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DATA PAPER

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

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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.

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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

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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 monolayered 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.

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

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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 m^2 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 m^2 ha^{-1}) and volume stock per hectare (V m^3 ha^{-1}) were derived for each plot and species group, pine and beech. Additional coniferous and deciduous species 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

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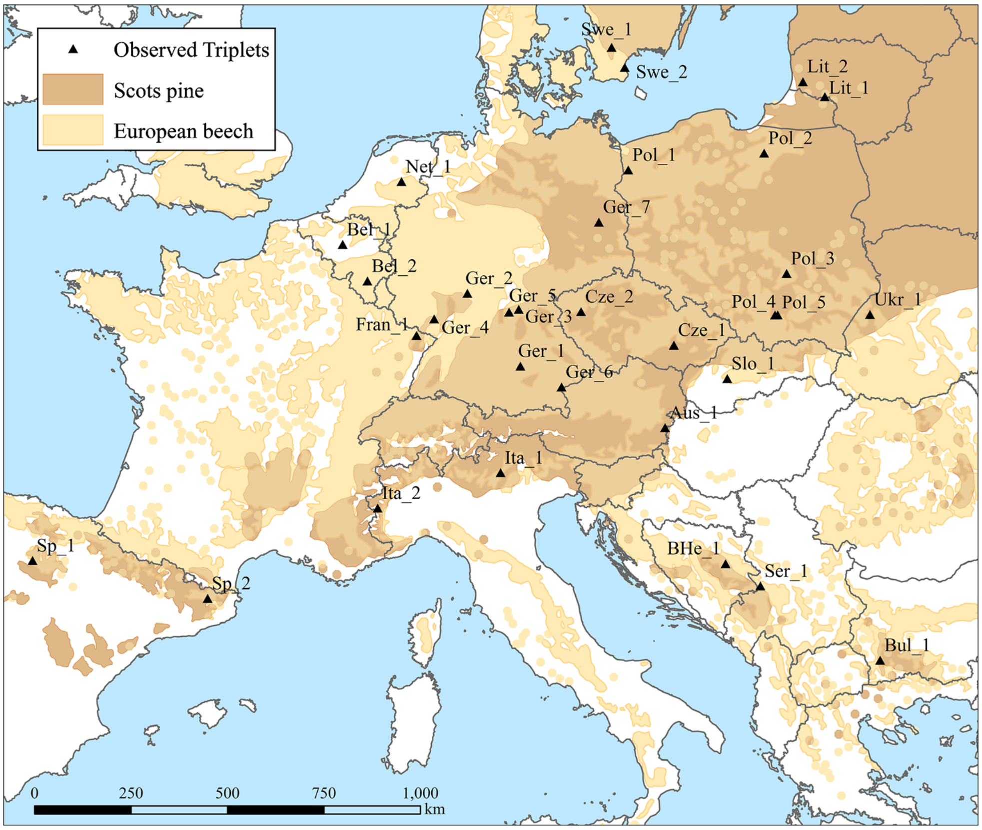

Fig. 1 Distribution of the triplet locations across Europe and distribution of European beech and Scots pine according EUFORGEN (www.euforgen.org). *Triangles* represent triplet locations

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/?uuid=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* (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

Country	Triplet name	Triplet	Longitude	Latitude	Age	Altitude	Slope	Aspect	*t*	*p*	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 mezotrofic
Czech Republic	Cze_2	1058	13° 12′ 45.90″	49° 58′ 02.50″	55	554	11	328	7.1	656	Dystric 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	0	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	Cambisoil
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 Petterson 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

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
	Increment cores	2 core samples/tree, 10–20 trees/plot/species
	Local density	1–2 angle count measurements/cored tree; m^2 ha^{-1}
Optional	*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 (m^2) and *V;* merchantable volume per hectare (m^3). All variables refer to the main species and 1 ha

Country	Triplet	Plot	Year	Species	Age	*N*	dg (cm)	hg (m)	BA (m^2 ha^{-1})	V (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 $= a^{*}\mathrm{dbh}^{b}$, 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.

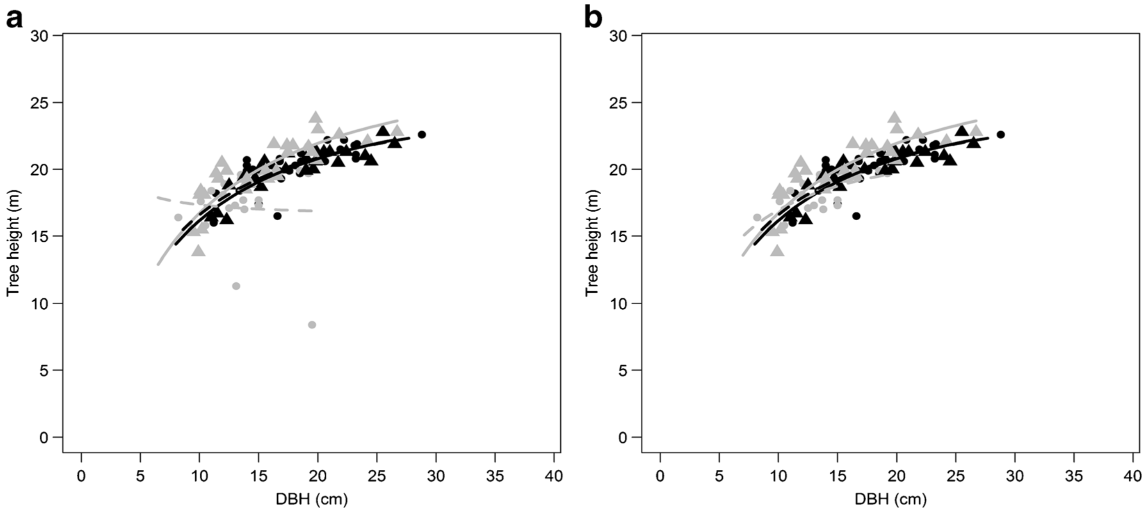

Fig. 2 Detecting (*left side,* **a**) and correcting (*right side,* **b**) inconsistent height measurements. Data from triplet 1032 for pine (*black*) and beech (*grey*) in pure (*triangles*) and mixed stands (*circles*). *Dashed and solid lines* representing species-specific Petterson height curve for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

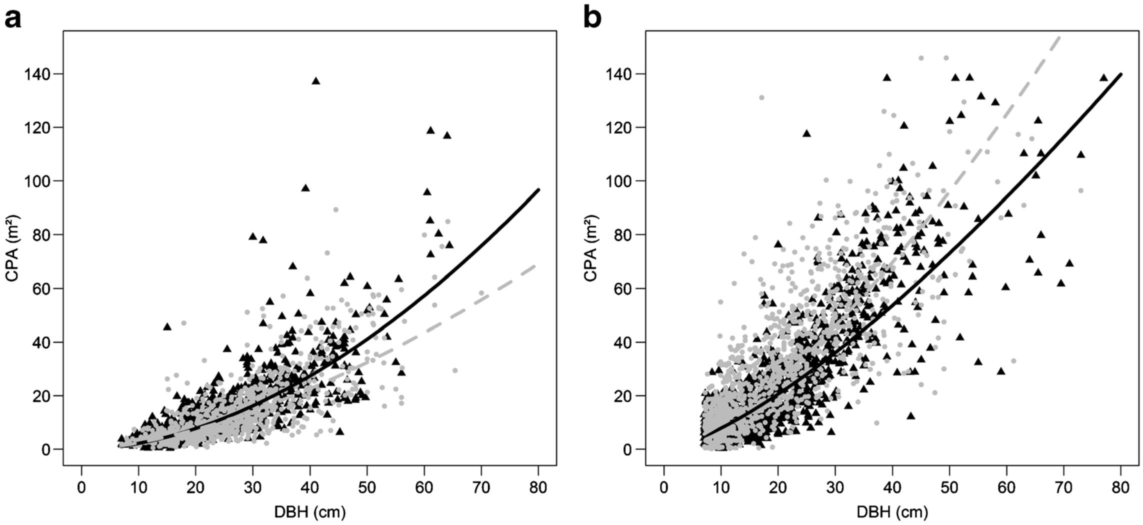

Fig. 3 Crown projection area (cpa) and diameter at breast height (dbh) for all measured pine (*left side*) and beech (*right side*) in pure (*triangles*) and mixed stands (*circles*). Allometric relationships are described by *solid* (*pure stands*) and *dashed lines* (*mixed stands*)

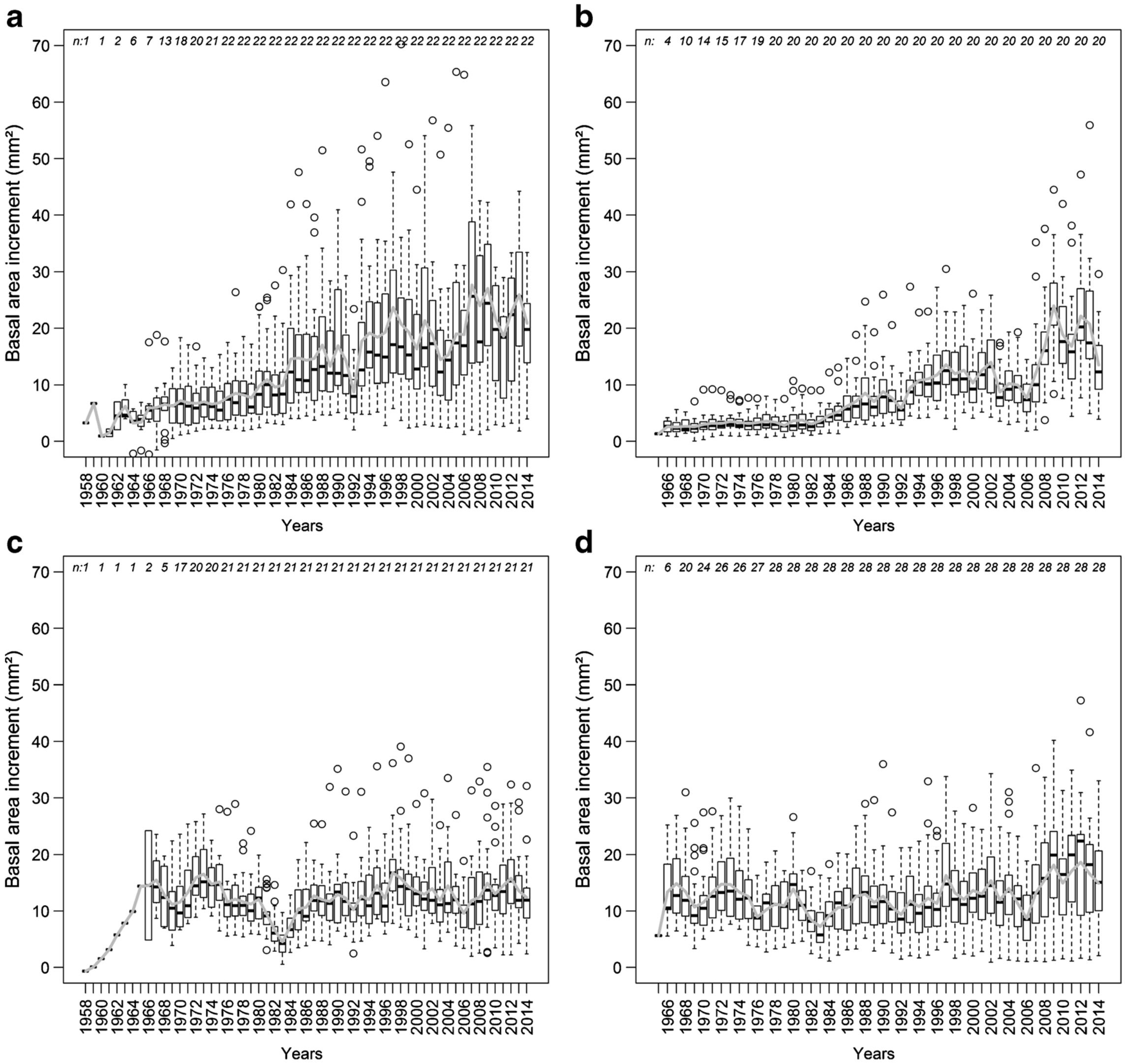

Fig. 4 Example of basal area increment per calendar year for beech (*upper*; **a**, **b**), and pine (*lower*; **c**, **d**), in pure (*left*; **a**, **c**) and mixed stand (*right*; **b**, **d**), for triplet 1035. *Grey solid lines* represent arithmetic means and *n* refers to number of cores for years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

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Compliance with ethical standards

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