate intensities of stress/productivity and low (stress-tolerant competitors) or moderate disturbance (stress-tolerant ruderals; cf. Grime, 2001). We expected a higher number of stress-tolerant species within the low-intensively managed sites, especially in FIR due to lower nutrient inputs and light availability. Species planted as Christmas trees or for greenery production (*A. nordmanniana*, *A. procera* and *Picea pungens* Engelm.) were excluded from all analyses.

2.4 | Statistical analysis

For detecting significant differences between the plantation types, (generalised) linear mixed models (LMM; GLMM) were applied (R package lme4). Site was used as a random factor. Plantation type was included in the models as a nominal fixed factor, and the analysed parameters were used as dependent variables. Depending on the distribution of the variables, either proportional binomial (percentage data), Poisson (count data) or linear models (for normally distributed variables or log-/square-root transformed variables) were run. Overdispersion was reduced within the models (proportional binomial/Poisson) by adding observation level random effects (Harrison, 2014). The overall effect of plantation type on the dependent variables was analysed by comparing the full models with reduced models without plantation type as the fixed factor and applying likelihood ratio tests. Pairwise comparisons of the plantation types were done using Tukey contrasts (glht function, R package multcomp).

Furthermore, an indicator species analysis (ISA; Dufrêne and Legendre, 1997) was carried out for identifying indicator species for each plantation type. For this, square-rooted cover values were used. Species composition was analysed by non-metric multidimensional scaling (NMDS, R package vegan, metaMDS function). For this purpose, the Bray–Curtis distance served as a distance measure and a maximum number of 100 random starts in search for a stable solution were used. Species with a frequency of <3 were excluded from the analysis.

The analyses were carried out with R 3.4.2 (GLMM; LMM; NMDS; R Core Team, 2019) and PCORD 5 (ISA).

3 | RESULTS

3.1 | Soil conditions

In contrast to the three different types of CTP (OPEN, WIND and ORG), soils in FIR were significantly more acidic (Table 1). Soils in CTP-ORG had the highest total carbon contents and differed significantly from CTP-OPEN. All three CTP types were characterised by significantly higher potassium contents compared to FIR. In contrast, there was no effect of plantation type on phosphorus and mineralised nitrogen content.

3.2 | Habitat structure

The plantation types differed significantly in habitat structure (Table 1). A tree layer was only present in FIR, whereas a distinct shrub layer with a similar cover occurred in all plantation types. The herb-layer cover and its composition differed substantially between the four plantation types (Table 1). CTP-ORG had the highest herb-layer cover and differed significantly from those of CTP-WIND and FIR. In CTP-OPEN, the plants in the herb layer were significantly higher compared to CTP-ORG and FIR. The cover of herbs was highest in CTP-OPEN and CTP-WIND and differed significantly from those of FIR. On the contrary, grass cover was significantly higher in CTP-ORG and FIR compared to CTP-OPEN and CTP-WIND. The cryptogam cover was significantly highest in FIR, differing from those of all three types of CTP (Table 1). The proportion of stones/gravel was highest in CTP-WIND and differed significantly from those of CTP-ORG and FIR. In contrast, plantation type had no effect on the cover of litter and bare ground (Table 1). Furthermore, there were no significant differences in the cover of planted trees (Christmas/greenery trees) among the different plantation types, and the height of Christmas trees was similar among all types of CTP (Table 1).

3.3 | Phytodiversity and species composition

The total number of detected species was highest in CTP-ORG (130) and FIR (129), followed by CTP-OPEN (105) and CTP-WIND (81). CTP-ORG had the highest mean species number and differed significantly from CTP-OPEN and CTP-WIND (Figure 1a). The number of threatened species was low in all plantation types with a mean ≤0.3 species and did not differ among the types (Figure 1b). Species richness of neophytes was highest in conventional CTP (CTP-OPEN and CTP-WIND), significantly differing from those of FIR (Figure 1c). In contrast, stress-tolerant species peaked in CTP-ORG and FIR, significantly differing from CTP-OPEN and CTP-WIND (Figure 1d).

TABLE 1 Mean values ($\pm SE$) of soil and habitat-structure parameters of the four plantation types (see Section 2 for explanation of abbreviations)

Parameter	CTP-OPEN	CTP-WIND	CTP-ORG	FIR	*p*
Soil characteristics					
pH	4.9 ± 0.14^b	4.8 ± 0.15^b	5.4 ± 0.24^b	4.1 ± 0.10^a	***
C (%)	2.9 ± 0.16^a	4.6 ± 0.30^{ab}	7.6 ± 1.12^b	4.2 ± 0.48^{ab}	**
N_{min} (mg/100 g)	3.5 ± 0.39	4.2 ± 0.49	3.8 ± 0.74	2.6 ± 0.50	n.s.
P (PO_4^{3-}) (mg/100 g)	0.5 ± 0.06	0.3 ± 0.05	0.5 ± 0.14	0.6 ± 0.10	n.s.
K (mg/100 g)	22.5 ± 1.79^b	18.3 ± 1.92^b	18.9 ± 3.05^b	8.8 ± 1.95^a	**
Habitat structure					
Cover [%]					
Tree layer	0.0 ± 0.00^a	0.0 ± 0.00^a	0.0 ± 0.00^a	33.6 ± 5.06^b	***
Shrub layer	47.0 ± 4.38	39.8 ± 7.18	40.4 ± 5.44	19.1 ± 4.68	n.s.
Herb layer	48.6 ± 3.94^{ab}	36.2 ± 5.19^a	68.6 ± 3.15^b	38.9 ± 4.53^a	**
Herbs	45.0 ± 3.52^b	35.0 ± 5.21^b	30.8 ± 3.64^{ab}	17.4 ± 2.48^a	**
Grasses	5.2 ± 2.54^a	1.9 ± 0.93^a	49.8 ± 4.94^b	25.2 ± 4.92^b	***
Cryptogams	22.3 ± 4.49^a	18.9 ± 4.95^a	17.3 ± 3.72^a	46.7 ± 5.39^b	***
Litter	26.7 ± 2.74	27.4 ± 5.63	33.6 ± 3.61	34.2 ± 3.19	n.s.
Bare ground	8.1 ± 2.55	7.3 ± 2.76	4.9 ± 1.55	1.4 ± 0.62	n.s.
Stones/gravel	4.8 ± 1.56^{ab}	11.4 ± 2.87^b	1.4 ± 0.65^a	2.5 ± 1.20^a	**
Christmas/ greenery trees	47.8 ± 3.91	37.8 ± 5.78	41.2 ± 4.93	46.7 ± 3.71	n.s.
Height (cm)					
Herb layer	47.4 ± 5.97^b	35.2 ± 3.52^{ab}	22.3 ± 1.86^a	21.9 ± 2.23^a	**
Christmas trees[†]	112.9 ± 8.05	112.9 ± 15.11	115.6 ± 16.32	> 300	n.s.

Note: N = 18 per type. Pairwise comparisons were done by Tukey contrasts (see Section 2 for details). Plantation types without consistent letters indicate significant differences (*p* < 0.05).
*p < 0.05, ***p* < 0.01, ****p* < 0.001, n.s. = not significant.
[†]Heights of greenery trees were not measured. Accordingly, statistic comparison was only conducted for the three types of CTP.

ISA detected indicator species for all four plantation types (Table 2). CTP-ORG was characterised by the highest number of indicator species. For this plantation type, several grassland species, such as *Cirsium palustre*, *Agrostis capillaris* and *Festuca rubra* agg., were detected as indicator species. In contrast, for CTP-OPEN and CTP-WIND, several herb species were revealed as indicator species, such as *Sonchus arvensis* and *Epilobium ciliatum* for CTP-OPEN and *Sonchus asper* and *Senecio vulgaris* for CTP-WIND. For FIR, woody species and herbs were indicator species, among them were *Acer pseudoplatanus*, *Galeopsis tetrahit* and *Senecio ovatus*. NMDS distinguished two clear groups due to vegetation composition along the first axis: CTP-OPEN and CTP-WIND were clearly separated from CTP-ORG and FIR (Figure 2).

4 | DISCUSSION

Our study discovered clear differences in soil characteristics, habitat structure and phytodiversity among the different plantation types due to current management. However, former land use had only little impact, as the differences between the two conventional CTP, CTP-OPEN and CTP-WIND, were only small. Soil conditions were similar among the three types of CTP compared to FIR. In contrast, habitat structure and phytodiversity differed especially between the two conventional CTP and the less intensively managed CTP-ORG and FIR. Conventional CTP were characterised by open vegetation with relatively low overall plant species richness and a low number of stress-tolerant species, but some neophytes. In contrast, CTP-ORG and FIR had a high cover of grasses, the highest species richness of all and stress-tolerant species.

In general, CTP are fertilised, and Christmas trees require relatively high amounts of potassium, as shortages of this nutrient decrease the resistance of trees towards stressors, such as drought, frost or pests (Matschke, 2005). Accordingly, soils in CTP are usually characterised by relatively high potassium contents compared to other habitats, such as grasslands or forests (Streitberger and Fartmann, 2020). In line with this, we found much higher potassium contents within all three types of CTP compared to FIR. Due
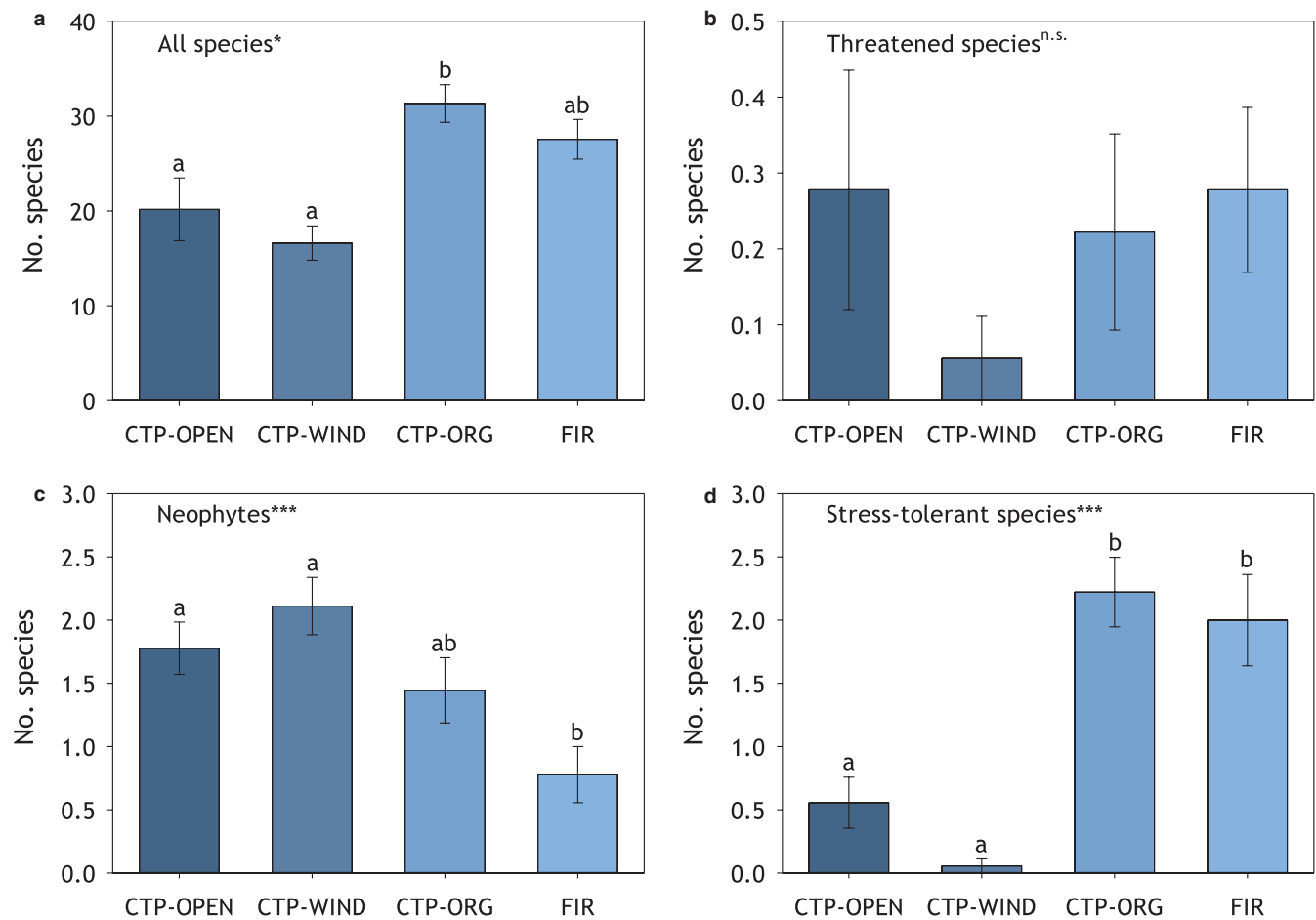
FIGURE 1 Mean values ($\pm$ SE) of plant species richness of the four plantation types (see Section 2 for explanation of abbreviations). $N = 18$ per type. Comparison between groups was done by Tukey contrasts (see Section 2 for details). Plantation types without consistent letters indicate significant differences ($p < 0.05$). *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, n.s. = not significant

to the enhanced cation availability, pH values were also higher in CTP in comparison to FIR. However, fertilisation in CTP must be carried out with caution, depending on local soil conditions; an unbalanced nutrient supply reduces the quality of the Christmas trees (Matschke, 2005; Maurer, 2014). Excessive nitrogen loads can be especially critical, as they have negative effects on tree growth and increase the sensitivity of trees towards diseases (Matschke, 2005). Consequently, mineralised nitrogen content was similar within all four plantation types, and in general, nitrogen availability was comparable to unfertilised habitats in the study area, such as windthrows or forests (Streitberger and Fartmann, 2020). However, carbon content was higher in CTP-ORG compared to CTP-OPEN. As soils in the study area do not contain lime, the higher carbon contents within CTP-ORG most likely resulted from accumulation of organic material by organic fertilisation and increased vegetation development by low-intensive vegetation management. In contrast, CTP-WIND and FIR had an intermediate carbon content, which can be explained for CTP-WIND by the former use as spruce forests, where accumulation of litter was generally high. This also holds true for FIR, where vegetation management is low, causing increased accumulation of organic matter compared to CTP-OPEN.
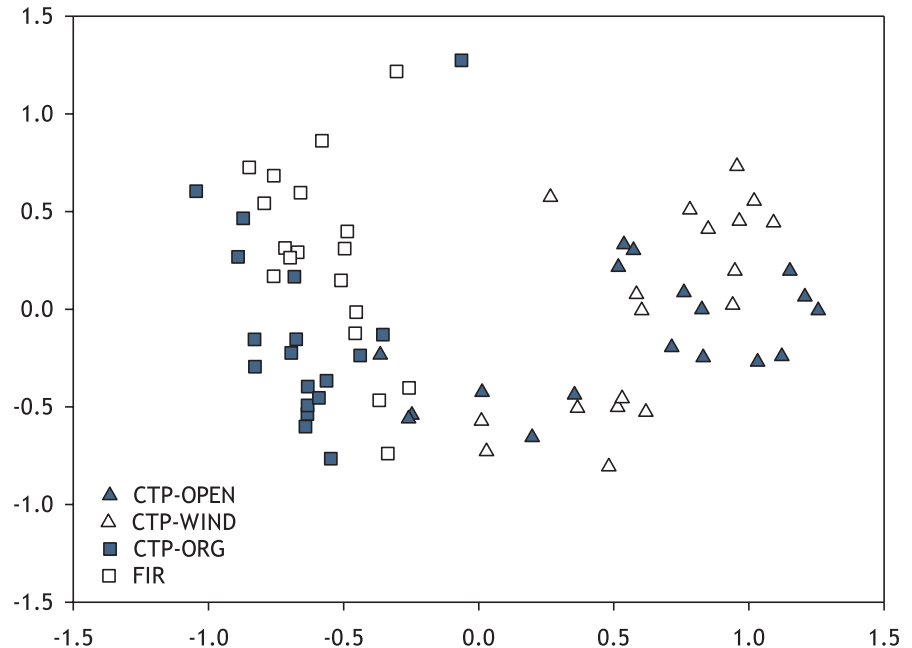
In conventional CTP, vegetation management is the most important factor influencing vegetation structure and species communities (Streitberger and Fartmann, 2020). For promoting the desired growth of Christmas trees, a vegetation-free environment is favoured by the farmers, as high herb and grass cover reduces tree survival and quality (Sæbø et al., 2009; Saha et al., 2020). Therefore, vegetation management is intensively pursued within conventional CTP, resulting in a high proportion of bare ground and stones/gravel (this study; see also Streitberger and Fartmann, 2020). This holds especially true for younger plantations with a high need for vegetation management due to the low height of the Christmas trees. In older CTP, vegetation management occurs infrequently. However, vegetation structure and composition in old CTP are very similar to those of young ones (Streitberger and Fartmann, 2020). The most striking difference in management between conventional and organic CTP is the lack of herbicide use in organic CTP (see Introduction and Material and methods). As demonstrated by our study, vegetation structure and composition differed between conventional and organic CTP, most likely due to differences in vegetation management. In contrast to conventional CTP, organic CTP were grazed by

TABLE 2 Results of ISA (Dufrêne and Legendre, 1997) for the four plantation types (see Section 2 for explanation of abbreviations)

Species	p	CTP-OPEN IV	CTP-WIND IV	CTP-ORG IV	FIR IV
Sonchus arvensis L.	***	62.1	.	.	.
Epilobium ciliatum Raf.	***	48.1	.	.	.
Vicia cracca L.	**	36.7	.	.	.
Veronica persica Poir.	**	27.3	.	.	.
Salix caprea L.	**	25.2	.	.	.
Sonchus asper (L.) Hill	***	.	57.8	.	.
Senecio vulgaris L.	***	.	45.4	.	.
Chenopodium album L.	**	.	31.8	.	.
Poa annua L.	**	.	30.5	.	.
Persicaria maculosa Gray	**	.	30.2	.	.
Polygonum aviculare L.	*	.	25.8	.	.
Cirsium palustre (L.) Scop.	***	.	.	55.6	.
Agrostis capillaris L.	***	.	.	47	.
Festuca rubra agg.	***	.	.	45.9	.
Cerastium holosteoides Fr.	***	.	.	45.1	.
Ranunculus repens L.	***	.	.	45.1	.
Myosotis arvensis (L.) Hill	***	.	.	44.1	.
Trifolium repens L.	**	.	.	41.4	.
Dactylis glomerata L.	**	.	.	41	.
Holcus lanatus L.	**	.	.	40.1	.
Urtica dioica L.	**	.	.	39.9	.
Taraxacum sect. Ruderalia Kirschner, H. Øllg. & Štěpánek	**	.	.	34.9	.
Rumex obtusifolius L.	**	.	.	34.6	.
Galium aparine L.	*	.	.	31.2	.
Poa trivialis L.	*	.	.	29.5	.
Galeopsis bifida Boenn.	**	.	.	27.8	.
Fragaria vesca L.	**	.	.	27.8	.
Cirsium vulgare (Savi) Ten.	*	.	.	27.6	.
Acer pseudoplatanus L.	***	.	.	.	56.7
Fraxinus excelsior L.	***	.	.	.	52
Quercus robur L.	***	.	.	.	51.5
Rubus fruticosus agg.	***	.	.	.	41.9
Galeopsis tetrahit L.	**	.	.	.	40.4
Sorbus aucuparia L.	***	.	.	.	38.9
Senecio ovatus ([G.] Gaertn., B. Mey. & Scherb.) Willd.	**	.	.	.	36.3
Digitalis purpurea L.	**	.	.	.	30.7
Hypericum perforatum L.	**	.	.	.	30.7
Prunus avium L.	**	.	.	.	28.6
Mycelis muralis (L.) Dumort.	**	.	.	.	28.5

Note: $N = 18$ per type. The maximum indicator values for significant indicator species are shown. Only species with a maximum indicator value (IV) ≥25 are presented. Species are sorted by IV for the considered plantation type. Grey shaded values: Species are indicator species for this plantation type. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

FIGURE 2 NMDS ordination with vegetation samples of the four plantation types (see Section 2 for explanation of abbreviations). $N = 18$ per type. Four dimensions, stress: 12.5

sheep and often sown with grassland species (own observation). Accordingly, they had a higher grass cover compared to conventionally managed CTP. Besides vegetation management, organic CTP also differ in terms of fertilisation from conventional CTP (application of organic substances in organic CTP, see Material and methods). However, as soil conditions were similar among both types of CTP, we believe that the fertiliser which was used had only little impact on species composition. In contrast, organic CTP were often situated on smaller sites adjacent to forests compared to conventional CTP (own observation). Therefore, it is possible that edge effects also influenced phytodiversity within organic CTP.

Compared to CTP, vegetation management in FIR is less intensive (see Section 2). Within our study area, the greenery plantations were composed of taller trees than in CTP and, therefore, had a more forest-like character compared to CTP. However, greenery is harvested by regularly cutting off the branches. Therefore, the trees are characterised by slim crowns, and the plantations have a light canopy and denser ground vegetation compared to intensively managed non-native coniferous forests, which are widespread within the study area and characterised by low structural and species diversity (Streitberger and Fartmann, 2020).

In contrast to the conventional CTP, the less intensively managed plantations, CTP-ORG and FIR, had a higher species richness, which most likely resulted from the lack of herbicide use and reduced herbicide input respectively. This is in line with other studies documenting positive effects of organic farming on phytodiversity within perennial cropping systems, such as vineyards, due to abandonment of herbicide application (e.g. Puig-Montserrat et al., 2017). In general, plant species richness in conventional CTP is similar to the most widespread habitat types within the study region, grasslands, windthrows and non-native spruce forests (Streitberger and Fartmann, 2020).

The diverse management across the different plantation types favoured specific species traits and characteristic plant communities. As highlighted by the NMDS, the conventional CTP (CTP-OPEN and CTP-WIND) were clearly separated from CTP-ORG and FIR in terms of species composition. Although both types of conventional CTP differed in former land use, current land use is similar and very likely explains their comparable plant communities. The two types of conventional CTP were characterised by disturbance-dependent vegetation composed of herb species that typically dominate in agricultural habitats (cf. Marshall et al., 2003; Salonen et al., 2011). Ruderal species, such as *Senecio vulgaris*, *Sonchus arvensis* or *Veronica persica*, were identified as indicator species for conventional CTP. Additionally, conventional CTP promoted the occurrence of neophytes compared to FIR. *Epilobium ciliatum* was especially dominant within conventional CTP, which is most likely due to its resistance to herbicides such as glyphosate (cf. Matulevičiūtė, 2016).

Although NMDS showed weak differences in species composition among CTP-ORG and FIR, ISA revealed different indicator species for these two plantation types, which is most likely attributed to management. Due to sowing of grassland species and grazing, most indicator species of CTP-ORG were typical grassland species, such as *Agrostis capillaris* and *Festuca rubra* agg. In contrast, FIR were characterised by woodland-type vegetation composed of typical forest and woody species. CTP-ORG were often situated adjacent to forests, and woodland species occurred regularly (own observation). Therefore, CTP-ORG were floristically more similar to FIR than to conventional CTP, as shown by NMDS. In line with this, CTP-ORG and FIR had a higher number of stress-tolerant species compared to conventional CTP. These especially included stress-tolerant competitors typical for nitrogen-poor soils (e.g. *Pimpinella saxifraga* L.) or low light availability (e.g. *Epilobium montanum* L. or *Scrophularia nodosa* L.). In FIR, nitrogen availability was slightly lower compared to CTP. Furthermore, light availability was lower due to the higher

growth of the planted trees. In addition to low disturbance, these two factors favour stress-tolerant competitors in FIR. In CTP-ORG, nitrogen availability was comparable to those of the conventional CTP. Most likely, stress-tolerant competitors occur more frequently within CTP-ORG due to low disturbance and the adjacency to forests from which species adapted to nutrient-poor and/or shady conditions invade the sites.

CTP and fir-greenery plantations had a low importance for threatened species. This also holds true for the dominant habitat types found within the study area, such as non-native spruce forests and improved grasslands (Streitberger and Fartmann, 2020). However, prior studies highlighted the importance of conventional CTP as breeding habitats for threatened bird species, such as the woodlark (*Lullula arborea* L.; Fartmann et al., 2018). The high proportion of open ground favours arthropod activity within CTP (Bagge et al., 2012) and offers access to food for insectivorous or granivorous bird species.

In conclusion, our study revealed that vegetation composition and plant species diversity in CTP were strongly determined by management. Low-intensity land use with a lack of herbicide application and a reduced herbicide input, as undertaken within organic CTP and greenery plantations, respectively, favoured species diversity compared to conventional CTP.

4.1 | Implications for conservation

According to the results of this study, we recommend a reduction in management intensity, especially herbicide application, for promoting plant species diversity in CTP. Instead, alternative methods for vegetation management should be preferred, such as grazing or mechanical removal by mowing or mulching, which are carried out within organic Christmas-tree cultivation. This holds especially true for small-scale parcels where these methods are more feasible than in large-scale production. For the establishment of grazed CTP, we recommend the strict use of regional seed mixtures or natural revegetation. Besides these measures, other non-chemical vegetation management methods are applied in CTP, such as the application of organic or inorganic mulch (e.g. hardwood chips, black plastic mulch), thermal vegetation management (e.g. flaming) or the establishment of cover crops (Sæbø et al., 2009; Saha et al., 2020). However, within our study area, these methods are uncommon. Until now, knowledge on the effects of these vegetation management methods on phytodiversity is limited (cf. Saha et al., 2020). Next to reduced chemical input, alternative measures for vegetation management may be associated with other positive ecological side-effects. For example, the application of organic mulch can increase soil moisture—for example by reduced evapotranspiration and increased percolation and retention—and increases soil nutrients by its decay (Saha et al., 2020).

Nonetheless, non-chemical vegetation management, such as grazing or mulching, is labour-intensive (Saha et al., 2020) and hardly applicable within large-scale cultivation. Herbicide treatment is, therefore, still the most feasible method for vegetation management within large-scale plantations. Due to the open vegetation structure, such plantations even promote threatened bird species (Fartmann et al., 2018). However, for reducing herbicide inputs into the environment, we recommend the avoidance of herbicide application as much as possible (e.g. by the abandonment of herbicide treatment along the plantation fences and tramlines; Fartmann et al., 2018).

For increasing habitat heterogeneity within large-scale CTP, which are usually conventionally managed, we recommend a diversification of local management intensities. This can be achieved by establishing differently aged parcels requiring different intensities of vegetation management. Furthermore, greenery plantations increase habitat diversity within CTP. As shown by our study, these plantations represent nutrient-poor and more species-rich habitats compared to conventional CTP and, thus, contribute to species diversity within homogeneous, intensively managed landscapes, such as large-scale CTP.

The establishment of new CTP should be restricted to homogeneous landscapes with habitats of low conservation value (Streitberger and Fartmann, 2020). Studies on bird communities showed that CTP increased bird species richness within homogeneous landscapes dominated by intensively managed grasslands, while this was not the case within heterogeneous landscapes (Gailly et al., 2017). Generally, the establishment of CTP should be avoided within heterogeneous habitats, such as windthrows, as these habitats play an important role for biodiversity (e.g. as breeding habitats for threatened bird species; Fartmann et al., 2018).

CONFLICT OF INTEREST

No conflicts of interest have been declared.

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