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European Union's Natura 2000 network: an effective tool for nature conservation? The relic pine forests of the Franconian Jura

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Abstract

Land use change and intensification are the most important direct drivers of decreasing biodiversity globally. Therefore, the European Union created the Natura 2000 network to protect endangered species and habitats. Here we are interested how the ambitious European goals are actually implemented studying a Natura 2000 habitat, the "Sarmatic steppe pine forests" (Code 91U0) in a national hotspot of biodiversity in Franconia (Germany). These forests are a relic of the postglacial warm stage, preserved by human land use since the Neolithic, but are now heavily declining due to abandonment of traditional land use practices. Applying a long-term monitoring over 30 years including all existing (>600) stands and a Random Forest classification model, we show that less than a quarter of the area of 1990 and only about 1% of 1950 still exists. Immigration of spruce and beech and forest conversion was responsible for this massive loss, impacting the light-demanding species composition. However, nearly no conservation efforts were undertaken, and replanting with broadleaved trees is still ongoing even after the designation as protected habitat in 2008. Therefore, these forests demonstrate how land use change and intensification (i.e. global change) continuously endanger a habitat protected by national and European law.

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Introduction

Across the world, human population growth together with rising per-capita demands for natural resources and energy are increasing human impacts on nature (Steffen et al. 2015). These impacts are caused by land use change and intensification, which are considered the most important direct drivers of declines in biodiversity and ecosystem services (Díaz et al. 2006; Cardinale et al. 2012; IPBES 2018a, b; IPBES 2019). Worldwide ~ 50% of natural terrestrial ecosystems have been converted to crop and pasture land, managed forest or settlement areas (Gaston and Spicer 2004). In particular, tropical forests experienced a heavy decline, e.g. in East Africa forest have undergone a nearly complete decline of 93% since 1900 (Aleman et al. 2018). A recent example in highly developed regions with a stagnant population is the massive decline of biomass, abundance, and number of arthropods, in particular insects during the last decade in Germany, mainly due to the intensification of agriculture (Seibold et al. 2019).

Another widespread phenomenon of land use change in Europe is the abandoning of traditional land use practices (e.g. grazing and mowing) resulting in either different fallow and succession stages or the substitution by more intensified modern land use. Both means in most cases the decline of endangered and rare species (Leuschner and Ellenberg 2017; Vera 2000; Silva et al. 2019). To reduce the loss of biodiversity, the states of the European Union have adopted the Habitats Directive (HD, or Flora Fauna Habitat Directive, FFH) (Council Directive 92/43/EEC (1992)) as a cornerstone to ensure the conservation of over 1000 rare, threatened or endemic plant and animal species together with their 233 listed habitats within a continental-scale network of Special Areas for Conservation (SAC)—the Natura 2000 network.

The Northern Franconian Jura, a mountain range of about 2,000 km^2 in Bavaria, famous for its rich calcareous flora was designated as a national biodiversity hotspot of Germany with a large share of Natura 2000 sites. Here, smallholder agriculture has created a mosaic of different vegetation and land use types during the last centuries, where the highest species richness is recorded in habitats with moderate human impact such as dry grasslands, but particularly Scots pine (*Pinus sylvestris*, hereinafter partly referred to as pine) forests on dolomite. These pine forests are classified in the Buphthalmo-Pinetum (Hemp 1995) association.

The occurrence of the Buphthalmo-Pinetum is partly due to geological and climatic peculiarities: Most important was the formation of reef dolomites in the Jurassic Sea. They represent the initial substrate for the dry, sandy dolomite soils on which the Buphthalmo Pinetum grows. Dolomite is quite abundant in this area (around 20% of the Northern Franconian Jura) in contrast to the Southern Franconian Jura and the adjacent Swabian Jura where it is nearly missing (Meyer 1972). Furthermore, the pan-like depression of the central parts of the Northern Franconian Jura situated below 500 m a.s.l., where most of the still existing pine forests occur, is located in the rain shadow and receives less precipitation than the higher edges of the Franconian Jura. Other factors include the existence of a reef barrier in the Jurassic sea influencing the content of marl in the seawater and with this the scarcity of loamy soils in the study area (Hemp 1995).

Besides these abiotic site conditions, anthropogenic influence promoted the development of the pine forests on dolomite (Hemp 1995): Already in the early Neolithic, about 6000 BP humans with their herds of cattle and shifting cultivation had indirectly favoured the pine that occurred in the area since the pre-Boreal. This prevented the later immigrating beech from gaining a foothold and replacing the pine. Anthropogenic influences during

the Middle Ages reaching to modern times successively increased and forest pastures together with litter raking enhanced the dominance of pine in the dolomitic central parts of the Franconian Jura. Those relict pine stands are therefore testifying the once abundant, postglacial vegetation cover of the Franconian Jura together with the (pre)historical anthropogenic influences. Therefore, most of these forests are not part of the Potential Natural Vegetation (PNV) but "anthropo-zoophylact" relic forests preserved by humans and their grazing livestock over several thousands of years (Hemp 1995).

Natural regeneration of pine needs disturbance to create crown gaps and open soil (Aleksandrowicz-Trzcińska et al. (2013); Bílek et al. 2018; Brooker et al. 2006; Muscolo et al. 2017; Vera 2000). Historical land use practices such as wood pasture are considered well suited to maintain *Pinus sylvestris* stands due to the creation of open soil, grass defoliation, and intensive browsing of broadleaved trees (Gams 1930; Gauckler 1938; Hemp 1995). Similarly, wood pasture and litter use promote understory diversity of plant, bird, insect, and fungi species. This has been studied extensively in pine stands worldwide (Osem et al. 2017; Lindgren and Sullivan 2012; Hancock et al. 2010; Helbing et al. 2014; Hemp 1995; Hemp and Hemp 2003).

However, during times with intensive wood pasture and litter raking, degradation of the forest and tree damage has been observed and lead to lower timber harvesting compared to current wood production in forests (Rebel 1920; Vera 2000). The study area was the center of litter raking in Bavaria with the highest amount of harvested litter, where in particular beech and spruce were suffering the most (Rebel 1920; Zenneck 1960). Therefore, these types of forest uses have been abandoned in Bavaria, when more efficient feeding practices for cattle were introduced in the 1950s. However, due to these changes of land use, extent and species composition of those stands are changing drastically (Hemp 1995) and in 2008 they were designated as Natura 2000 habitat ("Sarmatic steppe pine forests", code 91U0).

This strong declining trend of pine forests on dolomite in the past decades is enhanced by active planting of broadleaved trees, which is in line with the widely accepted objective of forest policy in Germany of converting pure monocultures of pine and spruce into more productive and ecologically stable mixed stands rich in hardwood. However, this contradicts their status as protected habitats by Bavarian law on nature conservation and as Natura 2000 habitat. Similar problems occur in another protected pine forest habitat in Bavaria, the Central European lichen pine forests, code 91T0 (LWF 2012) and in the Mediterranean pine forests within the habitat 2270* (Bonari et al. 2018).

Another aspect in this forestry—nature conservation conflict is climate change. The potential for climate adaptation of no other dominant tree species in Europe is discussed as controversially as in the case of pine (Bolte et al. 2009), and its vitality especially with increasing periods of heat and drought and related prognoses for climate adaptation are assessed very divergently (e.g. Bose et al. 2020; Eickenscheidt et al. 2019; Savolainen et al. 2011; Seidel and Menzel 2016).

On the background of the current discussion regarding agenda and aims of the global Post-2020 Global Biodiversity Framework (as part of the UN Convention on Biodiversity (CBD) we test the achievements of Natura 2000, using as example the current situation of the "Sarmatic steppe pine forests", a flagship vegetation type for nature conservation in Europe under the responsibility of Germany. For this, we evaluated three inventories from 1990, 2012, and 2020 monitoring the extent of all existing (> 600) forest stands before and after their designation as Natura 2000 protected habitat in 2008 belonging to three different districts. We expect a similar declining trend of their extent in all three districts after 2008, however with differences inside (slower shrinking) and outside (faster shrinking) SAC. We compared the results with the historical distribution of pine forests on dolomite around

1950 before the abandonment of the traditional land use assessed by a Random Forest classification model. Furthermore, we studied "passive" and "active" causes of habitat loss (i.e. successional colonization of other tree and shrub species on one side and active replanting on the other, both resulting in degradation of the light-demanding herb layer) and expect that natural succession is more important than replanting. Finally, we monitored the vitality of *Pinus sylvestris* after the last extreme dry and hot years expecting an increasing mortality. With this, we inspected for the first time the condition of a complete Natura 2000 habitat inside and outside protected areas examining how a wealthy country like Germany (and Europe) implements the obligations of the UN Convention on Biodiversity.

Materials and methods

Study area

Location

The study area is located in southeastern Germany and amounts to an area of about 2,500 km^2. The area lies in the Franconian Jura which can be split into a northern, central, and southern part. The whole Franconian Jura amounts to about one-tenth of Bavaria. The study area includes the main distribution area of Franconian pine forest on dolomite (Hemp 1995) comprising the whole area of the Northern Franconian Jura and partially the adjacent Middle Franconian Jura as shown in Fig. 1, i.e. about one third of the total extension of the Franconian Jura. Administratively, it belongs to the three districts of Middle Franconia, Upper Franconia and Upper Palatinate. Today around 43% of the study area is covered by forest, of which three-quarter is privately owned (Bavarian forestry administration 2019).

Geology

The landscape formation of the Franconian Jura results from Jurassic sedimentation and riff colonization (Keupp et al. 2007) about 200–150 mya ago. Through the uptake of magnesium, Upper Jurassic limestone partially transformed into the more weathering resistant dolomite (Nollau 1989). Due to changing weathering resistance of the bedrock types and due to the tough structure of dolomite, the landscape shows a high variety of formations and stratifications, providing many different habitats. As dolomite dissolves into a sandy substrate, it also offers restricted water availability during the year. Dolomitic sands promoting water drainage provide especially dry and stressful conditions for the covering vegetation. Thus, the dolomite substrate is a prerequisite for the occurrence of the ecosystem under study (Hemp 1995).

Topography and climate

The study area ranges from 280 to 650 m a.s.l. elevation with most of the area being between 450 and 500 m a.s.l. (Hemp 1995), i.e. in the submontane zone. The landscape is dominated by numerous dolomitic hills, partly crowned with exposed dolomite rocks, remnants of the former reefs (Fig. 2a).
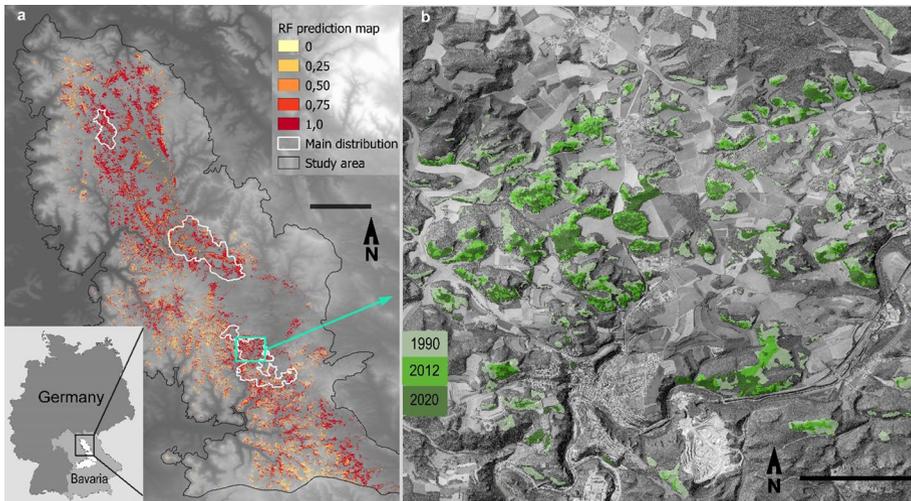
Fig. 1 Maps showing modelled and surveyed distribution of pine forests on dolomite. **a** Random Forest prediction map for the whole study area, showing the modelled extent at around 1950 in five probability classes (with red being the most probable class and yellow the lowest) for forest areas on dolomite bedrock (details see in method section), white bordered areas indicate present main distribution areas, **b** part of the present main distribution area in the central Northern Franconian Jura showing the extent of pine forests on dolomite 1990, 2012 and 2020. Scale bars indicate 10 km (**a**) and 1 km (**b**). Map source: Landesamt für Digitalisierung, Breitband und Vermessung, München (2021)

Mean annual precipitation ranges between around 700 and 1100 mm with median values of about 930 mm, and the mean annual temperature is 7–8 °C (DWD 2018).

Vegetation records

In total, 2500 vegetation plots (relevés) were taken in the Franconian Jura mainly in the years 1990–2000 following the method of Braun-Blanquet (1964). These plots comprise all occurring vegetation types (about 150 associations) with over 1000 vascular plant species. Based on a cluster analysis, pine forests on dolomite (Buphthalmo-Pinetum) were floristically delineated (data and vegetation tables in Hemp, 1995). During three field surveys (1990, 2012, and 2020) the extent of pine forests on dolomite was mapped solely by the first author assuring that the results are comparable. The survey of 2012 was partly in the frame of a pine forest inventory in Bavaria (LWF 2012), where the methodology is explained. Topographical maps 1:5000 with contour lines, aerial photographs of the same scale and GPS were used for the delineation of Buphthalmo-Pinetum stands in the field. In all stands presence of immigrating young trees and shrubs (mainly *Picea abies*, *Fagus sylvatica* and *Corylus avellana,* which represent the major threats for the light-demanding herb layer) were recorded during the survey of 2012. Stands with a dense (> 50%) coverage of such species in the shrub layer were excluded.

To assess the impact of the extreme dry and hot years 2018–2020 on the vitality of *Pinus sylvestris*, pine trees older than 60 years with recent dead crowns (i.e. > 60% dead) were recorded during the survey of 2020, disregarding old standing deadwood. Presence / absence data of affected trees were used to calculate the share of stands with sick trees
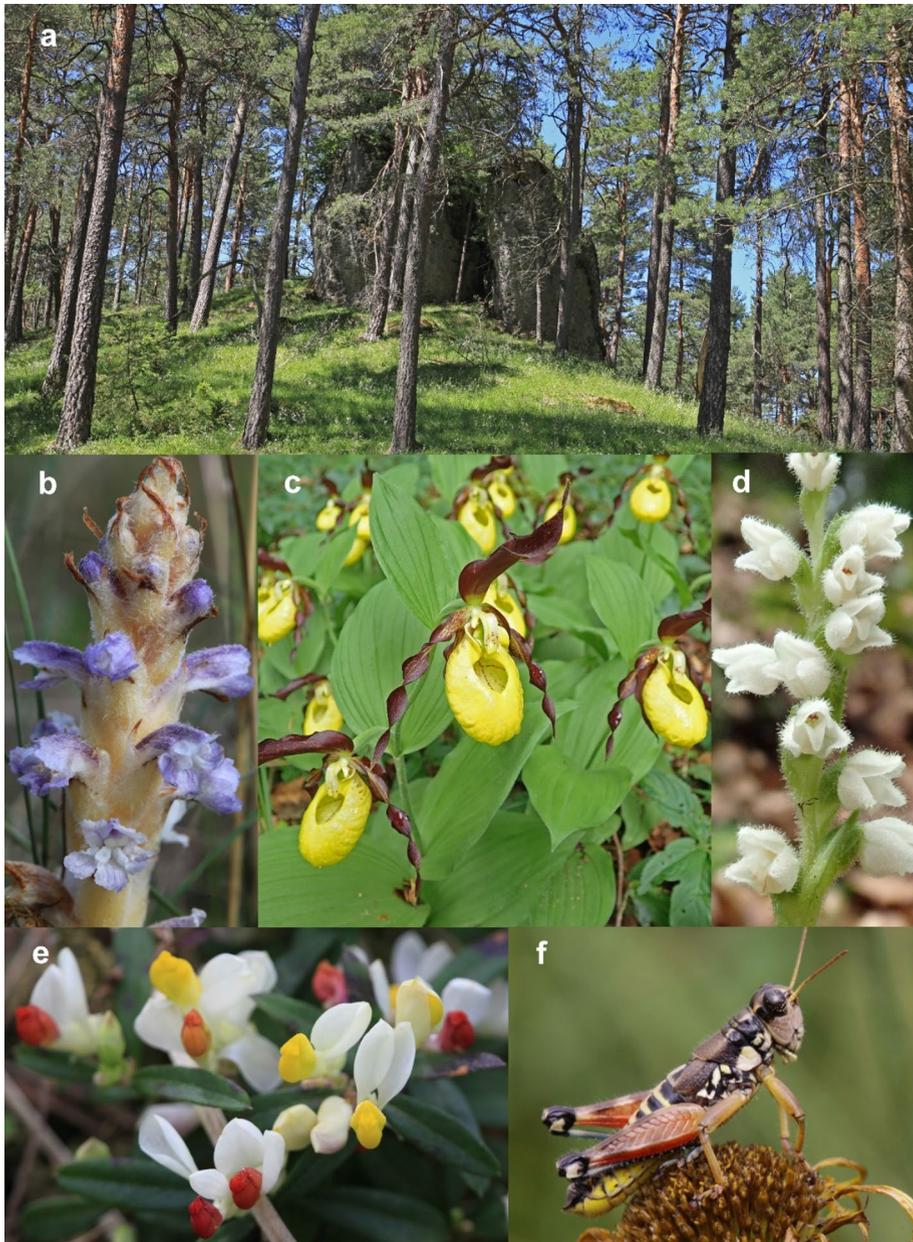
Fig. 2 Biodiversity of pine forests on dolomite. **a** Typical forest stand with dolomite reef from the Jurassic period. **b** *Orobanche coerulescens*, a species originating from Asiatic steppe, in Germany restricted to fringe vegetation of pine forests on dolomite. **c** Yellow lady's slipper (*Cypripedium calceolus*), an Annex II species of the Habitats Directive. **d** *Goodyera repens*, an orchid with main distribution range in nordic continental regions, which lost most of its habitats in the pine forests on dolomite during the last decades due to invading spruce. **e** *Polygala chamaebuxus*, a prealpine species. **f** *Podisma pedestris*, the common mountain grasshopper, a relict species from the ice age

disregarding the area of the stands. The open character of pine forests on dolomite and the conspicuous visibility of bright brown crown parts enabled a very rapid result during the vegetation mapping. With this easy and simple approach it was possible to deal with the large number of stands and to achieve good mapping results for a large area.

Data analysis

In a preliminary study with a slightly modified dataset, different modelling techniques were compared for assessing the historical distribution of pine forests on dolomite before the abandonment of traditional land use around 1950 (Philipp 2019). Random Forest (RF) yielded the most realistic results, showing distribution patterns in accordance to the patterns of the remaining stands nowadays, therefore we chose the RF classification algorithm for the final assessment of the distribution area. We used *proportional stratified random sampling* (Kuhn et al. 2008) to split our ground reference objects (318 presence points and 236 absence points) into separate training and testing sets. Absence points were selected partially out of the 2500 vegetation records (Hemp, unpub. data) not containing stands of pine forests on dolomite and partially taken in the field at forest stands which have been checked for long-term absence of pine obvious by composition and age of the occurring trees. We used 75% of the samples (n = 416) for training the RF model, while the remaining 25% (n = 138) were used as an independent hold-out test set for the accuracy assessment. Model performance was assessed based on k-fold cross-validation (k = 10) of three metrics: Cohen's Kappa, True Skill Statistik (TSS) and Receiver Operating Curve (ROC) (Hao et al. 2019; Martínez et al. 2012).

For modelling, we chose environmental variables linked to the distribution of the pine forest stands, proposed by Hemp (1995): temperature, precipitation, solar radiation, and geology. Elevation (using a Digital Elevation Model (DEM) provided by the Bavarian Land Survey Office) was then used as a proxy for temperature and precipitation as the elevation data is more precise (25 × 25 m raster data) than the data provided by the national weather agency (DWD, 1000 × 1000 m). For estimating solar radiation uptake, we used the tables of Buffo et al. (1972), which who give the amount of energy for different inclinations, expositions and latitudes. As the bedrock of the pine forests on dolomite is exclusively dolomite, we used a dummy variable for geology where dolomitic bedrock is marked with 1 and all other bedrock types with 0. Geological data was retrieved from the Bavarian Environment Agency (Bayerisches Landesamt für Umwelt, LfU). We decided not to use soil databases such as e.g. soilgrids.org, since we exclusively built our model on dolomite, which generates in general shallow sandy soils of 20–30 cm depth in the study area with a low water storage capacity (dry rendzina, brown calcareous soil; Hemp (1995). With this, we excluded the loamy, deep soils with high available moisture and nutrient content (loamy overlaying formation), consisting of weathered material of formerly overlaying layers of the Jurassic and Cretaceous period (Meyer 1972). Furthermore, the resolution of soilgrids. org was much courser compared with the resolution of the dolomitic GIS layer. All data was aggregated (nearest neighbor method) to raster data with a resolution of 25 × 25 m, as this was the resolution level of the DEM.

To compare the relevance of environmental variables, variable importance was calculated according to Louppe et al. (2013). This approach incorporates the correlation score of the prediction error for the standard model and for the model after permuting each predictor variable randomly (Thuiller et al. 2009). Variable importance was finally obtained

by proportionally ranking each variable according to its correlation score, with values between [0;1].

Final prediction maps of historical pine forests on dolomite before 1950 were calculated based on one run of the model with the whole data set (n = 554). Hence, all the available data was incorporated in order not to waste valuable information for final predictions (Breiner et al. 2015). The extent of the model was then further narrowed by considering only areas with forest cover. Also, state forests and federal forests, being of minor importance in the study area were excluded as litter raking and grazing—important factors influencing the distribution of the pine forests on dolomite—were regulated and less intensive compared to private forests (Rebel 1920).

To evaluate model performance, we used two threshold dependent metrics, namely True skill statistic (TSS) (Peirce 1884) and Cohen's Kappa (Cohen 1960) and with ROC one threshold-independent metric. Kappa and TSS are based on presence/absence confusion matrices, using Sensitivity (probability that a model correctly classifies a presence) and Specificity (probability that a model correctly classifies an absence) in the calculation as well as a threshold value for presence and absence probability. If Sensitivity and Specificity are equal, Kappa, ranging between [− 1;1], reaches its maximum. Kappa has been criticized due to its dependency on prevalence rates (Lawson et al. 2014; McPherson et al. 2004). Nevertheless, it is a useful method on balanced prevalence data and is most used as a threshold dependent metric in ecology (Allouche et al. 2006; Lawson et al. 2014; Manel et al. 2001). The calculation of TSS is closely related to the Kappa metric but is less sensitive to prevalence rates (Allouche et al. 2006). The Receiver-Operating Curve (ROC) is a threshold-independent metric commonly used in assessing the predictive performance of models (Hand 1997; Marcot 2012). For ROC, true positive classifications (Sensitivity) is plotted against false positive classifications (1- Specificity), but without using threshold values for presence or absence classification (McPherson et al. 2004). ROCs are considered independent of prevalence as the calculation is based on proportions of both presence and absence sites (Zweig and Campbell 1993).

Analysis of the vegetation mapping during the tree field surveys was done with ArcGIS 10.8.1. To analyze the retreat of the forest extent we fitted linear functions using R^2 as the measure of fit. Distribution maps of the modelling approach were created using QGIS 3.8. The statistical analysis was performed with R. 3.6.1.

Results

RF model of the historical distribution of pine forests on dolomite before 1950

ROC ranged between 0.852 and 0.944, which indicates a moderate to excellent fit. Both TSS and Kappa were greater than 0.6, with mean values at 0.714 respectively 0.724. The relation of correct predictions to all predictions was greater than 0.82. On average, 86.77% of the predictions were correct. Variable importance calculation showed that the binary variable for presence/absence of dolomite was by far the most important variable (Mean Gini Decrease 0.592). Elevation ranked second (0.312) and the solar radiation index was least important (0.137). The model indicated high probabilities for the most north-eastern part of the Franconian Jura as well as the central part spreading to the south-eastern edge of the study area. Considering the optimum threshold calculated by TSS (TSS > 0.921, probability > 0.727), the area of occurrence prediction was 18,500 ha (Table 1). Relating the

Table 1 Area and number of stands of pine forests on dolomite in the Northern Franconian Jura

Year	Area (ha)	Mean area (ha)/stand	Max. area (ha)/stand	Area (ha) inside SAC	Number stands	Number stands > 1 ha	Number stands inside SAC
ca. 1950	18,500	NA	NA	NA	NA	NA	NA
1990	824.4	1.3 (2.6)	30.6	NA	632	195 (31%)	NA
2012	300.1	0.8 (1.6)	11.4	131 (44%)	377	78 (21%)	144 (38%)
2020	190.4	0.3 (0.7)	6.7	89.8 (47%)	757	45 (6%)	303 (40%)

results to the current forest cover, around 17% of the total forest cover in the study region would have belonged to pine forests on dolomite. Comparing the patterns of the model predictions, RF presented realistic results. The current main distribution areas as presented in Fig. 1, were reflected in high probabilities according to the model.

Forest loss

Compared to 1990 only 23% of the area of pine forests on dolomite still existed in 2020 and compared with the modelled extent in 1950, only 1% remained (Table 1, Fig. 3). Between 1990, 2012 and 2020 not only the area, but also the number and the size of pine forests stands changed. In 1990, the mean size was 1.3 ha, the share of stands with an area > 1 ha was 31%. The largest stand covered 31 ha. In the year 2012 only 59% of these stands still existed due to the loss of most of the smaller stands, the mean size was only 0.8 ha and the share of stands with an area of > 1 ha was 21%. The largest stand covered 11 ha. 38% of the stands comprising 44% of the area were located inside the designated Natura 2000 areas (SAC). In 2020 the share of larger plots > 1 ha (6%) decreased drastically, resulting in a comparatively high number of mainly very small stands, the biggest covering only about 7 ha. 40% of the still existing stands were located inside SAC.

During the survey of 2012, the succession stage of the mapped stands was recorded. In most cases, spruce and/or beech were invading the pine forests (82%). However, in 13% of the remaining stands, active planting of mainly beech and spruce had happened (Table 2).

During the survey of 2020 pine trees with dead crowns (i.e. > 60% dead) were recorded in only 6 of the 757 mapped stands. These records consisted only of single trees with a maximum of three in one mapped stand, but not of groups or complete stands.

Discussion

Pine forest loss since 1950

Compared to 1990 only less than a quarter of the area of pine forests on dolomite remained in 2020. This is a dramatic loss in 30 years and compared with the modelled extent in 1950, when the above described traditional land use was still practiced, the reduction during 70 years is drastic, with only 1% remaining in 2020, which would suggest an exponential decline (Table 1, Fig. 3a). If this trend continued, these forests will disappear during the next decades.

Due to fragmentation of larger stands their number increased since 2012 resulting in the increasing share of small stands < 1 ha. These still remaining isolated stands with their characteristic species pool are a potential reservoir for restoring pine forests on dolomite by landscape care activities. However, since 96 stands had an area of less than 100 m² in 2020 (mainly small remnants surrounded by dense young stands of spruce or beech) it is very likely that most of them will disappear during the next few years.

The main reason for these trends was scrub encroachment. In most cases spruce and/or beech were responsible for habitat degradation in 2012 (Table 2), spruce invading mostly the north-facing slopes and beech mainly southern expositions. However, also active planting of mainly beech and spruce occurred. Even after the designation as protected Natura 2000 habitat in 2008 this trend continued. These trends were similar inside and outside SAC (Table 1).
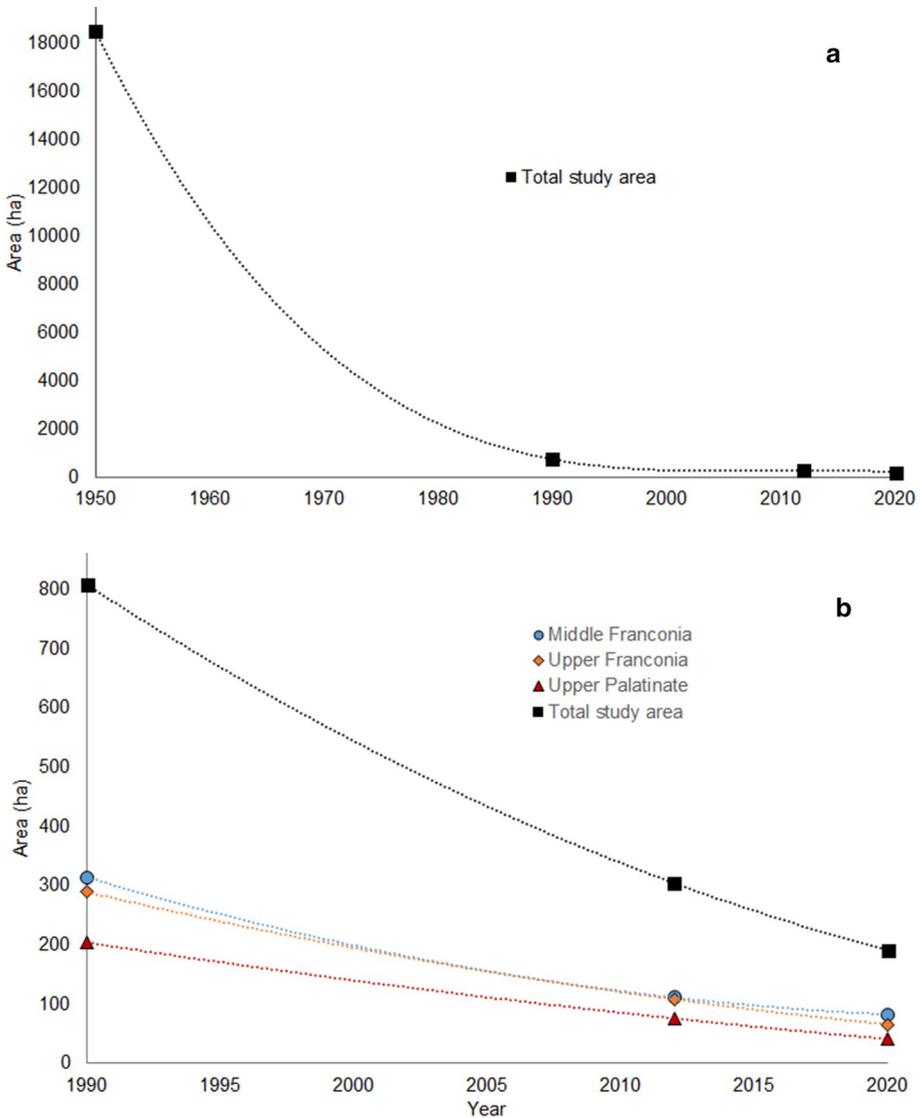
Fig. 3 Retreat of the pine forests on dolomite **a** since 1950 in the whole study area (Northern Franconian Jura) based on a Random forest model and **b** during the last 30 years based on the field surveys 1990–2012–2020 in the whole Northern Franconian Jura and separately for the three districts Middle Franconia, Upper Franconia and Upper Palatinate showing different trends. Polynomial regression of degree 2, $R^2 = 1$

The trend of rapidly disappearing open pine forests can be visualized by a map of one of the main distribution centres (as shown in Fig. 1a), which is part of the FFH (HD) area 6335–306.02. In 1990 pine forests on dolomite covered 234 ha, in 2012 104 ha and in 2020 81 ha. Although these trends are at first glance similar in all parts of the Franconian Jura, there is one striking difference. The area displayed in Fig. 1b belongs to the district Middle Franconia, where landscape care activities took place, mainly after 2010, improving about

Table 2 Main causes of pine forest degradation 2012

	Number stands
Picea abies	132 (35%)
Picea abies and shrubs (mainly *Corylus avellana*)	11 (3%)
Fagus sylvatica	72 (19%)
Fagus sylvatica and *Picea abies*	83 (22%)
Fagus sylvatica, *Picea abies* and shrubs (mainly *Corylus avellana*)	10 (3%)
Fagus sylvatica and shrubs (mainly *Corylus avellana*)	10 (3%)
Shrubs (mainly *Corylus avellana*)	10 (3%)
Planting (mainly *Fagus sylvatica* and/or *Picea abies*)	49 (13%)

30 ha and restoring about 10 ha of pine forests by removing mainly young spruces and beeches. Furthermore, the district forestry office abandoned replanting activities in close dialogue with nature conservation authorities since the 1990s. Therefore, the negative trends in this district are leveling (Fig. 3b), whereas the observed negative trends continued undamped in the other two districts of Upper Franconia and Upper Palatinate, where nearly no nature conservation activities in favour of pine forests on dolomite were undertaken and even replanting with beech and spruce continued.

Impact on biodiversity

Pine forests on dolomite harbour a very high species number in their dense herb layer (mean + 50 species, and maximum + 70 species on a plot size of 300m^2), in particular of endangered and rare species (Fig. 2). Altogether 330 plant species were recorded in these forests, including 14 species of orchids, e.g. *Cypripedium calceolus*, an Annex II species of the Habitats Directive. This creates a unique combination of plants originating from the Mediterranean, eastern continental steppe, and the Alps (Hemp 1995). For a comprehensive nature conservation assessment of the about 150 plant associations of the Northern Franconian Jura regarding e.g. occurrences of regionally rare and red list species, based on over 2,000 vegetation plots, pine forests on dolomite occupied the highest ranks in the upper 10% of the investigated plant communities (Hemp 1995).

In a study of several different succession stages starting from a pine forest with an open tree layer of about 30–40% cover, to a beech forest with a tree cover of 90% a nearly complete exchange of the understory species composition was observed, where the light-demanding species were replaced by shade-tolerant, mainly widespread forest species and the total species number was reduced by 50% (Hemp 1995). Marozas et al. (2014) made similar observations in relict pine stands in Lithuania. For maintaining a high richness and diversity of rare understory species in pine forests on dolomite, it is therefore important that shade-tolerant tree species are excluded.

In parallel to this decline of open pine forests also other habitat types were affected, in particular xerotherm fringe vegetation along the edges of the pine forests and on dolomite reefs inside the forests with their rock vegetation. Here, very rare and endangered (red list) species occur, e.g. *Orobanche coerulescens* (the only occurrence in Germany), the grasshopper species *Psophus stridulus* as well as relicts of the ice age (*Cardaminopsis hispida* and *Podisma pedestris*, another grasshopper). All these species had massive losses in their

population numbers and sizes during the last decades (Hemp 1996a,b; Hemp and Hemp 1996, 2003).

Pine forests on dolomite under climate change

The years 2018–2020 were extremely dry and hot in Germany. However, during the survey of 2020 pine trees with dead crowns (i.e. > 60% dead) were recorded only in less than 1% of the 736 mapped stands. These records consisted of single trees, but not of groups or complete stands as in some other regions in Northern Bavaria.

The vitality of pine especially with increasing periods of heat and drought and related predictions for climate adaptation are assessed very divergently (Bose et al. 2020; Savolainen et al. 2011; Seidel and Menzel 2016). It is particularly critical that, based on regional findings, conclusions are mainly drawn directly about the climate adaptation of the whole species, neglecting provenance effects or genetic adaptability (Bolte et al. 2009; Kätzel 2008; Taeger et al. 2013). As a species with the largest Eurasian distribution (Meusel et al.1965) under contrasting environmental conditions, *Pinus sylvestris* shows ample differences in morphological traits due to genotypic variation and phenotypic plasticity with a high competitive ability in particular on dry sites (Vidaković 1991; Pyhäjärvi et al. 2019). Our results confirm this for the study area, which belongs to the "Franconian coniferous forest area", where pine was always present during the postglacial surviving climatic fluctuations with higher temperatures than today (Firbas 1949). This reflects the long-lasting interplay between anthropogenic influence since the Neolithic and the postglacial migration history of tree species in Franconia (Hemp 1995).

Perspectives for nature conservation

The poor conservation status of most Natura 2000 forest habitats is well documented (Winkel et al. 2015; McKenna et al. 2014; Ferranti et al. 2010). It holds the same for other pine forests in Germany such as Central European lichen pine forests (Code 91T0, LWF 2012). However, here we present for the first time the conservation status of a complete Natura 2000 habitat type in and outside of Natura 2000 sites monitoring the full area extent of all existing stands. Instead of using vague criteria such as 'favourable conservation status' (Council Directive 92/43/EEC) not defined for specific habitats or species and with diverging specifications (Winkel et al. 2015; Hernando et al. 2010) we use a complete area as a hard basic fact. The documented and modeled dynamics suggest that the "Sarmatic Steppe Pine Forests" have been facing a dramatic decline even after their designation as Natura 2000 habitat in 2008 demanding an urgent need of conservation efforts within the next few years. If this plant community and most of its understory vegetation are vanishing completely, evidence of a once widespread, historical landscape element will be lost forever. Relict flora and fauna elements from glacial times would be disappearing from one of their last refuges outside the alpine area.

The best way to protect the last remaining pine forest stands on dolomite would be the designation of a nature reserve with a higher protection status and means for restoration. Furthermore, the land owners have to be compensated for the expected loss of income when removing young beeches and spruce. Also, legal statutes which prevent necessary and effective management policies such as wood pasture must be reconsidered. Within certain areas the effect of grazing and litter raking should be monitored. Furthermore, the "Sarmatic Steppe Pine Forests" should be reclassified as one of the 71

priority habitats, i.e. a habitat type in danger of disappearance and whose natural range mainly falls within the territory of the European Union.

Another argument for protecting the Sarmatic steppe pine forests is climate change. In our study we found that the pines of the Buphthalmo-Pinetum were nearly not affected by the extremely dry and hot last years. Therefore, the pines of the Franconian Jura seem to belong to an autochthonous provenance well adapted to climatic changes, which could serve as a source of seed material suitable for regions in Germany and Europe, where pines are suffering from drought. For this, studies of their genotypic variation and phenotypic plasticity and the resulting competitive ability in particular on dry sites would be necessary. This could be an example, how human well-being benefits from preserving (genetic) biodiversity.

Beside neglect of immediate protection efforts, the conflict of interests between forestry and nature conservation in the past added to deterioration of this unique and highly valuable ecosystem although this contradicts its status as protected habitat by national and European law. In December 2010, the United Nations proclaimed the decade from 2011 to 2020 to be the UN Decade of Biological Diversity. The decade was intended to support the implementation of the Strategic Plan of the Convention on Biological Diversity (CBD). Since a new strategic framework—the Global Biodiversity Framework (GBF)—for the period after 2020 is currently being prepared in the CBD, Germany must take this into account and improve its National Strategy on Biological Diversity (NBS), which failed in many respects (BMU 2021). The European Commission has therefore decided to refer Germany to the European Court of Justice for not respecting its obligations under the Habitats Directive in March 2021 (European Commission press release 2021). The successful preservation of an outstanding Natura 2000 habitat as part of a national hotspot of biodiversity would be another touchstone how Germany (and Europe) implement their obligations and care about their environmental responsibilities. Otherwise, guidelines and directives of the NBS would be proved as similar meaningless as the European Union's Green Deal announced in December 2019, aiming to make Europe the first climate-neutral continent by 2050. In reality, EU member states are outsourcing environmental damage to other countries, while taking the credit for green policies at home (Fuchs and Rounsevell 2020).

Declarations

Competing interest The authors declare that they have no competing interest.

Clinical trials registration Not applicable.

Consent to participate Not applicable.

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