Free European data on forest distribution: overview and evaluation

J. Trombik[1], T. Hlásny[1,2]

[1]*Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic*

[2]*National Forest Centre – Forest Research Institute Zvolen, Zvolen, Slovak Republic*

ABSTRACT: A growing need for the evaluation of prospects and sustainability of forest resources calls for the availability of harmonized data on forest distribution. We described and evaluated nine datasets providing such information: Corine LandCover, four European forest maps and four tree species distribution maps. Apart from providing a condensed overview of these datasets, we focused on the match between selected forest maps and forest management plans (FMPs) of Slovakia, which can be thought of as highly accurate information on forest distribution. The degree of match between forest and species area, within 306 forest administrative districts of Slovakia, was used as an indicator of accuracy. In addition, the match between the total forest and species area in Slovakia, given by FMPs and by evaluated datasets, was addressed. We found a high degree of match for the datasets on forest distribution (R-square 0.77–0.93, depending on the dataset), as well as strong agreement in total forest area (± 5%). Both indicators are worse in the case of forest type evaluation (coniferous and broadleaved). Poor results were obtained for tree species maps, which under- or overestimated species areas by tens of per cent, although differences were highly variable among species. The obtained results are valid mainly for temperate forests.

Keywords: tree species distribution; data quality; forest management plans; accuracy assessment

An increasing number of studies focus on the transboundary or even pan-European evaluation of forest resources (e.g. Badea et al. 2004; Percy, Ferreti 2004). These activities are often limited by a lack of suitable data on forest distribution for such large-scale use. In fact, forest management plans of many European countries contain high-quality forestry data, including a range of stand and site variables, with fine spatial resolution. However, despite the recent effort of most countries to establish legislation on free access to public data, access to national or institutional databases is often limited, and such data are not obviously available for research or commercial activities. Recently, climate change-related research has become an important area to suffer from the low quality of forestry data, which lags behind the continuously increasing resolution of climate models. In addition, forest area is one of the indicators for sustainable forest management in Europe (MCPFE 2003), and information on tree species distribution is important in the assessment of forest-related biodiversity, in connection with the United Nations Convention on Biological Diversity and affiliated European processes (Tröltzsch et al. 2009). The development of European forest maps is also needed for protection and conservation, carbon storage evaluation or forest planning (Schuck et al. 2003). For these reasons, several initiatives have been taken to develop unified datasets on forest distribution in Europe. The availability of such datasets may lead to improved forest resource modelling, able to deal with high-resolution forest diversity in Europe (Brus et al. 2011). Undoubt-

Supported by the Slovak Research and Development Agency, Project No. APVV-0111-10, and by the Czech University of Life Sciences by the Internal Grant Agency (IGA), Project No. 20134327; and by the Ministry of Agriculture of the Czech Republic, Project No. QJ1220316.

edly, CORINE Land Cover (EEA 1994, 2006 a,b) has been recognised as an extremely useful dataset, and has been used in dozens of studies since its first release (e.g. Sifakis et al. 2004; Traustason, Snorrason 2008; Mag et al. 2011). Later, an increase in the quality and availability of remote sensing data, as well as methodological advances in the processing of spatial data, led to the development of numerous forest maps with different geographical coverage, providing diverse information on forests. In addition to forest and forest-type maps, maps of tree species distribution have been found to be extremely important for forest resources evaluation, biodiversity assessment and forest planning (e.g. Tröltzsch et al. 2009; Brus et al. 2011). In addition, there are specialized forest maps, such as forest management maps by Hengeveld et al. (2012), forest biomass maps by Barredo et al. (2012), or various global forest and landcover maps (e.g. Defries et al. 2000; Bartholomé, Belward 2005; Ahlenius 2012), which are not, however, addressed in this study.

Despite the availability of numerous forest maps with European coverage, a critical evaluation of their quality and suitability for various objectives is missing. For this reason, this article aims to describe the freely available data on forest distribution, with mostly pan-European coverage, and evaluate the limits and assets of such data. In particular, we focused on:

– surveying the sources of freely available data on forest distribution in Europe;
– evaluating the content, quality, accuracy, coverage and other attributes of such data;
– evaluating the quality of selected datasets on forest distribution in Europe, on the basis of their match with forest management plans (FMPs) of Slovakia.

We hypothesize that datasets containing information on forest distribution and the distribution of forest types (broadleaved, coniferous and mixed) could show a very good match with the FMPs. This assumption is grounded in the fact that currently available satellite imagery and classification algorithms, which are used for the development of most of the addressed dataset, allow for the highly accurate delineation of forest areas (e.g. Kempeneers et al. 2011; Potapov et al. 2011). On the other hand, we suppose lower quality of data on tree species distribution, in terms of their match with FMPs. This assumption issues from the fact that the spatial interpolation of point data on the species proportion, which is generally applied for the development of evaluated datasets, could produce largely uncertain results, depending on the spatial density of data and the pattern of spatial autocorrelation specific to analysed species. In addition, we assume that maps of species with scattered distribution may have poorer quality when compared to maps of species with contagious range.

DATA AND METHODS

Evaluated datasets

Two groups of forest maps have been evaluated. The first group contains maps on the distribution of category 'forest', which is divided further in some datasets into subcategories coniferous, broadleaved and mixed. CORINE Land Cover data (EEA 1994, 2006 a,b) and four European forest maps were included into this group (Schuck et al. 2002; Pekkarinen et al. 2009; Gunia et al. 2011; Kempeneers et al. 2011). The second group contains maps providing information on forest tree species distribution such as EUFORGEN maps (EUFORGEN 2009), tree species distribution maps based on the Forest Focus data (FORESTMOD 2013), and two results of statistical mapping of tree species distribution in Europe (Tröltzsch et al. 2009; Brus et al. 2011) were included into this group.

CORINE Land Cover (CORINE – EEA 1994)

The CORINE (**Co**o**r**dinate **In**formation on the **E**nvironment) database is a pan-European land cover map, developed by the European Environmental Agency (EEA) in cooperation with national partner institutions. The dataset covers the 27 countries of the European Union (EU27), as well as Albania, Bosnia and Herzegovina, Croatia, Macedonia, and Liechtenstein. Three land-cover categories define the forests: broadleaved (proportion > 75%); coniferous (> 75%); and mixed forests (remaining forest land) (EEA 1994). The dataset was developed on the basis of multispectral satellite imagery acquired by Landsat and Spot instruments, and additional national data such as topographic maps, thematic maps, statistical information and aerial photographs (EEA 1994, 2006 a,b), with the minimum mapping unit of 25 ha. The dataset is available through the web portal of the EEA as raster files (TIFF format with a resolution of 100 and 250 m) and vector files (ESRI shp file). CORINE 2006 is currently the latest update; the version available in ESRI shp file format was used in this study.

Forest Map 2000 (FMAP 2000; Pekkarinen et al. 2009)

FMAP 2000 contains the information on forest and non-forest categories, derived from 415 Landsat ETM+ satellite scenes and CORINE Land Cover 2000, with a spatial resolution of 25 m. The map covers the EU-27 countries, Norway, Switzerland, Lichtenstein, Albania, Croatia, Macedonia, Montenegro and Serbia. The map's overall point-level agreement exceeds 80%, and it approaches 90% in Central Europe. A comparison with the country-level forest area statistics shows that, in most cases, the difference between the forest proportion of the derived map and that computed from the published forest area statistics is below 5% (Pekkarinen et al. 2009). The maps can be downloaded from the website of the Joint Research Centre of the European Commission (http://forest.jrc.ec.europa.eu) as raster data (TIFF format).

Forest map 2002 (EFMAP 2002; Schuck et al. 2002)

EFMAP 2002 represents the proportion of coniferous and broadleaf forests per land area in a 1 × 1 km pixel resolution. The map was derived from NOAA-AVHRR satellite imagery, and calibrated to conform to statistical information on forest area, such as national inventory reports and data from international data-collection processes of the United Nations Economic Commission for Europe/Food and Agriculture Organisation (UNECE/FAO 2000; Päivinen et al. 2001). The difference between the map and inventory statistics varies around ± 5% (higher in the coastline and small island area) (Schuck et al. 2003). EFMAP 2002 includes all European countries except for Cyprus and Turkey. The map can be downloaded from the European Forest Institute (EFI) website (http://www.efi.int/projects/euromap/phase2/register.php), as raster data (IMAGINE Image format).

Forest Map 2006 and Forest Type Map 2006 (FTYP 2006; FMAP 2006; Kempeneers et al. 2011)

The FMAP 2006 contains forest, non-forest and water categories, while the FTYP 2006 contains broadleaved and coniferous categories. The resolution of both datasets is 25 m. The maps were produced using IRS-LISS-3 and SPOT4/5 satellite scenes, acquired in 2006. Multitemporal information obtained from the MODIS sensor (NASA) was added to improve the classification. FMAP 2006 and FTYP 2006 cover the same area as FMAP 2000, but they also include Turkey. The result can be downloaded from the EC-JRC website (http://forest.jrc.ec.europa.eu) as raster data (TIFF format).

Forest map 2011 (EFMAP 2011; Gunia et al. 2011)

EFMAP 2011 represents the modified version of FMAP 2006 (Kempeneers et al. 2011), which was aggregated from the original 25 m spatial resolution to 1 km, by summing up the forest area for each 1 km pixel (the proportion of forests is given). Forest share estimates taken from the 1 km resolution EFMAP 2002 (Schuck et al. 2002) have been used to extend the map up to the Ural Mountains, covering Belarus, Ukraine, Moldova and the European part of the Russian Federation. The map can be downloaded from the EFI website (http://www.efi.int/projects/euromap/phase2/register.php) as raster data (IMAGINE Image).

Tree species distribution maps 1 (EUFORGEN – EUFORGEN 2009)

The European Forest Genetic Resources Programme (EUFORGEN) produced a series of pan-European maps of forest tree species distribution. The maps were produced by members of the EUFORGEN Networks and other experts, on the basis of diverse information sources. The dataset contains polygonal data with the area of occurrence of 34 tree species across Europe. The dataset is available through the EUFORGEN web (http://www.euforgen.org/distribution_maps.html) as ESRI shape files (shp). The maps are updated irregularly.

Tree species distribution maps 2 (TMAP 2009; Tröltzsch et al. 2009)

TMAP 2009 is based on tree species information from plot data of the ICP (International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests) Forests, with the spacing of 16 × 16 km, which is combined with other spatial and statistical information. The point data were interpolated using the kriging method, and produced maps were scaled and calibrated to make the maps correspond to the Forest Map of Europe, version 2002 (Schuck et al. 2002) at a pixel level, and to national forest inventory statistics at regional or national levels (Tröltzsch et al. 2009). The outputs are pan-European maps with a resolution of 1 km, containing proportions of the main tree species groups as a percentage of the total land area. The maps were developed for pine, spruce, fir, birch, beech and oak species groups. All remaining species were grouped into categories 'other coniferous' and other broadleaf. The maps cover the entire Europe except for countries for which ICP and/or detailed national forest inventory were not available (e.g. Macedonia, Cyprus, parts of Russia, Andorra, Liechtenstein).

Tree species distribution maps 3 (TMAP 2011; Brus et al. 2011)

TMAP 2011 contains maps with a proportion of 18 tree species in a 1 × 1 km resolution grid. The ICP-Level-I plot data on tree species distribution (6,238 plots) and National Forest Inventory data of eighteen countries (335,360 plots, Nabuurs 2009) were used for the development of this dataset. In areas with national forest inventory data, species area proportions were obtained by compositional kriging. For the rest of Europe, a multinomial logistic regression model was used, using various abiotic factors as predictors (soil, biogeographical zones, climate data). The regression results were scaled to fit NUTS-II forest inventory statistics and the European Forest Map, according to Tröltzsch et al. (2009) and Schuck et al. (2002). Maps of 20 tree species are available in the dataset. The accuracy of produced maps was highly variable, depending on the species; the overall accuracy equals 43%. In areas with NFI plot data, the accuracy was 57%, and outside these areas 33%. GIS data are available for download from the EFI website (http://www.efi.int/projects/tree-species-map/register.php) as raster files (ESRI file geo-database).

Tree species distribution maps 4 (FMOD; FORESTMOD 2013)

The map contains information on tree species proportions in a 1-km resolution grid. The Forest Focus database (Forest Focus 2003) containing information about the tree species composition on the basis of a systematic network of observation points and observation plots was the main source of data. The point data were interpolated and then scaled to FMAP 2000 (Pekkarinen et al. 2008). The results contain the distribution of 24 tree species. The maps cover the EU-27, as well as Norway, Switzerland, Lichtenstein, Albania, Croatia, Macedonia, Montenegro and Serbia. The maps can be acquired using the FORESTMOD map viewer (http://forest.jrc.ec.europa.eu/efdac/applications/species-distrbution/) as raster files (TIFF format).

Modification of low-resolution raster data

Some of the datasets described above contain data in a 1-km resolution grid. To improve the visual and analytical properties of these data, we applied the following modification. The original grid data were transformed to vector format, and the produced polygons were intersected with forest polygons from CORINE Land Cover data. Then, forest cells, or their parts lying outside the forest area specified by CORINE Land Cover, were removed. In the case of tree species maps, CORINE categories 'Coniferous' and 'Mixed' were used to modify the coniferous species, and CORINE categories 'Broadleaved' and 'Mixed' were used to modify the broadleaved species. EFMAP 2002 and 2011, TMAP 2011 and FMOD datasets were modified using this methodology. The effect of such modification on the map accuracy was evaluated.

Forest management plans of Slovakia

We evaluated the accuracy of selected freely available data using the Slovakian FMPs (National Forest Centre, Slovakia, internal data), which represent the information on forest tree species distribution, independent of all evaluated data sources. The information on tree species proportions in the FMPs is associated with forest subcompartments, of the average size approximately 5 ha. This data can be a priori thought of as more accurate when compared with the evaluated datasets, because FMPs are compiled on the basis of regular 10-year step field surveys, i.e. one tenth of country's forested area is updated annually. This implies that used FMPs refer to the period 2003–2012 (the analysis was run in 2013). This fact introduces certain temporal inconsistency into the analysis, as well as temporal mismatch between the FMPs and evaluated datasets on forest distribution. Considering the scale which the analysis focuses on and relatively low forest dynamics at this scale, such inconsistency cannot be expected to affect the results.

Accuracy assessment

As most of the evaluated datasets can be expected to have a relatively low informative value at the stand scale, owing to the inherent effect of their low spatial resolution, we focused our evaluation on the scale of 306 forest administrative districts (FADs) of Slovakia, with an average size of 150 km^2. The accuracy assessment was focused on a comparison of the extent of forest categories in the evaluated datasets with data from FMPs of Slovakia within FADs.

To facilitate this analysis, the map of FADs was transformed from the national coordinate system (S-JTSK Krovak) to Lambert Azimuthal Equal Area (LAEA) projection on the ETRS ellipsoid using the ArcInfo GIS (ESRI 2010) tools; ETRS LAEA was the system of all evaluated datasets. The error due to this transformation is not expected to affect the analysis. FMPs were not transformed, and forest, forest type and species areas within FADs were calculated in the original national coordinate system (S-JTSK Krovak).

In the case of forest type evaluation (coniferous, broadleaved, mixed), species proportions in FMPs were classified so as the definition of a given forest type corresponded with the definition of this forest type in the evaluated dataset. No limit was imposed on stand density, age and other attributes in the FMPs, and all forest compartments were used in the analysis.

Correlation analysis was applied to describe the relationship between these variables, and to evaluate the strength of correlations using the R-square. The analysis was performed separately for FADs, with mean elevation above and below 600 m a.s.l., as well as for all FADs regardless of their elevation. In addition, a comparison of total forest, forest type and species areas, given by

FMPs and evaluated datasets, was made. In the case of tree species maps, we focused on selected temperate forest tree species with contagious and scattered distribution: European beech (*Fagus sylvatica*), Norway spruce (*Picea abies*) and Silver fir (*Pinus sylvestris*).

RESULTS

Summary information on all addressed datasets is given in Table 1. Correlation analysis of forest and forest type areas within FADs indicated remarkable differences between the match of FMPs and evaluated datasets (Table 2). FMAP 2000 with the resolution of 25 × 25 m performed best out of all datasets (R-square 0.93 in all FAD), and showed equally high R-squares in both elevation zones addressed (below and above 600 m a.s.l.). CORINE Land Cover reached similar accuracy. However, it slightly outperformed the FMAP 2000 in FADs at elevations below 600 m a.s.l. (R-square 0.97).

FMAP 2006 with 25-m resolution and EFMAP 2011 with 1-km resolution showed balanced, and

Table 1. Basic properties of forest maps addressed in this study; map abbreviations are explained in the text

Dataset	Format	Resolution	Coverage	Main data sources	Forest categories	Attribute	Reported accuracy
CORINE 2006	raster, vector	1 : 100,000; 100 × 100 m; 250 × 250 m	EU-27, Albania, Bosnia and Herzegovina, Croatia, Macedonia, and Liechtenstein	Landsat and Spot satellites, national topographic and thematic maps, statistical information and aerial photographs	broad-leaved, coniferous, mixed	presence/ absence	> 85%
EFMAP 2002	raster	1 × 1 km	all European countries from Portugal to Ural Mts., except Cyprus and Turkey	AVHRR-NOAA; forest inventory statistics	forest/ non-forest; broad-leaved; coniferous	forest or forest type proportion	variable, overall ± 5%, lower accuracy in the coastline area
FMAP 2000	raster	25 × 25 m	EU-27, Norway, Switzerland, Lichtenstein, Albania, Croatia, Macedonia, Montenegro and Serbia	Landsat ETM+ imagery; Corine LandCover 2000	forest/non-forest	presence/ absence	> 80%
FMAP 2006 FTYP 2006	raster	25 × 25 m	EU-27 and Norway, Switzerland, Lichtenstein, Albania, Croatia, Macedonia, Montenegro, Serbia and Turkey	IRS-LISS-3; SPOT4/5; Corine LandCover 2000	forest/ non-forest; broad-leaved; coniferous	presence/ absence	> 80%
EFMAP 2011	raster	1 × 1 km	same as FMAP 2006; added Belarus, Moldova, Ukraine and Russian Federation (from Schuck et al. 2002)	IRS-LISS-3; SPOT4/5; Corine LandCover 2000 and AVHRR-NOAA; forest inventory statistics	forest/non-forest	forest proportion	> 80%; lower for Belarus, Ukraine, Moldova and Russia
EUFORGEN	vector	unspecified	all European countries; except Cyprus, Turkey and Russia	national experts; bibliography	34 forest tree species	presence/ absence	not specified
TMAP 2009	raster	1 × 1 km	Pan-European area except Macedonia, Cyprus, parts of Russia other than the Leningrad and Kaliningrad regions, Andorra and Liechtenstein	ICP Level 1 plots; European Forest Map; Forest inventory statistics; selected environmental variables	6 forest tree species	species proportion	variable between the countries, correlation from cross-validation 0.2 to 0.8
TMAP 2011	raster	1 × 1 km	Pan-European area except Macedonia, Cyprus, parts of Russia other than the Leningrad and Kaliningrad regions, Andorra and Liechtenstein.	NFI plots; Forest inventory statistics; selected environmental variables	20 forest tree species	species proportion	43%, highly variable among species
FOREST-MOD	raster	1 × 1 km	EU-27, Norway, Switzerland, Lichtenstein, Albania, Croatia, Macedonia, Montenegro and Serbia	FMAP 2000; Forest Focus database	24 forest tree species	species proportion	not specified, highly variable among species and locations

Table 2. R-squares calculated between areas occupied by main forest type categories within forest administrative districts in Slovakia, taken from the FMPs of Slovakia and six maps of forest distribution in Europe (CORINE – EEA 1994; FMAP 2000; EFMAP 2002; Schuck et al. 2002; FMAP 2006; FTYP 2006; Pekkarinen et al. 2009; EFMAP 2011, Gunia et al. 2011; Kempeneers et al. 2011)

Category	Elevation zone	FMAP		EFMAP 2002	EFMAP			FTYP 2006	CORINE
		2000	2006		2002*	2011	2011*		
Forest	all districts	0.93	0.88	0.88	0.77	0.88	0.82	–	0.89
	< 600 m a.s.l.	0.94	0.94	0.82	0.76	0.92	0.90	–	0.97
	> 600 m a.s.l.	0.94	0.87	0.93	0.83	0.88	0.80	–	0.86
Broadleaved	all districts	–	–	0.66	0.60	–	–	0.93	0.98
	< 600 m a.s.l.	–	–	0.77	0.65	–	–	0.92	0.97
	> 600 m a.s.l.	–	–	0.69	0.80	–	–	0.82	0.95
Coniferous	all districts	–	–	0.91	0.86	–	–	0.91	0.92
	< 600 m a.s.l.	–	–	0.54	0.72	–	–	0.85	0.92
	> 600 m a.s.l.	–	–	0.93	0.84	–	–	0.90	0.90
Mixed	all districts	–	–	–	–	–	–	–	0.77
	< 600 m a.s.l.	–	–	–	–	–	–	–	0.74
	> 600 m a.s.l.	–	–	–	–	–	–	–	0.77

*modification of the original dataset using CORINE Land Cover data described in the text

in the case of the latter dataset, the applied modification by CORINE Land Cover did not affect the R-square substantially. The R-square of FMAP 2006 and EFMAP 2011 at elevations < 600 m a.s.l. was equal to FMAP 2000 map performance in all districts, but at elevations > 600 m a.s.l. it was, however, weaker. EFMAP 2002 with 1-km resolution had lower accuracy as compared with FMAP 2000 (R-square 0.88 vs. 0.93 in all districts). Surprisingly, the map modification by CORINE Land Cover reduced the R-square, and it reached 0.77 in all districts. Hence, such modification is not advisable in the case of this map.

Much higher variability of R-squares was observed among datasets, forest type categories and elevation zones in the case of coniferous and broadleaved forest type classes. CORINE outperformed the EFMAP 2002 and FTYP 2006 in both coniferous and broadleaved classes (mixed is not included in the latter two datasets). A high degree of match with FMPs was found in the case of the CORINE broadleaved category (R-square 0.98 in all districts), while it reached 0.92 for the coniferous and 0.77 for the mixed categories (definition of these categories in FMPs was the same as CORINE forest classes). EFMAP 2002 was found to have the lowest performance, and its R-square

Table 3. R-squares calculated between areas occupied by three forest tree species within forest administrative districts in Slovakia, taken from the "forest management plans" of Slovakia and two maps of tree species distribution in Europe (TMAP 2011; Brus et al. 2011; FMOD – FORESTMOD 2013)

Species	Elevation zone	TMAP 2011	TMAP 2011*	FMOD	FMOD*
European beech	all districts	0.52	0.67	0.52	0.49
	< 600 m a.s.l.	0.59	0.60	0.55	0.52
	> 600 m a.s.l.	0.53	0.82	0.50	0.55
Silver fir	all districts	0.33	0.54	0.17	0.20
	< 600 m a.s.l.	0.14	0.67	0.55	0.71
	> 600 m a.s.l.	0.40	0.46	0.07	0.08
Norway spruce**	all districts	0.83	0.85	–	–
	< 600 m a.s.l.	0.35	0.87	–	–
	> 600 m a.s.l.	0.85	0.81	–	–

*modification of the original dataset using CORINE Land Cover data described in the text, **spruce was not included in the FMOD dataset reached only 0.66 in all broadleaved districts. Better results were obtained for coniferous categories in all districts (R-square 0.91), but R-square in the elevation zone < 600 m a.s.l. was only 0.54 (improved by CORINE modification to 0.72). Modification by CORINE Land Cover did not improve the results in other cases. FTYP 2006 with 25-m resolution showed high performance in both coniferous and broadleaved categories, and R-square reached 0.93 and 0.91, respectively, in all districts. For the visual evaluation of selected datasets see Fig. 1.

The analysis of tree species maps was focused on TMAP 2011 (Brus et al. 2011) and FMOD maps (FORESTMOD 2013; Table 3), both with 1-km resolution. In contrast to the analysis of forest types, modification by CORINE resulted in substantial improvement in all three species in both datasets.

The highest degree of match with FMPs was observed in spruce from the TMAP 2011 (R-square 0.83 in all districts), though R-square in elevations up to 600 m a.s.l. was only 0.35. This value, however, increased remarkably after modification by CORINE Land Cover, and reached 0.87. A similar effect was observed in the case of Silver fir at an elevation of up to 600 m a.s.l., where the R-square reached only 0.14 in the original TMAP 2011, and 0.55 in the original FMOD. After modification, these values reached 0.67 and 0.71, respectively. In the case of beech, original TMAP 2011 reached the same R-square as FMOD (0.52). Modification by CORINE Land Cover was beneficial only in the case of TMAP 2011 (R-square 0.67), while it caused a minor worsening in the case of FMOD (R-square 0.49). Maps for Silver fir, which occurs mainly as an admixture species, showed low performance, and R-square reached 0.33 in TMAP 2011 and 0.17 in FMOD (case of all districts). A substantial effect of modification by CORINE Land Cover was observed in TMAP 2011 (R-square 0.54), while this effect was only minor in FMOD (R-square 0.2). For the visual evaluation of beech and fir distributions see Figs 2 and 3.

In addition to the presented analysis, we evaluated the match among the total area of forest, forest types and tree species, taken from the FMPs and from the evaluated datasets (presented forest and forest tree species areas are different from official national statistics, because of different methodology used in these calculations) (Table 4). Datasets providing information on forest and forest type distribution were found to correspond very well with the respective areas from FMPs, except for FMAP 2000, which overestimated the total forest area by ca 20%. Modification by CORINE Land Cover had

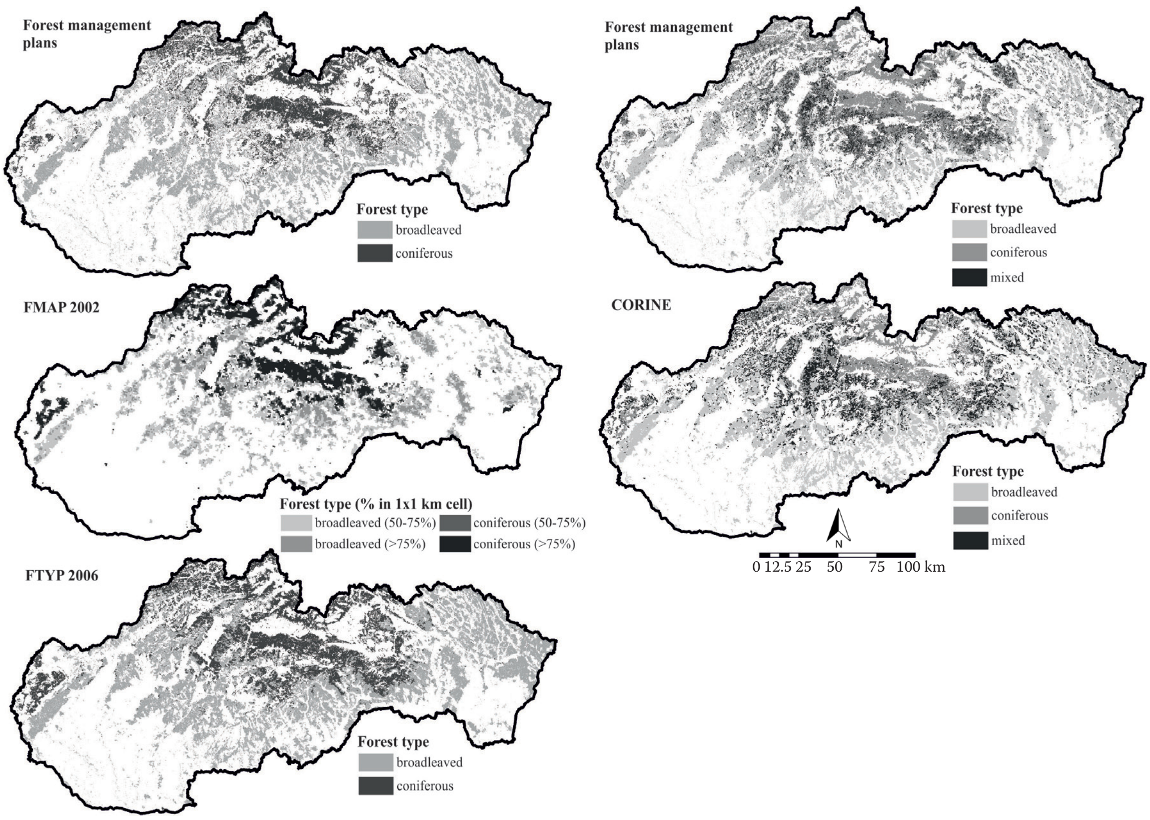

Fig. 1. Maps of forest type distribution, taken from forest management plans of Slovakia and from three freely available datasets on forest distribution in Europe

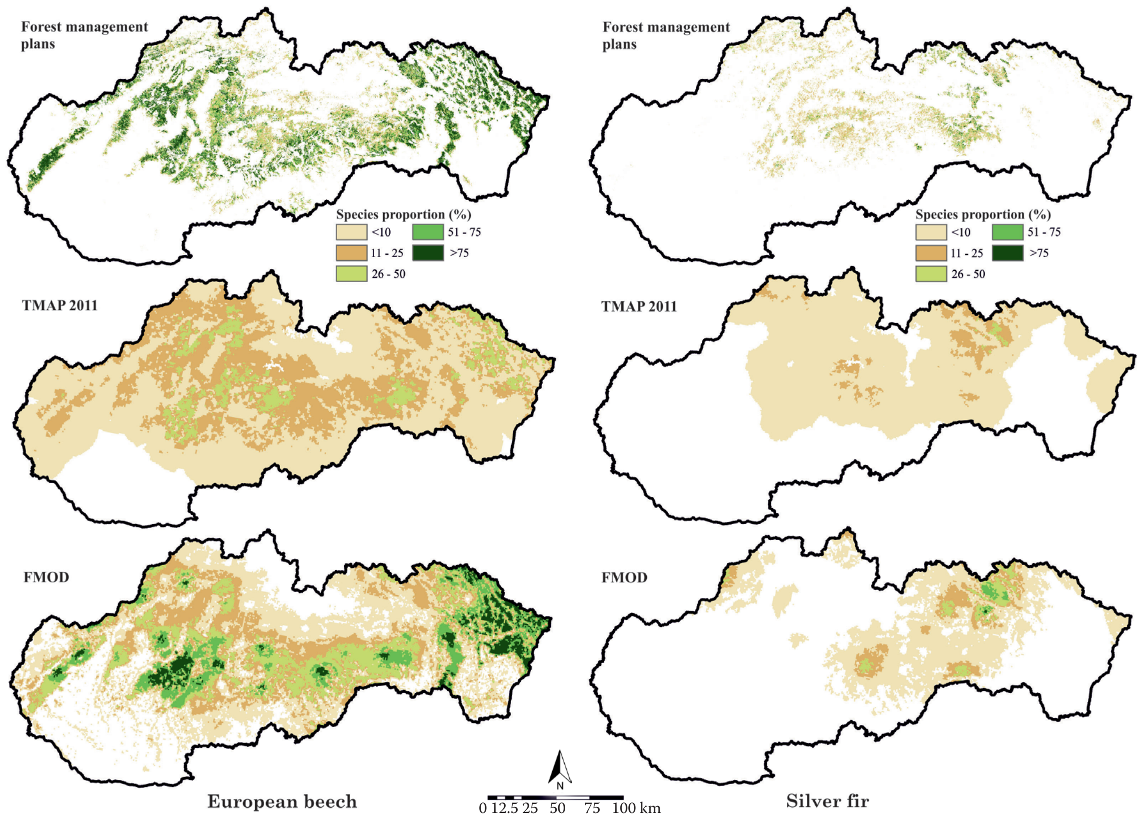

Fig. 2. Distribution maps of European beech and Silver fir, taken from forest management plans of Slovakia and two freely available datasets, based on statistical mapping

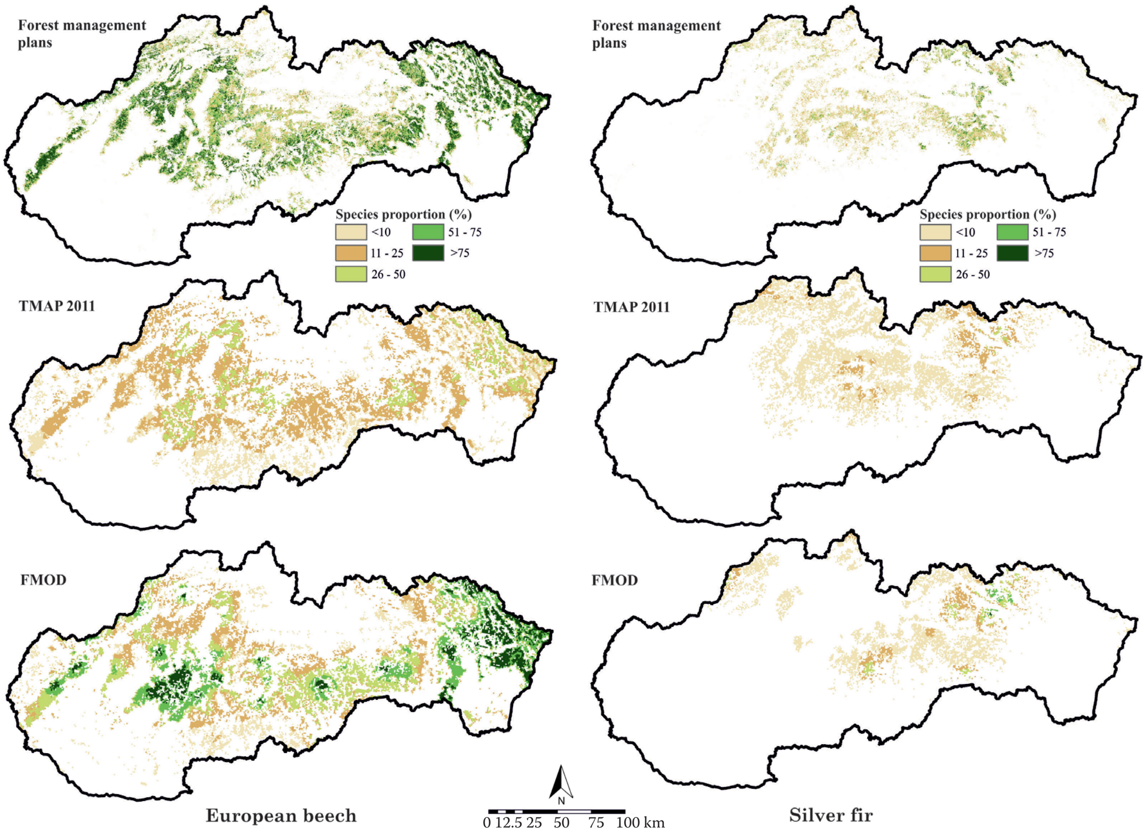

Fig. 3. Distribution maps of European beech and Silver fir, taken from forest management plans of Slovakia and two freely available datasets, based on statistical mapping, the maps were modified by CORINE Land Cover

Table 4. Comparison of areas occupied by the total forest area, forest types and three forest tree species in Slovakia, taken from forest management plans and from 8 European datasets on forest distribution

Dataset	Forest	Coniferous	Broadleaved	Mixed	*F. sylvatica*	*A. alba*	*P. abies*
FMPs (km^2)	18,272	7,288	10,683	3,636	7,687	800	6,198
FMAP 2000 (%)	+19.8	–	–	–	–	–	–
FMAP 2006 (%)	–5.3	–	–	–	–	–	–
EFMAP 2002 (%)	+1.9	–0.2	+7.6	–	–	–	–
EFMAP 2002* (%)	–33.0	–3.5	–29.4	–	–	–	–
EFMAP 2011 (%)	–0.3	–	–	–	–	–	–
EFMAP 2011* (%)	–23.4	–	–	–	–	–	–
FTYP 2006 (%)	–	–1.9	+7.0	–	–	–	–
CORINE (%)	+2.9	–3.6	–3.3	+5.0	–	–	–
TMAP 2011 (%)	–	–	–	–	–44.5	+86.9	–1.9
TMAP 2011* (%)	–	–	–	–	–70.9	–10.5	–59.2
FMOD (%)	–	–	–	–	+5.2	–22.4	–
FMOD* (%)	–	–	–	–	–31.9	–64.2	–

*modification of the original dataset using CORINE LandCover data described in the text

a detrimental effect on all maps, and the removal of parts of the forest area distributed outside the CORINE forest classes caused a substantial underestimation of the total forest area, as compared with FMPs. Poor results were obtained for tree species maps, which under- or overestimated species areas in tens of per cent in both evaluated datasets (TMAP 2011 and FMOD).

EUFORGEN maps represent another dataset containing data on the distribution of forest tree species, which has not been addressed in the previous analyses. Visual investigation of the match between several EUFORGEN maps (European beech, Norway spruce and Silver fir) and FMPs revealed erroneous geographical projection, which resulted in the shifted and distorted position of evaluated species maps. The distortion was remarkable for both beech and spruce, and increased to the southeast of Europe. Provided that this problem has been fixed, the EUFORGEN maps can be expected to match the real tree species distribution very well.

DISCUSSION AND CONCLUSIONS

This study used consistent information from several datasets which provide free access to data on forest distribution, with approximately pan-European coverage. In addition to the general description of this data, we evaluated the accuracy of selected datasets by their comparison with forest management plans of Slovakia. In line with hypotheses stated at the beginning of this study, we found a high agreement between forest management plans and maps describing forest and forest type distribution, in terms of both performed correlation analysis and comparison of the extent of total forest area in the country. Such results agree with evaluations provided by the authors of the maps, who indicate their accuracy to exceed 80% in all datasets. Our findings corroborate the validity of these evaluations, and emphasize the suitability of evaluated datasets for Central Europe. Hence, the use of these data seems advisable for most pan-European or transboundary initiatives, such as the Carpathian Initiative or the Danube Strategy. The high performance of CORINE Land Cover in all three forest types (coniferous, broadleaved, mixed), and the fact that CORINE Land Cover is the only dataset containing the 'mixed forest' category, makes it outstandingly valuable. Such accuracy is undoubtedly related to the active participation of Slovak institutions in the development of this dataset. The dataset, however, does not contain any data for Ukraine, which is addressed in many initiatives focusing on the Carpathians bioregion. Therefore, a combination with other forest maps is needed.

The evaluation of datasets on tree species distribution did not yield as satisfactory results as datasets on forest and forest types. The spatial pattern of Silver fir distribution, according to both evaluated datasets (Brus et al. 2009; FORESTMOD 2013), was found to correspond with FMPs only very roughly, though the proposed modification using CORINE Land Cover brought substantial improvements (Figs 2 and 3). These facts may generate concern about the applicability of maps of other tree species with scattered distribution. Better results were obtained for species with contagious distribution – Norway spruce and European beech – in terms of both correlation analysis and visual match of maps with FMPs. However, the map ability to reproduce the total species areas in the country was poor, which may limit some applications for forest resources evaluation (e.g. carbon stocks). Hence, neither did the use of a number of national forest inventory data in both datasets allow for reaching a higher accuracy using methods based on the interpolation of point distributed data.

In pan-European evaluations, another problem may arise from the spatially varied accuracy, related to the variable density of source point data used for the interpolation of species proportions. Hence, a spatially explicit indicator of uncertainty, such as a map of kriging variance, should be used, along with species distribution maps. Generally, the evaluated species distribution maps should be used with care, and mainly for large-scale applications. In this regard, Tröltzsch et al. (2009) suggested that such maps can provide only a rough estimate of species distribution, and cannot replace highly detailed national inventory maps.

In addition to the datasets addressed in this study, there are, for example, products with global coverage, such as a global percentage tree cover map (Defries et al. 2000), or the World Map of Forest Distribution (Ahlenius 2012), which were not considered because of their supposed limited informative value for Europe. However, exploring the quality of these data and their suitability for European conditions could be useful, and can be subjected to future research. The presented results indicated some deficiencies of evaluated datasets, and may initiate their future improvements. Owing to the overwhelming importance of European forest maps for the community and natural resource management such improvements are desperately needed.

References

Ahlenius H. (2012): World Map of Forest Distribution (Natural resources – forests). UNEP/GRID-Arendal. Available at http://www.grida.no/graphicslib/detail/world-map-of-forest-distribution-natural-resources-forests_2215 (accessed 8 September 2013).

Badea O., Tanase M., Georgeta J., Anisoara L., Peiov A., Uhlirova H., Pajtik J., Wawrzoniak J., Shparyk Y. (2004): Forest health status in the Carpathian Mountains over the period 1997–2001. Environmental Pollution, ***130***: 93–98.

Barredo J.I., San Miguel J., Giovanni G., Busetto L. (2012): A European Map of Living Forest Biomass and Carbon Stock. Ispra, Joint Research Centre of the European Commission and Institute for Environment and Sustainability, Forest Resources and Climate Unit: 10.

Bartholomé E., Belward A.S. (2005): GLC2000: A new approach to global land cover mapping from Earth observation data. International Journal of Remote Sensing, ***26***: 1959–1977.

Brus D.J., Hengeveld G.M., Walvoort D.J.J., Goedhart P.W., Heidema A.H., Nabuurs G.J., Gunia K. (2011): Statistical mapping of tree species over Europe. European Journal of Forest Research, ***131***: 145–157.

Defries R. S., Hansen M.C., Townshend J.R.G., Janetos A.C., Loveland T.R. (2000): A new global 1-km dataset of percentage tree cover derived from remote sensing. Global Change Biology, ***6***: 247–254.

EEA (2006a): The thematic accuracy of CORINE land cover 2000. Assessment Using LUCAS (Land Use/Cover Frame Statistical Survey), Technical report No 7/2006. European Environmental Agency, Copenhagen. Available at http://www.eea.europa.eu/publications/ technical_report_2006_7/at_download/file (accessed 8 September 2013).

EEA (2006b) European forest types, categories and types for sustainable forest management reporting and policy, Technical report NO 9/2006. European Environmental Agency, Copenhagen. Available at http://www.eea.europa.eu/publications/technical_report_2006_9/at_download/file (accessed 8 September 2013).

EEA (1994): CORINE Land Cover: Technical Guide. European Environmental Agency: European Topic Center/ Land Cover: 130.

ESRI (2010): ArcMap 10.0. Environmental Systems Resource Institute, Redlands, California.

EUGORGEN (2009): Distribution maps. European Forest Genetic Resources Programme. Available at http://www.euforgen.org/distribution_maps.html (accessed 8 September 2013).

Forest Focus (2003): Regulation (EC) No 2152/2003. Forest Focus: Monitoring of Forests and Environmental Interactions in the Community.

FORESTMOD (2013): Tree Species Distribution. Joint Research Centre of the European Commission. Available at http://forest.jrc.ec.europa.eu/activities/climate-change/species-distribution/ (accessed 8 September 2013).

Gunia K., Päivinen R., Zudin S., Zudina E. (2011): Forest map of Europe. European Forest Institute, Joensuu. Available at http://www.efi.int/portal/virtual_library/information_services/ mapping_ services/ forest_map_of_europe/ (accessed 8 September 2013).

Hengeveld G.M., Nabuurs G., Didion M., Wyngaert I., van Den Clerkx A.P.P.M., Schelhaas M. (2012): A forest management map of European forests. Ecology and Society, ***17***: 53.

Kempeneers P., Sedano F., Seebach L., Strobl P., San-Miguel-Ayanz J. (2011): Data fusion of different spatial resolution remote sensing images applied to forest-type mapping. IEEE Transactions on Geoscience and Remote Sensing, ***49***: 4977–4986.

Mag Z., Szép T., Nagy K., Standovár T. (2011): Modelling forest bird community richness using CORINE Land Cover data: a study at the landscape scale in Hungary. Community Ecology, ***12***: 241–248.

MCPFE (2003): Background information for improved Pan-European indicators for sustainable forest management, Liaison Unit, Vienna. Available at http://www.foresteurope.org/ docs/reporting/CI_Backgr_Info_03_02_03.pdf (accessed 8 September 2013).

Nabuurs G.J. (2009): NFI plot level database gathered from 18 European countries. Digital database. Alterra and European Forest Institute.

Päivinen R., Lehikoinen M., Schuck A., Häme T., Väätäinen S., Kennedy P., Folving S. (2001): Combining Earth Observation Data and Forest Statistics. EFI Research Report 14. European Forest Institute, Joint Research Centre – European Commission. Available at http://www.efi.int/files/attachments/publications/efi_rr14.pdf (accessed 8 September 2013).

Pekkarinen A., Reithmaier L., Strobl P. (2009): Pan-European forest/non-forest mapping with Landsat ETM+ and CORINE Land Cover 2000 data. ISPRS Journal of Photogrammetry and Remote Sensing, ***64***: 171–183.

Percy K.E., Ferretti M. (2004): Air pollution and forest health: towards new monitoring concepts. Environmental Pollution, ***130***: 113–126.

Potapov P., Turubanova S., Hansen M.C. (2011): Regional-scale boreal forest cover and change mapping using Landsat data composites for European Russia. Remote Sensing of Environment, ***115***: 548–561.

Schuck A., Päivinen R., Häme T., Van Brusselen J., Kennedy P., Folving S. (2003): Compilation of a European forest map from Portugal to the Ural mountains based on earth observation data and forest statistics. Forest Policy and Economics, ***5***: 187–202.

Schuck A., Van Brusselen J., Päivinen R., Häme T., Kennedy P., Folving S. (2002): Compilation of a calibrated European forest map derived from NOAA-AVHRR data. EFI Internal report No. 13. European Forest Institute, Joensuu. Available at http://www.efi.int/files/attachments/publications/ir_13_bw.pdf (accessed 8 September 2013).

Sifakis N., Paronis D., Keramitsoglou I. (2004): Combining AVHRR imagery with CORINE Land Cover data to observe forest fires and to assess their consequences. International Journal of Applied Earth Observation and Geoinformation, ***5***: 263–274.

Traustason B., Snorrason A. (2008): Spatial distribution of forests and woodlands in Iceland in accordance with the CORINE Land Cover classification. Icelandic Agricultural Sciences, ***21***: 39–47.

Tröltzsch K., van Brusselen J., Schuck, A. (2009): Spatial occurrence of major tree species groups in Europe derived from multiple data sources. Forest Ecology and Management, ***257***: 294–302.

UNECE/FAO (2000): Forest resources of Europe, CIS, North America, Australia, Japan and New Zealand (Industrialized temperate/boreal countries). New York and Geneva, United Nations Economic Commission for Europe, Food and Agriculture Organization of the United Nations: 445.

Received for publication September 11, 2013
Accepted after corrections November 5, 2013

Corresponding author:

doc. RNDr. Tomáš Hlásny, PhD., National Forest Centre – Forest Research Institute Zvolen, T.G. Masaryka 22, 960 92 Zvolen, Slovak Republic
e-mail: hlasny@nlcsk.org