Ann. For. Res. 61(2): 129-146, 2018
DOI: 10.15287/afr.2018.1185

**ANNALS OF FOREST RESEARCH**
www.afrjournal.org

# The German Forest Strategy 2020: Target achievement control using National Forest Inventory results

**Martin Lorenz[§], Hermann Englert, Matthias Dieter**

**Lorenz M., Englert H., Dieter M.,** 2018. The German Forest Strategy 2020: Target achievement control using National Forest Inventory results. Ann. For. Res. 61(2): 129-146.

**Abstract.** In the year 2011 the German Federal Government adopted its Forest Strategy 2020. This strategy includes 60 goal formulations in nine action fields. The present paper analyses to which extent the results of the German National Forest Inventory (BWI) prove achievements of those of the 60 goals, which are quantitatively verifiable. The results reveal that forestry in Germany in general meets its own standard of multi-functionality, securing that forests fulfil manifold demands of the society. However, while the objectives of nature and climate protection are on track for being achieved, the prospects for objectives related to employment, income and value added are less encouraging. Total forest area and forest growth are increasing, forests currently constitute a carbon sink, and the naturalness and structural diversity of forests are growing. Also the high but sustainable use of the wood fosters currently the income of and employment in forest enterprises and timber industries. But the ongoing regeneration of forest stands predominantly with deciduous tree species is expected to cause a long-term lack of faster growing and higher valuated coniferous stands. The resulting lack of highly demanded softwood of small or medium-sized diameters will raise problems to timber industries. Moreover, shrinking timber production due to a decreasing share of coniferous forests has adverse consequences not only from the economic point of view. It will also decrease the climate-friendly use of wood products, in particular due to the foregone substitution effect. The results of the study also show that BWI is an indispensable source of information for forest politics and forest science particularly in view of its long-term time series. The preservations of time series must be kept in mind whenever changes in the methods of BWI are considered.
**Keywords:** forest strategy, forest inventory, forest ecosystem services, biodiversity, wood production, carbon sequestration

**Authors.** Thuenen Institute of International Forestry and Forest Economics Leuschnerstr. 91, D-21031 Hamburg, Germany.
[§] Corresponding author: Martin Lorenz (martin.lorenz@thuenen.de)
**Manuscript** received November 4, 2018; revised December 26, 2018; accepted December 29, 2018; online first December 31, 2018.

## Introduction

Rising societal demands for natural resources have triggered the need for sustainable land use at a global scale (FAO 2009). This holds true in particular for sustainable forest management (SFM), as forests account for about one third of the total land area of the world (FAO 2010), constitute a renewable resource, and provide an unparalleled wealth of ecosystem services. The increasing demands for manifold forest ecosystem services have considerably changed the paradigms in forest assessments. This holds true in particular for national forest inventories (NFIs) (Lorenz et al. 2005). Based on statistical sampling methods, NFIs are carried out regularly by many countries, especially in Europe (Tomppo et al. 2010). At country level, NFIs provide comprehensive information on forest resources, their condition, and their development. While stressing the need for further international harmonization of definitions, parameters, and methods of NFIs, Vidal et al. (2016) analyze the role of European NFIs for international forestry reporting. A good example is the FAO Global Forest Resources Assessment (FRA), which has been assessing the forests of the world at five to ten year intervals since 1946 also based on NFI information (FAO 2010). Given environmental challenges such as protection of biodiversity and mitigation of climate change with entailing burdens like heat, drought, biotic calamities, forest fires, storms and floods, the reporting of NFI data contributes to the information base of international processes of forest and environmental policies. This holds true in particular for the United Nations Framework Convention on climate change (UNFCC) (UNFCC 2009), as forests can act both as a sink and as a source of carbon dioxide. The NFIs of several countries were adjusted in order to comply with relevant reporting needs (Dolman et al. 2013). Moreover, NFI data are used for checking criteria and indicators for the effective implementation of SFM under Forest Europe - the former Ministerial Conference on the Protection of Forests in Europe (MCPFE). Forest Europe develops common strategies for its 47 signatories (46 European countries and the European Union) on how to protect and sustainably manage their forests (Forest Europe, UNECE and FAO 2015).

In order to ensure sustainable forest management and the implementation of multifunctional forestry in Germany, the German Federal Government adopted in 2011 its “Forest Strategy 2020” (BMELV 2011). The Forest Strategy 2020 is a programmatic formulation of general German forest political guidelines. Starting from a comprehensive description of the current forest political debate on challenges and opportunities for forests, the strategy includes 74 solution approaches subdivided into nine areas of action. Sixty of these solution approaches are formulated as goals to be reached by the year 2020 (Section 2). The extent to which these goals can be expected to be implemented within the given time frame is explored by the German Federal Ministry of Food and Agriculture (BMEL) in cooperation with Thünen-Institute of International Forestry and Forest Economics by means of a variety of approaches including population surveys as well as inquiries among relevant associations and the forest administrations of the German Länder.

## Material and methods

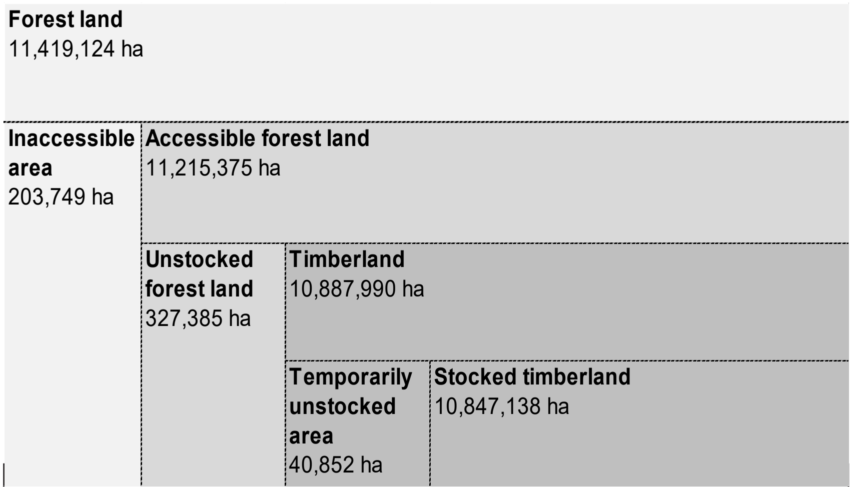
The majority of the 60 goals of the Forest Strategy are formulated in a general manner and are not substantiated by quantitative target figures. Only 10 of these goals turned out to refer to indicators assessed by BWI, to be quantitatively verifiable and to be therefore suitable for target achievement control using BWI data. These 10 goals were identified in the following six areas of action: (i) silviculture, (ii) biodiversity and forest conservation, (iii) protection of soil and water management, (iv) raw materials, use and efficiency, (v) property, work and income (value added) and (vi) hunting.

In accordance with these six areas of action, the presentation of the results of the study (Section 3) is subdivided into six sub-sections 3.1 to 3.6. In each of these sub-sections, the wording of the respective goal(s) is quoted from the Forest Strategy. The 10 goals aim at the (1) extension of forest area, (2) establishment of stable and productive mixed stands, (3) increase of the naturalness of stands, (4) increase of the biological diversity of stands, (5) avoidance of clearcuttings, (6) increase of wood harvest maximally up to the average annual increment, (7) improvement of wood mobilization in line with the timber market, (8) broad diversification of private property, (9) Preservation and, if possible. extension of the ecological and social functions of the forest, (10) wildlife stock control permitting natural regeneration without fencing.

The achievement of the above mentioned goals is checked by means of numerical analyses of aggregated results of three BWI survey periods. As a repetitive forest inventory, BWI was carried out until now three times (BWI 1987, BWI 2002, and BWI 2012) on permanent sample plots of a nation-wide basic grid of 4 x 4 km. For some regions, this basic grid was densified up to a 2 x 2 km grid. BWI 1987 was carried out in the Federal Republic of Germany prior to its unification with the former German Democratic Republic of Germany. Results for the main variables derived are statistically representative at the national scale (Polley et al. 2004). BWI is designed for achieving statistical significance regarding main forest variables such as forest area and volume of growing stocks on federal and provincial state levels (except for city states). Statistical significance is besides the variability of the concerned variable especially a matter of the number of involved sampling elements. Disaggregating the BWI-sample to individual provincial states and/or the area of individual tree species groups and/or individual forest ownership classes reduces the involved sampling elements and increases the random sampling error of the respective estimations. The interpretation of the results has to take into account that estimations related to small evaluation units are possibly of low statistical significance (Polley et al. 2004). Survey results are published as printed technical reports (BMELV 2005) and in the internet (Thünen Institut 2014). They refer to forest area, growing stock, increment, timber harvest and timber loss. Moreover, typical for a contemporary forest inventory, BWI does not only assess dendrometrical attributes but also a full range of ecological information, such as silviculture, deadwood and biogeography, as well as administrative attributes. A description of the methods and algorithms used for the calculation of the published survey results is provided by Riedel (2017). The survey results refer to different categories of forest land. For these categories, BWI uses an explicitly defined terminology (Figure 1).

In order to estimate and compare sustainable wood utilization potentials, the BWI-based Forest Development- and Timber Volume Modeling (German: WEHAM) was used (BMEL, 2016; Rock et al. 2016). WEHAM is an empirical, distance-independent single-tree growth model. It was developed by experts of the Federal Government and institutions of the Federal States (Rock et al. 2016). Following the finalization of the BWI 2012, the so-called "WEHAM 2012 baseline scenario" was developed. The scenario covers the entire forest of Germany and describes the courses of action most probable to take place in the future. Like the above mentioned survey results, WEHAM results of the 2012 baseline scenario are also published on the BWI website (Thünen-Institut 2014). These results are projected data on growing stock, increment, wood potential and removals.

Of the published BWI and WEHAM results, data on the following attributes were evaluated for implementation of the goals of the Forest Strategy: (a) forest area (by type of owner-




**Accessible forest land:** This is where the inventory teams surveyed data
**Inaccessible area:** Not accessible, for example, due to bans on access or hazardous grounds
**Timberland:** Area permanently serving the purposes of wood production
**Unstocked forest land:** Forest areas not considered timberland, such as forest tracks, rides and firebreaks over 5 meters wide, and landings
**Stocked timberland:** Timberland on which trees grow
**Temporarily unstocked area:** Timberland on which trees temporarily are not growing

**Figure 1** Categories of forest land according to BMEL (2014)

ship), (b) area of timberland (by accessibility and restriction of utilization), (c) area of new forest land (by type of ownership and type of land use), (d) woodland conversion area (by type of ownership and type of land use), (e) area of stocked timberland (by tree species, tree age, stocking type, stocking type of the regeneration layer, stand structure, naturalness, accessibility, and restriction of utilization), (f) volume of wood increment (by tree species and type of ownership), (g) volume of wood utilization (by tree species, type of utilization and type of ownership), (h) wood utilization potential (by type of ownership).

Depending on the goal to be checked for implementation, the data taken from BWI and WEHAM required individual numerical analyses such as interpolations as well as the calculation of frequency distributions and periodic changes. These calculations are explained individually along with the descriptions of the respective results in the following section.

## Results

### Silviculture

Silviculture is the key instrument for securing the continuous provision of the manifold forest ecosystem services demanded by the society. For this reason, the achievement of most of the aims of the Forest Strategy 2020 depends directly or indirectly on silvicultural measures. The aims of the area of action "Silviculture" of the Forest Strategy are comprehensive: where possible forest area should be extended and land usage for settlements and infrastructure should be reduced, diverse, stable and productive mixed forests should be established, forest area in Germany should be preserved and stability, diversity and naturalness of the forests should be increased; this is supported by cultivation of primarily indigenous tree species.

Regarding the aim of an extension of the forest area, the size of new forest land can be directly taken from BWI 2012. The total new forest land across all types of ownership is 107,875 ha (Table 1, Supporting Information). By far the largest share of this area, namely 63,873 ha, originated from previous agricultural land. With a share of 35,236 ha about half as much originated from previous building areas. Most of the woodland originating from other types of land use is private forest (65,129 ha). The new forest land, however, does not indicate the net change, i.e. by how much the forest area in 2012 actually exceeded that in 2002. This requires a balancing with the conversion of forests into other types of land use during the same period. In total 58,278 ha of forest were converted. Of this forest area by far the largest share (41,322 ha) was converted into building area (Table 2, Supporting Information).

The net change in forest area balances the new forest land against the conversion area (Table 3, Supporting Information). Negative entries indicate a decrease while positive entries indicate an increase in forest area. Percentages show that changes in relative terms over ten years were small. The total forest land over all types of ownership increased from 2002 to 2012 by 0.44 % resembling 49,597 ha. An area of 48,714 ha of agricultural land and 6,970 ha of water and wetlands were turned into woodland. At the same time woodland of 6,086 ha was converted into building area. The net increase of forest land was largest in private forest (32,546 ha or 0.60 %) and in corporate forest (12,248 ha or 0.55 %).

The aim of diverse, stable and productive mixed forests is intended to safe-guard the ecological forest functions. Particularly in Germany many forest lands have been reforested with mono-species coniferous stands following extensive clear-cuttings for reparations after the Second World War. This holds true in particular for Norway spruce (*Picea abies* (L.) Karst.) and partly also for Scots pine (*Pinus silvestris* L.). In view of ecological drawbacks of pure coniferous stands on many forest sites, the increase of the share of deciduous and mixed forests has been an objective of close-to-nature forestry practiced in Germany for the past three decades. The increase of the share of deciduous trees poses also a socio-economic aim. The population of Germany was found to have a willingness to pay for an improvement of the scenery by an increased share of deciduous trees (Elsasser et al. 2010).

For the coniferous and deciduous tree species in Germany Table 4 (Supporting Information) compares the areas and percentages of areas of stocked timberland in the years 2002 and 2012. Timberland means land permanently foreseen for timber production. This excludes forest roads broader than five meters, timber stockyards, clearings, gaps in stocking and stands, as well as not accessible areas. The comparison between the two surveys, however, is hampered by the fact that BWI 2002 assessed too small a number of plots and consequently too small a survey area. BWI 2012 reports the absolute change in area, but for a conclusive interpretation the change relative to the correct area of the year 2002 is needed. The correct area of the year 2002 was obtained by subtracting the absolute change from the area of the year 2012.

The net increase of forest land by nearly 50.000 ha (Table 4, Supporting Information) is in favour of the share of the deciduous tree species. In absolute terms the deciduous forest area has increased from 4.412 Mio ha in 2002 by 315 thousand ha to 4.727 Mio ha in 2012. This includes not only the changes of coniferous stands into deciduous stands, but also the deciduous stands of new forest land. In relative terms the share of deciduous forests has changed from 41.7% in 2002 to 44.5% in 2012, resembling a relative increase by 7.1% in ten years. More than half of this increase is contributed by common beech (*Fagus sylvatica* L.) and the species group “Oak” consisting of mainly pendunculate oak (*Quercus robur* L.), sessile oak (*Quercus petraea* (Matt.) Liebl.)., and red oak (*Quercus rubra* L.). Accordingly, the coniferous forest area has decreased from 6.167 Mio ha in 2002 by 267 thousand ha to 5.900 Mio ha in 2012. In relative terms this resembles a decrease of the share of coniferous forest area from 58.3% in 2002 by 4.3% to 55.5% in 2012. This decrease reflects mainly that of Norway spruce and the species group "Pine" consisting of mainly Scots pine. In contrast, the area of the less abundant coniferous species groups "Fir", "Douglas fir", and "Larch" consisting of mainly silver fir (*Abies alba* Mill.), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), and European larch (*Larix decidua* Mill.), respectively, shows an increase.

The shift of the area of stocked timberland from coniferous towards deciduous species is closely related to tree age (Table 5, Supporting Information). Of the area of the deciduous species groups, the relative increase is clearly larger for the category "other deciduous species" than for the main species groups oak and beech. Of the deciduous tree species, spruce shows the largest relative and absolute decrease, whereas Douglas fir shows by far the largest relative increase. The total of all species reveals the opposed development of the area of younger and older trees. In all three age classes between 1 and 60 years the area has decreased, in total by about 460,000 ha. In contrast, in five out of the six age classes older than 60 years the area has increased. The total increase over all six age classes older than 60 years is about 526,000 ha. This reflects the difference between the development of the age structure of deciduous and coniferous trees. The area of the deciduous trees has in total decreased by about 53,000 ha in the age classes from 1 year to 60 years and has in total increased by about 370,000 ha in the age classes older than 60 years. In contrast, the area of the coniferous trees of age classes 1 to 60 years has in total decreased by about 406,000 ha and has in total increased by about 139,000 ha in the age classes older than 60 years.

The shift of forest area from coniferous towards deciduous species is also reflected by the regeneration of the trees (Table 6, Supporting Information). The share of the forest regeneration layer under canopy in deciduous forests has increased slightly from 67.9% in 2002 to 69.9% in 2012. This reflects in particular the increase of the percentage of the regeneration of the beech-type from 24.4% in 2002 to 29.9% in 2012. Vice versa the share of the forest regeneration layer under canopy in coniferous forest has decreased in the same period from 25.9% to 23.6%. This reflects the decrease of the percentage of the regeneration layer under canopy of the spruce-type, namely from 19.9% in 2002 to 17.6% in 2012.

Changes in naturalness from 2002 to 2012 are small, both for the totals of all stocking types and for individual stocking types (Tables 7 and 8, Supporting Information). Exceptions are the ash-type and the pine-type standing out with relatively large changes in particular classes. The share of very naturalistic and naturalistic ash-type stands decreased from 48.5% in 2002 to 40.0% in 2012. During the same period its share of partly semi-natural stands increased from 41.9% to 47.0%. The share of the partly semi-natural pine-type stands decreased from 68.5% to 62.8% while the share of the culturally conditioned pine-type stands increased from 12.9% to 18.3%.

## Biodiversity and forest conservation

In line with the Convention on Biological Diversity (CBD) adopted by the United Nations Conference on Environment and Development (UNCED), the National Biodiversity Strategy (NBS) of Germany aims at a reversal of the loss of biological diversity (BMU 2007). An enhancement of forest biodiversity increases the potential of forest ecosystems to provide multifunctional services for the society. For this reason one of the aims of the Forest Strategy 2020 reads as follows : "The biological diversity of the forests should be increased pursuant to the aims of the National Biodiversity Strategy (NBS), e.g. by means of forest areas with no intervention, increase of natural forest reserves and deadwood areas, and cross-linking of Natura2000 areas."

Forest biodiversity reveals itself mainly through floristic and faunistic species richness as well as through structural richness of forest ecosystems. These characteristics are too complex for being assessed by large-scale inventories such as BWI. However, BWI provides several indicators the analysis of which can provide hints on changes in biological diversity. The indicators suitable for analysis within this study are the composition of tree species, the abundance of deadwood, and the structure of forest stands. Another indicator is the size of forest areas with no or minimum active intervention.

The development of the composition of tree species was presented in Sub-section "Silviculture". Between the years 2002 and 2012 the formerly less abundant species common beech, pendunculate oak, sessile oak, red oak, silver fir, Douglas fir, and European larch have become more abundant. This trend towards higher species diversity is particularly pronounced for the deciduous trees. The increased share of deciduous forests speaks in favour of increased biodiversity because mixed forests in general possess higher tree species diversity.

The trend towards a higher diversity of tree species is also reflected by a change in the distribution of stocking types (Figure 2). Within the period of observations the shares of the more frequent types have evidently decreased whereas the shares of the rare types have increased.

The abundance of deadwood is a proximity indicator for biodiversity because many - in particular rare - species use deadwood as food source, sanctuary and breeding ground. This holds true in particular for a large variety of lichens, fungi, insects, and birds. The volume of deadwood in the forests of Germany amounts to about 20 $m^3$ $ha^{-1}$, depending on the assessment criteria. As these criteria were recently changed, a comparison between the volumes of 2012 and 2002 must be based on the previous definition of deadwood. In compliance with this definition, the volume of deadwood

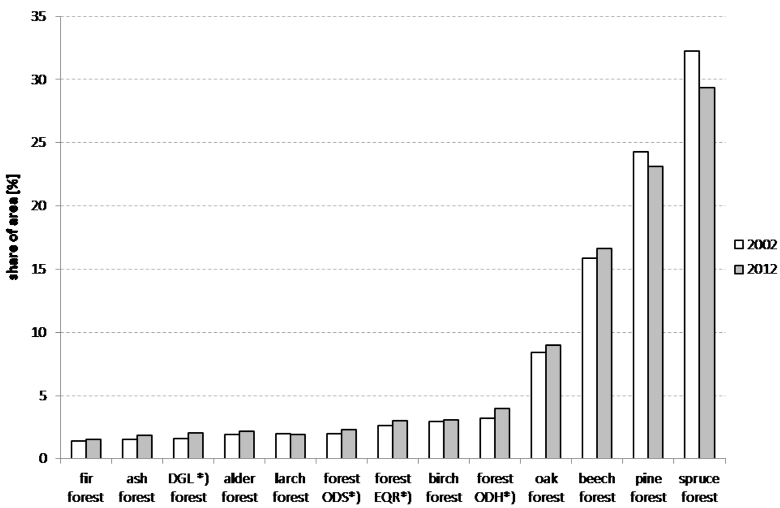



**Figure 2** Percentages of stocking types of total timberland
Abbreviations: ODS - other deciduous species with short life expectancy, ODH - other deciduous species with high life expectancy, EQR - several equally ranking tree species, DGL - Douglas fir.

has increased from 11.6 $m^3$ $ha^{-1}$ in 2002 by 2.1 $m^3$ $ha^{-1}$ to 13.7 $m^3$ $ha^{-1}$ in 2012 (BMEL 2014).

Stand structure is related to biodiversity because a highly layered canopy provides a habitat for a rich flora and fauna. Moreover, a well-structured stand can more easily adapt to changing environmental conditions. The share of single storied stands has clearly decreased from 2002 to 2012 (Table 9 for 2002 and from Table 10 for 2012, Supporting Information). It was 45.9% in 2002 and only 32.0% in 2012 for the total of all stocking types. This development towards a higher structuring of the canopy reflects mainly the decrease of the share of single storied stands of the most abundant stocking types. The shares of single storied stands of the oak-, beech-, spruce-, and pine-type all decreased by about one third. Vice versa, the shares of stands with two and with multiple canopy layers - taken together - have increased from 54.1% in 2002 to 68.1% in 2012, i. e. by nearly one third. If only the two-layered stands are considered, the respective share increased from 45.1% to 57.3%. This increase of the two-layered stands is particularly pronounced for Douglas fir. For the Pseudotsuga-type the share of two-layered stands increased by about one third from 30.5% to 46.0%. This increase is even more pronounced for multi-layered Pseudotsuga-type stands (from 3.1% to 6.5%) but as the shares of multi-layered stands are low, their changes are less relevant for the total result.

Forest biodiversity is maintained or raised by the presence or disclosure of areas with no or minimum intervention. In these areas there is no or minimum logging possible, permitted, or currently foreseen. These are mainly biotopes which are protected by nature conservation law or forest law as well as not accessible forest areas. According to the results of BWI, the share of such forest areas has increased from 5.9% in 2002 to 10.0% in 2012 (Table 11, Supporting Information).

**Protection of soil and water regime**

For the protection of forest soils and water regime the Forest Strategy 2020 foresees an abdication of clear cuttings. Under the area of action "Protection of soil and water regime" the respective aim is formulated as follows: "In view of the importance of soils as valuable production capital, clearcuttings should be avoided within the framework of the corresponding provisions of the forest acts of the German Laender (provinces)."

BWI data can be used to estimate the extent of different types of logging operations like clearcutting and selective cutting. It must be kept in mind, however, that BWI does not record which of the trees felled between two inventories were felled in the course of clearcutting. It can only be tried to estimate the type of logging operation from the presence or absence of sample trees on the plots. Table 12 (Supporting Information) shows for each species group the volume of the cut timber (merchantable wood with diameter over 7 cm o. bark) for the following three logging types distinguished by BWI: "Selective cutting" means that a number of sample trees were cut on the plot and that at least one sample tree had been left standing.

"Areal cutting" means that all sample trees on the plots were cut. This does not necessarily imply clear cutting of the whole stand, but may be due to e.g. opening of the canopy in parts of the stand. "Cut, but not utilized" refers to felled trees having remained in the forest.

"Missing trees" means that trees were assessed in the year 2002, but that neither the trees themselves nor their stumps were found in the year 2012. The sub-total "Utilization" comprises the utilized selective and areal cuttings (including the missing) trees. The total "All types of cut or loss" stands for the sum of all cut and missing trees.

The volume of all trees utilized between 2002 and 2012 amounted to 95.9 Mio $m^3$ $ha^{-1}$ $yr^{-1}$. Of these, 78.8 Mio $m^3$ $ha^{-1}yr^{-1}$ were selectively utilized (Table 12, Supporting Information). This resembles a share of 82.2%. The share of selectively utilized deciduous trees (91.8%) was larger than that of the coniferous trees (79.1%). During the same period areal cuttings occurred on 16.1 Mio $m^3$ $ha^{-1}yr^{-1}$ resembling a share of 16.8%. The respective share was 6.5% for the deciduous and 20.2% for the coniferous trees. Among the individual species the high share of areal cuttings of spruce (27.5%) is conspicuous.

**Raw materials**

The aims dealt with in the previous three sub-sections refer mainly to the protection of forests and their ecological benefits. Besides these the Forest Strategy also comprises several economic aims. These economic aims refer mainly to wood increment, wood exploitation and the sustainable wood utilization potential. The sustainable wood utilization potential in terms of the Forest Strategy is the amount of wood removals calculated by means of a model simulating forest development and wood supply (WEHAM). The simulations are based on a scenario developed jointly by the Federal Government and the German Laender. The scenario reflects the usual silvicultural practices applied and the experiences gained by the Laender over many years. In the Forest Strategy, the following economic aims are formulated under the action "Raw materials and their efficient use": "Wood harvest should be increased maximally up to the average annual increment. For Germany, this amounts to approximately 100 Mio $m^3$ per year, corresponding with the reference scenario of the Federal Government for the international climate negotiations. The sustainable raw-materials potential should be better mobilized and should be made available in line with the market."

The maximally possible sustainable wood harvest (including the amount of cut but not utilized wood) is determined in principle by the size of stocked timberland and by mean annual increment. The latter is influenced by a variety of factors, the most important ones being standing volume, tree age structure, thinning regime, and rotation period. Despite an increase of total forest area by 3.1% from 2002 to 2012 – the stocked timberland without restriction of wood harvest has decreased by 1.3% (Table 13, Supporting Information). The main reason for this decrease is the increase of the forest area of the category "wood harvest not permitted or not to be expected" by nearly 400%. Also increased – but with 8.6% far less – has the not accessible forest area. The increase of both categories together, i. e. the area with currently no wood harvest, amounts to 151.2%. If the increase of the area with wood harvest partly not permitted (24.7%) is added, the resulting increase of the area with not or partly not permitted wood harvest is 73.4%.

Mean current annual increment, mean annual wood utilization, and the wood which was cut without being utilized in the period from 2002 to 2012 are balanced in Table 14 (Supporting Information) for the main species groups (merchantable wood with diameters over 7 cm o. bark). The column at far right contains the totals of all types of cut in percent of the increment. For the total of the main species groups, 87.5% of the increment was cut. The respective percentage is 66.6% for the deciduous and 98.3% for the coniferous species groups. Spruce stands out as the single species of which the cut was larger (by 15.0%) than the increment. This implies that the aim of a wood harvest not exceeding forest growth is reached. The harvest exceeds the reference scenario of 100 Mio $m^3$ but is with about 106.3 Mio $m^3$ per year 12.5% smaller than the mean annual increment of about 121.6 $m^3$.

A calculation of the change in wood utilization must be confined to the "old" German Laender because the BWI 1987 was carried out in the Federal Republic of Germany prior to its unification with the former German Democratic Republic of Germany. From the first to the second period the wood cuttings were raised from 49.7 Mio $m^3$ to 60.9 Mio $m^3$ $yr^{-1}$ which is an increase by 22.6% (Table 15, Supporting Information). This reflects an actual increase of wood cuttings per hectare and is not mainly due to the slight increase of stocked forest area between both periods. The average wood utilization per hectare was increased from 6.6 $m^3$ $ha^{-1}yr^{-1}$ under bark (u.b.) by 1.2 $m^3$ $ha^{-1}yr^{-1}$ u.b. to 7.9 $m^3$ $ha^{-1}yr^{-1}$ u.b. (Table 16, Supporting Information). This is an increase by 18.2%.

In contrast to wood utilization, the wood utilization potential can be calculated for total Germany. Hence, the actual wood utilization of the years 2002 to 2012 is compared with the sustainable wood utilization potential of the same period (Table 17, Supporting Information). This potential is calculated by WEHAM 2002 assuming the "basic scenario" agreed upon by the Federal Government and the German Laender (see above). WEHAM calculates a potential of 74.654 Mio $m^3$ $yr^{-1}$ (harvestable volume under bark for all types of ownership). This value, however, refers to the main stand and has to be extrapolated to the total stand, i.e. to all canopy layers. The required extrapolation factor can be estimated as 1.05 from the ratio of the total volume (of all canopy layers) assessed by BWI and the volume of the main canopy modelled by WEHAM. With this factor, the extrapolation yields 78.386 Mio $m^3$ $yr^{-1}$ With a stocked forest area of 10.376 Mio ha according to the WEHAM basic scenario, the respective potential per unit area is 7.6 $m^3$ $ha^{-1}$ $yr^{-1}$.

The respective actual wood utilization of 75.680 Mio $m^3$ $yr^{-1}$ divided by the actual stocked forest area of 10.832 Mio ha $yr^{-1}$ (figures in Table 17, Supporting Information) according to BWI) yields 7.0 $m^3$ $ha^{-1}yr^{-1}$. This means that the wood utilization potential of 7.6 $m^3$ $ha^{-1}yr^{-1}$ calculated by WEHAM for all types of ownership was exploited by a rate of 92.0%. The rate of exploitation differs clearly between individual types of ownership, ranging from 85.0% for the private forest to 103.6% for the provincial state forest.

## Ownership, labour and income

The sustainable production and use of wood as a renewable raw material is not only a contribution to carbon sequestration (Section 4) but ensures labour and income in forest enterprises, timber industries and their numerous related branches. Under the action field "Ownership, labour and income" of the Forest Strategy the following economic aims are formulated: "The Federal Government will continue to guarantee a broad diversification of private property. Forestry is the basis for an efficient and internationally competitive timber industry. The frame conditions are to be shaped in a way that the ecological and social functions of the forest as well as the related employment and added value can also in the future be ensured and extended."

The change in the diversification of private and public ownership can be derived from the results of BWI 2002 and BWI 2012 in terms of the respective forest areas. The largest percentage of forest area is covered by private forest with 44.0% in 2002 and 47.1% in 2012 (Table 18, Supporting Information). These figures exclude trusteeship forest which is a remnant of the forests of the former German Democratic Republic (GDR). After the re-unification of the two German states, the forests of the GDR became property of a trust institution (Treuhandanstalt) with the aim to convert this "trusteeship forest" into private property. The disposal of about 301.000 ha of trusteeship forest to private owners is the main reason for the increase of private forest area by about 373.000 ha between the years 2002 and 2012. In the same period, the trusteeship forest area has accordingly decreased. The area of federal and provincial state forest as well as of corporate forest have remained nearly unchanged.

In 2002 the private forest area comprised 5,229,609 ha, including 405,887 ha trusteeship forest, as assessed by BWI 2002 (Figure 3). The extrapolation backwards from BWI 2012 yields 5,413,414 ha private forest area incl.

trusteeship forest which is 183,805 ha larger than assessed by BWI 2002. This difference is due to the fact that the area surveyed in 2012 was larger than the one surveyed in 2002. As this difference cannot be separated into private forest without trusteeship forest on the one hand and trusteeship forest on the other hand, it is assumed that the trusteeship forest was fully assessed in 2002 so that the difference is totally part of 5,007,526 ha of private forest without trusteeship forest.

The private forest area assessed by BWI 2012 is 5,485,678 ha including the trusteeship forest. Of the 405,887 ha of trusteeship forest assessed in 2002, a remnant of 105,308 ha has remained while 300,579 ha were transferred into private forest. In addition, an increase of private forest land by 72,265 ha was found. It originates partly from federal and provincial forest and partly from the afforestation of 32,583 ha (Table 2, Supporting Information). The resulting area of private forest without trusteeship forest is 5,380,370 ha.

The share of forest enterprises of ownership size classes below 20 ha has decreased from 57.2% in 2001 by 11.2% to 50.8% in 2012. In contrast, the shares of all other classes have increased by 9.7% to 21.3% (Table 19, Supporting Information).

The second aim quoted at the beginning of this Sub-section contains two contradictory postulates. Ecological and social functions on the one hand as well as employment and added value on the other hand are both claimed to be ensured and extended. However, trade-offs between the objectives of nature protection and the objectives related to employment and added value are likely. On the one hand, the results presented in Sub-sections “Silviculture”, “Biodiversity and forest conservation”, and “Protection of soil and water regime“ prove an extension of ecological and social functions. On the other hand, several of these ecological benefits, in particular those based on abandonment of forest management do hardly go along with and are partly detrimental to economic benefits such as employment and added value (Chapter Discussion, see further).

#### Hunting

BWI does not assess any information directly on wildlife stock and its control. However, information on regeneration, fencing and browsing is assessed. This permits an indirect check of the implementation of the following aim formulated in the Forest Strategy: Wildlife stocks should be controlled in a way that natural regeneration can be guaranteed for the main tree species without fencing: “BWI 2012 provides the share of browsed plants for the regeneration area and for young growth stands. Of the trees with heights between 20 cm and 130 cm a share of 12.1% was damaged by simple browsing (i.e. browsing of only the terminal bud within the last 12 months) and a share of 15.5% was damaged by multiple browsing (i.e. browsing of several buds including or not including the terminal bud, within a period longer than 12 months). Taken together the share of these browsed plants amounts to 27.6%. Of these browsed plants, the largest share (43.3%) consists of oak trees. The smallest share (6.4%) is represented by spruce.”

A comparison with the results of BWI 2002 shows a share of 18.3% of browsed plants within the preceding 12 months, i.e. clearly more than the respective figure of 12.1% in 2012. Strictly speaking, this difference must be interpreted with care because the assessment criterion in 2002 was defined as “browsing” instead of “browsing of the terminal bud”. It may be assumed, however, that this difference in the assessment criteria had little impact on the assessment results. The reason for this assumption is that the share of plants showing browsing without browsing of the terminal buds was probably small and moreover not even counted as browsed. This means that the observed decrease of the share of browsed trees from 2002 to 2012 is largely real. For an in-depth analysis of browsing and its development, however, the

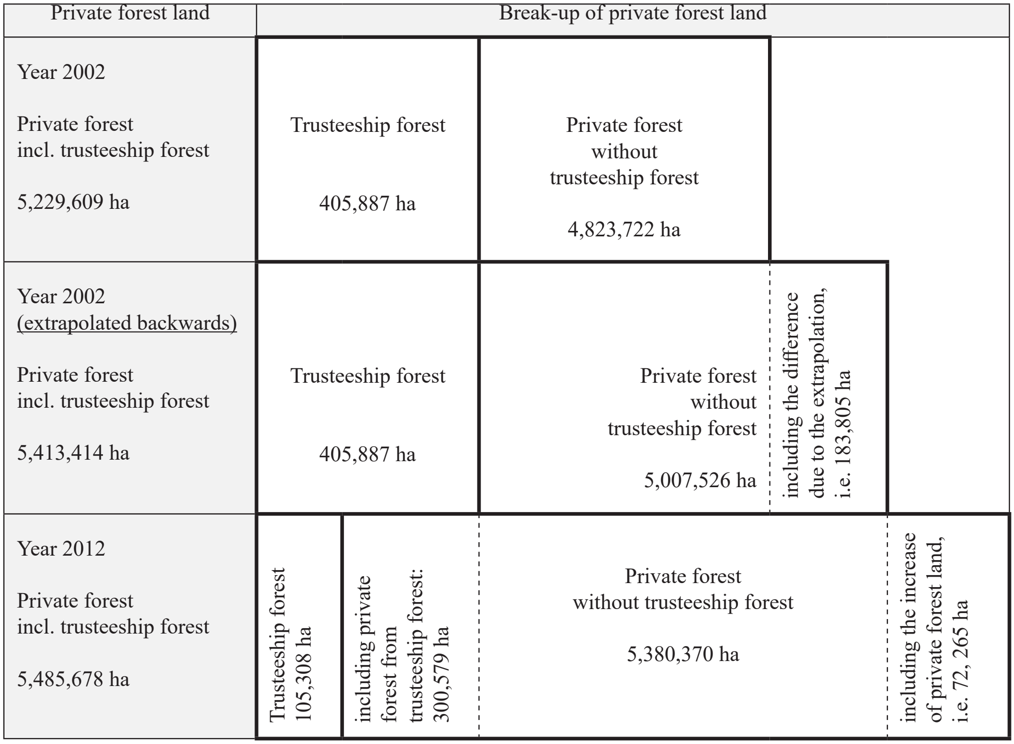



**Figure 3** Relationship between the increase of the survey area, the disposal of trusteeship forest, and the increase of private forest between the years 2002 and 2012.

BWI results are not suitable. As to be expected, the regeneration area comprises the largest share of fenced areas (Tables 20 and 21, Supporting Information). This holds true for each type of ownership. Also in each type of ownership wildlife fencing was reduced from 2002 to 2012 on timberland, in young growth and in regeneration areas. An exception is the private forest where the share of fenced areas increased slightly from 3.0% to 3.1% on timberland.

## Discussion

Sustainable forest management is deemed to be an appropriate measure to preserve forests as valuable ecosystems, crucial for the protection of bio-diversity and concurrently to warrant the provision of forest ecosystem services, vital for the wellbeing of mankind. Criteria and indicators to categorize and assess sustainable forest management have been elaborated in the past decades at all regional levels (Meier, 2014). At international level the criteria and indicators for sustainable forest management of ITTO (International Tropical Timber Organization) (ITTO 2015) and of the Montréal Process (officially denoted Montréal Process Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests; Montreal Process, 2015) could be mentioned. At European level a process has also been launched under Forest Europe to develop and further adapt criteria and indicators for sustainable forest management. The latest set is stipulated in the Madrid Ministerial Declaration from October 2015. It comprises 34 quantitative indicators and 11 qualitative indicators.

The German Forest Strategy 2020 does not refer directly to the pertinent Forest Europe criteria and indicators. Though there are substantial parallels between the aims of the German Forest Strategy 2020 and the criteria of Forest Europe. The following issues are addressed by both systems: (i) forest area, (ii) increment and fellings, (iii) diversity of tree species, (iv) naturalness, (v) deadwood, (vi) protected forests, (vii) forest holdings and (viii) wood consumption. They reflect the broad understanding of sustainable forest management. A more in detail comparison of these aims and indicators, respectively, is not possible, though. The aims of the German Forest Strategy 2020 do not comprise a definition of the respective issues but in most cases their formulation includes an indication of the intended direction of change. For the Forest Europe indicators the situation is reverse.

The size of forest area in Germany was not only preserved but has increased by 50,000 ha from 2002 to 2012. This corresponds to the aim to extend forest area as postulated by the Forest Strategy 2020. However, despite this net extension, considerable parts of the forest were converted, mostly into building and traffic areas. The converted stand and the newly established young forest stand differ in their provision of forest ecosystem services. This does not mean that ecosystem services provided by old-growth forest are necessarily to be rated higher than ecosystem services provided by young forests. For instance, natural woodland formation by means of succession on former open land may lead to young forests with great importance for species conservation. Consequently, the appraisal of the fact that forest area has increased may differ depending on whether quantitative or qualitative aspects are considered. For the appraisal of qualitative aspects of changes in forest area, however, the Forest Strategy 2020 does not set any targets. It could be shown that the increase of woodland occurred at the expense of agricultural land. The weighing between the positive effects of increasing forest area against the resulting negative effects of e.g. increasing imports of agricultural commodities from abroad can only be mentioned here and goes beyond the scope of this paper.

For the protection of forest soils, the Forest Strategy 2020 stipulates an abdication of clear fellings. The results of BWI show that only less than one sixth of the timber harvested in Germany stems from intentional areal cuttings or losses due to calamities. One should keep in mind that areal cuttings do not equal clear cuttings by definition as areal cuttings can affect also only parts of the stand. Of the small share of clear felled forest stands, the high percentage of spruce trees is conspicuous. This is explainable by the fact that the stability of individual spruce trees is low, especially because of their shallow root systems on many soil types. For this reason, spruce stands are reliant on a high collective stability against wind throw. This collective stability would be disturbed by means of selective cuttings in old-growth spruce stands.

The idea of forest soil protection by means of an abdication of areal utilization rests on empirical studies of the effects of clear cuttings on soil organic matter and nutrient leaching (e.g. Covington 1981). These studies revealed a considerable increase of mineralization of soil organic matter after stand removals. Recent reviews, however, show that these findings do not hold true for all types of site (e.g. Yanai 2003). There is a range of studies showing very high nitrate leaching with percolate water not only after clear cuttings but even after smaller disturbances like gap fellings (e.g. Bauhus and Bartsch 1995, Mellert et al. 1998). But this nitrate leaching is not necessarily or solely caused by accelerated mineralization but can also be explained by an interruption of nutrient uptake and by enhanced percolation of precipitation water due to tree removals (Vitousek and Melillo 1979). This shows that the effects of areal regeneration on nutrient budgets depend greatly on the development of the vegetation after the disturbance. For this reason no generally accepted direct relationship between areal regeneration and the abovementioned aspects of forest soil protection can be postulated. Yet the avoidance of nutrient leaching and the conservation of soil organic matter is more likely to be ensured without areal removals of tree. This holds true in particular for nitrogen saturated forest ecosystems and for sites at which most of the organic matter is stored in the humus layer (e.g. Kohlpaintner et al. 2009, Jerabkova et al. 2011, Christophel et al. 2013). Because of the importance of this issue, currently used parameters of BWI should be critically reviewed, amended, and further developed if appropriate.

The shares of ownership classes have slightly changed in favour of private forests from 2002 to 2012. This is mainly a consequence of the disposal of trusteeship forest to private forest owners. In 2012 about 48% of the forests were privately owned. Otherwise the ownership structure has in general remained stable. The structure of private forest land by size classes has slightly changed at the expenses of small scale forest enterprises. About half of the private forest is owned by small scale forest owners (< 20 ha). This shows that the goal of a broad distribution of private forest ownership is met.

The mobilization of the wood utilization potential was clearly improved. For the total of all types of ownership, the exhaustion of the potential between 2002 and 2012 was 92.5%. This exhaustion, however, differs greatly between tree species. On the one hand, of several deciduous species only half of the potential was utilized. On the other hand, the utilization of spruce exceeded the growth because of high demand for spruce wood and because of the storm event "Kyrill" in the year 2007.

The current ratio between increment and utilization (or losses) is explainable partly by means of a consequence of the Second World War. During the post-war period, clear cuttings resulting from reparation payments by Germany were reforested mainly by coniferous species because of availability of plant and seed material and because of lower plantation costs. The resulting coniferous stands contribute largely to the high wood increment in Germany but are not yet mature. Consequently, the difference between utilization and increment should therefore not be understood as not exhausted potential. Also to be taken into account is the fact that depending on silvicultural concepts there is a full range of definitions of the potential. For instance, one of the WEHAM scenarios features a potential to the amount of the increment, whereas according to another scenario the potential is clearly lower than the increment (Polley and Kroiher 2006).

BWI data on wood production and utilization contribute greatly to the understanding of the carbon cycle. Preservation of the carbon-sink function of the forest is another aim of the Forest Strategy 2020. Respective target achievement control was already subject of previous studies by the Thünen Institute. Together with results of the National Forest Soils Inventory (BZE) carbon storage of forest vegetation and forest soils is calculated (Wellbrock et al. 2014). These results are contributed to the annual greenhouse gas reporting of Germany (UBA 2014). Because of the abovementioned development of the age structure the carbon sink function of the forest can change at the medium term. Yet the energetic and material substitution effect remains, i.e. the utilization of wood continues to replace the utilization of fossil fuels and other raw materials. This substitution effect caused by lower $CO_2$ emissions is currently about 3.8 times as high as the carbon storage in the forest and in forest products taken together (Rüter et al. 2011; Knauf et al. 2013). This supports also the climate and energy targets of the German Federal Government.

The benefit of the development towards a higher share of deciduous trees for the adaptation of forests to climate change cannot be asserted with general validity. The decreasing share of drought tolerating Scots pine as well as the increasing cultivation of Common beech in the northeast-German lowlands give rise to skepticism. In contrast, the increasing share of less abundant species and the increasing share of mixed stands of the main species can be rated as favourable for the adaptation to climate change because higher species diversity lowers the risk of calamities. It should be noted, however, that mixed stands can be more susceptible to drought than the respective mono-species stands would be (Grossiord et al. 2014).

The implementation of the aim of wildlife stock control guaranteeing regeneration of the main species without fencing cannot be verified directly, as BWI assesses neither wildlife stock nor its control. Moreover, the success and the quality of the regeneration cannot be guaranteed solely by fencing. Fencing, however, is normally successfully applied to protect the regeneration against browsing by wildlife, so that correlations between wildlife stock, browsing, fencing, and regeneration can be expected. Though the intensities of browsing and fencing are unspecific indicators for regeneration, both were compared in the present study as an approximate assessment of the change in game pressure between the years 2002 and 2012. The comparison, however, is hampered by a change in the assessment methods for browsing between the two assessment years. Browsing, though still at a high level, was found to have decreased from 2002 to 2012 (as far as a comparison between both years is possible). At the same time, the share of fenced forest land was reduced, indicating a reduction of game pressure.

## Conclusions

Several indicators for the aims of the Forest Strategy 2020 analyzed in the present study reveal a positive development. The size of forest area in Germany was not only preserved, but increased slightly. Forest conversion in recent years led to a higher share of deciduous tree species in general and higher shares of previously less abundant tree species in particular. In addition, the share of those forest sites at which no timber is harvested anymore, has grown. The same holds true for forests falling into a protection category. Also the area of forests rated as semi-natural, naturalistic and very naturalistic has grown. Moreover, the vertical structure of the canopy has improved, the abundance of rare stocking types has increased, and the amount of deadwood in forests has grown in recent years. The development of all these indicators suggests an improved availability of habitats for a larger variety of forest species, which corresponds to the aim of increasing species diversity formulated in the Forest Strategy 2020 and previously in the National Biodiversity Strategy. The majority of the timber harvest in Germany stems from selective cuttings. Only less than one sixth of the timber was harvested by means of intentional areal cuttings or losses due to calamities.

No evidence is found for the establishment of more productive stands. In view of the increasing share of deciduous trees, rather the opposite is to be expected. In addition, the decrease of the share of coniferous species with their high productivity and high utilization potential for long-lasting wood products will be disadvantageous to climate protection.

The improved mobilization of the wood utilization potential up to now indicates a high contribution of the forest to employment and income in forest enterprises and their downstream branches of industry and trade. In future, however, considerable changes are to be expected. At the medium term, timber supply in general will remain sufficient. However, the small- and medium-diameter softwood assortments highly demanded by timber industries will become scarce while high-diameter assortments will prevail. Moreover, the average age of the stands has increased. Forest stands of higher mean age offer a wider range of possible uses on the one hand. On the other hand, however, older stands have lower growth and higher production risks due to e.g. drought, storm, insects and fungi. Without silvicultural countermeasures and in view of the expected natural regeneration of hardwood species a considerable decline of the softwood supply will occur. This implies a collapse of the production base for a competitive timber industry in Germany. It can be hardly expected that this loss can be compensated by means of broadleaved species utilization or by means of a commercialization of other forest ecosystem services. On top of that, the share of timberland without restriction of timber harvest has decreased.

BWI has proven to be an indispensable source of information for the control of the achievement of targets of forest policies. Its informative value increases with each inventory period. For this reason, potential changes and amendments of its methods should be made keeping in mind that breaks of time series should be avoided as far as possible. With respect to the Forest Strategy 2020 the analysis of BWI data shows that forestry in Germany in general meets its own standard of multi-functionality. Multifunctional and sustainable forestry in Germany has not only secured but partly even increased its contributions to meeting the manifold demands of society. As regards the achievement of future political targets of the German Federal Government, however, an imbalance becomes evident: While the targets of nature and climate protection are on track to be achieved, the indicators for property, income and employment give evidence of a long-term change for the worse. It remains within the responsibility of the policy to draw the consequences from these diverging developments. If economical targets shall be kept up, particularly in compliance with the conversion towards bio-economy, silvicultural and technical compensations are necessary.

## Acknowledgements

The authors thank Thomas Riedel (Thünen-Institute for Forest Ecology in Eberswalde, Germany) for support in the numerical analysis and interpretation of BWI data. The authors also owe their thanks to Friederike Lang and Jürgen Bauhus (University of Freiburg, Freiburg, Germany) for their comments on the relationships between clear-cuttings and soil protection.

## References

Bauhus J., Bartsch N., 1995: Mechanisms of carbon and nutrient release and retention within beech forest gaps. I. Microclimate, water balance and seepage water chemistry. Plant and Soil 168-169, 579-584. DOI: 10.1007/BF00029371

BMEL, 2014: The Forests in Germany – Selected Results of the Third National Forest Inventory. Bundesministerium für Ernährung und Landwirtschaft, Berlin, 56 p.

BMEL, 2016. Wald und Rohholzpotenzial der nächsten 40 Jahre. Ausgewählte Ergebnisse der Waldentwicklungs- und Holzaufkommensmodellierung 2013 bis 2052 [Forest and wood potential of the coming 40 years. Selected model results on forest development and timber supply from 2013 to 2052]. Bundesministerium für Ernährung und Landwirtschaft, Berlin, 64 p.

BMELV, 2005. Die zweite Bundeswaldinventur – BWI2. Der Inventurbericht [The second National Forest Inventory - BWI2. Technical inventory report]. Technical Report. Editor: Federal Ministry of Food, Agriculture and Consumer Protection, Berlin.

BMELV, 2011. Forest Strategy 2020 – Sustainable Forest Management – An opportunity and a challenge for society. Federal Ministry of Food, Agriculture and Consumer Protection, Bonn, 35 p.

BMU, 2007. Nationale Strategie zur biologischen Vielfalt [National Strategy on Biological Diversity. Federal Ministry of Environment, Nature Protection and Nuclear Safety]. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Berlin, 178 p.

Christophel D., Spengler S., Schmidt B., Ewald J., Prietzel J., 2013. Customary selective harvesting has considerably decreased organic carbon and nitrogen stocks in forest soils of the Bavarian Limestone Alps. Forest Ecology and Management 305: 167-176. DOI: 10.1016/j.foreco.2013.05.054

Covington W.W., 1981. Changes in the forest floor organic matter and nutrient content following clear cutting in northern hardwoods. Ecology 62: 41–8. DOI: 10.2307/1936666

Dolman A .J., Valentini R., Freibauer A., 2013: The continental-scale greenhouse gas balance of Europe. Springer.

Elsasser P., Englert H., Hamilton J., Müller H.A. 2010: Nachhaltige Entwicklung von Waldlandschaften im Nordostdeutschen Tiefland: Ökonomische und sozioökonomische Bewertungen von simulierten Szenarien der Landschaftsdynamik [Sustainable development of forested landscapes in the lowlands of North Eastern Germany: Economic valuation of simulated scenarios of landscape dynamics]. Hamburg: von-Thünen-Institut. Arbeitsbericht vTI-OEF 2010/1, 96 p.

FAO, 2009. State of the World's Forests. United Nations Food and Agriculture Organization, Rome, 168 p.

FAO, 2010: Global forest resources assessment 2010. Main report, FAO Forestry Paper 163, United Nations Food and Agriculture Organisation, Rome, 340 p.

Forest Europe, UNECE and FAO, 2015. State of Europe's Forests 2015. FOREST EUROPE Liaison Unit Madrid, Spain.

Grossiord C., Granier A., Ratcliffe S., Bouriaud O., Bruelheide H., Chećko E., Forrester D.I., Dawud S.M., Finér L., Pollastrini M., Scherer-Lorenzen M., Valladares F., Bonan D., Gessler A., 2014. Tree diversity does not always improve resistance of forest ecosystems to drought. Proceedings of the National Academy of Sciences 111(41): 14812-14815. DOI: 10.1073/pnas.1411970111

ITTO, 2015. Voluntary guidelines for the sustainable management of natural tropical forests. ITTO Policy Development Series No. 20. International Tropical Timber Organization, Yokohama, Japan.

Jerabkova L., Prescott C.E., Titus B.D., Hope G.D., Walters M.B., 2011. A meta-analysis of the effects of clearcut and variable-retention harvesting on soil nitrogen fluxes in boreal and temperate forests. Canadian Journal of Forest Research 41: 1852–1870. DOI: 10.1139/x11-087

Knauf M., Frühwald A., Köhl M., 2013. Beitrag des NRW Clusters ForstHolz zum Klimaschutz [Contribution of the "NRW Cluster "Forest and Wood" to climate protection. Regional Authority on Forest and Wood, Northrhine-Westfalia]. Landesbetrieb Wald und Holz Nordrhein-Westfalen, Münster, 200 p.

Kohlpaintner M., Huber C., Weis W., Göttlein A., 2009. Spatial and temporal variability of nitrate concentration in seepage water under a mature Norway spruce [*Picea abies* (L.) Karst] stand before and after clear cut. Plant and Soil 314: 285-301. DOI: 10.1007/s11104-008-9729-7

Lorenz M., Bahamondez C., Brack C., Clarke M., Gillis M., Hirvonen H., Kleinn C., Riebau A., Sase H., Totsuka T., Varjo J., 2005. Forest assessment for changing information needs, In: Mery G., Alfaro R., Kanninen M., Lobovikov M. (eds.): Forests in the global balance – changing paradigms, IUFRO World Series Volume 17, Helsinki, 318 p.

Meier E., 2014. Nachhaltigkeitsbewertung - Logical Framework-Ansatz zur kontextbezogenen Operationalisierung von Nachhaltigkeit auf Basis gesellschaftlicher Nachhaltigkeitskonzepte [Sustainability rating - logical-framework-approach for contextual operationalisation of sustainability on the basis of societal sustainability concepts]. Hamburg, University of Hamburg, Fachber Biologie, 263 p.

Mellert K.-H., Kölling C., Rehfuess K.E., 1998. Vegetationsentwicklung und Nitrataustrag auf 13 Sturmkahlflächen in Bayern [Vegetation development and nitrete leaching on 13 storm damage sites in Bavaria]. Forstarchiv 69: 3-11.

The Montréal Process, 2015. Criteria and indicators for the conservation and sustainable management of temperate and boreal forests. Québec City, Canada.

Polley H., Kroiher F., 2006. Struktur und regionale Verteilung des Holzvorrates und des potenziellen Rohholzaufkommens in Deutschland im Rahmen der Clusterstudie Forst- und Holzwirtschaft. Arbeitsbericht des Institutes für Waldökologie und Waldinventuren 2006/3 [Structure and regional distribution of timber stocks and potential timber supply in Germany according to the analysis of the forest based sector]. Eberswalde: Bundesforschungsanstalt für Forst- und Holzwirtschaft.

Polley H., Hennig P., Schwitzgebel F., Dunger K., 2004. Die Bundeswaldinventur an der strategischen Schnittstelle zwischen Forst- und Holzwirtschaft [The National Forest Inventory at the strategical interface between the forest and wood sector]. BFH-Nachrichten Hamburg 42(4): 36-37.

Riedel T., Hennig P., Kroiher F., Polley H., Schmitz F., Schwitzgebel F., 2017. Die dritte Bundeswaldinventur (BWI 2012). Inventur- und Auswertungsmethoden [The third National Forest Inventroy (BWI 2012). Inventory and analysis methods.]. Johann Heinrich von Thünen-Institut. Braunschweig, 124 p.

Rock J., Gerber K., Klatt S., Oehmichen K., 2016. Das WEHAM 2012 "Basisszenario": Mittellinie oder Leitplanke? [The WEHAM 2012 "Baseline scenario": Center line or guardrail?]. Forstarchiv 87: 66-99.

Rüter S., Rock J., Köthke M., Dieter M., 2011. Wie viel Holznutzung ist gut fürs Klima? Die CO2-Bilanzen unterschiedlicher Nutzungsszenarien 2013-2020 [How much wood is good for the climate? The $CO_2$ balance sheets of different usage scenarios 2013-2020]. AFZ-DerWald 66(15): 19-21.

Tomppo E., Gschwantner T., Lawrence M., McRoberts R.E., 2010. National Forest Inventories - Pathways for common reporting. Springer Netherlands, Dordrecht. DOI: 10.1007/978-90-481-3233-1

UBA, 2014. Nationaler Inventarbericht Deutschland -2014 [National Inventory Report. German Environment Agency]. Umweltbundesamt, Berlin, Nr. 24/2014.

UNFCCC, 2009. United Nations Framework Convention on Climate Change. Web: http://unfccc.int/657 2860.php. Accessed 10 September 2015.

Vidal C., Alberdi I., Redmond J., Vestman M., Lanz A., Schadauer K., 2016. The role of European National Forest Inventories for international forestry reporting. Annals of Forest Science 73: 793-806. DOI: 10.1007/s13595-016-0545-6

Vjtousek P.M., Melillo J.M., 1979. Nitrate losses from disturbed forests: Patterns and mechanism. Forest Science 25: 605-619.

Wellbrock N., Grüneberg E., Stümer W., Rüter S., Ziche D., Dunger K., Bolte A., 2014. Wälder in Deutschland

speichern Kohlenstoff. AFZ-DerWald 69(18): 38-39.
Yanai R.D., Currie W.S., Goodale C.L., 2003. Soil carbon dynamics after forest harvest: an ecosystem paradigm reconsidered. Ecosystems 6: 197-212. DOI: 10.1007/s10021-002-0206-5

## Supporting Information

The online version of the article includes Supporting Information:

**Tables 1-21** (containing resumed results based on NFI data)