



EuMIXFOR empirical forest mensuration and ring width data from pure and mixed stands of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) through Europe

Michael Heym, Ricardo Ruíz-Peinado, Miren del Río, Kamil Bielak, David I. Forrester, Gerald Dirnberger, Ignacio Barbeito Sanchez, Gediminas Brazaitis, Indrė Ruškytkė, Lluís Coll, et al.

► To cite this version:

Michael Heym, Ricardo Ruíz-Peinado, Miren del Río, Kamil Bielak, David I. Forrester, et al.. Eu-MIXFOR empirical forest mensuration and ring width data from pure and mixed stands of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) through Europe. *Annals of Forest Science*, 2017, 74 (3), 10.1007/s13595-017-0660-z . hal-01690261

HAL Id: hal-01690261

<https://hal.science/hal-01690261>

Submitted on 26 May 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Copyright

EuMIXFOR empirical forest mensuration and ring width data from pure and mixed stands of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) through Europe

Michael Heym¹ · Ricardo Ruíz-Peinado^{2,3} · Miren Del Río^{2,3} · Kamil Bielak⁴ · David I. Forrester⁵ · Gerald Dirnberger⁶ · Ignacio Barbeito⁷ · Gediminas Brazaitis⁸ · Indrė Ruškytė⁸ · Lluís Coll⁹ · Marek Fabrika¹⁰ · Lars Drössler¹¹ · Magnus Löf¹¹ · Hubert Sterba⁶ · Václav Hurt¹² · Viktor Kurylyak¹³ · Fabio Lombardi¹⁴ · Dejan Stojanović¹⁵ · Jan Den Ouden¹⁶ · Renzo Motta¹⁷ · Maciej Pach¹⁸ · Jerzy Skrzyszewski¹⁸ · Quentin Ponette¹⁹ · Géraud De Streel¹⁹ · Vit Sramek²⁰ · Tomáš Čihák²¹ · Tzvetan M. Zlatanov²² · Admir Avdagic²³ · Christian Ammer²⁴ · Kris Verheyen²⁵ · Buraczek Włodzimierz⁴ · Andrés Bravo-Oviedo^{2,3} · Hans Pretzsch¹

Received: 24 January 2017 / Accepted: 25 July 2017 / Published online: 28 August 2017
© INRA and Springer-Verlag France SAS 2017

Abstract

• **Key message** This data set provides unique empirical data from triplets of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) across Europe. Dendrometric variables are provided for 32 triplets, 96 plots, 7555 trees and 4695 core samples. These data contribute to our understanding of mixed stand dynamics. Dataset access at <http://dx.doi.org/10.5061/dryad.8v04m>. Associated metadata available at <https://metadata-afs.nancy.inra.fr/geonetwork/apps/georchestra/?uuid=b3e098ca-e681-4910-9099-0e25d3b4cd52&hl=eng>.

Handling Editor: Marianne Peiffer

Contribution of the co-authors

All co-authors contributed to the data set with establishing the triplets, supervising and undertaking field campaigns, data providing, synchronizing core data. M.H. wrote the data paper, all coauthors reviewed it and H.P. coordinated the transect study.

Electronic supplementary material The online version of this article (<http://dx.doi.org/10.1007/s13595-017-0660-z>) contains supplementary material, which is available to authorized users.

Keywords EuMIXFOR data · Mixed and monospecific stands · Mixed stand dynamics · Scots pine · European beech

1 Background

During the last decade, empirical research often showed superiority of ecosystem functions of mixed forest stands compared to monocultures, e.g. productivity (Río and Sterba 2009; Pretzsch et al. 2010, 2013; Vallet and Perot 2011, Condés et al. 2013; Bielak et al. 2014; Liang et al. 2016), structural diversity (Río et al. 2016a) or stability (Knoke et al. 2008). However, the underlying processes are often still poorly understood. Moreover, generalizations require empirical data from different growing conditions, e.g. soil and climate. This unique data set includes 32 triplets across 16 European countries (Fig. 1) representing different ecoregions. Each triplet includes two pure stands and one with the two species in mixture, all with similar climatic and soil conditions. Effects of mixing these species can be analysed with respect to their corresponding pure stands. Under the umbrella

✉ Michael Heym
Michael.Heym@lrz.tum.de

Ricardo Ruíz-Peinado
ruizpein@inia.es

Miren Del Río
delrio@inia.es

Kamil Bielak
kamil.bielak@wl.sggw.pl

David I. Forrester
david.forrester@wsl.ch

Gerald Dirnberger
gerald.dirnberger@boku.ac.at

of COST Action FP1206 EuMIXFOR (European Network on Mixed Forests), these triplets were established for the common European tree species, Scots pine and European beech. These species differ in their functional traits, and the data set provides a unique opportunity to develop a general understanding of the causes and patterns of mixing responses

2 Methods

2.1 Study sites

All stands (plots) represent mostly even-aged and mono-layered forests. Intra-specific age (species in pure vs species in mixed stand) within each triplet is always similar; however, inter-specific age may differ. Plots within a triplet are mostly rectangular in shape ranging from 0.01 to 1.6 ha in size. The geographical location, altitude, slope, aspect, mean annual temperature, annual precipitation and substrate are available for each plot (Table 1). Due to the established gradient, these variables differ between triplets but are similar within each triplet.

Ignacio Barbeito
ignacio.barbeito@nancy.inra.fr

Gediminas Brazaitis
gediminas.brazaitis@asu.lt

Indrė Ruškytė
Indre.Ruskyte@asu.lt

Lluís Coll
lluis.coll@ctfc.es

Marek Fabrika
fabrika@tuzvo.sk

Lars Drössler
lars.drossler@slu.se

Magnus Lof
Magnus.Lof@slu.se

Hubert Sterba
hubert.sterba@boku.ac.at

Václav Hurt
vhurt@email.cz

Viktor Kurylyak
vikur@ukr.net

Fabio Lombardi
fabio.lombardi@unirc.it

Dejan Stojanović
dejan.stojanovic@uns.ac.rs

Jan Den Ouden
Jan.denOuden@wur.nl

2.2 Survey protocol

A standard protocol for data collection was established and applied for each triplet. For all trees exceeding diameter at breast height of 7 cm, mandatory attributes (Table 2) were defined and collected including tree number (Nr), tree species, diameter at breast height (dbh), tree height (h) and crown base height (cbh). In addition, on each plot, increment core samples for 10–20 dominant trees per species and angle count samples (acs) for the sampled trees were collected (Bitterlich 1952). Specific information is assigned to each tree indicating its status (alive, dead or damaged). Only standing trees were recorded. Spatial location (Cartesian coordinates) of individual trees was defined as an optional variable but was measured on most plots.

The tree numbering system is in ascending order starting from 1 for trees located within the plot and, if recorded, 901 for trees outside but with part of their crowns inside the plot. For all labelled trees, the corresponding species was determined. Diameter at breast height was measured for all trees using girth tape while a digital hypsometer was used for measuring tree height

Renzo Motta
renzo.motta@unito.it

Maciej Pach
rlpach@cyf-kr.edu.pl

Jerzy Skrzyszewski
rlskrzys@cyf-kr.edu.pl

Quentin Ponette
quentin.ponette@uclouvain.be

Géraud De Streel
geraud.destreel@uclouvain.be

Vit Sramek
sramek@vulhm.cz

Tomáš Čihák
cihak@vulhm.cz

Tzvetan M. Zlatanov
tmzlatanov@gmail.com

Admir Avdagic
a.avdagic@sfsa.unsa.ba

Christian Ammer
Christian.Ammer@forst.uni-goettingen.de

Kris Verheyen
Kris.Verheyen@UGent.be

Buraczyk Włodzimierz
wburaczyk@wp.pl

Andrés Bravo-Oviedo
bravo@inia.es

and crown base height. Increment cores aiming to reach the pith were taken at 1.30 m height in north and east directions from the stem using increment borers. Likewise, 1–2 angle count samples (acs) were recorded using a relascope with basal area factor 4 or 1 m² ha⁻¹. All data were stored using predefined templates. In total, 7555 trees were measured and 4695 core samples were taken.

For 24 triplets, optional data of individual tree location and crown radii were collected. Crown radii (m) were mostly measured in N, NE, E, SE, S, SW, W and NW cardinal directions with a minimum of four directions. Tree spatial information is given in Cartesian coordinates referring to a point of origin, e.g. the south west corner post of the corresponding plot.

2.3 Data processing—stand level data

Stand characteristics such as mean tree dimension, basal area (BA m² ha⁻¹) and volume stock per hectare (V m³ ha⁻¹) were derived for each plot and species group, pine and beech. Additional coniferous and deciduous spe-

cies within the mixed stands were grouped either as pine or beech, respectively. In pure stands, all additional species were assigned to the corresponding main species. Stand attributes are based on all surveyed living trees within the corresponding plot and are expressed per ha. A Petterson height curve function (Petterson 1955) was parameterized for each plot and species group. Missing tree heights and the height of quadratic mean diameter tree (hg) were calculated applying the corresponding height curve function. Stand volume was derived while taking into account each individual tree's diameter at breast height, derived tree height and species-specific form factors (Franz 1971). All stand characteristics (Table 3) were calculated using standard evaluation software available at the Chair of Forest Growth and Yield Science, TU München (Biber 2013).

3 Access to data and metadata description

The data set is available from the Dryad Digital Repository <http://dx.doi.org/10.5061/dryad.8v04m> (Heym

Hans Pretzsch
Hans.Pretzsch@lrz.tum.de

¹ Chair for Forest Growth and Yield Science, Technische Universität München, Munich, Germany

² Department of Silviculture and Forest Systems Management, INIA-CIFOR, Madrid, Spain

³ Sustainable Forest Management Research Institute University of Valladolid & INIA, Valladolid, Spain

⁴ Department of Silviculture, Warsaw University of Life Sciences, Warsaw, Poland

⁵ Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf, Switzerland

⁶ Department of Forest and Soil Science, BOKU University of Natural Resources and Life Sciences, Vienna, Austria

⁷ Laboratoire d'Etude des Ressources Forêt Bois (LERFoB), INRA centre of Nancy, Champenoux, France

⁸ Institute of Forest Biology and Silviculture, Faculty of Forest Science and Ecology, Aleksandras Stulginskis University, Studentu str. 11, Akademija, LT-53361 Kaunas dist, Lithuania

⁹ Department of Agriculture and Forest Engineering – Forest Sciences Centre of Catalonia (CTFC), University of Lleida, Lleida, Spain

¹⁰ Department of Forest Management and Geodesy, Faculty of Forestry, Technical University in Zvolen, Zvolen, Slovakia

¹¹ Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, Alnarp, Sweden

¹² Department of Silviculture, Mendel University, Brno, Czech Republic

¹³ Forestry Academy of Sciences of Ukraine, Lviv, Ukraine

¹⁴ Dipartimento di AGRARIA, Università Mediterranea di Reggio Calabria, Contrada Melissari, Loc. Feo di Vito, 89122 Reggio Calabria, Italy

¹⁵ Institute of Lowland Forestry and Environment, University of Novi Sad, Novi Sad, Serbia

¹⁶ Forest Ecology and Forest Management Group, Wageningen University & Research, Wageningen, The Netherlands

¹⁷ Department of Agricultural, Forest and Food Sciences DISAFA, University of Turin, Turin, Italy

¹⁸ Department of Silviculture, Institute of Forest Ecology and Silviculture, University of Agriculture, Krakow, Poland

¹⁹ Faculty of Bioscience Engineering & Earth and Life Institute, Université catholique de Louvain, Louvain-la-Neuve, Belgium

²⁰ Forestry and Game Management Research Institute, Opocno, Czech Republic

²¹ Forestry and Game Management Research Institute, Jíloviště, Czech Republic

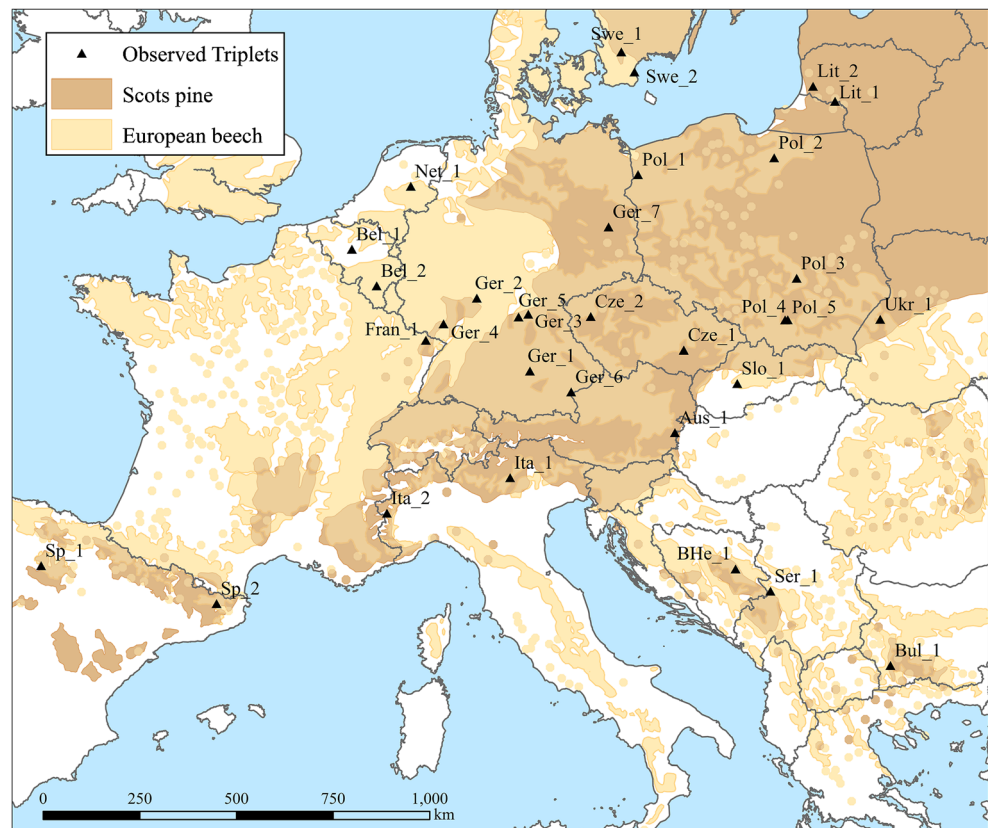
²² Department of Silviculture, Forest Research Institute, Sofia, Bulgaria

²³ Faculty of Forestry, University Sarajevo, Sarajevo, Bosnia and Herzegovina

²⁴ Abteilung Waldbau und Waldökologie der gemäßigten Zonen, Georg-August-Universität Göttingen, Göttingen, Germany

²⁵ Faculty of Bioscience Engineering, Forest & Nature Lab, Ghent University, Melle, Gontrode, Belgium

Fig. 1 Distribution of the triplet locations across Europe and distribution of European beech and Scots pine according EUFORGEN (www.euforgen.org). Triangles represent triplet locations



et al. 2017) and cover five files (*Contact.txt*, *TripletInformation.txt*, *Trees.txt*, *Crowns.txt* and *Cores.txt*). *Contact.txt* file includes all contact information of the specific data provider. Associated metadata available at <https://metadata-afs.nancy.inra.fr/geonetwork/apps/georchestra/?uuiid=b3e098ca-e681-4910-9099-0e25d3b4cd52&hl=eng>.

TripletInformation.txt provides plot and stand characteristics. The first two columns (*Triplet* and *Plot*) identify each plot. Plot characteristics cover year and month of the survey (*year* and *month*), plot size (*area*), location (*longitude* and *latitude*), elevation above sea level (*altitude*), inclination (*slope*), exposition (*aspect*), temperature (*t*), precipitation (*p*) and substrate (*substrate*). Stand characteristics cover tree species (*species*), age (*Age*), number of trees (*N*), quadratic mean diameter (*dg*) and corresponding height (*hg*), basal area (*BA*) and merchantable stand volume over bark (*V*). All variables refer to 1 ha and the main species (*species*) pine or beech, respectively. Additional species are assigned either as pine or beech as described in methods.

Trees.txt includes all measured tree attributes. Each row describes one tree and can be identified by columns *Triplet*, *Plot* and *Nr*. Tree information covers scientific species name (*species*), tree's spatial information (*x* and *y*), diameter at breast height (*dbh*), tree height (*h*), crown base height (*cbh*) and two angle count measurements for the cored trees (*acs_1* and *acs_2*). Column *cored* distinguishes cored trees (1) and non-cored trees (0). Any additional information is given in column *remarks*.

Crowns.txt contains all measured crown radii (*distance*) with its corresponding cardinal direction (*azimuth*). Column *Triplet*, *Plot* and *Nr* ensure the link to the corresponding tree in *Trees.txt*. In addition *y_axis_to_north* describes the deviation of the *y*-axis to north direction.

Cores.txt file contains all year ring width values (*rw*) for each year (*year*) and the two different directions (*azimuth*). Column *Triplet*, *Plot* and *Nr* ensure unique tree identification and link the corresponding tree attributes.

Missing information is always described using *NA*. All tables can be linked based on the columns *Triplet*, *Plot* and

Table 1 Overview of all triplets with: *Country*; corresponding country, *Triplet name*; name of the triplet in Fig. 1, *Triplet*; triplet identification number, *longitude* and *latitude* (for mixed stands), *age*; average age for the triplet (years, yr), *altitude*; elevation above sea level (m), *slope*

Country	Triplet name	Triplet	Longitude	Latitude	Age	Altitude	Slope	Aspect	<i>t</i>	<i>p</i>	Substrate
Austria	Aus_1	1048	16° 23' 20.00"	47° 22' 34.00"	40	525	18	213	8.5	750	Loamy sand
Belgium	Bel_2	1063	04° 19' 29.60"	50° 45' 06.10"	115	160	1	270	7.5	852	Loam
Belgium	Bel_1	1057	05° 27' 00.00"	50° 01' 48.00"	150	545	3	180	11	1175	Stony loam
Bosnia & Herzegovina	BHe_1	1059	18° 29' 56.12"	44° 13' 34.56"	135	697	25	225	9.5	939	Humus-silicate soil-ranker
Bulgaria	Bul_1	1047	23° 21' 03.00"	41° 53' 43.00"	65	1187	18	350	6	750	Loamy sand
Czech Republic	Cze_1	1049	16° 36' 08.78"	49° 18' 14.40"	45	440	7	45	7.5	620	Cambisol mezotrophic
Czech Republic	Cze_2	1058	13° 12' 45.90"	49° 58' 02.50"	55	554	11	328	7.1	656	Dystic and podzol cambisol
France	Fra_1	1040	07° 29' 13.60"	48° 58' 41.80"	60	275	34	315	9.7	948	Sandstone sandy soil
Germany	Ger_1	1033	11° 14' 12.49"	48° 34' 57.95"	57	430	1	45	8.5	700	Slightly loamy sand
Germany	Ger_2	1031	09° 03' 54.36"	50° 06' 48.74"	55	250	0		9	720	Slightly loamy sand
Germany	Ger_3	1032	10° 58' 13.12"	49° 53' 11.64"	47	250	2	30	8	650	Loamy sand
Germany	Ger_4	1071	08° 01' 03.88"	49° 24' 57.77"	65	40	1	60	9	675	Loamy sand
Germany	Ger_5	1034	08° 10' 48.58"	48° 59' 11.66"	57	370	3		10	675	Slightly loamy sand
Germany	Ger_6	1070	12° 44' 08.30"	48° 11' 12.47"	65	400	0		8	560	Slightly loamy sand
Germany	Ger_7	1061	13° 36' 54.28"	52° 04' 45.47"	80	73	0		8.6	520	Sandy
Italy	Ita_1	1055	10° 56' 10.61"	46° 04' 02.93"	40	1034	8	31	7.8	1050	Cutanic luvisoil
Italy	Ita_2	1062	07° 03' 53.30"	44° 54' 12.49"	55	1475	25	315	7.9	938	Inceptisol
Lithuania	Lit_1	1051	22° 24' 24.10"	55° 04' 47.30"	90	25	0		6.5	750	Sand and slightly loamy sand
Lithuania	Lit_2	1052	21° 32' 23.44"	55° 27' 02.80"	111	20	0		6.5	800	Sand and slightly loamy sand
Netherlands	Net_1	1043	06° 01' 20.42"	52° 25' 40.55"	47	34	2	68	9.7	825	Coarse sand
Poland	Pol_2	1036	19° 54' 42.27"	53° 48' 19.15"	81	136	0		7.9	666	Loamy sand and sand
Poland	Pol_1	1035	14° 36' 17.51"	53° 20' 07.40"	55	60	0		9.2	556	Slightly loamy sand
Poland	Pol_3	1037	20° 41' 08.90"	50° 59' 27.96"	76	383	2	275	7.8	662	Sandstone loamy sand and loam
Poland	Pol_4	1044	20° 13' 45.84"	50° 01' 27.60"	57	208	1	0	8.2	650	Slightly loamy sand
Poland	Pol_5	1045	20° 19' 37.26"	50° 01' 36.00"	55	213	0		8.2	650	Loamy sand
Serbia	Ser_1	1056	19° 37' 30.00"	43° 42' 17.40"	75	1080	21	0	7.7	1020	Loam with a little sand
Slovakia	Slo_1	1046	18° 31' 11.19"	48° 33' 09.18"	55	524	15	90	6.9	730	Cambisol
Spain	Sp_1	1042	03° 10' 19.00" W	42° 05' 57.00"	40	1293	47	120	8.9	860	Sandy loam
Spain	Sp_2	1041	02° 15' 44.23"	42° 10' 18.09"	50	1116	30	135	8	1100	Loam slightly clay
Sweden	Swe_1	1054	13° 35' 35.00"	56° 09' 12.00"	80	120	13	222	8	700	Loamy sand
Sweden	Swe_2	1053	14° 11' 46.00"	55° 42' 33.00"	65	25	8	120	7	800	Sandy till
Ukraine	Ukr_1	1060	23° 39' 44.00"	49° 57' 05.00"	105	316	0		7.6	673	Slightly loamy sand

Nr. Detailed description of the metadata can be found in the supplementary material (*EuMIXFOR Scots pine - European beech data.xlsx*).

4 Technical validation

Validation of each data set was performed including crosschecks by hand, graphical and numerical tests. First, the unit of tree attributes and year ring width was carefully validated. Tree and corresponding core labels were compared manually and corrected where needed. Cross-dating of radial increment was performed by each collaborator and inconsistent cores were dropped. The relationship of individual tree height to its corresponding diameter at breast height, expressed by a Peterson height curve, was analysed for each triplet, shown as an example for triplet 1032 in Fig. 2.

Crown base height was validated by visualizing cbh and corresponding tree height. If spatial information was

(degrees), *aspect* (degrees [clockwise from north]), *t*; mean annual temperature (C°), *p*; annual precipitation (mm) and *substrate*. Altitude, slope and aspect represent average plot values

Table 2 Overview of measured mandatory and optional descriptive and dendrometric attributes

	Variable	Description
Mandatory	Longitude	Plot specific
	Latitude	Plot specific
	Altitude	Plot specific; m (E. a.s.l.)
	Slope	Plot specific; degrees
	Aspect	Plot specific; degrees
	Plot size	Plot specific; hectares
	Date of establishment/measurement	Triplet specific; yyyy-mm
	Age	Species and plot specific; years
	Tree number	Living trees; ascending order
	Tree species	Scientific species name
	Diameter at breast height	Tree specific; cm
	Tree height	Tree specific; m
	Crown base height	Tree specific; m
Optional	Increment cores	2 core samples/tree, 10–20 trees/plot/species
	Local density	1–2 angle count measurements/cored tree; m ² ha ⁻¹
	x-coordinate	Tree specific (Cartesian)
	y-coordinate	Tree specific (Cartesian)
	Crown radii	Tree specific; azimuth (degrees) and distance (m)

Table 3 Example (triplet 1033) of main stand characteristics per plot with: *Country*; corresponding country for the triplet, *Triplet*; triplet identification number, *Plot* plot identification (*pibe*; *mixed stand pi*; pure pine, *be*; pure beech), *Year*; year of survey, *Species*; species name,

Age; plot age at survey, *N*; number of trees, *dg*; quadratic mean diameter (cm), *hg* height of quadratic mean diameter (m), *BA*; basal area (m²) and *V*; merchantable volume per hectare (m³). All variables refer to the main species and 1 ha

Country	Triplet	Plot	Year	Species	Age	<i>N</i>	<i>dg</i> (cm)	<i>hg</i> (m)	<i>BA</i> (m ² ha ⁻¹)	<i>V</i> (m ³ ha ⁻¹)
Germany	1033	pibe	2013	Pine	50	330	25.5	22.8	16.8	175
		pibe	2013	Beech	50	818	15.7	19.5	15.9	157
		pibe	2013	Total		1148			32.8	332
		pi	2013	Pine	65	286	33.2	26	24.7	295
		be	2013	Beech	53	1032	17	24	23.3	279

available, visual inspection was applied to validate tree position and crown measurements. In addition, allometric relationships between diameter at breast height and crown projection area (*cpa*), calculated based on mean squared crown radii, $cpa = a \cdot dbh^b$, were validated visually (Fig. 3).

Location of border trees was inspected by means of graphical output. Core data were also compared with species-specific variation of basal area increment in pure and mixed stands within each triplet (Fig. 4).

All data were imported into an access database and technical plausibility checks were applied, e.g. data types or duplicates.

5 Reuse potential and limits

The original data set covers attributes at the tree level, increments cores, stand and triplet characteristics and has been used for different purposes by Pretzsch et al. (2015, 2016), Río et al. (2016b, 2017), Dirnberger et al.

(2016) and Forrester et al. (2017). The data set presented here describes the original data, but ongoing projects can complement the published data by additional measurements of resource supply, nutritional status and wood properties. Furthermore, it has the potential to reveal the effect of site conditions on the mixing responses at the stand, species and individual tree level. Available spatial information allows analyses of crown projection (Dirnberger et al. 2016), crown architecture or light regimes. The available core data allow retrospective analyses and can be linked to corresponding tree attributes, e.g. Pretzsch et al. (2016) or Río et al. (2017). Reconstructing stand characteristics provides temporal stand level information, e.g. Pretzsch et al. (2015). Moreover, spatial information of most of the plots allows for distance dependent analysis at small scales.

However, for specific analyses, some plot sizes could be too small. Tree and stand characteristics are only available for the year of survey. Therefore, temporal analyses require reconstructions at the tree and stand levels.

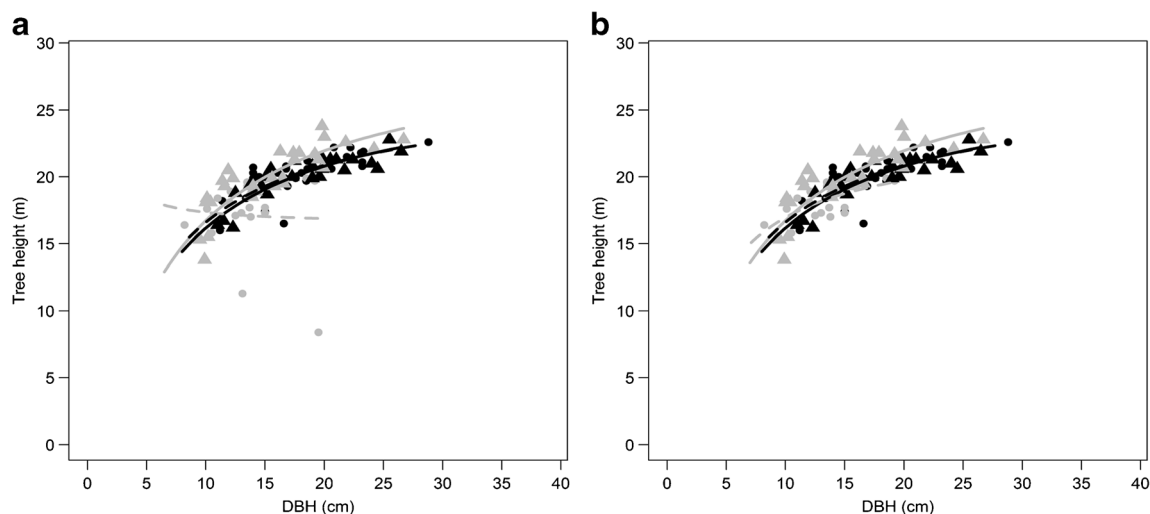


Fig. 2 Detecting (left side, **a**) and correcting (right side, **b**) inconsistent height measurements. Data from triplet 1032 for pine (black) and beech (grey) in pure (triangles) and mixed stands (circles). Dashed and solid

lines representing species-specific Petterson height curve for mixed and pure stands, respectively

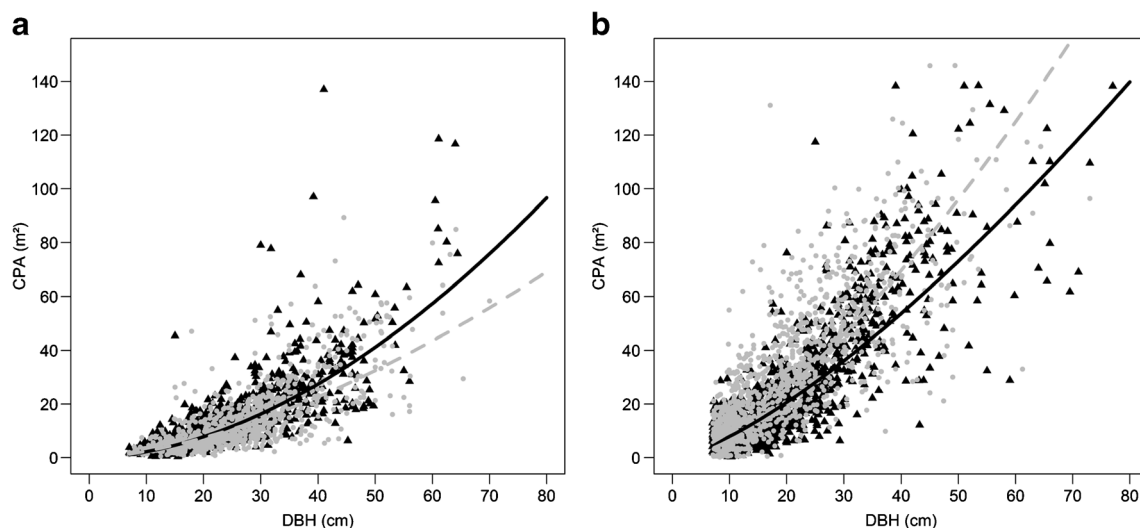


Fig. 3 Crown projection area (cpa) and diameter at breast height (dbh) for all measured pine (*left side*) and beech (*right side*) in pure (*triangles*) and mixed stands (*circles*). Allometric relationships are described by *solid* (pure stands) and *dashed* lines (mixed stands)

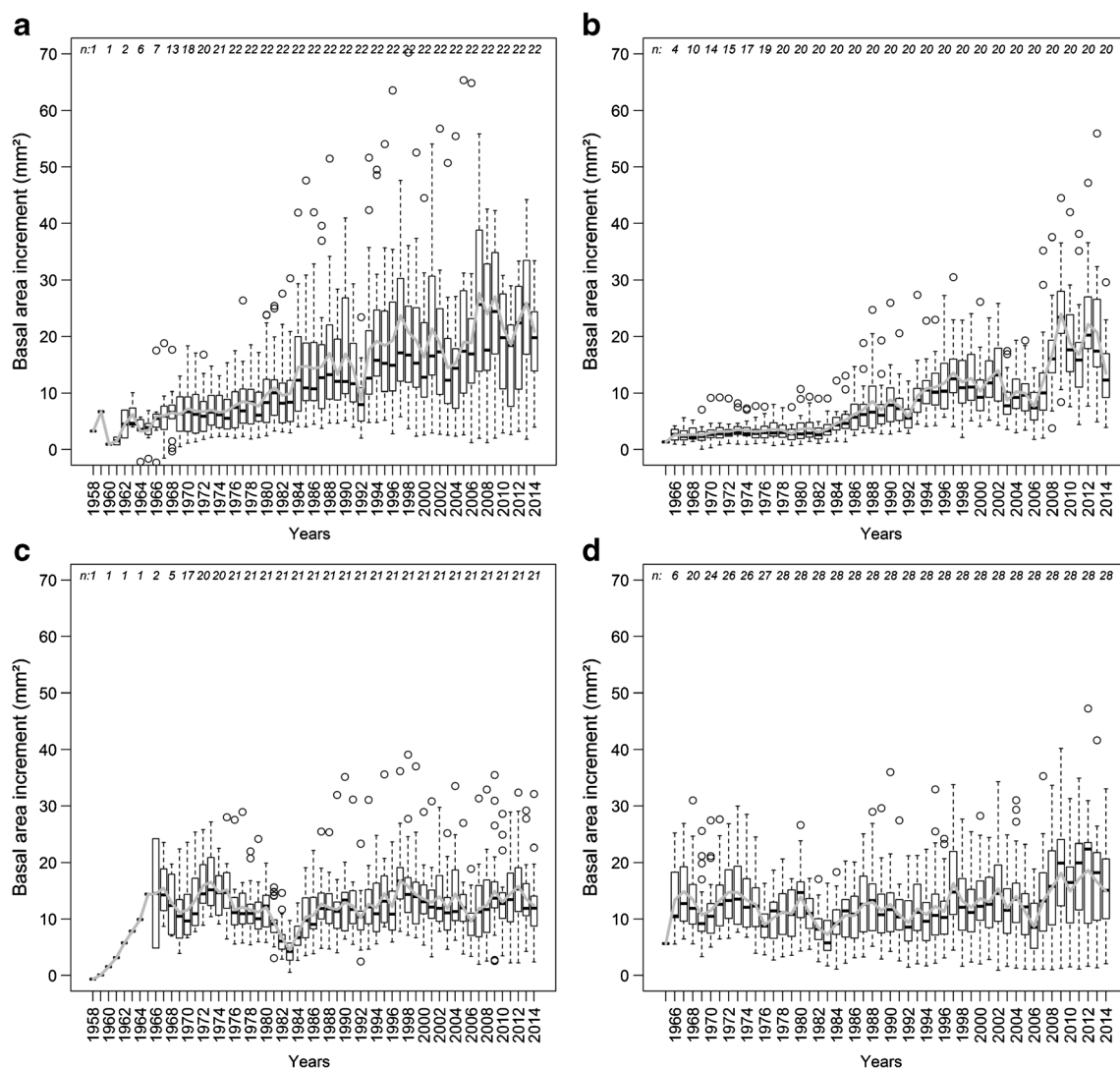


Fig. 4 Example of basal area increment per calendar year for beech (*upper; a, b*), and pine (*lower; c, d*), in pure (*left; a, c*) and mixed stand (*right; b, d*), for triplet 1035. Grey solid lines represent arithmetic means and *n* refers to number of cores for years shown on x-axis

Acknowledgements This article is based upon work from COST Action FP1206 (EuMIXFOR), supported by COST (European Cooperation in Science and Technology). All contributors thank their national funding institutions and the woodland owners for agreeing to establish, measure, analyse and reuse data from the triplets. Many thanks to the anonymous reviewer and data paper handling editor Marianne Peiffer for their helpful comments to improve the early draft of the manuscript.

Compliance with ethical standards

Funding Networking for the design and discussion of the transect study was supported by COST Association during FP1206 COST Action (EuMIXFOR: European mixed forests – Integration Scientific Knowledge in Sustainable Forest Management). Funding for the establishment of the plots and collection of the data belonged to co-author.

References

- Biber P (2013) Kontinuität durch Flexibilität – Standardisierte Datenauswertung im Rahmen eines waldwachstumkundlichen Informationssystems. Allg. Forst- u. J.-Ztg., 184. Jg., 7/8:167–177
- Bielak K, Dudzińska M, Pretzsch H (2014) Mixed stands of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst) can be more productive than monocultures. Evidence from over 100 years of observation of long-term experiments. For Syst 23:573–589
- Bitterlich W (1952) Die Winkelzählprobe. Forstwiss Cbl 71:215–225
- Condés S, Río M, Sterba H (2013) Mixing effect on volume growth of *Fagus sylvatica* and *Pinus sylvestris* is modulated by stand density. For Ecol Manag 292:86–95
- Dirnberger G, Sterba H, Condés S, Ammer C, Annighöfer P, Avdagic A, Bielak K, Brazaitis G, Coll L, Heym M, Hurt V, Kurylyak V, Motta R, Pach M, Ponette Q, Ruiz-Peinado R, Skrzyszewski J, Šrámek V, de Streel G, Svoboda M, Zlatanov T, Pretzsch H (2016) Species proportions by area in mixtures of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) Eur J For Res. <http://dx.doi.org/10.1007/s10342-016-1017-0>
- Forrester DI, Ammer C, Annighöfer PJ, Barbeito I, Bielak K, Bravo-Oviedo A, Coll L, Río Md, Drössler L, Heym M, Hurt V, Löf M, Ouden Jd, Pach M, Pereira MG, Plaga B, Ponette Q, Skrzyszewski J, Sterba H, Svoboda M, Zlatanov T, Pretzsch H (2017) Effects of crown architecture and stand structure on light absorption in mixed and monospecific *Fagus sylvatica* and *Pinus sylvestris* forests along a productivity and climate gradient through Europe. J Ecol 00:1–15. <http://dx.doi.org/10.1111/1365-2745.12803>
- Franz F (1971) Funktionen und Tabellen der Derbholzformhöhen für die wichtigsten Baumarten in Bayern. München, Manuskriptdruck, Lehrstuhl für Waldwachstumskunde, Technische Universität München, unpublished
- Heym M, Ruiz-Peinado R, del Río M, Bielak K, Forrester DI, Dirnberger G, Barbeito I, Brazaitis G, Ruškytė I, Coll L, Fabrika M, Drössler L, Löf M, Sterba H, Hurt V, Kurylyak V, Lombardi F, Stojanović D, den Ouden J, Motta R, Pach M, Skrzyszewski J, Ponette Q, de Streel G, Sramek V, Čihák T, Zlatanov TM, Avdagic A, Ammer C, Verheyen K, Włodzimierz B, Bravo-Oviedo A, Pretzsch H (2017) EuMIXFOR empirical forest mensuration and ring width data from pure and mixed stands of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) through Europe. Dryad Digital Repository. [Dataset]. <http://dx.doi.org/10.5061/dryad.8v04m>
- Knoke T, Ammer H, Stimm B, Mosandl R (2008) Admixing broadleaved to coniferous tree species: a review on yield, ecological stability and economics. Eur J For Res 127:89–101
- Liang J, Crowther TW, Picard N, Wiser S, Zhou M, Alberti G, Schulze E-D, McGuire AD, Bozzato F, Pretzsch H, de-Miguel S, Paquette A, Hérault B, Scherer-Lorenzen M, Barrett CB, Glick HB, Hengeveld GM, Nabuurs G-J, Pfautsch S, Viana H, Vibrans AC, Ammer C, Schall P, Verbyla D, Tchebakova N, Fischer M, Watson JV, HYH C, Lei X, Schelhaas M-J, Lu H, Gianelle D, Parfenova EI, Salas C, Lee E, Lee B, Seok Kim H, Bruelheide H, Coomes DA, Piotta D, Sunderland T, Schmid B, Gourlet-Fleury S, Sonké B, Tavani R, Zhu J, Brandl S, Vayreda J, Kitahara F, Searle EB, Neldner VJ, Ngugi MR, Baraloto C, Frizzera L, Bałazy R, Oleksyn J, Zawila-Niedźwiecki T, Bouriaud O, Bussotti F, Finér L, Jaroszewicz B, Jucker T, Valladares F, Jagodzinski AM, Peri PL, Gonmadje C, Marthy W, O'Brien T, Martin EH, Marshall AR, Rovero F, Bitariho R, Niklaus PA, Alvarez-Loayza P, Chamuya N, Valencia R, Mortier F, Wortel V, Engone-Obiang NL, Ferreira LV, Odeke DE, Vasquez RM, Lewis SL, Reich PB (2016) Positive biodiversity-productivity relationship predominant in global forests. Science 354(6309):196. <http://dx.doi.org/10.1126/science.aaf8957>
- Petterson H (1955) Die Massenproduktion des Nadelwaldes. Mitt Forstlichen Forschungsanstalten Schwedens 45(1):1–392
- Pretzsch H, Block J, Dieler J, Dong PH, Kohnle U, Nagel J, Spellmann H, Zingg A (2010) Comparison between the productivity of pure and mixed stands of Norway spruce and European beech along an ecological gradient. Ann For Sci 67:1–12
- Pretzsch H, Bielak K, Block J, Bruchwald A, Dieler J, Ehrhart H-P, Kohnle U, Nagel J, Spellmann H, Zasada M, Zingg A (2013) Productivity of pure versus mixed stands of oak (*Quercus petraea* (MATT.) LIEBL. and *Quercus robur* L.) and European beech (*Fagus sylvatica* L.) along an ecological gradient. Eur J For Res 132:263–280
- Pretzsch H, Río M, Ammer C, Avdagic A, Barbeito I, Bielak K, Brazaitis G, Coll L, Dimberger G, Drössler L, Fabrika M, Forrester D, Heym M, Hurt V, Kurylyak V, Löf M, Lombardi F, Mohren F, Motta R, den Ouden J, Pach M, Ponette Q, Schütze G, Schweig J, Skrzyszewski J, Sramek V, Sterba H, Stojanović D, Svoboda M, Vanhellemont M, Verheyen K, Wellhausen K, Zlatanov T, Bravo-Oviedo A (2015) Growth and yield of mixed versus pure stands of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) analysed along a productivity gradient through Europe. For Ecol Manag 373:149–166
- Pretzsch H, Río M, Schütze G, Ammer C, Annighöfer P, Avdagic A, Barbeito I, Bielak K, Brazaitis G, Coll L, Drössler L, Fabrika M, Forrester DI, Kurylyak V, Löf M, Lombardi F, Matovic B, Mohren F, Motta R, den Ouden J, Pach M, Ponette Q, Skrzyszewski J, Sramek V, Sterba H, Svoboda M, Verheyen K, Zlatanov T, Bravo-Oviedo A (2016) Mixing of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) enhances structural heterogeneity, and the effect increases with water availability. For Ecol Manag 373:149–166
- Río M, Sterba H (2009) Comparing volume growth in pure and mixed stands of *Pinus sylvestris* and *Quercus pyrenaica*. Ann For Sci 66:1–11
- Río M, Pretzsch H, Alberdi I, Bielak K, Bravo F, Brunner A, Condés S, Ducey MJ, Fonseca T, von Lüpke N, Pach M, Peric S, Perot T, Souidi Z, Spathelf P, Sterba H, Tijardovic M, Tomé M, Vallet P, Bravo-Oviedo A (2016a) Characterization of the structure, dynamics, and productivity of mixed species stands: review and perspectives. Eur J For Res 135:23–49
- Río M, Pretzsch H, Ruiz-Peinado R, Ampoorter E, Annighöfer P, Barbeito I, Bielak K, Brazaitis G, Coll L, Drössler L, Fabrika M, Forrester DI, Heym M, Hurt V, Kurylyak V, Löf M, Lombardi F, Madrickiene E, Matović B, Mohren F, Motta R, den Ouden J, Pach M, Ponette Q, Schütze G, Skrzyszewski J, Sramek V, Sterba H, Stojanović D, Svoboda M, Zlatanov T, Bravo-Oviedo A (2016b) Data from: Species interactions increase the temporal stability of community productivity in *Pinus sylvestris*-*Fagus sylvatica*

- mixtures across Europe. Dryad Digital Repository. [Dataset]. <http://dx.doi.org/10.5061/dryad.fq4tk>
- Río M, Pretzsch H, Ruíz-Peinado R AE, Annighöfer P, Barbeito I, Bielak K, Brazaitis G, Coll L, Drössler L, Fabrika M, Forrester DI, Heym M, Hurt V, Kurylyak V, Löf M, Lombardi F, Madrickiene E, Matović B, Mohren F, Motta R, den Ouden J, Pach M, Ponette Q, Schütze G, Skrzyszewski J, Sramek V, Sterba H, Stojanović D, Svoboda M, Zlatanov T, Bravo-Oviedo A (2017) Species interactions increase the temporal stability of community productivity in *Pinus sylvestris*-*Fagus sylvatica* mixtures across Europe. *J Ecol* 105(40):1032–1043. <http://dx.doi.org/10.1111/1365-2745.12727>
- Vallet P, Perot T (2011) Silver fir stand productivity is enhanced when mixed with Norway spruce: evidence based on large-scale inventory data and a generic modelling approach. *J Veg Sci* 22:932–942