Nature Conservation 42: 89–112 (2020)
doi: 10.3897/natureconservation.42.58173
https://natureconservation.pensoft.net

RESEARCH ARTICLE

A peer-reviewed open-access journal
Nature Conservation
Launched to accelerate biodiversity conservation

Suitability of contract-based nature conservation in privately-owned forests in Germany

Laura Demant[1,2], Erwin Bergmeier[2], Helge Walentowski[3], Peter Meyer[1]

1 *Northwest German Forest Research Institute, Department of Forest Conservation, Prof.-Oelkers-Str. 6, 34346 Hann. Münden, Germany* **2** *University of Göttingen, Department of Vegetation and Phytodiversity Analysis, Untere Karspüle 1a, 37073 Göttingen, Germany* **3** *HAWK University of Applied Sciences and Arts Hildesheim/Holzminden/Göttingen, Faculty of Resource Management, Büsgenweg 1a, 37077 Göttingen, Germany*

Corresponding author: Laura Demant (laura.demant@nw-fva.de)

Academic editor: S. Chelli | Received 31 August 2020 | Accepted 25 November 2020 | Published 17 December 2020

http://zoobank.org/F8D01FEE-776A-45D9-B358-54B3A3DD1994

Citation: Demant L, Bergmeier E, Walentowski H, Meyer P (2020) Suitability of contract-based nature conservation in privately-owned forests in Germany. Nature Conservation 42: 89–112. https://doi.org/10.3897/natureconservation.42.58173

Abstract

The successful implementation of contract-based nature conservation in privately-owned forests requires a framework of reasonable operational measures. Our study aimed at developing such a framework by; 1) defining forest conservation objects including structures, processes, and habitat types, 2) assessing their conservation value based on the need for, and worthiness of, protection, 3) reviewing the suitability of contract-based measures for conservation. Overall, we defined 67 conservation objects, with 8 of them used as case studies: deadwood, habitat trees, natural succession after large-scale disturbance, coppice-with-standards, bog and fen woodlands, dry sand pine forests, and beech forests. We considered contract-based conservation suitable if, within the contract period, outcomes of measures resulted in ecological upgrading or avoidance of value loss. We identified contract-based conservation suitable for 42 combinations of objects and measures. Our approach of assessing the potential of contract-based measures for forest conservation is novel with regards to its broad range of objects, defined criteria, and various contract periods. It can help to progress conservation and improve outcomes of measures, especially in privately-owned forests in Germany. Further prerequisites are sufficient financial resources, effective administration, consultancy and the mid- to long-term stability of funding programmes.

Keywords

Forest conservation objects, funding, nature conservation value, need for protection, private forests, suitability assessment, worthiness of preservation

Introduction

In the European Union (EU-28), about 60% of the forested area is privately owned, with huge differences among the member states (Eurostat 2018). Germany, which lies slightly below the EU-28 average with about half of its forest area privately-owned (Polley et al. 2016), may serve as an example to highlight the problems and opportunities for nature conservation in private forests. Implementing conservation measures in private forests may cause additional costs or expenses for forest owners (Sotirov 2017). At present, forest conservation measures in private forests are implemented in Germany primarily through regulations, rather than through subsidies. In stark contrast to agriculture, contractual agreements and funding instruments to compensate for economic losses caused by the implementation of nature conservation measures are rarely used in German forestry (Güthler et al. 2005; Franz et al. 2018b). However, German legislation indicates that the country grants voluntary agreements preference over legal regulations and constitutes in § 3(3) of the German Federal Nature Conservation Act that "… priority shall be given to reviewing whether the intended purpose could also be achieved via contractual agreements". Contract-based agreements are assumed to have a higher acceptance among private forest owners than purely regulatory measures (Franz et al. 2017). The National Strategy on Biological Diversity seeks to "promote contract-based nature conservation in 10% of privately-owned forest land" (BMU 2007), but this target is still far from being achieved, not least because the conditions for contract-based forest conservation have not yet been met (Franz et al. 2018a). Furthermore, overall funding frameworks, for instance for the implementation of Natura 2000, are lacking (Geitzenauer et al. 2017; Sotirov 2017). In contrast to regulations, contract-based nature conservation strives to achieve a consensual, bilateral agreement. In Germany, such voluntary agreements are usually contracted between private forest owners and funding bodies such as the country, federal states, foundations, or private investors. Context-specific conservation measures, referring to specific conservation objects, funding periods and amounts, as well as possible monitoring to verify success, are contractually agreed upon. A broad consensus among different stakeholders in Germany with respect to conservation objectives (Demant et al. 2019) may further promote the implementation of contract-based conservation in private forests.

A prerequisite for the implementation of nature conservation measures in forests is the identification of an operational catalogue of forest conservation objects covering all aspects of forest habitat and biodiversity conservation. An approach using conservation objects accounts for temporal context-specificity and spatial variability, if there is a broad selection of widely accepted and properly defined objects and consensus about suitable preservation measures. At present, the most commonly addressed conservation objects in private forests are habitat trees, deadwood, and historical types of forestry use, such as coppicing or wood pasture (Franz et al. 2018b). However, numerous further objects may be taken into consideration in order to fully tap the potential of private and other forests for the restoration and preservation of biodiversity.

The aim of our study was to develop a comprehensive catalogue of forest conservation objects and measures eligible for contract-based funding. We built on the framework of conservation objectives suggested by Demant et al. (2019) and focussed on forest habitat types, structural elements, and developmental processes as the most relevant conservation objects. We identified the conservation value of the objects by assessing the need for protection (owing to threat, endangerment) and the worthiness of preservation. The guiding questions for our study were:

(1) How can forest conservation objects be assessed in a way that reflects their nature conservation value, particularly in terms of their need for, and worthiness of, preservation?
(2) Which forest conservation objects are suitable for effective contract-based conservation measures and over which contractual periods should measures reasonably be funded?
(3) What consequences for nature conservation practitioners and forest owners can be derived?

Methods

Assessment of the nature conservation value of forest conservation objects

To assess the nature conservation value of a forest conservation object, we considered the initial value (before conservation measures were implemented) and the conservation value achieved after application of a measure over varying time periods. According to Frenz and Müggenborg (2016), worth of preservation alone is not enough for an object to justify a legal priority protection setting – conservation objects must also be (potentially) threatened. Thus, we differentiated between the two components 'worthy' (contributing to the preservation of characteristic species and gene pools in natural or semi-natural landscapes or ecosystems) and 'need' or 'urgency' (degree of threat as a result of adverse effects of land-use and environmental changes) to assess the conservation value of the objects (Fig. 1).

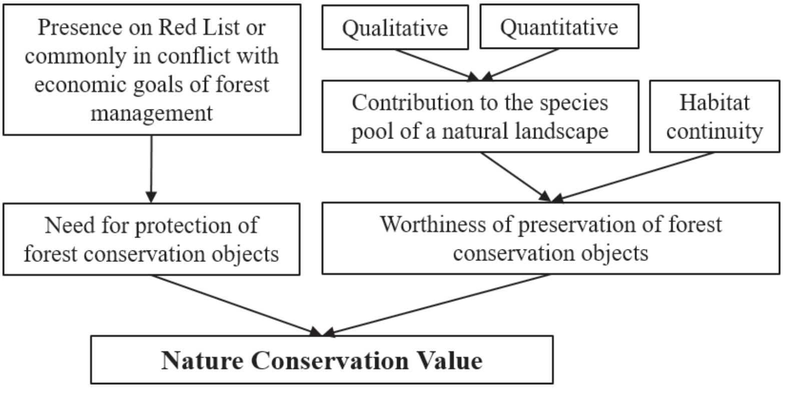

Figure 1. Assessment of the nature conservation value of forest conservation objects.

Table 1. German Red List categories of habitat types and their translation into numerical and verbal reference values.

Red List category	Description	Need for protection	Value
0	Collapsed	Very high	5
1!	Critically endangered (acutely)	Very high	5
1	Critically endangered	Very high	5
1–2	Endangered to critically endangered	High	4
2	Endangered	High	4
2–3	Vulnerable to endangered	Moderate	3
3	Vulnerable	Moderate	3
3-V	Near threatened to vulnerable	Low	2
V	Near threatened	Low	2
*	No current risk of loss trend (least concern)	Very low	1
#	Classification not meaningful, or no risk	No	0

We based the assessment of the need for protection on the national and the European Red List status categories (Janssen et al. 2016; Finck et al. 2017) translated into an ordinal scale (Table 1). The Red List status categories encompass long-term threat (assessed at national and regional levels), the current trend (stable, increasing, decreasing), rarity, and the ability to regenerate (Finck et al. 2017). Threats are "human activities or processes that have impacted, are impacting, or may impact the status of the taxon being assessed" (IUCN 2013).

The forest structures and processes that we assessed have a high urgency for protection. For example, the retention of deadwood and a natural forest development are commonly in conflict with the economic goals of forest management.

Based on an assumption that the maintenance of core ecosystem functions was of high value we selected forest conservation objects, whether they represent structures, processes, or habitat types, as worthy of preservation if they are integral parts of natural self-sustaining, or semi-natural, managed forest ecosystems (Frenz and Müggenborg 2016). We also assumed that higher value would be placed on objects with a greater importance for a region's natural and cultural heritage. The longer the habitat continuity, i.e. the period in which a conservation object has evolved its typical biodiversity, the more important it is to be preserved (Nordén et al. 2014). As the habitat continuity increases, so, too, does the responsibility of preserving the conservation object to meet "the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Wood-pastures, for example, have a centuries-long habitat continuity (Bergmeier et al. 2010; Plieninger et al. 2015), and are regarded as being part of the European cultural-natural heritage (Leuschner and Ellenberg 2017).

Apart from habitat continuity, other factors determining the worth of a conservation object were the quantitative (absolute number of species) and qualitative (relative to a desired reference state) contribution of a conservation object to the species pool of a natural landscape. For example, intact peat bog woodlands may have a relatively low absolute number of species, but a high qualitative contribution to the typical diversity of the natural landscape. We based our assessment of the worthiness on expert valuations and distinguished six levels in a qualitatively ranked ordinal scale (Table 2).

Table 2. Variables for the evaluation of the worthiness of preservation.

Habitat continuity (HC)		Quantitative contribution (Q1)		Qualitative contribution (Q2)		Worthiness = [HC+ ((Q1+Q2)/2)]/2
Very long	5	Very high	5	Very high	5	5
Long	4	High	4	High	4	4
Medium	3	Moderate	3	Moderate	3	3
Short	2	Low	2	Low	2	2
Very short	1	Very low	1	Very low	1	1
None	0	None	0	None	0	0

Q1 = quantitative (absolute) contribution, Q2 = qualitative contribution to the typical diversity of the natural landscape.

For example, dry oak-hornbeam forests (*Galio-Carpinetum*) have a Red List status of 1–2 (Endangered to Critically endangered; Finck et al. 2017) which means their need for protection was high (4). Furthermore, they have a very long habitat continuity (HC = 5), a high quantitative (Q1 = 4), and a very high qualitative (Q2 = 5) contribution to the diversity of the natural landscape. Their worthiness of preservation resulted in 'very high' ([5+ ((4+5)/2)]/2 = 4.75).

We assert that structures and processes, as essential components of natural forests, are highly worthy insofar as they allow maintenance of key ecosystem functions (Walentowski and Winter 2007). The final nature conservation value resulted from the calculation of the mean values of the two protection criteria, worthiness and need, with the classes 0 = no, 1 = very low, 2 = low, 3 = moderate, 4 = high, and 5 = very high conservation value. In the example above the final conservation value is high ((4.75+4)/2 = 4.375).

Forest conservation objects

The nature conservation value assessment was carried out for eight forest structural elements, four processes, and 55 forest-related habitat types (Finck et al. 2017; see Suppl. material 1: Table S1). In the main body of the present paper, representative assessments for 8 out of 67 forest conservation objects were made, characterised in Table 3.

Suitability assessment scheme

We assessed the suitability of contract-based funding for forest conservation objects by comparison of the initial and final conservation value (Fig. 2). The initial conservation value of the conservation object was scaled between very low (0) and high (5). After projecting the expected development and outcomes over a contract length, we calculated a final conservation value, again scaled between very low and high (Fig. 2). As relevant development periods differ greatly among conservation objects, we considered three potential contractual periods: short-term (< 10 years), mid-term (10–30 years), and long-term (> 30 years).

The assessment of the worthiness of, and need for, protection of forest conservation objects resulted in a single nature conservation value, although each individual variable may have different values (Suppl. material 2: Table S2). Conservation objects

Table 3. Characteristics of 8 case study forest conservation objects.

Conservation object	Characteristics	Possible conservation measure during contract period	References
Deadwood	Key structure in forest ecosystems, variable in terms of amount, decay stages, size classes, wood diameters, microclimatic conditions, and tree species.	Retention of dead trees or logging residues; supply ring-barking, crown cutting, felling or knocking-over of trees.	Harmon et al. 1986; Davies et al. 2008; Lassauce et al. 2011; Lindenmayer et al. 2012; Agnew and Rao 2014; Seibold et al. 2015;
Habitat trees	Characterised by various tree-related microhabitats (e.g., hollows or dead branches), indicating habitat continuity; important for countless species supported by dieback structures of old-growth forest stages.	Protection of existing habitat trees and retention of potential once; creation of structures by breaking-off branches, making bark injuries or bark-removal, constructing cavities, dendrothelms (water-filled tree hollows).	Winter and Möller 2008; Fedrowitz et al. 2014; Kraus et al. 2016; Larrieu et al. 2018; Asbeck et al. 2019; Gustafsson et al. 2019; Mölder et al. 2020
Natural forest development	Characterised by typical regional and local-scale old-growth forest structures and associated biodiversity. With ongoing cessation of forestry interventions, typical developmental and structural features gradually develop over long periods of time.	Continuation of natural forest development initiated several decades ago, recent decommissioning of near-natural commercial forests. Minimum standards as defined by Engel et al. (2016, p. 38) apply.	Meyer and Schmidt 2008; Vandekerkhove et al. 2011; Kraus and Krumm 2013; Paillet et al. 2015
Natural succession after large-scale disturbance	Natural disturbances (e.g., by wildfires, windstorms, or insect infestations; intensity and frequency are expected to increase under climate change) are important drivers of forest dynamics and associated biodiversity. They contribute to maintaining pioneer species and habitats, enhance structural heterogeneity, and make forests more resilient to future disturbances.	Allowing and supporting natural development in early-successional stages.	Runkle 1989; Franklin et al. 2002; Lindenmayer et al. 2008; Swanson et al. 2011; Seidl et al. 2017; Thorn et al. 2018; AK Waldökologie GfÖ 2019; Müller et al. 2019
Coppice-with-standards	Two-layered stands with an overstorey consisting of mature trees (standards) used for timber and fruit setting. Even-aged understorey regrowth (coppice) consists of multi-stemmed trees cut at a 20–30-year rotation cycle. Offer a mosaic of habitats and structures favourable for light-demanding and thermophilic species due to conditions of alternating shade and light. Abandoned coppice-with-standards with all trees left uncut ('overstood', stems having the size of mature forest stands) are commonly converted to high forests (even-aged forest stands).	Continuation and resumption of coppice-with-standard management.	Barnthöl 2003; Groß and Konold 2009; Kirby et al. 2017; Meyer et al. 2018; Unrau et al. 2018
Bog and fen woodlands	Ecosystems of coniferous or broadleaved trees and shrubs on low-productive peaty soils with high water level. When intact, they contribute to climate protection, if drained, they emit greenhouse gases at high rates. Habitats for many specialised, rare and endangered species, and highly threatened by hydrological changes caused by forest management and drainage.	Restoration of degraded bog and fen woodlands by raising the water level, regeneration of the acrotelm, the active peat zone containing living plants, removal of non-native tree species and renouncement of peat extraction.	Moore and Knowles 1989; Joosten 2012; EEA 2013; Joosten et al. 2015; EEA 2019
Dry sand pine forests	Lichen-rich dry pine forests on nutrient-poor, acidic sands with low shrub, herb, and litter cover. Being the result of historical land use (mainly litter raking and sod cutting) they depend on nutrient removal to accommodate typical epigeous (growing on the soil surface) lichen species. They are highly endangered, mainly due to discontinuation of litter raking, and by nitrogen deposition caused by agriculture and traffic emissions and have both high historic-cultural and biodiversity significance.	Protection of extant lichen-rich pine forests and restoration of degraded lichen-poor sand pine forests through litter and topsoil removal.	Heinken 1990; Heinken 2008; Fischer et al. 2009; Fischer et al. 2014; Brackel and Brackel 2016; Stefańska-Krzaczek et al. 2018
Beech forests	Naturally self-sustaining ecosystems dominated by beech (*Fagus sylvatica*), but commonly managed as productive high forests.	Prolonging of rotation cycles beyond conventional harvesting age, thus preserving old-growth-associated biodiversity, and enhancing natural regeneration.	Kroiher and Bolte 2015; Meyer et al. 2015; Winter et al. 2016

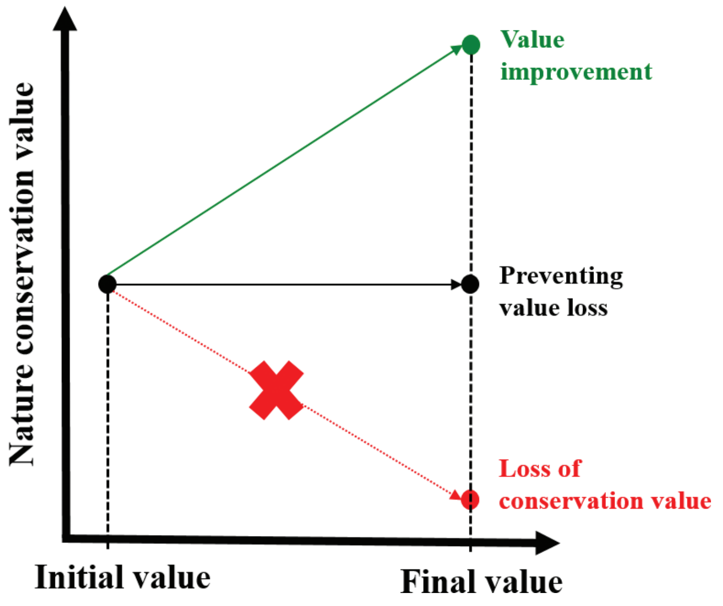

Figure 2. Development pathways of the initial nature conservation value.

Table 4. Description and assignment of the final nature conservation value (NCV) to the suitability assessment of conservation measures and the corresponding colour in Table 7 and Supplement S1.

Final nature conservation value	Description	Suitability of conservation measures	Colour
0	No NCV	Not suitable	Red
1	Very low NCV	Not suitable	Red
> 1 – 2	Low NCV	Not suitable	Red
> 2 – 3	Moderate NCV	Moderately suitable	Yellow
> 3 – 4	High NCV	Suitable	Light green
> 4 – 5	Very high NCV	Very suitable	Dark green

may achieve a high value when preservation measures have been implemented and have produced positive results, when degraded objects have been restored successfully (restoration measures), or when the objects have been newly created. A high conservation value towards the end of a contractual period indicates an improvement of an initially lower conservation value, or the prevention of value loss of an initially high value.

Contract-based funding would be particularly suitable for conservation objects with high initial conservation value that would suffer value loss in the absence of conservation measures, or for objects with rather low initial value but considerable restoration potential to achieve a higher final value. If the conservation value of a newly created conservation object (initial value = 0) was likely to increase over a given contract period, contract-based funding of conservation measures was also considered reasonable. If both initial value and restoration potential were low, contract-based conservation was deemed inappropriate. The suitability assessment is depicted as a four-level colour scheme, reflecting the final value (Table 4).

Results

Initial nature conservation value of forest conservation objects

More than 82% of all conservation objects were assessed as being highly or very highly worthy of preservation. However, only 39% had a high to very high need for protection and these were found exclusively within the group of objects of high to very high worthiness. Thus, some conservation objects can be regarded as very valuable, but are not seriously threatened, such as mesic beech forests or riparian alluvial forests (Suppl. material 1: Table S1). Forest structures and processes made up only a small proportion of all conservation objects. For forest structures, the proportion of low-value and non-threatened objects was higher than that of highly valuable and threatened ones, since many structures are being developed or newly implemented (e.g., the active supply of deadwood, or the designation of potential habitat trees).

One quarter of all forest conservation objects were assessed as having a high to very high initial nature conservation value (Fig. 3). The conservation objects coppice-with-standards, wood pastures, intact bog and fen woodlands, continuation of natural forest development, natural succession after large-scale disturbance, deadwood retention, eyrie tree protection (nesting sites for birds of prey) and protection of habitat trees were assessed as having very high conservation value. About three quarters of all conservation objects were ascribed a moderate to very high initial conservation value. Habitat types, comprising 55 out of the 67 identified forest conservation objects, made a major contribution to high conservation-value objects (initial value higher than 3; Table 5).

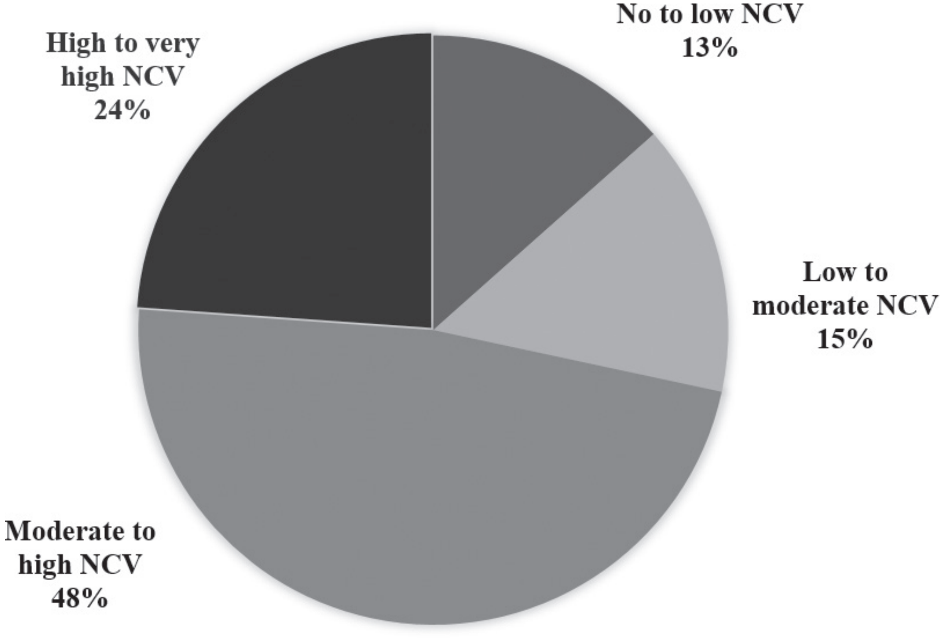

Figure 3. Initial nature conservation value (NCV) of all 67 forest conservation objects analysed.

Table 5. Distribution of the shares of the initial nature conservation value (NCV) classes for all 67 forest conservation objects.

Description	NCV	Habitat types	Structures	Processes
No to low NCV	0 – 2	3	5	1
Low to moderate NCV	> 2 – 3	9	0	1
Moderate to high NCV	> 3 – 4	32	0	0
High to very high NCV	> 4 – 5	11	3	2

Table 6. Suitability assessment proportions of forest conservation objects for different contract terms (years).

Suitability	Contract duration (years)	Forest conservation object group		
		Structures (8)	Processes (4)	Habitat types (55)
Not suitable	<10	1	0	22
	10–30	0	0	23
	>30	0	0	23
Moderately suitable	<10	0	1	3
	10–30	1	0	2
	>30	0	1	2
Suitable	<10	3	0	22
	10–30	0	2	18
	>30	1	0	18
Very suitable	<10	4	3	8
	10–30	7	2	12
	>30	7	3	12
Total proportion [%]		**11.9**	**6.0**	**82.1**

Suitability of contract-based forest conservation

As many as 42 out of 67 forest conservation objects proved suitable for contract-based conservation measures (Suppl. material 1: Table S1). Most of the assessed forest structures and processes were considered suitable or very suitable for contract-based conservation, irrespective of the contract period. For forest habitat types, accounting for the largest part of all assessed conservation objects, the findings are more nuanced. Short-term contracts (<10 years) were found to be very suitable for 15 out of 67 forest conservation objects (3 process-related, 4 structural and 8 habitat types; Table 6 and Suppl. material 1: Table S1). The conversion of forest stands of non-native trees, the continuation of traditional forest management (wood pastures, coppice-with-standards), and the retention of deadwood belong in this category. Mid-term contracts (10–30 years) were found to be very suitable for 31% of all conservation objects, including the resumption and continuation of traditional forest management, the restoration of degraded habitat types, the active creation of habitat trees, micro-habitats, as well as the conservation management of high-valued habitat types (Suppl. material 1: Table S1). Long-term contracts (>30 years) were assessed as being very suitable for about 33% of all conservation objects, mostly the same as for mid-term contractual periods, though with a few exceptions, such as the continuation of a natural forest development, or the retention of potential habitat trees. Contract-based agreements were rated not suitable for 34% of all conservation objects, regardless of the contractual period. This category includes almost exclusively habitat types, chiefly because they are either legally protected habitats (Box 1) or low-valued pioneers.

Table 7. Suitability assessment of representative forest conservation objects and conservation measures for different contract duration periods. For the scaling of the nature conservation value (NCV), based on worthiness of preservation and need for protection see Tables 1, 2 and 4.

		Forest conservation object	Possible conservation measure during contract period	Period (years)	Initial NCV: Worthiness	Initial NCV: Need	Final NCV: Increase in value with contract–based conservation	Final NCV: Loss of value without contract-based conservation	Suitability for contract-based conservation
Structural elements		**Deadwood**	Active deadwood provisioning to ensure continuous supply of a certain amount	< 10	0	0	4	No	s
				10–30			5		vs
				> 30			5		vs
			Retention of naturally supplied or silvicultural routine deadwood	< 10	5	5	5	Yes	vs
				10–30					vs
				> 30					vs
		Habitat trees	Retention of potential habitat trees	< 10	0	0	0–1	No	ns
				10–30			3		ms
				> 30			5		vs
			Initial creation of microhabitats	< 10	0	0	4	No	s
				10–30			5		vs
				> 30			5		vs
			Protection of habitat trees	< 10	5	5	5	Yes	vs
				10–30					vs
				> 30					vs
Processes		**Natural forest development**	Recent near-natural forest set-aside	< 10	3	3	3	Yes	ms
				10–30			4		s
				> 30			5		vs
			Continuation of natural forest development initiated several decades ago	< 10	5	5	5	Yes	s
				10–30					vs
				> 30					vs
		Natural succession after large-scale disturbance	Sites of wind-throws or other disturbances in native forests left to itself	< 10	5	5	5	Yes	vs
				10–30			4		s
				> 30			3		ms
Habitat types		**Coppice-with-standards**	Resumption of traditional coppice-with-standard management	< 10	4	3	3.5	Yes	s
				10–30			5		vs
				> 30			5		vs
			Continuation of coppice-with-standard management	< 10	5	5	5	Yes	vs
				10–30					vs
				> 30					vs
	Bog/fen woodland	**Intact bog and fen woodlands** *	Renouncement of degrading measures	< 10	5	5	not assessable	No	ns
				10–30					ns
				> 30					ns
		Degraded bog and fen woodlands	Restoration (rewetting)	< 10	4	3	4	Yes	s
				10–30			5		vs
				> 30			5		vs
	Dry pine forests	**Intact lichen-rich dry sand pine forest (*Cladino-Pinetum sylvestris*)** *	Conservation- and habitat-adapted management	< 10	5	4	4.5	Yes	vs
				10–30					vs
				> 30					vs
		Degraded (lichen-poor) dry sand pine forest	Restoration through litter and topsoil removal	< 10	3	3	4	No	s
				10–30			5		vs
				> 30			5		vs
	Beech forests	**Dry limestone beech forest (*Carici-Fagetum*)** *		< 10	5	4	4.5	Yes	vs
				10–30					vs
				> 30					vs
		Mesic beech forest on base-rich sites (*Galio odorati-Fagetum, Mercuriali perennis-Fagetum*)	Conservation- and habitat-adapted management	< 10	5	2	3.5	Yes	s
				10–30					s
				> 30					s

NCV, nature conservation value. Colours: red = not suitable (ns), yellow = moderately suitable (ms), light green = suitable (s), dark green = very suitable (vs). * = legally protected habitat (§30 BNatSchG).

For most suitable conservation objects (82%) contract duration was considered of little relevance. Nevertheless, longer funding durations are to be preferred. This would not apply, however, to wind-throws or other large-scale disturbances left to natural succession, because here, the early succession stages are the intended objective.

Forest conservation objects – case studies

Deadwood

Measures to actively supply deadwood were assumed to have a positive short- to long-term effect on the richness of saproxylic (depending on dead or decaying wood) organisms (Table 7). Therefore, short-term contracts were considered suitable. When contracting for mid-term periods, it should be considered that, due to decay, deadwood needs to be replenished to ensure continuous provisioning of different deadwood qualities (see deadwood estimation tool, Meyer et al. 2009). With further contractual period extension, the conservation value is expected to increase, provided that a continuous deadwood supply is guaranteed. Natural deadwood, or silvicultural routine deadwood, has a very high initial conservation value, making even short-term contracts very suitable. Mid- to long-term contracts to secure continuous deadwood supply would result in a very high conservation value.

Habitat trees

We considered trees with trunk diameter far beyond the typical harvest size (DBH > 80 cm for deciduous trees on normal sites, for oaks > 90 cm), and/or the site-specific harvesting age (e.g., beech > 200 a, oak > 300 a), as well as trees rich in microhabitats and/or with very large crowns or low crown bases, to be particularly qualified to become habitat trees (Table 7). As the natural formation of tree microhabitats was assumed to take >50 years at minimum (Larrieu et al. 2012), only long-term contracts qualify. Trees with microhabitats created through management measures have no initial object-specific conservation value (Table 7), but this may increase soon, making even short-term contracts reasonable. Mid- to long-term contracts were considered very suitable to achieve very high conservation value.

Natural forest development

Forests with long habitat continuity, where forestry ceased many decades ago, contribute considerably to the biodiversity of the natural landscape. Therefore, their worthiness was rated very high (Table 7). Due to their low presence in German forests (only 2.8% of the total forest area; Engel et al. 2019), their need for protection is also very high. The continued protection of forests with a long-lasting natural development was recommended for all contractual periods. Semi-mature forests that have been recently decommissioned have a moderate need for protection. Positive effects on biodiversity of such forests may only be measurable after many years or decades. Therefore, contract-based decommissioning of forests was assumed to be suitable for mid- to long-term periods only. Follow-up contracts were recommended for prolonged natural development.

Natural succession after large-scale disturbance

Natural forest succession after major disturbance events requires silviculturists to refrain from salvage logging, deadwood removal and replanting. Untouched early-successional stages are rarely found in privately-owned forests and are thus regarded as highly vulnerable (Table 7). As such pioneer habitats support numerous warmth- and light-dependent species, they are worthy and, consequently, of high initial conservation value. As disturbed areas decrease in object-specific conservation value over time, mid-term contracts were considered particularly suitable. Long-term contracts would only be meaningful if non-disturbed, surrounding stands are simultaneously targeted beyond the given conservation object.

Coppice-with-standards

Traditional coppice-with-standards woodlands can be protected from being transformed into high forests by continuing their specific management. As coppice-with-standards contribute much to the biodiversity of the natural landscape, they were granted a very high worthiness (Table 7). Due to their extreme rarity (less than 0.4% of the forest area in Germany; Albert and Ammer 2012) and susceptibility to management change, they were also assessed as having a very high need for protection and risk of value loss. Therefore, all contract terms were considered suitable, with long-terms preferred.

Abandoned and 'overstood' coppice-with-standards may be restored by resuming the former management. As a moderate loss of habitat continuity and species richness was assumed, their worth of, and need for, protection were given medium ratings (Table 7). Since one rotation cycle usually takes 20–30 years, short-term contracts do little to increase the conservation value of 'overstood' coppice-with-standards. More suitable contract periods are mid- to long-term.

Bog and fen woodlands

As part of the landscape's natural vegetation, intact bog and fen woodlands have a very long habitat continuity and, consequently, very high worthiness. Due to their high level of endangerment, they also have an urgent need for protection (Table 7). Intact bog and fen woodlands have been protected under the Federal Nature Conservation Act. As mere preservation is not compensable (Box 1), contract-based conservation was considered unsuitable, unless combined with additional measures. As remnant or slightly degraded bog and fen woodlands may still contribute to the biodiversity of the natural landscape, they have been assigned medium to high worthiness and medium need for protection (Table 7). Because the restoration of slightly degraded bog and fen woodlands promptly leads to a value increase, even short-term contracts were deemed to be adequate.

Box 1. Legally protected habitat types.

Special case: Legally protected habitat types

Some German forest habitat types are legally protected according to § 30 BNatSchG. These are primarily natural and self-sustaining habitat types that do not require management, and include among others fen and bog woodlands, riparian forests, forests of ravines, slopes and screes, and xerothermic forests and shrub lands. Destruction or actions with significant adverse effects are prohibited by law. Forest owners are obliged to protect and maintain these habitats and to refrain from destruction or considerable impairment. Private land owners cannot be compensated for fulfilling these legal obligations. In contrast, for habitat types that rely on active conservation measures, such as mixed oak forests derived from coppicing, financial compensation appears reasonable.

Likewise, for restoration of degraded habitat types, such as drained swamp forests, financial compensation is possible. The successful restoration of degraded habitats may result in permanent restriction of the forest owner's right of disposal once the status of a legally protected habitat is reached. Franz et al. (2018a) argued that, for reasons of fairness, this permanent use restriction should be permanently compensated.

Dry sand pine forests

The qualitative contribution of lichen-rich dry sand pine forests to the biodiversity of the natural landscape was top-rated and, consequently, their worthiness was also high (Table 7). Being endangered, they have a very high need for protection. However, as a legally protected habitat type, forest owners cannot be compensated for its mere preservation (Box 1). Contract-based maintenance was therefore considered unsuitable unless combined with extra measures, such as rotational litter and topsoil removal.

For degraded forms, if still restorable and credited with medium conservation value, financial compensation for measures to initiate recolonisation of characteristic lichen species was recommended. Short-term contracts were considered suitable, although long-term contracts rendered higher conservation value.

Beech forests

A long habitat continuity and high relevance for the biodiversity of the natural landscape were assumed to result in very high worthiness (Table 7). Our assessment is that financial compensation for preservation-friendly management of dry and mesic beech forest complexes is highly recommendable, whatever the contractual period, if it clearly extends beyond regular forestry practice.

Discussion

Assessing the nature conservation value of forest conservation objects

By means of various indicators or criteria, evaluating conservation objects may be understood as the transfer of factual knowledge to a valuation scheme (Plachter 1991; Schultze et al. 2016). This valuation approach has formed the basis of many studies that have applied scoring techniques (Usher 1994; Gastauer et al. 2013; Capmourteres and Anand 2016; IUCN 2016), and we used it to develop our framework of reasonable and operational measures to assess the nature conservation value of forest conservation objects.

Our conservation valuation comprises different attributes, with single summarised scores, to allow for its country-wide application. With contextual modifications such as other Red List levels to specify the need for protection, the approach may be applicable in yet other regions. By including forest structures, processes, and habitat types, we tried to cover relevant attributes of forest biodiversity. The selected conservation objects are representative for forest conservation management and include those in urgent need of conservation actions. They are particularly relevant in times of climate change, as they encompass short-term objects (e.g., wind-throw sites), climax habitat types (e.g., beech forests), habitats of carbon sink relevance (bog and fen woodlands), habitats with climate-sensitive species (e.g., dry pine forests), and habitats with considerable economic potential for financial risk spreading (coppice-with-standards).

Contract duration to safeguard forest conservation objects

We showed that contractual agreements can be appropriate to support conservation measures in forests. The evaluation of 67 forest conservation objects showed that contract-based conservation agreements prove suitable for 42 objects, albeit with different contract durations. Short-term contracts are less suitable for the retention of habitat trees and for decommissioning semi-mature forests, while long-term contracts are not recommended for funding natural succession after large-scale disturbance. Contract-based conservation is particularly suitable for high-valued objects, such as coppice-with-standards, that depend on active conservation measures to prevent deterioration. Even short-term contracts may be adequate in cases of objects with low to medium initial conservation value if a prompt value increase is to be expected, e.g., newly created habitat trees. In contrast, short-term contracts are less meaningful for conservation objects with low initial conservation value and slow value improvement.

Permanent compensation and long-term agreements would be required for private owners of forests under permanent statutory use restriction (e.g., in bog and fen woodlands). A short contract duration, covering only initial investment expenses but no further maintenance measures, would fail to produce a return on landowner's investment. However, if there is a general willingness of forest owners to accept follow-up contracts, and if suitable funding resources are available, short-term contracts are better than no agreement.

Consequences for nature conservation and forestry practice

As far as forest habitat types are concerned, our conservation objects are in line with the EU Habitats Directive (Natura 2000) and the European Nature Information System (EUNIS) classification (Suppl. material 3: Table S3) and our approach may help to improve the mandatory assessment of the conservation status. In the EU Natura 2000 network, the preservation of diverse forest structures (e.g., deadwood, habitat trees) is a necessary element for a particular forest habitat type to achieve favourable conservation status (Winkel et al. 2015; Alberdi et al. 2019). Since a high proportion of European forest habitat types have been assigned an unfavourable conservation status (European Commission 2015), enhancing these forest structures helps to improve their conservation status.

Our suitability assessment revealed that the conservation or restoration of forest conservation objects may have synergetic effects and simultaneously result in the protection and improvement of other objects. These synergies should be given special consideration (Margules and Pressey 2000; Cimon-Morin et al. 2013). Potential trade-offs and competing objectives across conservation objects should be weighed in the light of the conservation objectives, site conditions and the expected value development. For instance, natural forest development and coppice-with-standards management cannot be implemented in the same site. In general, forest owners cannot meet all possible conservation objectives in a single stand. A contract usually covers a single conservation object and the necessary measures (setting, extent, feasibility, financial framework), but several contracts may be concluded for different objectives in the same forest stand.

Given an underlying value structure that aims to protect typical regional forest biodiversity, the responsibility to protect can only be justified for native species appropriate to the site and location, long-term natural and semi-natural processes and structures, and the cultural development history (Meyer 2013). Consequently, management in privately-owned non-cultural types of forest should be committed to close-to-nature forestry (extension of rotation periods, deadwood provisioning, and tree retention). Since this paradigm shift may cause additional costs for forest owners, suitable compensation structures are needed.

However, financial incentive systems in privately-owned forests are as yet lacking in Germany (Seintsch et al. 2018). Other countries successfully developed their own subsidy programmes, such as the 'English Woodland Grant Scheme' introduced in 2005 (Forestry Commission 2010; Fuentes-Montemayor et al. 2015), replaced in 2015 by 'Countryside Stewardship' grants. Such a country-wide system can lead to more transparency and acceptance among forest owners to support forest biodiversity conservation. Although some German federal states have developed their own incentive instruments, there is substantial variability in requirements and capacity for funding across states. For instance, the Bavarian contract-based forest conservation programme supports the conservation of coppice-with-standards woodlands, the preservation of habitat trees and deadwood. In Hesse, forest conservation measures are funded by the Natura 2000 Foundation, but only within the Natura 2000 network. Additional funding options with differing requirements and payment amounts exist in Germany, yet none of these have nation-wide applicability (BMEL 2019; European Commission 2020). Unfortunately, the operational implementation of these general systems has by no means reached the individual private forest owner. Franz et al. (2018a) pointed out that there is an urgent need for action and to create the prerequisites for contract-based conservation in privately-owned forests, such as a solid foundation of trust, the involvement of committed intermediaries, result-oriented payments, success bonuses, as well as the identification of suitable indicators. Our comprehensive catalogue of forest conservation objects and measures eligible for contract-based funding is valid throughout Germany and in line with the Federal Compensation Directive (BMU 2020) just published. It does not, however, explain the possible trajectories between initial and final conservation values of objects. Forest owners are encouraged to use our catalogue for their conservation intentions. Given that they know the tree species composition and structural characteristics of their forest stands, they can easily identify conservation objects such as potential habitat trees, and choose a reasonable contract duration. The biggest challenge yet for contract-based nature conservation is to find suitable funding options, which vary between the German federal states. Authorities, nature conservation agencies, or NGOs might assist on this point. Therefore, while this paper provides a rationale and an objective-related design for contract-based nature conservation on forests, it can't guide private forest owners towards an operational implementation. Such a guidance, generalised at the level of administrative units or federal states, remains yet to be elaborated.

Conclusions

The nature conservation value assessment of forest conservation objects provided in this paper enables forest owners to assess the conservation value of objects in their forest stands and to consider options for contract-based nature conservation, specifically in privately-owned forests in Germany. We also touch upon the much-discussed topic of conservation responsibility. We believe that the comprehensive catalogue of forest conservation objects and measures may be applicable in a wider Central European context. Furthermore, the nature conservation value assessment can help to improve the conservation status of Natura 2000 forest habitat types. We showed the suitability of many conservation objects to financial incentives and advocate conservation object-dependent variation in contract duration. We noticed a particular need for action in the case of conservation objects susceptible to an imminent loss of value in the absence of conservation measures.

Currently, however, a general framework for successful implementation of contract-based forest conservation, including factors such as legal security, fairness, continuity, and flexibility, is not available. The reference framework presented here and the considerable number of combinations of objects and measures found suitable for contract-based conservation, together with the recommendations for a forest conservation funding system given by WBW and WBBGR (2020), may help to enhance this implementation process. For the sake of diversified nature conservation in forests, politicians and stakeholders at all governmental levels should rethink and revise benefit payment programmes towards mid- to long-term contracts (Gemeinholzer et al. 2019), and thus encourage private forest owners to acknowledge biodiversity-related funding.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This study was conducted within the WaVerNa-project (grant number 22007015) and the MiStriKli-project (grant number 22WK416602). The authors thank the Agency for Renewable Resources FNR e. V. as project sponsor of the Federal Ministry of Food and Agriculture Germany (BMEL) for funding these research projects. We acknowledge the HAWK University of Applied Sciences and Arts Hildesheim/Holzminden/Göttingen for covering the costs of open-access publishing. We are very grateful to Robert Larkin for checking the language and thank two anonymous reviewers for their helpful and constructive comments.

References

Agnew JM, Rao S (2014) The creation of structural diversity and deadwood habitat by ring-barking in a Scots pine *Pinus sylvestris* plantation in the Cairngorms, UK. Conservation Evidence 1: 43–47. https://www.conservationevidence.com/individual-study/5487

AK Waldökologie GfÖ (2019) Wissenschaftler sehen Störungen in Wäldern auch als Chance für biologische Vielfalt und Klimaanpassung. Gesellschaft für Ökologie. [Retrieved August 25, 2020] https://gfoe.org/de/node/69

Alberdi I, Nunes L, Kovac M, Bonheme I, Cañellas I, Castro Rego F, Dias S, Duarte I, Notarangelo M, Rizzo M, Gasparini P (2019) The conservation status assessment of Natura 2000 forest habitats in Europe: Capabilities, potentials and challenges of national forest inventories data. Annals of Forest Science 76(2): 1–34. https://doi.org/10.1007/s13595-019-0820-4

Albert K, Ammer C (2012) Biomasseproduktivität ausgewählter europäischer Mittel- und Niederwaldbestände – Ergebnisse einer vergleichenden Metaanalyse. Allgemeine Forst- und Jagdzeitung 183: 225–237.

Asbeck T, Pyttel P, Frey J, Bauhus J (2019) Predicting abundance and diversity of tree-related microhabitats in Central European montane forests from common forest attributes. Forest Ecology and Management 432: 400–408. https://doi.org/10.1016/j.foreco.2018.09.043

Bärnthol R (2003) Nieder- und Mittelwald in Franken. Waldwirtschaftsformen aus dem Mittelalter. Fränkisches Freilandmuseum, Bad Windsheim.

Bergmeier E, Petermann J, Schröder E (2010) Geobotanical survey of wood-pasture habitats in Europe: Diversity, threats and conservation. Biodiversity and Conservation 19(11): 2995–3014. https://doi.org/10.1007/s10531-010-9872-3

BMEL Bundesministerium für Ernährung und Landwirtschaft (2019) Rahmenplan der Gemeinschaftsaufgabe „Verbesserung der Agrarstruktur und des Küstenschutzes" 2019–2022. Berlin.

BMU Bundesministerium für Umwelt, Naturschutz, und Reaktorsicherheit (2007) Nationale Strategie zur biologischen Vielfalt, Bonn.

BMU Bundesministerium für Umwelt, Naturschutz, und Reaktorsicherheit (2020) Bundeskompensationsverordnung (BKompV). Deutscher Bundestag, Drucksache 19/17344.

Capmourteres V, Anand M (2016) "Conservation value": A review of the concept and its quantification. Ecosphere 7(10): e01476. https://doi.org/10.1002/ecs2.1476

Cimon-Morin J, Darveau M, Poulin M (2013) Fostering synergies between ecosystem services and biodiversity in conservation planning: A review. Biological Conservation 166: 144–154. https://doi.org/10.1016/j.biocon.2013.06.023

Davies ZG, Tyler C, Stewart GB, Pullin AS (2008) Are current management recommendations for saproxylic invertebrates effective? A systematic review. Biodiversity and Conservation 17(1): 209–234. https://doi.org/10.1007/s10531-007-9242-y

Demant L, Meyer P, Sennhenn-Reulen H, Walentowski H, Bergmeier E (2019) Seeking consensus in German forest conservation: An analysis of contemporary concepts. Nature Conservation 35: 1–23. https://doi.org/10.3897/natureconservation.35.35049

EEA (2013) 91D0 Bog woodland – Report under the Article 17 of the Habitats Directive Period 2007–2012. EEA, European Environment Agency.

EEA (2019) Habitat assessments at EU biogeographical level. EEA, European Environment Agency. [Retrieved August 3, 2019] https://bd.eionet.europa.eu/article17/reports2012/habitat/summary/?period=3&subject=91D0

Engel F, Bauhus J, Gärtner S, Kühn A, Meyer P, Reif A, Schmidt M, Schultze J, Späth V, Stübner S, Wildmann S, Spellmann H (2016) Wälder mit natürlicher Entwicklung in Deutschland: Bilanzierung und Bewertung. Naturschutz und Biologische Vielfalt 145: 1–221.

Engel F, Meyer P, Demant L, Spellmann H (2019) Wälder mit natürlicher Entwicklung in Deutschland. AFZ, Der Wald 74: 30–33.

European Commission (2015) Natura 2000 and Forests Part I-II. Technical report 2015, 88. European Commission, DG Environment.

European Commission (2020) Rural development. [Retrieved February 26, 2020] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/rural-development

Eurostat (2018) Agriculture, forestry and fishery statistics. 2018 edition. doi:10.2785/340432

Fedrowitz K, Koricheva J, Baker SC, Lindenmayer DB, Palik B, Rosenvald R, Beese W, Franklin JF, Kouki J, Macdonald E, Messier C, Sverdrup-Thygeson A, Gustafsson L (2014) Can retention forestry help conserve biodiversity? A meta-analysis. Journal of Applied Ecology 51(6): 1669–1679. https://doi.org/10.1111/1365-2664.12289

Finck P, Heinze S, Raths U, Riecken U, Ssymank A (2017) Rote Liste der gefährdeten Biotoptypen Deutschlands – dritte fortgeschriebene Fassung (3rd ed.) Naturschutz und Biologische Vielfalt. Landwirtschaftsverlag Münster, Bonn-Bad Godesberg.

Fischer P, Heinken T, Meyer P, Schmidt M, Waesch G (2009) Zur Abgrenzung und Situation des FFH-Lebensraumtyps "Mitteleuropäische Flechten-Kiefernwälder" (91TO) in Deutschland. Natur und Landschaft 84: 281–287.

Fischer P, Bültmann H, von Drachenfels O, Heinken T, Waesch G (2014) Rückgang der Flechten-Kiefernwälder in Niedersachsen seit 1990. Informationsdienst Naturschutz Niedersachsen 34(1): 54–65.

Forestry Commission (2010) English Woodland Grant Scheme - EWGS Summary. [Retrieved October 1, 2020] http://adlib.everysite.co.uk/adlib/defra/content.aspx?doc=122813&id=122814

Franklin JF, Spies TA, Van Pelt R, Carey AB, Thornburgh DA, Berg DR, Lindenmayer DB, Harmon ME, Keeton WS, Frank DC, Bible K, Chen J (2002) Disturbances and structural development of natural forest ecosystems with slivicultural implications, using Douglas-fir forests as an example. Forest Ecology and Management 155(1–3): 399–423. https://doi.org/10.1016/S0378-1127(01)00575-8

Franz K, Dieter M, Möhring B (2017) Naturschutzförderung neu gedacht. AFZ, Der Wald 72: 44–47.

Franz K, von Blomberg M, Demant L, Dieter M, Lutter C, Meyer P, Möhring B, Paschke M, Seintsch B, Selzer AM, Spellmann H (2018a) Perspektiven für den Vertragsnaturschutz. AFZ, Der Wald 73: 30–33.

Franz K, von Blomberg M, Demant L, Lutter C, Seintsch B, Selzer AM (2018b) Umsetzung von Vertragsnaturschutz im deutschen Wald. AFZ, Der Wald 73: 13–15.

Frenz W, Müggenborg HJ (2016) Bundesnaturschutzgesetz Kommentar (2nd ed.). Erich Schmidt Verlag, Berlin.

Fuentes-Montemayor E, Peredo-Alvarez VM, Watts K, Park KJ (2015) Are woodland creation schemes providing suitable resources for biodiversity? Woodland moths as a case study. Biodiversity and Conservation 24(12): 3049–3070. https://doi.org/10.1007/s10531-015-0997-2

Gastauer M, Trein L, Meira-Neto JAA, Schumacher W (2013) Evaluation of biotope's importance for biotic resource protection by the Bonner Approach. Ecological Indicators 24: 193–200. https://doi.org/10.1016/j.ecolind.2012.06.014

Geitzenauer M, Blondet M, De Koning J, Ferranti F, Sotirov M, Weiss G, Winkel G (2017) The challenge of financing the implementation of Natura 2000-Empirical evidence from six European Union Member States. Forest Policy and Economics 82: 3–13. https://doi.org/10.1016/j.forpol.2017.03.008

Gemeinholzer B, Demant L, Dieterich M, Eser U, Farwig N, Geske C, Feldhaar H, Lauterbach D, Reis M, Weisser W, Werk L (2019) Artenschwund trotz Naturschutz. Biologie in Unserer Zeit 49(6): 444–455. https://doi.org/10.1002/biuz.201910689

Groß P, Konold W (2009) Mittelwald als Agroforstsystem zwischen geordneter Nachhaltigkeit und Gestaltungsvielfalt – Eine historische Studie. Allgemeine Forst- und Jagdzeitung 181: 64–71.

Gustafsson L, Bauhus J, Asbeck T, Augustynczik ALD, Basile M, Frey J, Gutzat F, Hanewinkel M, Helbach J, Jonker M, Knuff A, Messier C, Penner J, Pyttel P, Reif A, Storch F, Winiger N, Winkel G, Yousefpour R, Storch I (2019) Retention as an integrated biodiversity conservation approach for continuous-cover forestry in Europe. Ambio 49(1): 85–97. https://doi.org/10.1007/s13280-019-01190-1

Güthler W, Market R, Häusler A, Dolek M (2005) Vertragsnaturschutz im Wald – Bundesweite Bestandsaufnahme und Auswertung. BfN-Skripten 146: e182.

Harmon ME, Franklin JF, Swanson FJ, Sollins P, Gregory SV, Lattin JD, Anderson NH, Cline SP, Aumen NG, Sedell JR, Lienkaemper GW, Cromack K, Cummins KW (1986) Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research. Academic Press 15: 133–302. https://doi.org/10.1016/S0065-2504(08)60121-X

Heinken T (1990) Pflanzensoziologische und ökologische Untersuchungen offener Sandstandorte im östlichen Aller-Flachland (Ost-Niedersachsen). Tuexenia 10: 223–257.

Heinken T (2008) Synopsis der Pflanzengesellschaften Deutschlands Heft 10 Vaccinio-Piceetea (H7) Beerstrauch-Nadelwälder Teil 1: Dicrano-Pinion – Sand- und Silikat-Kiefernwälder. Floristisch-soziologische Arbeitsgemeinschaft. Göttingen.

IUCN (2013) Threats Classification Scheme (Version 3.2). IUCN, International Union for Conservation of Nature. [Retrieved June, 6, 2020] https://www.iucnredlist.org/resources/threat-classification-scheme

IUCN (2016) A global standard for the identification of Key Biodiversity Areas, Version 1.0. 1st. ed. IUCN, International Union for Conservation of Nature, Gland, Switzerland.

Janssen JAM, Rodwell JS, García Criado M, Gubbay S, Haynes T, Nieto A, Sanders N, Landucci F, Loidi J, Ssymank A, Tahvanainen T, Valderrabano M, Acosta A, Aronsson M, Arts G, Attorre F, Bergmeier E, Bijlsma RJ, Bioret F, Biţă-Nicolae C, Biurrun I, Calix M, Capelo J, Čarni A, Chytrý M, Dengler J, Dimopoulos P, Essl F, Gardfjel H, Gigante D, Giusso del Galdo G, Hájek M, Jansen F, Jansen J, Kapfer J, Mickolajczak A, Molina JA, Molnár Z, Paternoster D, Piernik A, Poulin B, Renaux B, Schaminée JHJ, Šumberová K, Toivonen H, Tonteri T, Tsiripidis I, Tzonev R, Valachovič M (2016) European Red List of Habitats. Part 2: Terrestrial and freshwater habitats. European Commission, Brussels. ISBN 978-92-79-61588-7. doi: 10.2779/091372

Joosten H (2012) Zustand und Perspektiven der Moore weltweit. Natur und Landschaft 87: 50–55.

Joosten H, Berghöfer A, Couwenberg J, Dietrich K, Holsten B, Permien T, Schäfer A, Tanneberger F, Trepel M, Wahren A (2015) Die neuen MoorFutures – Kohlenstoffzertifikate mit ökologischen Zusatzleistungen. Natur und Landschaft 90: 170–175.

Kirby KJ, Buckley GP, Mills J (2017) Biodiversity implications of coppice decline, transformations to high forest and coppice restoration in British woodland. Folia Geobotanica 52(1): 5–13. https://doi.org/10.1007/s12224-016-9252-1

Kraus D, Krumm F (2013) Integrative approaches as an opportunity for the conservation of forest biodiversity. European Forest Institute Freiburg.

Kraus D, Bütler R, Krumm F, Lachat T, Larrieu L, Mergner U, Paillet Y, Rydkvist T, Schuck A, Winter S (2016) Cataloque of tree microhabitats – Reference field list. Integrate + Technical Paper. European Forest Institute Freiburg.

Kroiher F, Bolte A (2015) Naturschutz und Biodiverstität im Spiegel der BWI 2012. AFZ, Der Wald 70: 23–27.

Larrieu L, Cabanettes A, Delarue A (2012) Impact of silviculture on dead wood and on the distribution and frequency of tree microhabitats in montane beech-fir forests of the Pyrenees. European Journal of Forest Research 131(3): 773–786. https://doi.org/10.1007/s10342-011-0551-z

Larrieu L, Paillet Y, Winter S, Bütler R, Kraus D, Krumm F, Lachat T, Michel AK, Regnery B, Vandekerkhove K (2018) Tree related microhabitats in temperate and Mediterranean European forests: A hierarchical typology for inventory standardization. Ecological Indicators 84: 194–207. https://doi.org/10.1016/j.ecolind.2017.08.051

Lassauce A, Paillet Y, Jactel H, Bouget C (2011) Deadwood as a surrogate for forest biodiversity: Meta-analysis of coorelations between deadwood volume and species richness of saproxylic organisms. Ecological Indicators 11(5): 1027–1039. https://doi.org/10.1016/j.ecolind.2011.02.004

Leuschner C, Ellenberg H (2017) Ecology of Central European Forests – Vegetation Ecology of Central Europe Volume I. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-319-43042-3

Lindenmayer DB, Burton PJ, Franklin JF (2008) Salvage Logging and Its Ecological Consequences. Island Press, Washington.
Lindenmayer DB, Laurance WF, Franklin JF (2012) Global Decline in Large Old Trees. Science 338(6112): 1305–1306. https://doi.org/10.1126/science.1231070
Margules CR, Pressey RL (2000) Systematic conservation planning. Nature 405(6783): 243–253. https://doi.org/10.1038/35012251
Meyer P (2013) Biodiversität im Wald – Aus der Sicht der Forstwissenschaft. AFZ, Der Wald 68: 24–25.
Meyer P, Schmidt M (2008) Aspekte der Biodiversität von Buchenwäldern – Konsequenzen für eine naturnahe Bewirtschaftung. Beiträge aus der NW-FVA 3: 159–162.
Meyer P, Menke N, Nagel J, Hansen J, Kawaletz H, Paar U, Evers J (2009) Abschlussbericht des von der Deutschen Bundesstiftung Umwelt geförderten Projekts – Entwicklung eines Managementmoduls für Totholz im Forstbetrieb, Abschlussbericht. Abschlussbericht des von der Deutschen Bundesstiftung Umwelt geförderten Projektes. http://www.nw-fva.de/?id=234
Meyer P, Spellmann H, Nagel RV, Fischer C (2015) „Gräben vertiefen, wo Brücken gebaut werden müssen" – Stellungnahme zum Beitrag ‚Alte Buchenwälder nehmen in Hessen drastisch ab' von Norbert Panek, Agenda zum Schutz deutscher Buchenwälder in Naturschutz und Landschaftsplanung 47(4): 124–125. Naturschutz und Landschaftsplanung 47(7): 225–226.
Meyer P, Schmidt M, Lorenz K, Bedarff U (2018) Vergleich von Artenvielfalt, Vegetation und Waldstruktur des Mittelwaldes „Heißum" und des Hochwaldes „Lewer Berg" im Niedersächsischen Forstamt Liebenburg. NW-FVA, Göttingen. https://www.nw-fva.de/index.php?id=683
Mölder A, Schmidt M, Plieninger T, Meyer P (2020) Habitat-tree protection concepts over 200 years. Conservation Biology 34(6): 1444–1451. https://doi.org/10.1111/cobi.13511
Moore TR, Knowles R (1989) The influence of water table levels on methane and carbon dioxide emissions from peatland soils. Canadian Journal of Soil Science 69(1): 33–38. https://doi.org/10.4141/cjss89-004
Müller J, Noss RF, Thorn S, Bässler C, Leverkus AB, Lindenmayer D (2019) Increasing disturbance demands new policies for intact forests. Conservation Letters 12(1): 1–7. https://doi.org/10.1111/conl.12449
Nordén B, Dahlberg A, Brandrud TE, Fritz Ö, Ejrnaes R, Ovaskainen O (2014) Effects of ecological continuity on species richness and composition in forests and woodlands: A review. Ecoscience 21(1): 34–45. https://doi.org/10.2980/21-1-3667
Paillet Y, Pernot C, Boulanger V, Debaive N, Fuhr M, Gilg O, Gosselin F (2015) Quantifying the recovery of old-growth attributes in forest reserves: A first reference for France. Forest Ecology and Management 346: 51–64. https://doi.org/10.1016/j.foreco.2015.02.037
Plachter H (1991) Naturschutz. UTB, G. Fischer, Stuttgart.
Plieninger T, Hartel T, Martin-Lopez B, Beaufoy G, Bergmeier E, Kirby K, Montero MJ, Moreno G, Oteros-Rozas E, Van Uytvanck J (2015) Wood-pastures of Europe: Geographic coverage, social-ecological values, conservation management, and policy implications. Biological Conservation 190: 70–79. https://doi.org/10.1016/j.biocon.2015.05.014
Polley H, Hennig P, Kroiher F, Marks A, Riedel T, Schmidt U, Schwitzgebel F, Stauber T (2016) Der Wald in Deutschland: Ausgewählte Ergebnisse der dritten Bundeswaldinventur. Federal Ministry of Food and Agriculture, Berlin, Germany.

Runkle JR (1989) Synchrony of Regeneration, Gaps, and Latitudinal Differences in Tree Species Diversity. Ecology 70(3): 546–547. https://doi.org/10.2307/1940199

Schultze J, Reif A, Gärtner S, Bauhus J, Engel F, Späth V (2016) Naturschutzfachliche Bewertung der Wälder mit natürlicher Entwicklung in Deutschland. Naturschutz und Biologische Vielfalt 145: 75–150.

Seibold S, Bässler C, Brandl R, Gossner MM, Thorn S, Ulyshen MD, Müller J (2015) Experimental studies of dead-wood biodiversity – A review identifying global gaps in knowledge. Biological Conservation 191: 139–149. https://doi.org/10.1016/j.biocon.2015.06.006

Seidl R, Thom D, Kautz M, Martin-Benito D, Peltoniemi M, Vacchiano G, Wild J, Ascoli D, Petr M, Honkaniemi J, Lexer MJ, Trotsiuk V, Mairota P, Svoboda M, Fabrika M, Nagel TA, Reyer CPO (2017) Forest disturbances under climate change. Nature Climate Change 7(6): 395–402. https://doi.org/10.1038/nclimate3303

Seintsch B, Franz K, Meyer P, Möhring B, Paschke M (2018) Das WaVerNa-Forschungsprojekt im Überblick. AFZ, Der Wald 73: 10–12.

Sotirov M (2017) Natura 2000 and forests: Assessing the state of implementation and effectiveness. What Science Can Tell Us 7. European Forest Institute, 146 pp.

Stefańska-Krzaczek E, Fałtynowicz W, Szypuła B, Kącki Z (2018) Diversity loss of lichen pine forests in Poland. European Journal of Forest Research 137(4): 419–431. https://doi.org/10.1007/s10342-018-1113-4

Swanson ME, Franklin JF, Beschta RL, Crisafulli CM, DellaSala DA, Hutto RL, Lindenmayer DB, Swanson FJ (2011) The forgotten stage of forest succession: Early-successional ecosystems on forest sites. Frontiers in Ecology and the Environment 9(2): 117–125. https://doi.org/10.1890/090157

Thorn S, Bässler C, Brandl R, Burton PJ, Cahall R, Campbell JL, Castro J, Choi CY, Cobb T, Donato DC, Durska E, Fontaine JB, Gauthier S, Hebert C, Hothorn T, Hutto RL, Lee EJ, Leverkus AB, Lindenmayer DB, Obrist MK, Rost J, Seibold S, Seidl R, Thom D, Waldron K, Wermelinger B, Winter MB, Zmihorski M, Müller J (2018) Impacts of salvage logging on biodiversity: A meta-analysis. Journal of Applied Ecology 55(1): 279–289. https://doi.org/10.1111/1365-2664.12945

Unrau A, Becker G, Spinelli R, Lazdina D, Magagnotti N, Nicolescu VN, Buckley P, Bartlett D, Kofman PD (2018) Coppice forests in Europe. Albert Ludwig University, Freiburg.

Usher MB (1994) Erfassen und Bewerten im Naturschutz. Quelle & Meyer, Heidelberg, Wiesbaden.

Vandekerkhove de K, Keersmaeker L, Walleyn R, Köhler F, Crevecoeur L, Govaere L, Thomaes A, Verheyen K (2011) Reappearance of Old-Growth Elements in Lowland Woodlands in Northern Belgium: Do the Associated Species Follow? Silva Fennica 45(5): 909–935. https://doi.org/10.14214/sf.78

von Brackel W, von Brackel J (2016) Ein Pilotversuch zur Wiederherstellung von Flechten-Kiefernwäldern. ANLiegen Natur 38: 1–9.

Walentowski H, Winter S (2007) Naturnähe im Wirtschaftswald – was ist das? Tuexenia 27: 19–26.

WBW and WBBGR (2020) Wege zu einem effizienten Waldnaturschutz in Deutschland. Stellungnahme. WBW and WBBGR, Wissenschaftlicher Beirat Waldpolitik und Wissenschaftlicher Beirat Biodiversität und Genetische Ressourcen. Berlin, 62 S. [Retrieved April, 21, 2020] https://www.bmel.de/SharedDocs/Downloads/DE/_Ministerium/Beiraete/biodiversitaet/stellungnahme-effizienter-waldnaturschutz.html

WCED (1987) Report of the World Commission on Environment and Development: Our Common Future. WCED, World Commission on Environment and Development. Oxford University Press, Oxford.

Winkel G, Blondet M, Borrass L, Frei T, Geitzenauer M, Gruppe A, Jump A, De Koning J, Sotirov M, Weiss G, Winter S, Turnhout E (2015) The implementation of Natura 2000 in forests: A trans- and interdisciplinary assessment of challenges and choices. Environmental Science & Policy 52: 23–32. https://doi.org/10.1016/j.envsci.2015.04.018

Winter S, Möller GC (2008) Microhabitats in lowland beech forests as monitoring tool for nature conservation. Forest Ecology and Management 255(3–4): 1251–1261. https://doi.org/10.1016/j.foreco.2007.10.029

Winter S, Begehold H, Herrmann M, Lüderitz M, Möller G, Rzanny M, Flade M (2016) Praxishandbuch – Naturschutz im Buchenwald Naturschutzziele und Bewirtschaftungsempfehlungen für reife Buchenwälder Nordostdeutschlands (2nd ed.). Land Brandenburg.

Supplementary material 1

Table S1

Authors: Laura Demant, Erwin Bergmeier, Helge Walentowski, Peter Meyer

Data type: Table

Explanation note: Suitability assessment of representative forest conservation objects and conservation measures for different contract duration periods. For the scaling of the nature conservation value (NCV), based on worthiness of preservation and need for protection see Tables 1, 2 and 4. German Red List Status 1! = critically endangered (acutely), 1 = critically endangered, 1-2 = endangered to critically, 2 = endangered, 2-3 = vulnerable to endangered, 3 = vulnerable, 3-V = near threatened to vulnerable, V = near threatened, * = no current risk of loss trend (least concern). Colors: red = not suitable (ns), yellow = moderately suitable (ms), light green = suitable (s), dark green = very suitable (vs). # = legally protected habitat (§30 BNatSchG).

Link: https://doi.org/10.3897/natureconservation.42.58173.suppl1

Supplementary material 2

Table S2

Authors: Laura Demant, Erwin Bergmeier, Helge Walentowski, Peter Meyer

Data type: Table

Explanation note: Proportions of the worthiness of preservation and need for protection of all forest conservation objects (FCO), and for each group.

Link: https://doi.org/10.3897/natureconservation.42.58173.suppl2

Supplementary material 3

Table S3

Authors: Laura Demant, Erwin Bergmeier, Helge Walentowski, Peter Meyer

Data type: Table

Explanation note: German Red List Status (1! = critically endangered (acutely), 1-2 = endangered to critically endangered, 2-3 = vulnerable to endangered, V = near threatened), Natura 2000 assignment and EUNIS (European Nature Information System) classification of the exemplary FCOs.

Link: https://doi.org/10.3897/natureconservation.42.58173.suppl3