# Compilation of a Calibrated European Forest Map Derived from NOAA-AVHRR Data

*Andreas Schuck, Jo Van Brusselen, Risto Päivinen,
Tuomas Häme, Pamela Kennedy and Sten Folving*

*(Contract No. 17223-2000-12 F1SC ISP FI)*

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# CONTENTS

# PREFACE

This Internal Report results from a number of activities. A project carried out for the European Commission, Joint Research Centre in 1999/2000 (Combining Geographically Referenced Earth Observation Data and Forest Statistics for Deriving a Forest Map for Europe; Contract no. 15237-1999-08 F1EDISPFI) studied the options of combining information from both remote sensing and forest inventory statistics. The developed calibration method was tested for the European Union countries and the methodology and the results were published in the European Forest Institute Research Report Series (No. 14). This Internal Report will therefore not describe the methodology again but refer to EFI Research Report 14. It will concentrate on the use of new data for the updated version of the forest map and the comparison of the inventory statistics with the AVHRR classified data and validation of the results.

Following these efforts a second phase, also carried out for the European Commission, Joint Research Centre (Contract No. 17223-2000-12 F1SC ISP FI), was initiated in order to produce a European forest map covering forests from Portugal to the Ural Mountains. The efforts included the integration of a timberline mask (arctic and elevation timberline) in order to minimise the misplacement of forest.

Due to the encouraging output of this exercise the European Forest Institute continued to improve the map both in terms of collecting more detailed forest statistical data and improving the timberline mask. Further a questionnaire was prepared to ask inventory experts on where they see room for improvement of the map and give input to potential applications.

After a short article had been published in the EFI News (No. 1, Vol 19, 2002) the authors received much feedback and questions on availability of the forest map and requests for concrete application within ongoing research activities. This encouraged the authors to produce this Internal Report on the making of the pan-European forest map.

This document complements forest map websites at the Joint Research Centre and the European Forest Institute. The websites also contain the possibility for users to download both forest map images and the actual forest map database.

The authors would therefore like to thank the following people for their help in preparing the map and this Internal Report: Mikko Lehikoinen, Kaj Andersson, Seppo Väätäinen, Laura Sirro, Minna Korhonen, Saku Ruusila from PihkaPojat and Prof. V. Strakhov for assisting in compiling the data for the Russian Federation. The authors would also like to express their thanks to the inventory and remote sensing experts: Jan Ilavský, Klaus Roemisch, Urs-Beat Braendli, Hubert Sterba, Gintautas Mozgeris (for Edmundas Petrauskas), Ivo Kupka, Konstantin von Teuffel, Jacques Rondeux, Harald Bugmann, Marco Marchetti (both via personal communication and replies to a questionnaire) for their valuable comments and suggestions as well as the various interested researchers and organisations for their interest in the output of the project activities.

*Joensuu, Espoo and Ispra*
*October 2002*
*The Authors*

# EXECUTIVE SUMMARY

Earth Observation (EO) data are regarded as a cost-efficient means for locating different types of vegetation cover at the ground level. Statistical data on forest area and its distribution for different forest classes are traditionally available through national forest inventory statistics and other national and international forest statistical sources. Such data permit in many cases the identification of the total share of a tree species in a particular country, region or province.

A project entitled 'Combining Geographically Referenced Earth Observation Data and Forest Statistics for Deriving a Forest Map for Europe' (JRC Contract no. 15237-1999-08 F1EDISPFI) was implemented in 1999/2000. It studied the options of combining information from both remote sensing and forest inventory statistics. The objective was to improve the knowledge on the distribution of forests in Europe. The percentage forest probability was estimated for each AVHRR pixel, using CORINE land use classification as training data to establish the link between different classes (forest, other wooded land, and within the forest class, coniferous, deciduous, and mixed forest classes) and AVHRR spectral response. In a second phase, the area of classes was calibrated to correspond to the area of forestland for country or regional level. The data sources were NOAA AVHRR 1996-1997 (Satellite data), the CORINE Land Cover database and Eurostat statistics (Ground data). That exercise had been applied to the EU 15 countries (Päivinen et al. 2001).

In 2000/2001 a follow-up study 'Forest tree groupings database of the EU-15 and pan-European area derived from NOAA-AVHRR data (Contract No. 17223-2000-12 F1SC ISP FI) used the calibration method for the pan-European area including the Russian Federation up to the Ural mountains. The tasks of the project were to:

- Produce a digital database with the target variables using an enhanced NOAA-AVHRR image mosaic
- Compile statistical data on broadleaved and coniferous forests class utilising national and international data sources.
  Data was collected at the sub-national level for EU15, European part of Russia, Czech Republic, Hungary, Norway, Poland and Switzerland). For the remaining European countries data was collected at the national level (Albania, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Estonia, Iceland, Latvia, Liechtenstein, Lithuania, Moldova, Romania, Slovakia, Slovenia, The FYR of Macedonia, Ukraine and Yugoslavia).
- Produce a timberline mask.
  The purpose of this exercise was to minimise the displacement of forest into areas that are considered above the timberline.

During 2002 the European Forest Institute updated the statistical datasets, refined the timberline mask and distributed a questionnaire to European inventory experts to comment the map products from a national perspective. The result of the efforts was a set of comprehensive and complete European forest maps (and within the forest class the sub-classes coniferous and broadleaved forest) and non-forest/water at 1 x 1 kilometre resolution and the production of derived map products such as e.g. coniferous forest map as a percentage of total forest in Europe.

# 1. INTRODUCTION

Data and maps represent important sources of information in the process of international agreements, policymaking and decision taking, forest planning at the local, national and international level and research. Forest data and maps find application in the fields of protection and conservation, forest resources analysis, questions on carbon storage and climate change, forest development and management scenarios and many others. Both EO and forest inventory information have fields of application. However, effort should be put into combing the two sources of information resulting in high quality data sets and maps.

## 1.1 EXISTING MAPS (EXAMPLES)

There are numerous initiatives of mapping forests world-wide and for Europe. They vary in the level of detail, scale, the sources of information and target groups. A few examples are listed below:

**1. The Commission of the European Communities (CEC), CORINE Land Cover Map**
The approach of the CORINE Land Cover map is based on computer-assisted photo-interpretation of earth observation satellite images, with the simultaneous consultation of ancillary data, into the categories of the CORINE Land Cover nomenclature. Out of 44 distinguished classes three are forest classes (coniferous, broadleaved, mixed) plus agro-forestry (EEA Task Force 1992). Forest areas smaller that 25 ha are not included as they fall below the threshold of the land use unit size.
http://etc.satellus.se/

**2. International Geosphere-Biosphere Programme, Data and Information System (1992):**
Global data set of land applications at a spatial resolution of 1 km derived from the AVHRR (Advanced Very High Resolution Radiometer) sensor. North America, South America, Europe and Africa have been completed. The classification system consists of 17 classes 5 of which are related to forest land (evergreen coniferous forests, evergreen broadleaf forests, deciduous coniferous forests, deciduous broadleaf forests and mixed forests. Two further classes describe closed and open shrub lands.

**3. Directorate Generals Agriculture and Information, Communication, Culture and Audiovisuals:**
Forest/non-forest map of Europe representing an up-date of the European Community Forest Map of 1987 (1:4,000,000) (Kommission der Europäischen Gemeinschaften 1987). It was compiled using the CORINE Land Cover Map. The European data sets used the WCMC global exercise and the ESA AVHRR-derived forest/non-forest map (ESA 1993). It was completed in 1997 (EC 1997).

**4. University of Maryland (Tree Cover Project)**
The University of Maryland has produced in its Tree Cover Project maps distinguishing the tree cover percentage, the percentage cover for evergreen and deciduous and the percentage cover of broadleaf and needleleaf. The work is based on Advanced Very High Resolution Radiometer (AVHRR) satellite data on the global to regional scale. The Tree Cover Project also covers the entire European continent http://glcf.umiacs.umd.edu/documents/treecover.html.

**5. JRC/SAI (Combining Geographically Referenced Earth Observation Data and Forest Statistics for Deriving a Forest Map for Europe)**

Recently the project "*Combining Geographically Referenced Earth Observation Data and Forest Statistics for Deriving a Forest Map for Europe"* under the contract of the Joint Research Centre/Space Applications Institute of the European Commission (Contract No. 15237-1999-08F1EDISPFI) has been completed under the activities of the EUROLANDSCAPE Project. The project developed and tested a calibration procedure for combing forest statistics and AVHRR satellite data. This calibration method was applied to the EU 15 countries (international forest statistics) and to three case study countries (national forest inventory information).

**6. Forest Resources Assessment 2000**

The FRA 2000 features a global set of forest cover maps. They are at a 1km spatial resolution and were produced at the U.S. Geological Survey (USGS) EROS Data Centre (EDC), using the Normalised Difference Vegetation Index (NDVI) as the primary input data (FAO, 2001)

**7. Secondary map products**

A number of initiatives are based on existing forest maps that add additional thematic layers to existing forest maps. As examples can be mentioned the initiative of the World Conservation Monitoring Centre on protected forest areas that of the World Resources Institute area on frontier forests.

*Example: Frontier Forests of the World (World Resources Institute)*

The Forest Frontiers Initiative (FFI) under the World Resources Institute is a multi-disciplinary effort to promote stewardship in and around the world's last major frontier forests by influencing investment, policy, and public opinion. Within this initiative a Frontier Forest Map has been produced as an interactive on-line map. It also covers the European continent. http://www.wri.org/ffi/maps/.

# 2. DATA AND DATA PROCESSING

## 2.1 COMPUTING AN ENHANCED DIGITAL DATABASE FOR THE FIVE TARGET VARIABLES USING AN AUGMENTED NOAA-AVHRR MOSAIC

### 2.1.1 Input data

*Imagery*

Due to cloud cover in parts of the project implemented in 1999/2000 project '*Combining Geographically Referenced Earth Observation Data and Forest Statistics for Deriving a Forest Map for Europe'* (Contract no. 15237-1999-08 F1EDISPFI), the original AVHRR image mosaic consisting of 49 images (Päivinen et al. 2001) were complemented by 14 new, nearly all cloud-free AVHRR images (acquisitions during summers 1997 and 1998; see Annex 1). However still some minor parts of Scotland showed some cloud cover. From the northernmost part of the European part of Russia completely cloudless image cover could also not be identified.

*GTOPO30 Digital Terrain Model*

The GTOPO30 Digital Terrain Model was downloaded from the archives of the US Geological Survey (http://edcdaac.usgs.gov/gtopo30/gtopo30.html). The model gives the elevation values in meters in the geodetic coordinate system. The pixel size in these raster-format models is 30 arc seconds, which corresponds to ground resolution of approximately 1 km. The datum is WGS84. Six DTM tiles were downloaded to cover the pan-European area.

The tiles were combined into one pan-European DTM that was transformed to the CORINE version of Lambert Azimuthal equal area projection using one-kilometer pixel size.

### 2.1.2 Image corrections

Atmospheric corrections were done to the new images using the SMAC program as was done in the computation of the earlier mosaic. The parameters applied for the SMAC program were:

- Atmospheric optical thickness at 550 nm: 0.1
- Water vapor 2.0 g/cm$^2$
- Ozone 0.35 cm-atm
- Air pressure 1013 hPa

Application of the same global parameters for all the images introduces uncertainty to image correction. However, it was not considered possible to find image-specific parameters that would have been more reliable than the used global parameters. In addition to the atmospheric correction, a BRDF model correction was utilised. The BRDF method was based on the Roujean model with forest surface parameters presented by Wu et al. (1995). The images were normalised to a nadir view with a solar zenith of 45°. The atmospheric correction was applied to every pixel. The output of the correction was reflectance (reflectance in percent x 10).

The images were geometrically corrected to the geodetic coordinate system. Just at the final stage the complete mosaic was transformed to the 'CORINE' coordinate system. The geometry of the image mosaic of the former project was further corrected because some inaccuracy was detected at its southeastern corner. The correction was done using the triangulation tool of ERMapper. Ground control points were selected from the GTOPO30 mosaic (in the geodetic projection) and from the old image mosaic (also in the geodetic projection). The mosaic was corrected using local polynomial coefficients that were computed for each triangle that was formed by the control points. Using this approach, a complete match with GTOPO30 (whose geometry was considered correct) was achieved (
Figure **1**).

The corrected old mosaic was used as the base map to automatically select ground control points for the new AVHRR images, which were rectified to the geodetic coordinate system. From the edges of each image, strips of 300 pixels were cut out and neglected to avoid using the most extreme viewing angles of the instrument.

### 2.1.3 Mosaic compilation

The mosaic was compiled by computing reflectance means of the overlapping pixels of cloudless images. Unlike the approach in the earlier study (Final report 2000), the cloudless pixels were defined automatically. In the compilation of the earlier mosaic, the cloudy areas were manually located. The following algorithm for cloudless pixel selection was applied for the new mosaic:

*If the total number of overlapping pixels equals 1*
    *Select the pixel*
    *Return*

*If the total number of overlapping pixels equals 2*
    *Select the one with maximum NDVI*

*Return*

*If the total number of overlapping pixels greater than 2*

*Sort all overlapping pixels to ascending order using red reflectance values*

*Find all pixels whose red reflectance is below a limit that is 1.5 times the reflectance of the lowest red value*

*If the lowest red reflectance is below 3.0 percent and at least 5 overlapping pixels are left*

*Remove the pixel with lowest red value. This pixel is assumed to be cloud shadow.*

*Sort pixels again using red values*

*Find all pixels whose red reflectance is below a limit that is 2.0 times the reflectance of the lowest red value*

*If less than 3 pixels are left*

*Increase the limit so that 3 pixels will be selected*

*Remove the pixel whose average Euclidean distance from the other pixels in the NIR is the greatest.*

*If total number of pixels left is 2*

*Select the one with maximum NDVI*

*Return*

*Else*

*Compute the average of all red pixels*

*Compute the average of all NIR pixels*

*Return*

1.

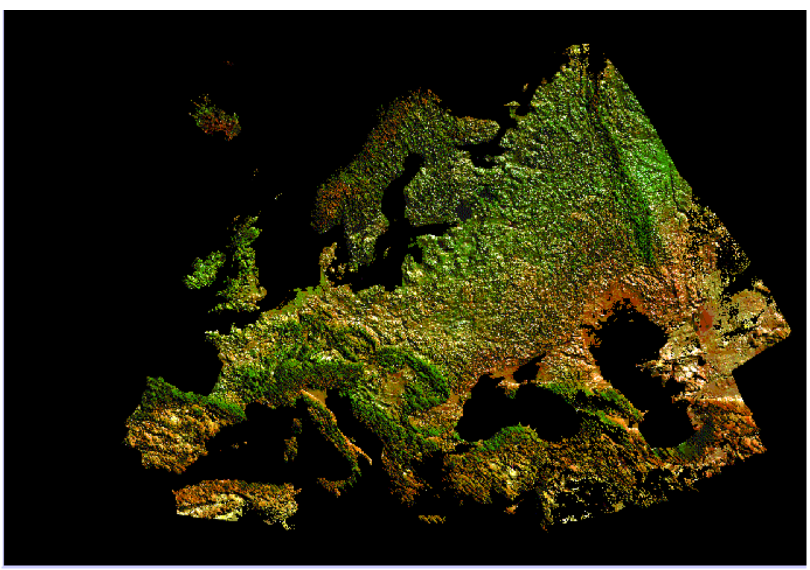

**Figure 1.** The mosaic with the GTOPO30 Digital terrain model.

The principle of the algorithm is to compute means of the lowest red reflectance pixels. The high red reflectance pixels are assumed to represent clouds. However, the lowest red reflectance pixel is removed when the algorithm assumes it to represent cloud shadow. Also the pixel with an anomalous near infrared reflectance is neglected. This rule removed among other things pixels with very high near infrared reflectance. These pixels were from images that had been acquired earlier in the growing season. As many cloudless pixels were used in mosaic compilation as possible, since computation of a mean reduced the random noise of the reflectance values of the individual images. If the number of overlapping pixels was two, a pixel with the maximum NDVI was selected.

The reflectance of the earlier mosaic of 49 AVHRR images was compared with the new mosaic of 63 images[1]. The comparison was made by subtracting the old mosaic of 49 images from the new mosaic of 63 images (Table 1). The modal value of the difference channel was registered within a 400 km by 400 km window.

The modal value was considered the most appropriate statistics because the higher proportion of cloudy areas in the old mosaic would have hampered the comparison of the mean value.

The comparison showed that reflectance changes between the mosaics were small. In regions with high proportion of agricultural land and broad-leaved tree forest, the reflectance values had slightly increased whereas in conifer-dominated areas they were often decreased. In the desert region the reflectance was practically unchanged. The comparison suggests that the new pixel selection and cloud selection procedures were successful.

**Table 1.** Difference of the modal reflectance value between the new mosaic and the old mosaic.

| Area | Red change<br>% units | NIR change<br>% units |
|---|---|---|
| Northern Russia | -0.16 | -0.17 |
| Finland | -0.16 | -0.07 |
| Poland | +0.14 | -0.22 |
| Germany | +0.73 | +1.2 |
| Central Russia | -0.07 | -0.02 |
| England | +0.41 | +0.26 |
| Central France | +0.22 | +0.17 |
| Northern Italy | +0.55 | +1.1 |
| Balkan | +0.60 | +1.8 |
| Spain | -0.16 | -0.60 |
| Desert northeast from Black Sea | +0.01 | -0.07 |

[1] Note that the earlier 49 images were included also in the new mosaic compilation, but the clouds were considered using the developed automatic procedure.

### 2.1.4 Target variable estimation

The five target variables were estimated using the spectral statistics that had been created in the previous study as had been used the same three geographic strata (Final report 2000; Päivinen et al. 2001; Figure 2).

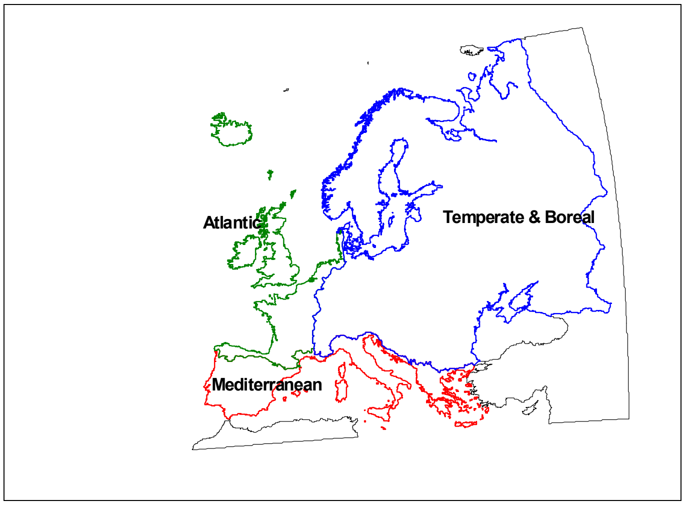


**Figure 2.** The three geographic strata used in the probability estimation.

The estimates were given in percents. The water areas were masked out using the near infrared channel and red channels of the mosaic:

*If red<6.0 % and NIR<12.0 % then water - give value 150*

The threshold for water separation was a compromise between assigning land as water and considering also narrow water bodies. For instance in Finland that has plenty of lakes with narrow arms, part of the known land was classified as water even though in the original image mosaic the land could be visually separated from water. This error was accepted because lower thresholds would have caused many arms of lakes to be classified as land. An alternative would have been not to mask water at all but to use an external mask for water separation. However a good water/land mask was not available. The water mask in the FIRS regionalisation is, for instance, much more generalized than what could be achieved by using the NIR (and red) channels in masking. Inclusion of the red band made it possible to remove some shaded areas in the mountains to be classified as water. The coastal lines were separated from the image mosaic using the GTOPO30 model. The western shore of the Caspian Sea has high forest cover estimates. This is most likely an error. The shore in the GTOPO30 database may be too far in the east.

It was attempted to separate the remaining clouds from snow but it must be stressed that this separation is only indicative. The following algorithm was developed:

*If red>NIR and 32.0 %<red<80.0 % then snow - give value 200*
*If red<NIR and 32.0 %<red<80.0 % then cloud - give value 250*
*If red≥80.0 % then cloud - give value 250*

The land area outside the area of interest was indicated with the intensity value 255. In the final masking result the proportion of snow is much less than what it should have been on the basis of the image mosaic. This was because dirty and melting snow had very similar reflectance to that in the semi-desert areas in Spain, for instance. Use of the DTM would have made it possible to use lower reflectance thresholds for snow but this procedure was not applied.

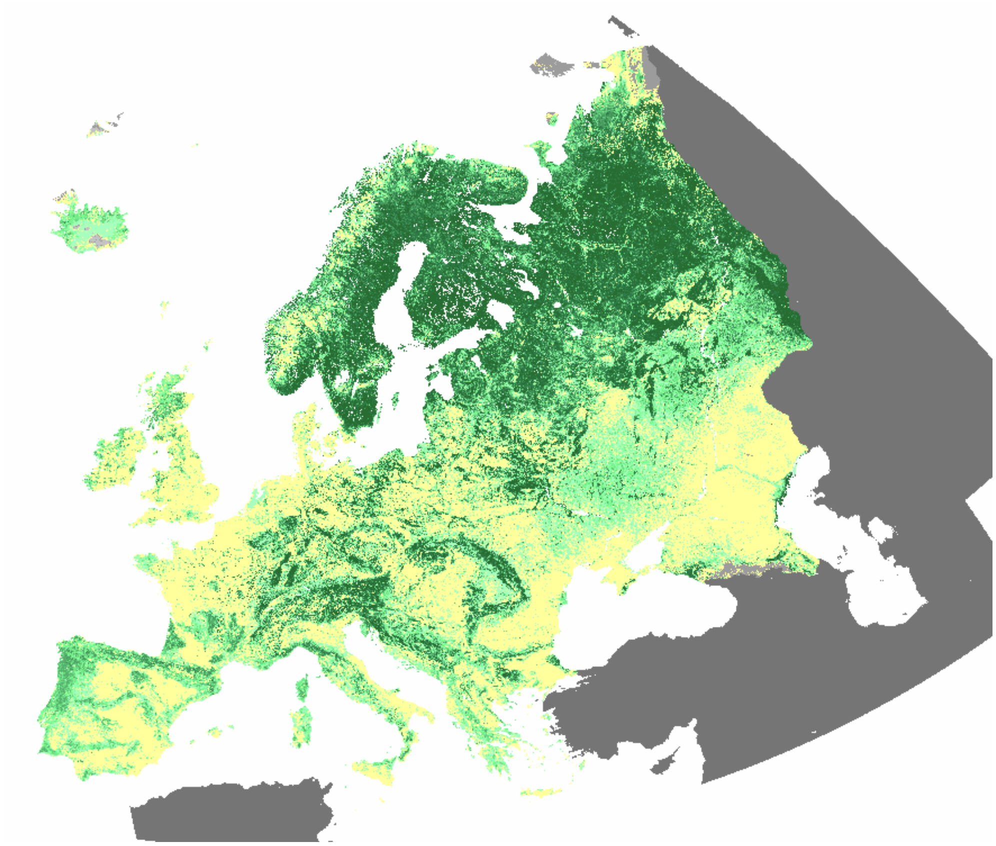

**Figure 3.** Estimate of class forest (variables 1+2+3). Original stratification. Color scale: yellow – forest less than ten percent; light green to dark green - forest 11 to 84 percent; gray – snow and cloud.

The Atlantic and Mediterranean strata had less area with high forest proportion than the temperate and boreal stratum, which can be seen in Figure 3. In the Mediterranean area this may reflect the true situation but in parts of France (the Landes area for instance), the small area of high forest proportion causes an obvious underestimate to the total forest area. The underestimation comes partly from the low coniferous forest percentage in the ground sampling from CORINE. In the Atlantic stratum, the maximum coniferous forest percentage in a spectral class (and consequently the maximum estimate for coniferous forest cover) was 53, whereas this percentage was 84 in the temperate and boreal stratum.

Forest cover estimation gave problematic results in Iceland, since the whole area outside the central glacier got an estimate value of more than ten percent. An alternative that could be applied in Iceland could be to subtract ten percent of all the forest area estimates before calibration using the forestry statistics.

To reduce the underestimation of coniferous forest, another stratification was experimentally applied. In this alternative, the Atlantic stratum included only the British Isles and Iceland. Whole continental Europe that formerly belonged to the Atlantic stratum was included in the temperate and boreal stratum. This experiment can be considered quite an exceptional approach. The ground sampling and the spectral statistics for the Atlantic stratum had been still computed following the original stratification. However, the spectral model and ground sampling that was computed including also the Atlantic parts of continental Europe, was only applied in non-continental Europe. The temperate and boreal model was applied also in the Atlantic part of the continental Europe although the model was developed excluding these areas. The forest coverage percentage clearly increased in the Atlantic part of the continental Europe after using the forest model for temperate forest. Some areas in northern Holland, that had less than ten percent forest in the primary approach, got more than ten percent coverage in the experiment (Figure 4).

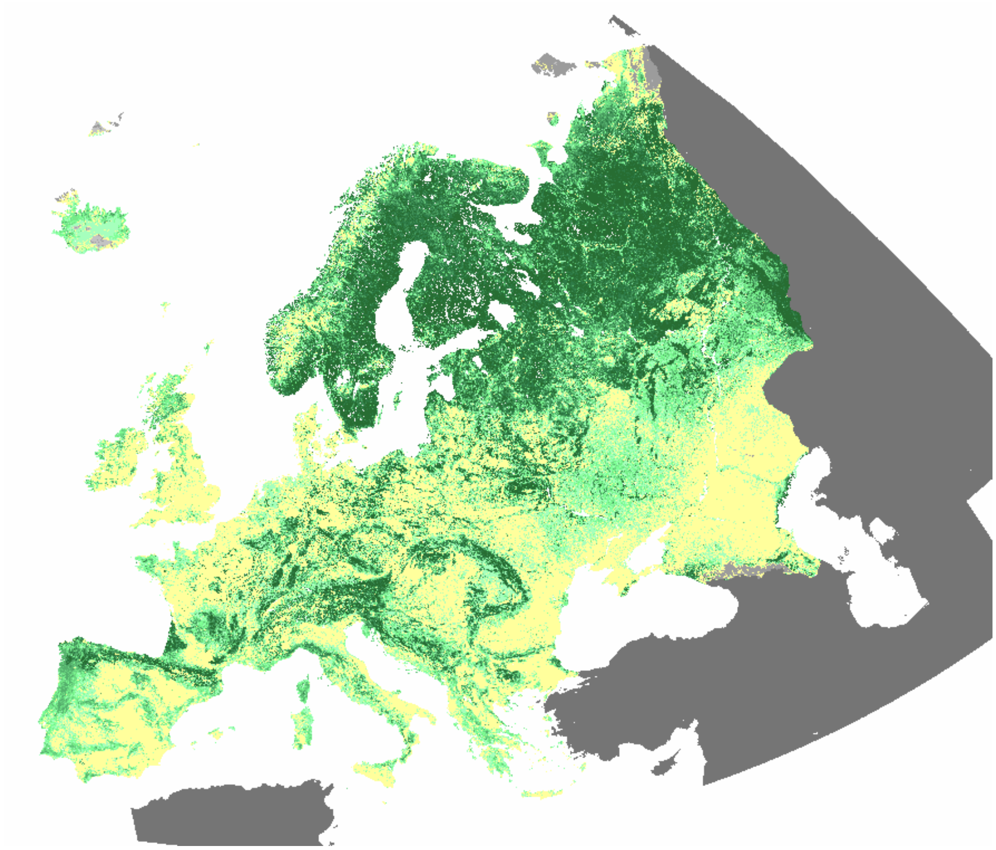

**Figure 4.** Estimate of class forest (variables 1+2+3). Experimental stratification.

## 2.2 Compiling country statistics at the sub-country level

### 2.2.1 Data input

*2.2.1.1 Polygons*

*European Union*
The NUTS nomenclature is a hierarchical coding system defined by Eurostat (Eurostat 1995). It subdivides the EU economic territory into 6 administrative levels, from country (level 0),

through regional (level 1,2,3) to local (level 4,5). There are 3 individual NUTS versions available (V5, V6 and V7) for two scale ranges (1 and 3 Million).

For the EU countries the NUTS level boundaries (Level 0-3) Version V were used both at the national and sub-country level (Figure 5, Table 2).

Some additional digitising that had to be performed already in the earlier project (Contract no. 15237-1999-08 F1EDISPFI) for Finland and Italy were used as input also for this exercise. The EU boundaries were kindly made available from EUROSTAT/Gisco.

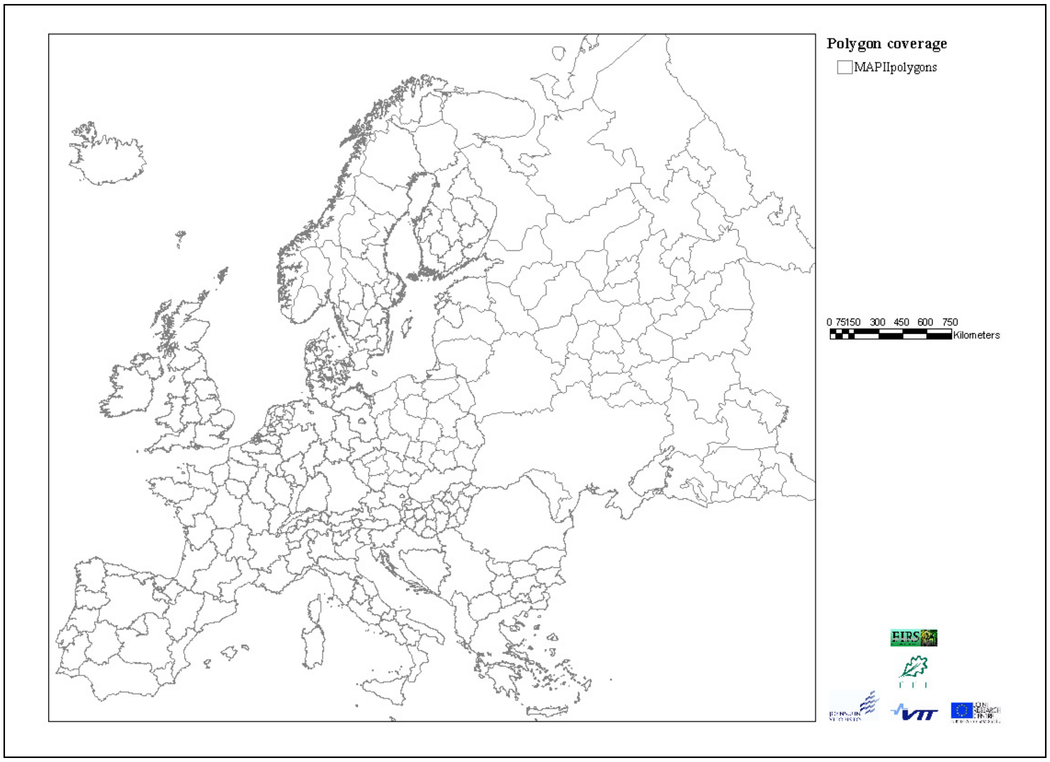


**Figure 5.** Polygon levels applied for the individual European countries represented in the study.

**Table 2.** Level of detail and source of the European country boundaries.

| Country | Level of detail | Map source |
|---|---|---|
| Austria | NUTS 2 (9 regions) | NUTS version V (Eurostat/Gisco) |
| Belgium | NUTS 1 (3 regions) | NUTS version V (Eurostat/Gisco) |
| Bulgaria | Sub-national level (9 regions) | Map of Bulgarian forest regions. Forest Research Institute. Bulgarian Academy of Sciences. |
| Czech | sub-nationall level (7 regions) | ESRI. 2001. ESRI DATA & MAPS - Media Kit. Redlands. Procedure: Image with the regions was rectified with the "Imagine" software and digitized with Arcview 3.1 |
| Denmark | NUTS 3 (15 regions) | NUTS version V (Eurostat/Gisco) |
| Finland | NUTS 3 (some digitising) | NUTS version V (Eurostat/Gisco) |
| France | NUTS 2 (22 regions) | NUTS version V (Eurostat/Gisco) |
| Germany | NUTS 1 (16 regions) | NUTS version V (Eurostat/Gisco) |
| Hungary | sub-national level (19 regions) | Same as data source. Procedure: Image with the regions was rectified with the "Imagine" software and digitized with Arcview 3.1 |
| Italy | NUTS 2 (partly NUTS 3) (21 regions) | NUTS version V (Eurostat/Gisco) |
| Luxembourg | NUTS 1 | NUTS version V (Eurostat/Gisco) |
| Netherlands | NUTS 2 (12 regions) | NUTS version V (Eurostat/Gisco) |
| Norway | 7 regions | ESRI. 2001. ESRI DATA & MAPS - Media Kit. Redlands. Procedure: Image with the regions was rectified with the "Imagine" software and digitized with Arcview 3.1 |
| Poland | sub-national level (16 regions) | Panstwowa Agencja Inwestycji Zagranicznych. 2001. Republic of Poland - administrative divisions (since 1999). http://www.paiz.gov.pl Procedure: Image with the regions was rectified with the "Imagine" software and digitized with Arcview 3.1 |
| Portugal | 5 regions | NUTS version V (Eurostat/Gisco) |
| Russia (European part) | (sub-national level (57 Oblasts) | ESRI. 2001. ESRI DATA & MAPS - Media Kit. Redlands. Procedure: Image with the regions was rectified with the "Imagine" software and digitized with Arcview 3.1 |
| Spain | 17 regions | NUTS version V (Eurostat/Gisco) |
| Sweden | 24 regions | NUTS version V (Eurostat/Gisco) |
| Switzerland | sub-national level (5 regions) | Same as data source. Procedure: Image with the regions was rectified with the Imagine software and digitized with Arcview 3.1 |
| United Kingdom | subnational level (11 regions) | NUTS version V (Eurostat/Gisco) |
| Albania | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Bosnia | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Croatia | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Estonia | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Greece | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Iceland | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Ireland | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Latvia | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Liechtenstein | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Lithuania | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Romania | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Slovakia | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Slovenia | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| FYR of Macedonia | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Yugoslavia | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Belarus | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Ukraine | NUTS 0 | NUTS version V (Eurostat/Gisco) |
| Moldova | NUTS 0 | NUTS version V (Eurostat/Gisco) |

*Polygons 'other European countries'*
In the case of the remaining European countries the vector data sets were dependent on the level of detail at which data was found to be available. For a number of EU candidate countries (Bulgaria, Czech Republic, Hungary, Poland), the European part of Russia, Norway and Switzerland polygon maps were prepared at the national and sub-country level. For Russia the sub-national administrative boundaries, the so-called Oblasts, were used (Figure 5).

For the remaining European countries the project used country level boundaries. The countries were namely Albania, Belarus, Bosnia-Herzegovina, Croatia, Cyprus, Estonia, Iceland, Latvia, Liechtenstein, Lithuania, Moldova, Romania, Slovakia, Slovenia, The FYR of Macedonia, Ukraine and Yugoslavia.

The sources for these polygon maps were manifold, including the Arc-View database (ESRI 2001), actual re-digitising or the utilisation of polygon maps provided by national research institutions. (Table 2).

*2.2.1.2 Statistics*

The level of detail required for the country data was pre-defined through the availability of inventory data and polygon maps. Best available data on forest was collected for coniferous, broadleaved forest. It was also attempted to compile data for mixed forest.

- *EU 15 countries*
  Data were prepared at the sub-national level. The level of detail varied considerably between countries. Sufficient data was identified for all EU countries at the sub-national level but Greece and Ireland. The data at the sub-national level did not meet the project requirements. In the case of Greece it was most likely the case that other wooded land was included into the forest class, (Eurostat 1995) or then not divided by regions (Eurostat 1998) Therefore, data were used from the TBFRA 2000 for Ireland and Greece at the country level.

- *EU candidate countries (Bulgaria, Czech Republic, Hungary, Poland); European part of Russia, Norway and Switzerland*
  Data were prepared at the national and sub-country level for Bulgaria, Czech Republic, Hungary, Poland, Norway and Switzerland at the sub-national level. In the case of Poland and Bulgaria latest data were provided through personal communication with the Forest Research Institute, Warsaw in Poland (Dr. Michalak) and the Bulgarian Academy of Sciences Forest Research Institute (Prof. Raev).

- Data for Russia has been taken from two sources: Pisarenko et al. (2001) and data sent by Prof. V. Strakhov from the ARICFR - All-Russian Research & Information Centre for Forest Resources, Moscow.
  - *Pisarenko et al. (2001):* The data on the Federal Forest Service land were available for 57 Oblasts by broadleaved forest class (hard, soft) and coniferous forest class. The data reference year for the Federal Forest Service land is 1998.
  - *Prof. Strakhov (data sent, June 2001)*
    The forest area for other ownership classes (Ministry of Agriculture, the Ministry of Education, the Ministry of Defence, Municipal authorities (city forests), could only be provided for the 'forest class' by the 57 oblasts. The statistical data of these ownership classes were proportionally divided to the classes broadleaves

and conifers (Reference year 1998). Also Prof. Strakhov delivered the total land area information by individual oblasts was delivered.

- *Other European countries*
  The source of the data was the TBFRA 2000 published in May 2000 (UN-ECE 2000). The data on forest area (predominantly coniferous, predominantly broadleaved, mixed) were available at the national level only. The countries based on this data source included Albania, Belarus, Croatia, Cyprus, Estonia, Iceland, Latvia, Liechtenstein, Lithuania, Moldova, Romania, Slovakia, Slovenia, Ukraine, Yugoslavia and the two EU countries Ireland and Greece.

  TBFRA 2000 had no information for any of the three classes for Bosnia-Herzegovina and The FYR of Macedonia. In this case data was used from the European Forest Information Scenario Model database (EFISCEN) available at EFI.

The forest definitions underlying the national statistics and the TBFRA classification are compiled and presented in Annex 2.

*Mixed forest*
Only some countries distinguish directly mixed forest class in their officially published statistics. At the national level the definitions for pure stands and mixed stands, where available, differ between countries. This made it very difficult to compare data on mixed forest between individual countries (Table 3).

Other countries provide data only either for coniferous and broadleaved forest, or by individual tree species. For countries that distinguished individual tree species the area of the species can be summed up to form the classes of coniferous and broadleaved, not however the mixed class proportion.

**Table 3.** Example of division of pure and mixed forest classes based on official statistics in 4 countries.

| | | | | |
|---|---|---|---|---|
| Netherlands | Coniferous or broadleaved | | | |
| | unmixed | Mixed with conifers | Mixed with broadleaf | |
| Germany | Coniferous or broadleaved | | | |
| | Mix (none; pure stands) | Mix < 10% | Mix >10% coniferous species | Mix >10% broadleaved species |
| Switzerland | Pure coniferous | Pure broadleaved | Mixed coniferous forest | Mixed broadleaved forest |
| | >90% of basal area conifers | Conifers max 10% | 51-90% conifers | 11-50% conifers |
| Austria | Pure stands | | | |
| | Coniferous share >8/10 | Spruce share >8/10 | Broadleaf share >8/10 | |
| | Mixed stands | | | |
| | Coniferous share 6/10-8/10 | Broadleaf share 5/10-8/10 | | |

The TBFRA 2000 distinguishes besides predominantly coniferous (>/= 75% conifers) and predominantly broadleaved (>/= 75% broadleaf) also the mixed forest class. Following an email correspondence with the UN-ECE/FAO the table including "mixed forests" is one of the sensitive TBFRA elements. It was mentioned that …."Expert estimations", and certain "experts judgements" had been unavoidable as it was the case when adjusting national data to the TBFRA 2000 definition of mixed forests (UN-ECE/FAO email correspondence, February 2001).

Due to these uncertainties and a lack of available data on mixed forests for all countries only the coniferous and broadleaved class were assigned. In the case of countries dividing their forest area by all three classes the share of mixed forest was proportionally assigned to the coniferous and broadleaved class.

*Other class*

The other class includes other land (e.g. agriculture lands). Water bodies were excluded for all countries. In the case of Sweden, Finland, Norway, Netherlands (North Sea areas excluded), and the European part of Russia data on water bodies was available by regions. For the other countries having only small percentages of water of the total area (mostly less than 5%), the amount of water bodies was proportionally divided to the individual polygons according to their total area size. The allocated water area was then subtracted from total area to have as a result the land area by polygon.

Where clearly indicated forest roads, potential forest land areas, clearcut areas were not included to the conifer or broadleaf class. That was e.g. the case in Finland (excluding forest roads, clearcut areas) and Austria (forest roads excluded). OWL, if specified as such, was aggregated to the 'Other class'. This was performed in the case of the countries based on the TBFRA 2000 data.

### *2.2.1.3 Elevation model and timberline mask*

*Timberline mask for Europe*

At the micro scale level, the timberline issue is very complex and the maximum elevation of the forest depends on many factors. In general, the following factors influence tree growth and forest formation at the timberline (according to Tranquillini 1979):

a) Geo-pedological factors: soil temperature, soil moisture, and salinity, soil rockiness, soil organic matter, mother substrate.

b) Climatic factors: Often the 10°C isotherm of the warmest month of the year is seen as representative for the climatic timberline definition (Veijola 1998; Tranquillini 1979). An even closer agreement is obtained between timberline and a mean daily maximum temperature of 11.1°C during the growing season, and thus mid-day temperatures in summer have similar values at all timberlines.

The following climatic factors also characterize the position of the timberline: light, temperature and wind, $CO_2$ content of atmosphere, atmospheric moisture.

c) Tree species characteristics: photosynthetic efficiency seed production, dispersal of seed, maturation of seed, germination, vegetative propagation, climatic resistance, frost damage, Ultraviolet and High Intensity Radiation damage, heat damage, mechanical damage, wind, snow, frost-drought damage.

d) Anthropogenic factors (Veijola 1998): Grazing - abundant reindeer browsing may lower the timberline, fire, felling, erosion, air pollution.

Much of the complexity described above can be set aside when looking at the timberline in more general terms at the pan-European scale. The resolution of the satellite imagery data used was 1x1 km and therefore the height of the timberlines above sea level (a.s.l.) may be defined by average values.

Available publications were studied and timberline experts contacted for compiling a comprehensive set of timberline data for the regions of Europe.

The conclusions from the literature review and expert consulting are shown in Table 4. These data were combined with the digital elevation model in order to create the actual timberline mask. For each of the specified regions, the pixels with an average position above the timberline were assigned the value 0. The timberline in Finnish Lapland was digitised from the map “Forest area database derived from LUOTI biotope plot data of Upper Lapland” that was put to the disposal for the project by the Finnish Forest and Park Service (Metsähallitus) – Ivalo station (Metsähallitus 2002). For the European part of Russia, the Arctic timberline was digitised from the map “Forests of the SSSR” (Goskomles SSSR 1990) from the State Forestry Committee of the USSR 1990. The map distinguishes forest by dominant tree species.

**Table 4.** Summary table on European timberlines as set in the timberline mask.

| **Region** | **Timberline (in meters a.s.l.)** | **Based on:** |
|---|---|---|
| Russian Arctic timberline | Digitised from map “forests of the USSR” | Lesa SSSR (karta: 1:2500000). M, Goskomles SSSR 1990. |
| Ural | | Expert consultation: Chertov, O. 2001. |
| Pripolyarny (Sub-Polar) Ural | 200 | |
| Northern Ural | 400 | |
| Mid-Ural | 600 | |
| Southern Ural | 1250 | |
| Finnish Lapland | Digitised from map “Forest area database derived from LUOTI biotope plot data of Upper Lapland” | Finnish Forest and Park Service Metsähallitus), Ivalo, Finland 2002 (Metsähallitus 2002). |
| Fenno-Scandia | | Kankaanpää, S. 1999.; Tasanen, T. 1997. |
| Southern Fenno-Scandia | 1200 | |
| Mid-Southern Fenno-Scandia | 800 | |
| Mid-Northern Fenno Scandia | 700 | |
| Northern Fenno-Scandia | 200-400 | |
| Scotland | 600 | Kelletat 1972. In: Jobbàgy, E.G., Jackson, R.B. 2000. |
| Pyrennees | 2400 | Expert consultation: of R. R. Soalleiro; Hollermann 1972. In: Jobbàgy, E.G., Jackson, R.B. 2000. |
| Alps | | Tranquillini, W. 1979.; |
| Northern Alps | 2000 | Karrasch 1973; Schimper 1903. In: Jobbàgy, E.G., |
| Southern Alps | 2100 | Jackson, R.B. 2000. |
| Apenines | 1600 | Gloria-Europe: http://www.gloria.ac.at/res/gloria_home/default.cfm; |
| Tatra | 1575 | Expert consultation: Leszek Kluziñsk; Magorzata Dominko Polish Forest Research Institute |
| Karpathians | | Expert consultation: L. Bouriaud French Institute of |
| Northern Karpathians | 1600 | Forestry, Agricultural and Environmental |
| Southern Karpathians | 1800 | Engineering (ENGREF) |
| Greek highlands | 1900 | http://www.gloria.ac.at/res/gloria_home/default.cfm; Expert consultation: Papanastasis, V. 2002. |
| West Caucasus | 1900 | Jobbagy, E.G., Jackson, R.B. 2000. |

*Elevation model*

The raster elevation map GTOPO30 was imported to the calibration environment and processed together with the timberline information resulting in a European timberline mask as presented in Figure 6. Areas considered above the timberline are shown as part of the class '0 to 1 percent forest proportion' in the calibrated forest maps.

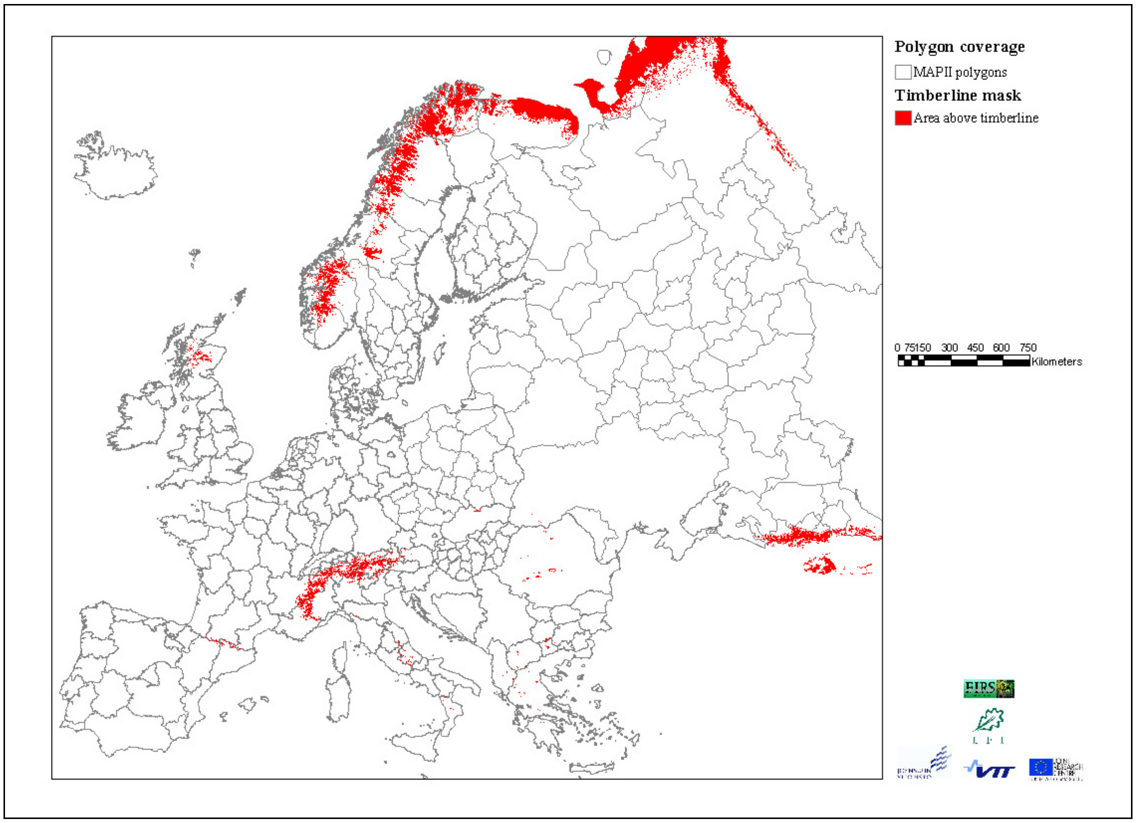


**Figure 6.** Timberline mask as used in the calibration process.

### 2.2.2 The processing of the statistical data

The data compiled from the national statistics and other sources (Eurostat and TBFRA 2000) were presented by broadleaved and coniferous class. The forest data were either already available from the statistics as coniferous, broadleaved class or presented by individual tree species (Figure 7).

1. Original data

| province | provincial area (1000 ha) | Pine | Spruce | Fir | conif. total | Oak | Beech | Horn-beam | Birch | Alder | Aspen | broad. total | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Poland** | **31258,625** | **6064,3** | **516** | **224,8** | **6805,1** | **549,6** | **407,4** | **39** | **540,5** | **462,6** | **46** | **2045,1** | **8850,2** |
| Dolnośląskie | 1986,472 | 261,1 | 149,4 | 0,6 | 411 | 70,5 | 17,2 | 0,6 | 37,4 | 19,2 | 5 | 150 | 561 |
| Kujawsko-pomorskie | 1796,972 | 344,5 | 2 | 0 | 346,5 | 20,1 | 2,2 | 0,9 | 15,4 | 15,9 | 1,7 | 56,1 | 402,6 |
| Lubelskie | 2511,499 | 360,8 | 1,4 | 8,5 | 370,8 | 68,2 | 13,4 | 7,5 | 45,6 | 36,1 | 10 | 180,7 | 551,5 |
| Lubuskie | 1398,444 | 594 | 3,4 | 0 | 597,3 | 22,7 | 8,1 | 0,7 | 26 | 16 | 0,8 | 74,2 | 671,5 |
| Łódzkie | 1821,911 | 314 | 1,1 | 1 | 316,1 | 12,8 | 0,7 | 0,6 | 22,2 | 17,5 | 1,2 | 55,1 | 371,2 |
| Małopolskie | 1512,837 | 129,1 | 88,3 | 81,3 | 298,7 | 25,6 | 62,9 | 5,1 | 18,3 | 16,7 | 2,2 | 130,8 | 429,5 |
| Mazowieckie | 3559,729 | 614 | 3,1 | 4,4 | 621,5 | 36,6 | 0,8 | 1,2 | 50,5 | 65,1 | 3,6 | 157,8 | 779,3 |
| Opolskie | 941,247 | 183,8 | 13,4 | 0,2 | 197,4 | 21,9 | 3,6 | 0,5 | 11,8 | 9,2 | 1,8 | 48,9 | 246,3 |
| Podkarpackie | 1792,628 | 287,6 | 18 | 90,4 | 395,9 | 27,4 | 139 | 13,7 | 20 | 51,4 | 2,4 | 254 | 649,9 |
| Podlaskie | 2017,958 | 381,7 | 46,7 | 0 | 428,4 | 35,6 | 0,2 | 2,4 | 59,8 | 64,7 | 3,6 | 166,2 | 594,6 |
| Pomorskie | 1829,288 | 511,6 | 23,4 | 0 | 535 | 20 | 50,5 | 0,8 | 29,5 | 11 | 0,8 | 112,6 | 647,6 |
| Śląskie | 1229,404 | 228,4 | 72,4 | 5,7 | 306,5 | 23,6 | 20 | 0,5 | 26,6 | 11,4 | 1,5 | 83,6 | 390,1 |
| Świętokrzyskie | 1167,234 | 231,9 | 1,8 | 25,7 | 259,4 | 15,5 | 9,9 | 1,2 | 13,5 | 12,6 | 1,5 | 54,2 | 313,6 |
| Warmińsko-mazurskie | 2420,295 | 435,3 | 59,8 | 0 | 495,1 | 56,7 | 24,9 | 2,3 | 76,5 | 49 | 5,4 | 214,9 | 710 |
| Wielkopolskie | 2982,559 | 622,7 | 5,6 | 0 | 628,2 | 53,9 | 4,8 | 0,7 | 30,7 | 27,7 | 2,8 | 120,6 | 748,8 |
| Zachodniopomorskie | 2290,148 | 557,4 | 27,9 | 0,8 | 586 | 39,8 | 53,4 | 0,9 | 58,1 | 41,8 | 2,6 | 196,6 | 782,6 |

Source: Forestry statistics provided by Dr. R. Michalak; total forest area year of reference – 31.12.1999.

2. Data processed for the three classes as % of total area

| | province | Coniferous | Broadleaved | Other |
|---|---|---|---|---|
| | **Poland** | 22 % | 7 % | 72 % |
| PL1 | Dolno śląskie | 20,69 % | 7,55 % | 71,76 % |
| PL2 | Kujawsko-pomorskie | 19 % | 3 % | 78 % |
| PL3 | Lubelskie | 15 % | 7 % | 78 % |
| PL4 | Lubuskie | 43 % | 5 % | 52 % |
| PL5 | Łódzkie | 17 % | 3 % | 80 % |
| PL6 | Ma łopolskie | 19,74 % | 8,65 % | 71,61 % |
| PL7 | Mazowieckie | 17,5% | 4,4% | 78,1% |
| PL8 | Opolskie | 21 % | 5 % | 74 % |
| PL9 | Podkarpackie | 22 % | 14 % | 64 % |
| PL10 | Podlaskie | 21 % | 8 % | 71 % |
| PL11 | Pomorskie | 29 % | 6 % | 65 % |
| PL12 | Śląskie | 25 % | 7 % | 68 % |
| PL13 | Świętokrzyskie | 22 % | 5 % | 73 % |
| PL14 | Warmi ńsko-mazurskie | 20 % | 9 % | 71 % |
| PL15 | Wielkopolskie | 21 % | 4 % | 75 % |
| PL16 | Zachodniopomorskie | 25,6% | 8,6% | 65,8% |

3. Data prepared as .sta file for the calibration.

| Code polygon | Classes: broad-leaves | conifers | mixed | OWL | other |
|---|---|---|---|---|---|
| PL1 | 7.55 | 20.69 | 0 | 0 | 71.76 |
| PL2 | 3.0 | 19.0 | 0 | 0 | 78.0 |
| PL3 | 7.0 | 15.0 | 0 | 0 | 78.0 |
| PL4 | 5.0 | 43.0 | 0 | 0 | 52.0 |
| PL5 | 3.0 | 17.0 | 0 | 0 | 80.0 |
| PL6 | 8.65 | 19.74 | 0 | 0 | 71.61 |
| PL7 | 4.4 | 17.5 | 0 | 0 | 78.1 |
| PL8 | 5.0 | 21.0 | 0 | 0 | 74.0 |
| PL9 | 14.0 | 22.0 | 0 | 0 | 64.0 |
| PL10 | 8.0 | 21.0 | 0 | 0 | 71.0 |
| PL11 | 6.0 | 29.0 | 0 | 0 | 65.0 |
| PL12 | 7.0 | 25.0 | 0 | 0 | 68.0 |
| PL13 | 5.0 | 22.0 | 0 | 0 | 73.0 |
| PL14 | 9.0 | 20.0 | 0 | 0 | 71.0 |
| PL15 | 4.0 | 21.0 | 0 | 0 | 75.0 |
| PL16 | 8.6 | 25.6 | 0 | 0 | 65.8 |

**Figure 7.** Example set of data for Poland and processing results.

In the latter case the species were summed to build the broadleaved and coniferous classes. Forest not distinguished further in the statistics (e.g. other forest, forest not under management, auxiliary areas etc.) were proportionally divided to the classes at the country or sub-national level.

The outcome of data processing, as presented for the example country Poland in Figure 7, were then compared with the results from the FRA 1990 (UN-ECE/FAO 1992) and the TBFRA 2000 (The full results for all countries are compiled in Annex 3.) The data matched in the majority of the cases rather closely with the UN-ECE/FAO Resources assessments as of 1990 and 2000 (Table 5). Besides others, Finland and Italy showed differences in percentages from the UN-ECE/FAO Resources Assessments (Finland: 98,5% of FRA 1990; 91% of TBFRA 2000; Italy: 99% of FRA 1990; 68% of TBFRA 2000). This may be due to the not including temporarily treeless area (clearcut areas) within the forest class or a shift of other wooded land to the forest class. Also the spontaneous afforestation of abandoned fruit plantations and pastures in the mountainous regions of Italy may have been included as an estimation to the TBFRA 2000 (Tosi 1999). In cases data used were from recently finalised inventories (e.g. Flanders region) resulting in a higher amount of forest in Belgium as indicated in the TBFRA 2000 results.

**Table 5.** Comparison of forest area data from national forest statistics and international resources assessments (UN-ECE/FAO 1992 and 2000).

| | **Forest area applied in this study (in 1000 ha)** | **Share of forest area applied in this study as % of international forest resources assessments** | |
|---|---|---|---|
| Country | | TBFRA 2000 | FRA 1990 |
| Austria | 3819 | 100 | 99 |
| Belgium | 689 | 107 | 111 |
| Bosnia-Herzegovina | 2276 | 100 | N.A. |
| Bulgaria | 3295 | 92 | 97 |
| Czech | 2583 | 98 | 98 |
| Denmark | 445 | 100 | 98 |
| Finland | 19781 | 91 | 99 |
| France | 14528 | 96 | 102 |
| Germany | 10741 | 100 | 102 |
| Hungary | 1767 | 98 | 105 |
| Italy | 6686 | 68 | 99 |
| Luxembourg | 89 | 102 | 102 |
| FYR Macedonia | 906 | 100 | N.A. |
| Netherlands | 334 | 99 | 100 |
| Norway | 8709 | 100 | 100 |
| Poland | 8850 | 99 | 102 |
| Portugal | 3382 | 100 | 123 |
| Russia (European part) | 167975 | N.A. | N.A. |
| Spain | 13961 | 103 | 166 |
| Sweden | 23446 | 86 | 96 |
| Switzerland | 1139 | 97 | 101 |
| United Kingdom | 2469 | 100 | 112 |

Note: Countries in which forest area is based on TBFRA 2000 results are not included in table 4.

# 3 CALIBRATION OF THE EUROPEAN FOREST MAP

## 3.1 CALIBRATION PROGRAM

The calibration programme was updated from the previous version used in the project "Combining Geographically Referenced Earth Observation Data and Forest Statistics for Deriving a Forest Map for Europe (Contract No. 15237-1999-08F1EDISPFI). Changes took place in the set-up of the constraints for the programme. In the previous version all polygons were iterated two rounds and after that the calibration stopped. Now it is possible to use three different constraints:

1. Maximum number of rounds (1 to n)
2. Threshold for stopping calibration process: If e.g. the calibration process is set to a particular threshold value (from the value that is set from the statistics file) and that value is met the calibration stops (0.01-100.00)
3. Criteria for last rounds: If the calibration results from the latest calibration round and the previous show the same value, the calibration stops. This prevents consuming too much time with the polygons that cannot be calibrated or do not close the value found from the statistics file.

## 3.2 CALIBRATION RESULTS

A number of examples are given below to illustrate the calibration results. The calibration results are presented for countries at the sub-country level for the EU and EU candidate countries, the European part of Russia (Oblast level) and national level (TBFRA 2000). The experimental stratification performed by VVT was calibrated for France and the results are included in this chapter. Annex 4 gives the full overview results of the calibration results for all countries.

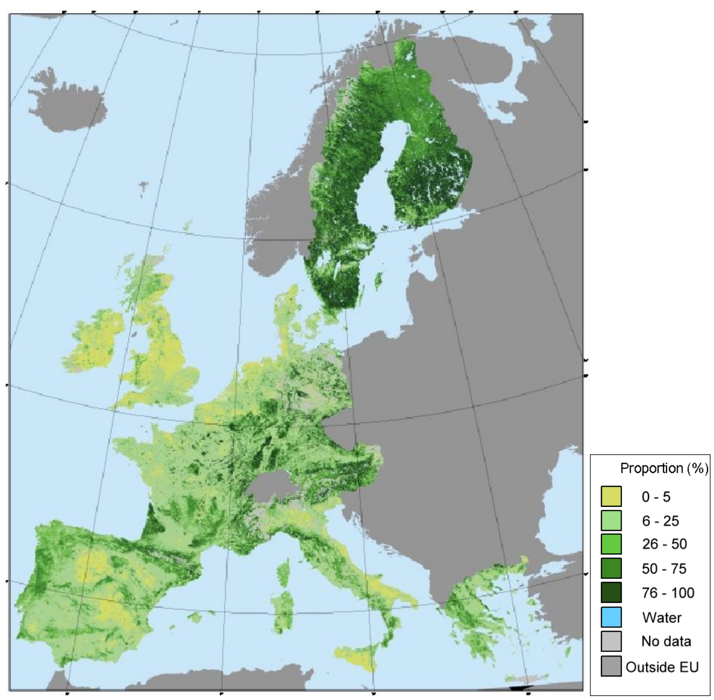


**Figure 8.** Forest proportion map of EU (Päivinen et al. 2001).

Figure 8 shows the calibrated forest map of the European Union produced within the project 'Combining Geographically Referenced Earth Observation Data and Forest Statistics for Deriving a Forest Map for Europe JRC' Contract no. 15237-1999-08 F1EDISPFI (Päivinen et al. 2001) based on Eurostat data (Eurostat 1998).

Figure 9, Figure 10 and Figure 11 illustrate this project's calibration results in map format. Compared with Figure 8, the maps in Figures 9 to 11 have an additional class for a forest probability proportion of 0 to 1 %. This class shows areas where it may be assumed that there is no forest.

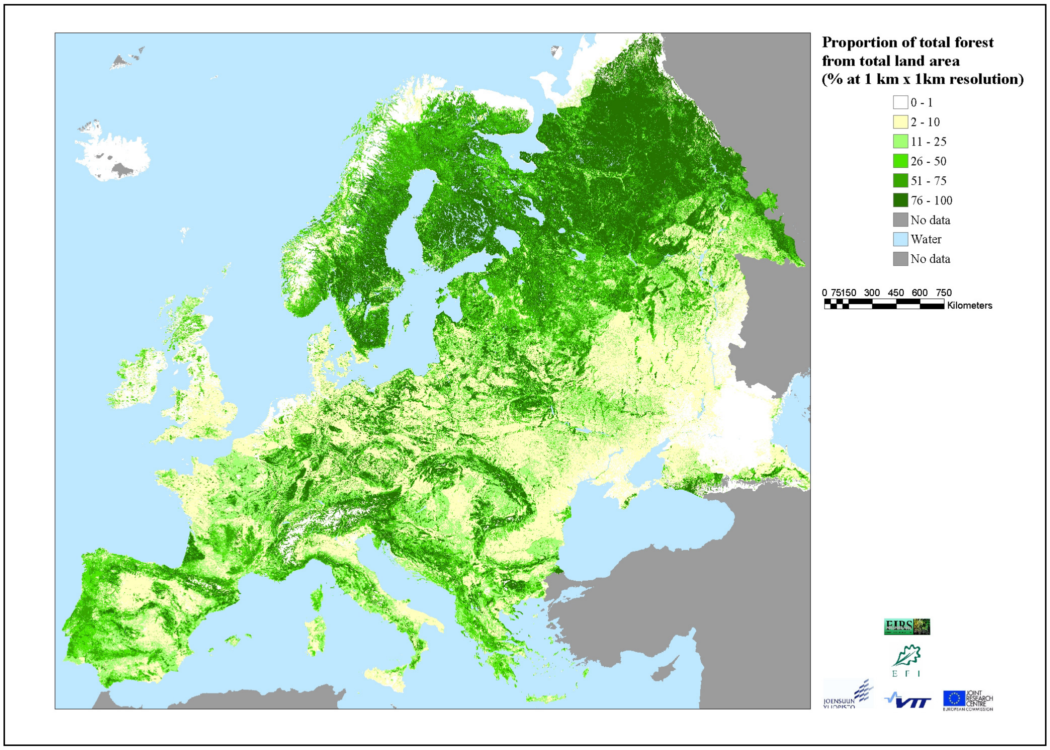


**Figure 9.** Calibrated forest proportion map of Europe.

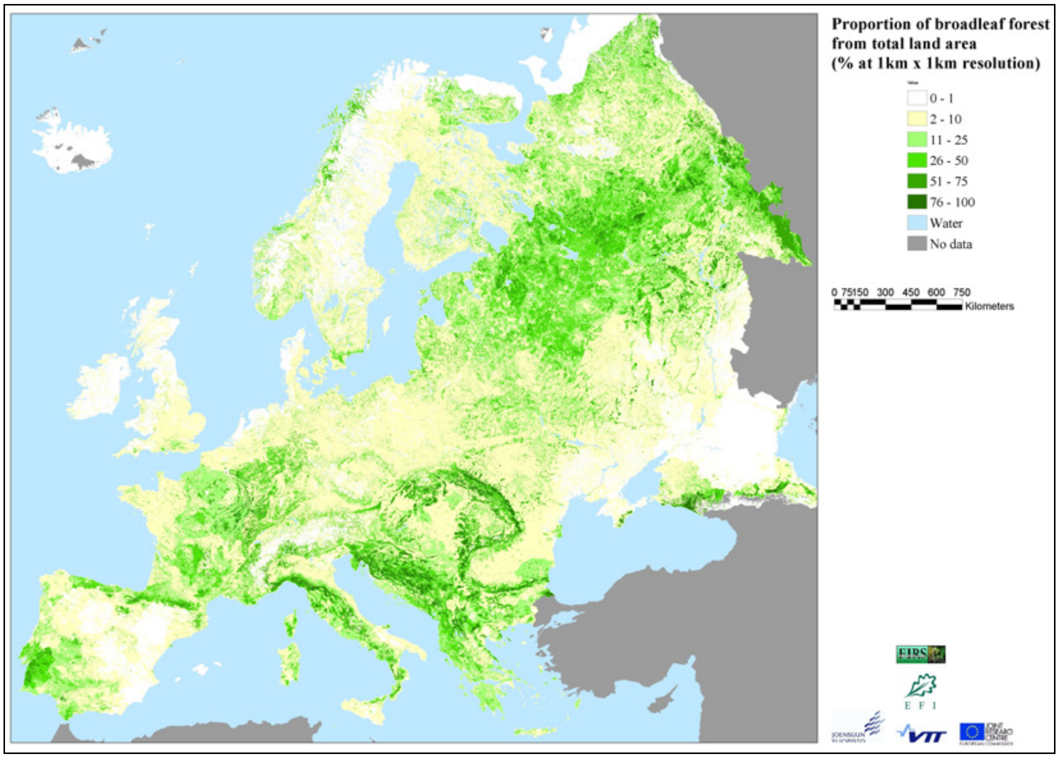


**Figure 10.** Calibrated broadleaved forest proportion map of Europe.

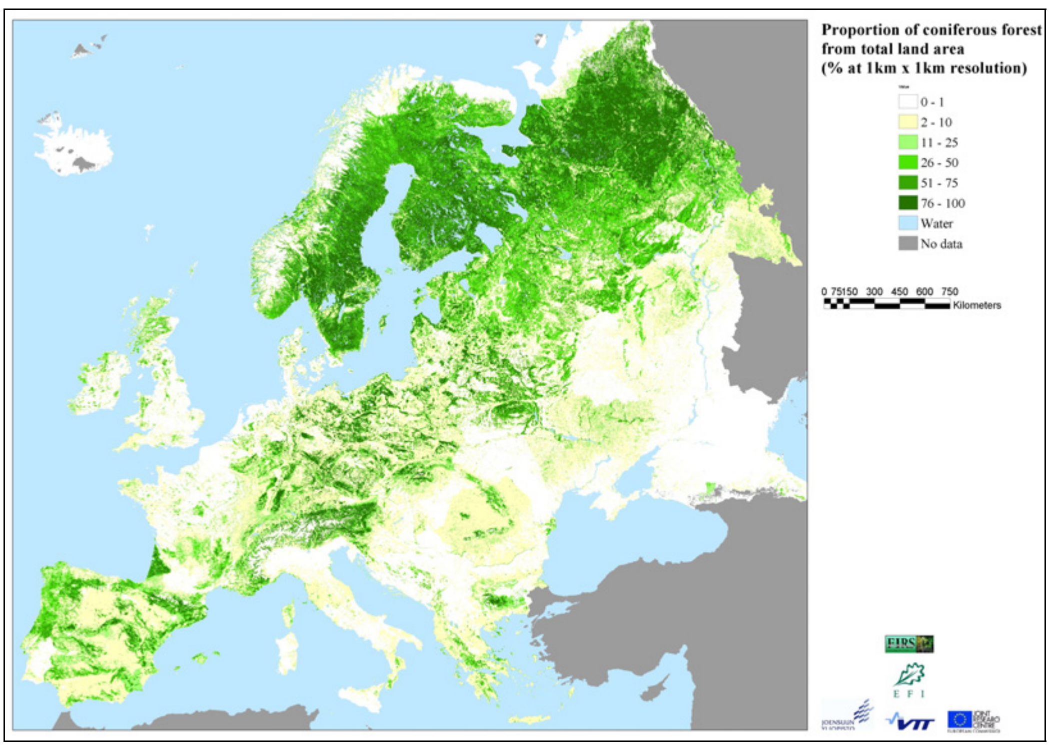


**Figure 11**. Calibrated coniferous forest proportion map of Europe.

Figure 12 and Figure 13 respectively show the proportion of broadleaf and coniferous forest from the total calibrated forest area on the basis of a 1km x 1km pixel resolution.

When interpreting these maps, it should be noted that a high proportion of e.g. coniferous forest from total forest does not necessarily mean that the area contains a lot of coniferous forest.

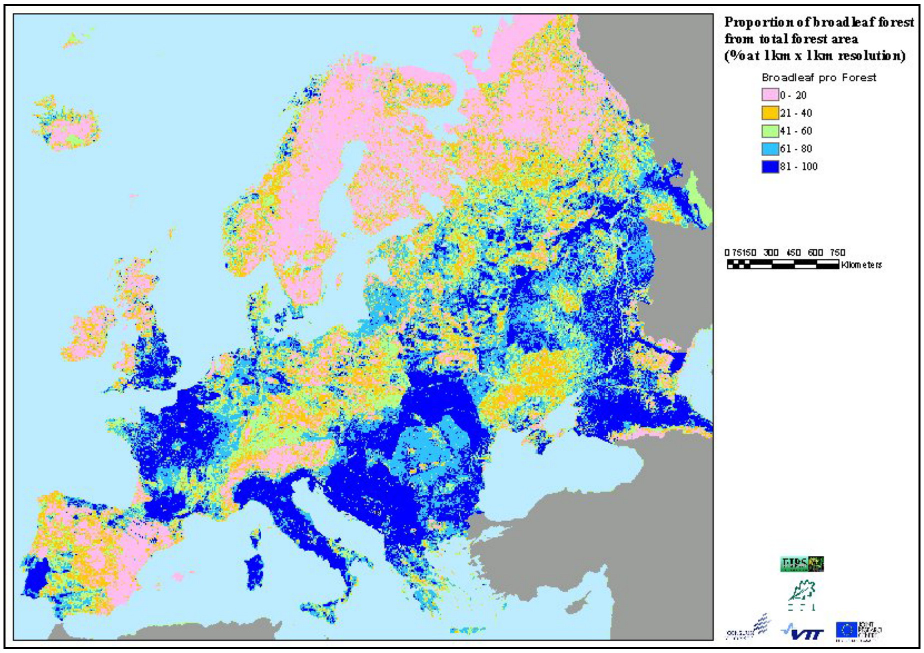


**Figure 12.** Proportion of broadleaf forest from the total calibrated forest area.

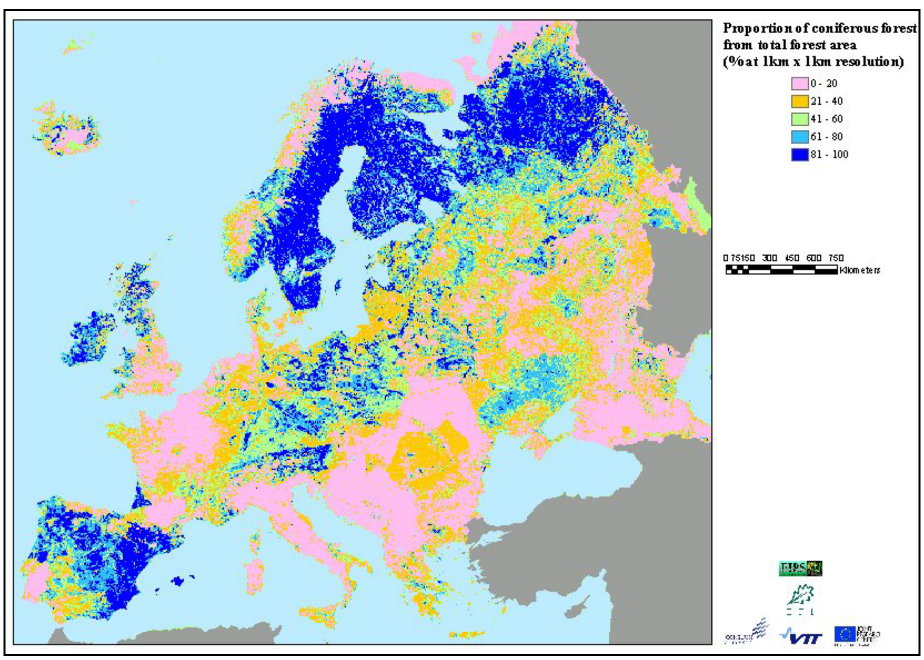


**Figure 13**. Proportion of coniferous forest from the total calibrated forest area.

The calibration procedure has worked satisfactory for all countries. The average number of iteration cycles was about three with the maximum rounds of ten and the minimum at one. This accounts in average to one additional cycle in comparison to the previous study where the limit was set to only two iterations. The new approach allowed a more flexible calibration of individual polygons. In a few cases such as Etelä-Savo, Finland (FI131) and in Flevoland, the Netherlands (NL23) the maximum number of 10 calibration cycles were run before the process was stopped. The set threshold of 0.3% units could not be met after 10 iterations. The two polygons are both areas with considerate amounts or adjacent of water bodies.

### 3.3 Comparison of inventory statistics with the AVHRR classified data

For comparing data derived from the forest inventory statistics and that of the AVHRR mosaic, their differences were calculated in unit percent. The results are visualised in Figure 14, Figure 15 and Figure 16.
The correlation between the forest inventory statistics and forest cover estimates from the AVHRR mosaic, calculated with the data for all polygons is presented in Table 6.

**Table 6.** Correlation between the forest inventory statistics and the forest cover estimates from the AVHRR mosaic.

| | Statistics - BRD | Statistics - CON | Statistics - FOR | Statistics - OTH |
|---|---|---|---|---|
| AVHRR classification - BRD | 0.718 | | | |
| AVHRR classification - CON | | 0.928 | | |
| AVHRR classification - FOR | | | 0.914 | |
| AVHRR classification - OTH | | | | 0.914 |

BRD: broadleaf; CON: coniferous; FOR: forest, i.e. BRD+CON; OTH: other

The forest inventory data and the forest cover estimates from the AVHRR classified data have the highest correlation for the coniferous forest class ($\rho = 0.928$). The correlation was lower for the broadleaf forest class ($\rho = 0.718$). This means that generally the calibration was most needed for the broadleaf class. The correlation factor only gives a very general idea and does not tell about the magnitude of the deviation between the two datasets on a regional level. These differences in unit percent are visualised for the ‘broadleaf’ class in Figure 14, for the ‘coniferous’ class in Figure 15 and for the ‘other’ class in Figure 16. The latter figure can also be interpreted as the inverted image for the deviations between the calibration input and output grid for the total forest class.

Especially in central Russia, the Balkans, North-central France and Southern Portugal, the forest inventory statistics, to which the image was calibrated, contained a considerably less amount of broadleaf forest. For the Spanish region ‘Galicia’ and the Portuguese region ‘Norte’, as well as the two Swiss regions ‘Jura’ and ‘Voralpen’, the calibration input grid contained higher amounts of broadleaf forest in the AVHRR calibration input grid than in the forest inventory statistics.

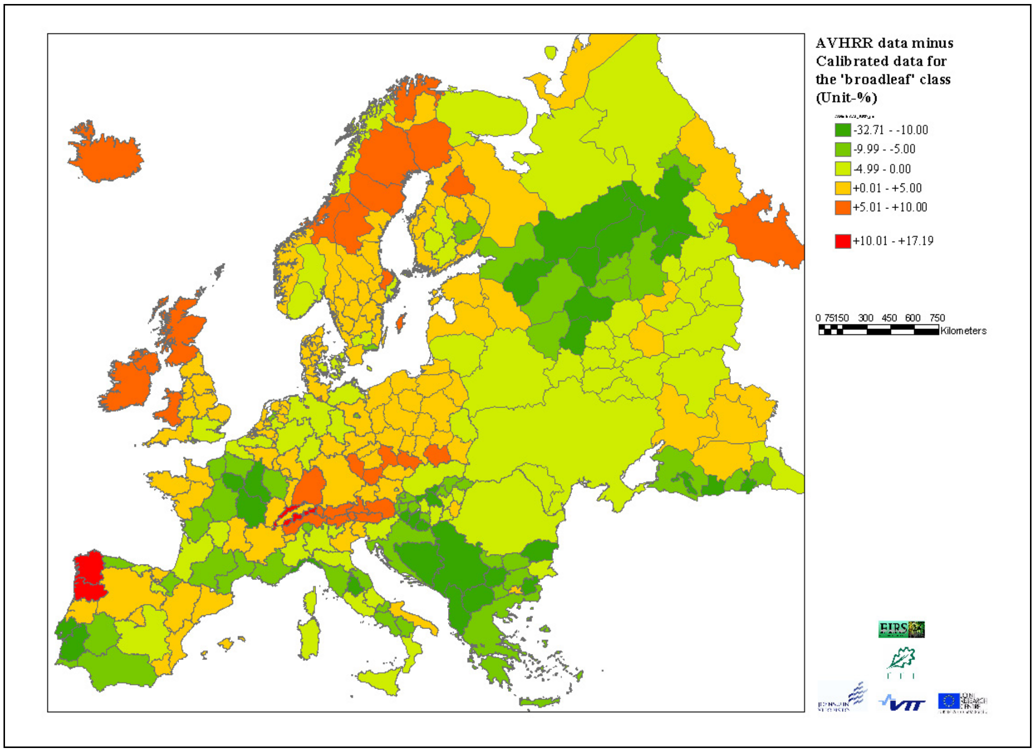


**Figure 14.** Forest Inventory Statistics minus AVHRR image-derived forest estimates for the "Broadleaf" class (Unit %); The regions are colored green where the AVHRR data underestimates the broadleaf forest proportion and red in the opposite case.

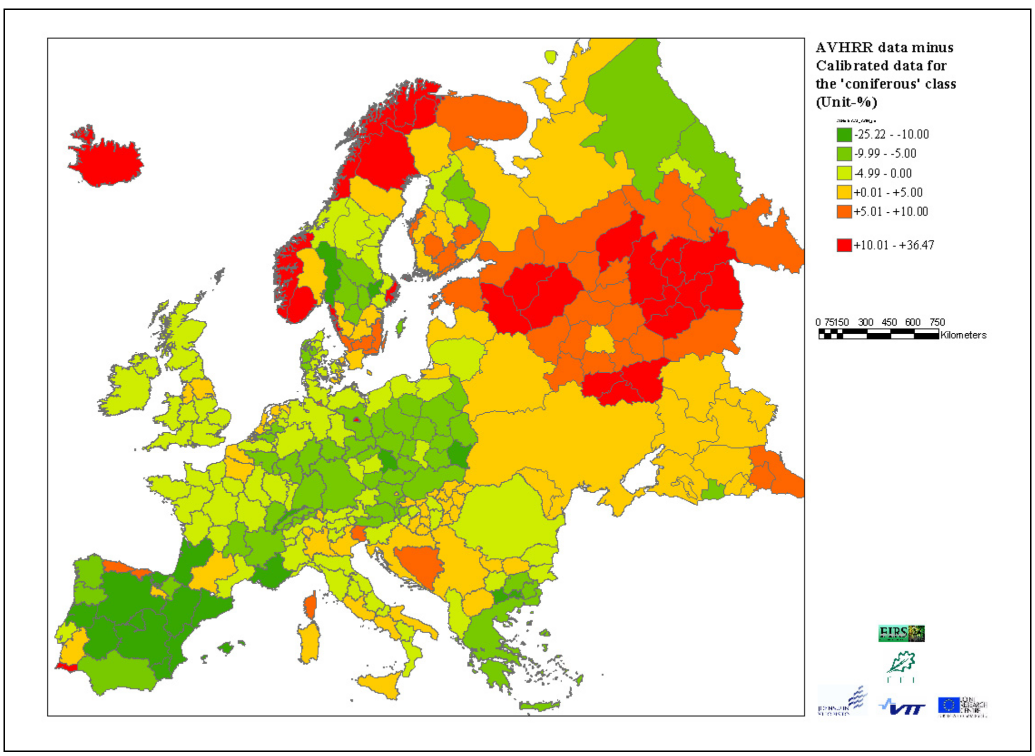


**Figure 15.** Forest Inventory Statistics minus AVHRR image-derived forest estimates for the "Conifer" class (Unit %); The regions are colored green where the AVHRR data underestimates the coniferous forest proportion and red in the opposite case.

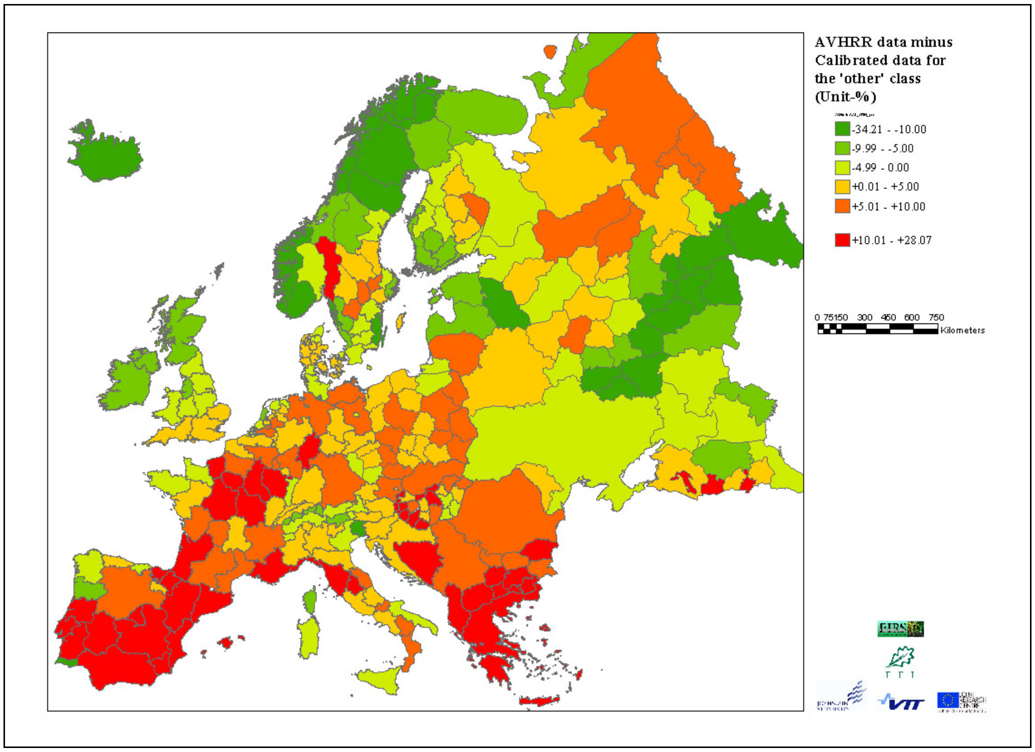


**Figure 16**. Forest Inventory Statistics minus AVHRR image-derived forest estimates for the "Other" class (Unit %); The regions are colored green where the AVHRR data underestimates the proportion of other land and red in the opposite case.

The *coniferous forest* seems to be over-represented in the AVHRR calibration input grid in central Russia, Northern Sweden and in the North and South of Norway. Especially in Spain and in Southern Portugal, the coniferous forest was significantly under-represented in the calibration input grid. This was also the case to a lesser extent for Greece, two regions in the South of France, Southern Germany, the Czech and Slovak Republics and in Poland. Once more the advantages of the calibration methodology are illustrated by the existence of serious discrepancies between the classified AVHRR input grid data and the forest inventory statistics, to which the input grid has been classified.

When looking at actual figures for quite a number of polygons the values differed strongly between the forest inventory statistics and the forest cover estimates from the AVHRR mosaic. Table 7 presents all differences that showed to be larger than 10 unit-%. The largest difference between the inventory statistics and the AVHRR mosaic was found in Norway (NO4: Rogaland, Hordaland, Sogn og Fjordane, More og Romsdal; NO7: Ostfold, Akershus/Oslo, Hedmark) with a unit value of –33% and 38.52% respectively for conifers and Portugal (PT14: Alentejo) 32.89 unit% for broadleaved forest.

The polygons of the European part of the Russian Federation showed notable differences both for broadleaved and conifers. Coniferous forest was generally overestimated in the AVHRR images as compared to the inventory statistics.

**Table 7.** Differences between forest inventory statistics and forest cover estimates from the AVHRR mosaic for the polygons with values larger than 10 unit-%. TBFRA2000 inventory data is marked with (*).

| Country | Region | NUTS | BRD | CON | Other |
|---|---|---|---|---|---|
| Albania (*) | Albania | AL0 | 18.22 | | -22.17 |
| Austria | Burgenland | AT11 | | | -11.93 |
| Bosnia and Herzegovina | Bosnia and Herzegovina | BA0 | 19.81 | | -11.01 |
| Bulgaria | North-East | BG3 | 11,91 | | -12,12 |
| Bulgaria | Middle | BG5 | 6,04 | 7,12 | -13,16 |
| Bulgaria | East | BG6 | 12,25 | | -14,10 |
| Bulgaria | South-West | BG7 | | 13,24 | -22,66 |
| Bulgaria | South | BG8 | | 25,36 | -22,68 |
| Bulgaria | South-East | BG9 | 14,69 | | -24,11 |
| Czech Republic | Vychodocesky | CZ6 | | 12.78 | |
| European Russia | Pskov | RU10 | | -13.94 | 18.43 |
| European Russia | Tver | RU14 | | -10.65 | |
| European Russia | Kaluga | RU15 | 13.97 | | |
| European Russia | Kostroma | RU16 | 22.07 | -12.14 | |
| European Russia | Moscow region + Moscow | RU17 | 11.62 | | |
| European Russia | Yaroslavl | RU22 | 12.48 | | |
| European Russia | Nizhniy Novgorod | RU23 | | -11.38 | |
| European Russia | Kirov | RU24 | 10.45 | | |
| European Russia | Rep. Mariy-El | RU25 | 13.84 | -13.56 | |
| European Russia | Rep. Mordovia | RU26 | | -12.27 | 14.55 |
| European Russia | Rep. Chuvashia | RU27 | | -12.64 | 10.50 |
| European Russia | Belgorod | RU28 | | -17.25 | 16.59 |
| European Russia | Voronezh | RU29 | | -10.99 | 10.21 |
| European Russia | Vologda | RU3 | 15.40 | | |
| European Russia | Kursk | RU30 | | -11.78 | 10.65 |
| European Russia | Tambov | RU32 | | | 13.86 |
| European Russia | Samara | RU35 | | -19.59 | 16.55 |
| European Russia | Penza | RU36 | | -16.00 | 15.81 |
| European Russia | Ulyanovsk = Simbirsk | RU38 | | -16.49 | 13.12 |
| European Russia | Nenetz Aut. District | RU4 | -10.67 | -17.38 | 28.05 |
| European Russia | Rep. Tatarstan | RU40 | | -12.10 | 11.88 |
| European Russia | Rep. Adygheya | RU45 | 15.57 | | -14.09 |
| European Russia | Rep.Northern Ossetia | RU48 | 14.93 | | -13.40 |
| European Russia | Rep. Karachayevo-Cherkessia | RU49 | 11.66 | | -16.59 |
| European Russia | Murmansk | RU5 | | -10.17 | |
| European Russia | Perm | RU53 | | 10.14 | |
| European Russia | Rep. Bashkortostan | RU56 | | | 15.08 |
| European Russia | Novgorod | RU9 | 16.46 | -16.39 | |
| Finland | Lappi | FI152 | | | 14.19 |
| Finland | Ahvenanmaa | FI2 | | -29.54 | 28.26 |
| France | Ile de France | FR1 | 14.03 | | -14.41 |
| France | Champagne-Ardenne | FR21 | 10.33 | | -11.84 |
| France | Haute-Normandie | FR23 | | | -11.05 |
| France | Centre | FR24 | | | -12.32 |
| France | Bourgogne | FR26 | 13.16 | | -16.02 |
| France | Lorraine | FR41 | | | -10.31 |
| France | Aquitaine | FR61 | | 13.21 | -16.27 |
| France | Midi-Pyrenees | FR62 | 10.01 | | |
| France | Provence-Alpes-Cote d'Azur | FR82 | | 12.20 | -18.03 |

**Table 7**. Continued.

| Country | Region | NUTS | BRD | CONr | Other |
|---|---|---|---|---|---|
| FYR Macedonia | FYR Macedonia | MK0 | 18.91 | | -18.58 |
| Germany | Berlin West-Stadt | DE3 | | -10.57 | |
| Germany | Hamburg | DE6 | | | 11.17 |
| Germany | Hessen | DE7 | | | -10.66 |
| Greece (*) | Greece | GR0 | | | -11.79 |
| Hungary | Komárom-Eszt. | HU10 | 14.49 | | -13.81 |
| Hungary | Nógrád | HU11 | 24.93 | | |
| Hungary | Nógrád | HU11 | | | -26.25 |
| Hungary | Pest+Budapest | HU12 | 15.41 | | -16.20 |
| Hungary | Vas | HU17 | | | -16.55 |
| Hungary | Veszprém | HU18 | 20.56 | | -22.59 |
| Hungary | Zala | HU19 | 19.40 | | -23.13 |
| Iceland (*) | Iceland | IS0 | | -15.08 | 23.16 |
| Italy | Liguria | IT13 | 10.47 | | -14.21 |
| Italy | Friuli V.G. | IT33 | | | 11.32 |
| Italy | Toscana | IT51 | | | -10.87 |
| Italy | Umbria | IT52 | 15.91 | | -17.78 |
| Norway | Finnmark | NO1 | | -11.40 | 16.34 |
| Norway | Nordland, Troms | NO2 | | -12.10 | |
| Norway | Rogaland, Hordaland, Sogn og Fjordane, More og Romsdal | NO4 | | -33.00 | 32.59 |
| Norway | Oppland, Buskerud, Vestfold | NO6 | | -15.68 | 15.06 |
| Norway | Ostfold, Akershus/Oslo, Hedmark | NO7 | | 38.52 | -36.59 |
| Poland | Podkarpackie | PL9 | | 11.00 | |
| Portugal | Norte | PT11 | -10.79 | | |
| Portugal | Centro | PT12 | | 16.24 | -11.69 |
| Portugal | Lisboa E Vale Do Tejo | PT13 | 10.64 | | -14.90 |
| Portugal | Alentejo | PT14 | 32.89 | | -28.25 |
| Portugal | Algarve | PT15 | | -20.91 | 14.35 |
| Spain | Galicia | ES11 | -11.60 | | |
| Spain | Páis Vasco | ES21 | | 12.52 | -12.37 |
| Spain | Comunidad Foral de Navarra | ES22 | | | -11.78 |
| Spain | Arágon | ES24 | | 16.28 | -13.16 |
| Spain | Comunidad de Madrid | ES3 | | 16.37 | -12.99 |
| Spain | Castilla y León | ES41 | | 11.18 | |
| Spain | Castilla-la Mancha | ES42 | | 13.11 | -13.54 |
| Spain | Extremadura | ES43 | | 14.26 | -22.44 |
| Spain | Cataluña | ES51 | | 24.97 | -22.12 |
| Spain | Communidad Valenciana | ES52 | | 17.52 | -14.91 |
| Spain | Islas Baleares | ES53 | | 17.33 | -12.64 |
| Spain | Andalucia | ES61 | | | -13.78 |
| Spain | Región de Murcia | ES62 | | 20.61 | -19.37 |
| Sweden | Sthm | SE011 | | -10.76 | |
| Sweden | Vstm | SE025 | | 10.37 | |
| Sweden | Kalm | SE033 | | | 10.72 |
| Sweden | Gtbg | SE052 | | -19.99 | 21.91 |
| Sweden | Nbtn | SE082 | | | 12.96 |
| Switzerland | Jura | CH1 | -11.12 | 13.52 | |
| Switzerland | Voralpen | CH3 | -17.19 | | |
| Yugoslavia (*) | Yugoslavia | YU0 | 10.84 | | |

When looking at individual countries (either at regional or country level) many countries showed comparable results for the calibrated forest database and the original non-calibrated AVHRR forest mosaic. This was the case e.g. in Belgium, which was calibrated at the regional level (3 polygons). The forest cover estimate from the AVHHR matched satisfactory with the reported statistics (Table 8 and Figure 17).

**Table 8.** Comparison of national forest statistics and the forest cover estimates derived from the AVHRR mosaic for coniferous and broad-leaved forest classes in Belgium by regions.

| NUTS | CLASS | Statistics | AVHRR classification | Calibrated classification | Iterations |
|---|---|---|---|---|---|
| BE1 | BRD | 10 | 5.58 | 10.02 | 2 |
| BE1 | CON | 1 | 5.79 | 1.00 | |
| BE1 | OTH | 89 | 88.62 | 88.97 | |
| BE2 | BRD | 6 | 5.59 | 5.97 | 2 |
| BE2 | CON | 5 | 2.11 | 4.85 | |
| BE2 | OTH | 89 | 92.30 | 89.18 | |
| BE3 | BRD | 17 | 17.02 | 16.95 | 5 |
| BE3 | CON | 16 | 9.07 | 15.89 | |
| BE3 | OTH | 67 | 73.90 | 67.16 | |

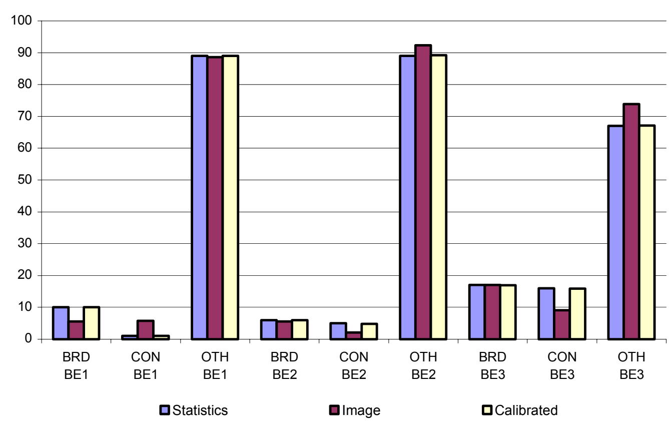


**Figure 17.** Comparison of national forest statistics and the forest cover estimates derived from the AVHRR mosaic for coniferous and broad-leaved forest classes in Belgium by regions.

In the case of the Czech Republic some slight differences were observed between the calibrated image and the AVHHR classification (Table 9 and Figure 18). In the calibrated image the proportion of coniferous forest is more dominating whereas the broadleaved forest is represented stronger in the AVHRR classification.

**Table 9.** Comparison of national forest statistics and the forest cover estimates derived from the AVHRR mosaic for coniferous and broad-leaved forest classes in Czech Republic by regions.

| NUTS | CLASS | Statistics | AVHRR classification | Calibrated classification | Iterations |
|---|---|---|---|---|---|
| CZ1 | BRD | 7 | 9.53 | 6.99 | 4 |
| CZ1 | CON | 18 | 14.95 | 17.88 | |
| CZ1 | OTH | 75 | 75.52 | 75.13 | |
| CZ3 | BRD | 3.9 | 13.44 | 3.90 | 5 |
| CZ3 | CON | 32.5 | 25.22 | 32.38 | |
| CZ3 | OTH | 63.6 | 61.33 | 63.72 | |
| CZ4 | BRD | 4.2 | 13.28 | 4.20 | 4 |
| CZ4 | CON | 35.5 | 31.17 | 35.38 | |
| CZ4 | OTH | 60.3 | 55.55 | 60.42 | |
| CZ5 | BRD | 11.24 | 15.66 | 11.23 | 4 |
| CZ5 | CON | 21.44 | 16.03 | 21.32 | |
| CZ5 | OTH | 67.32 | 68.31 | 67.44 | |
| CZ6 | BRD | 5.6 | 11.23 | 5.60 | 6 |
| CZ6 | CON | 26.6 | 13.82 | 26.47 | |
| CZ6 | OTH | 67.8 | 74.94 | 67.93 | |
| CZ7 | BRD | 11 | 11.72 | 10.98 | 5 |
| CZ7 | CON | 19 | 10.18 | 18.86 | |
| CZ7 | OTH | 70 | 78.10 | 70.17 | |
| CZ8 | BRD | 9 | 14.87 | 8.99 | 6 |
| CZ8 | CON | 29 | 19.48 | 28.88 | |
| CZ8 | OTH | 62 | 65.65 | 62.12 | |

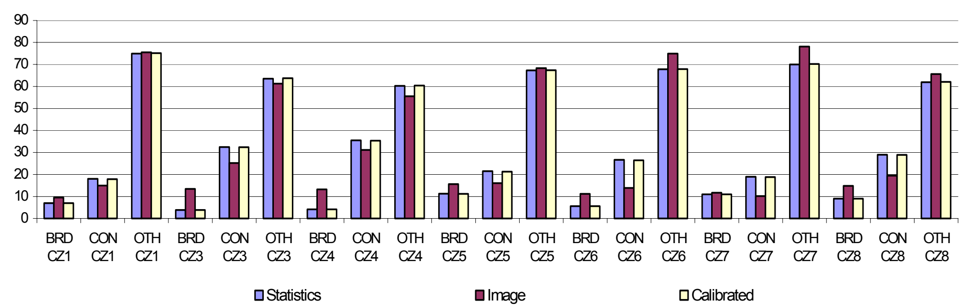


**Figure 18.** Comparison of national forest statistics and the for coniferous and broad-leaved forest classes in Czech Republic by regions.

To demonstrate the results for the European part of Russia, an extract of ten polygons -out of 57 polygons in all- is shown in Table 10 and Figure 19. The polygons represent the north-western and western "Oblasts" of the European part of Russia, which are rather large in area. The comparison of the forest statistics and the forest cover estimates derived from the AVHRR mosaic for the ten polygons yielded an overall higher proportion of the coniferous forest class in the AVHRR classification. Hence the proportion of the broadleaved class is higher in the statistics.

**Table 10.** Comparison of sub-country level statistics and the forest cover estimates derived from the AVHRR mosaic for coniferous and broad-leaved forest classes in the European part of Russia (extract of 10 Oblasts).

| NUTS | CLASS | Statistics | AVHRR classification | Calibrated classification | Iterations |
|---|---|---|---|---|---|
| RU2 | BRD | 13 | 10.46 | 12.96 | 3 |
| RU2 | CON | 61 | 61.85 | 61.06 | |
| RU2 | OTH | 26 | 27.69 | 25.98 | |
| RU3 | BRD | 33 | 17.60 | 32.95 | 3 |
| RU3 | CON | 40 | 49.59 | 40.07 | |
| RU3 | OTH | 27 | 32.81 | 26.98 | |
| RU14 | BRD | 26 | 17.57 | 25.98 | 3 |
| RU14 | CON | 29 | 39.65 | 29.13 | |
| RU14 | OTH | 45 | 42.77 | 44.89 | |
| RU17 | BRD | 22 | 10.38 | 22.00 | 3 |
| RU17 | CON | 20 | 28.37 | 20.14 | |
| RU17 | OTH | 58 | 61.25 | 57.85 | |
| RU22 | BRD | 30.24 | 17.76 | 30.23 | 3 |
| RU22 | CON | 20.41 | 29.42 | 20.47 | |
| RU22 | OTH | 49.35 | 52.82 | 49.29 | |
| RU24 | BRD | 28 | 17.55 | 27.945 | 3 |
| RU24 | CON | 35 | 43.25 | 35.09 | |
| RU24 | OTH | 37 | 39.20 | 36.96 | |
| RU26 | BRD | 18.3 | 20.58 | 18.35 | 4 |
| RU26 | CON | 8.3 | 20.57 | 8.32 | |
| RU26 | OTH | 73.4 | 58.85 | 73.32 | |
| RU36 | BRD | 15 | 14.81 | 15.07 | 3 |
| RU36 | CON | 7 | 23.00 | 7.03 | |
| RU36 | OTH | 78 | 62.19 | 77.90 | |
| RU51 | BRD | 23.6 | 16.36 | 23.58 | 3 |
| RU51 | CON | 57.9 | 55.69 | 57.87 | |
| RU51 | OTH | 18.5 | 27.95 | 18.55 | |
| RU53 | BRD | 27 | 29.97 | 27.01 | 4 |
| RU53 | CON | 41 | 30.86 | 40.82 | |
| RU53 | OTH | 32 | 39.17 | 32.16 | |

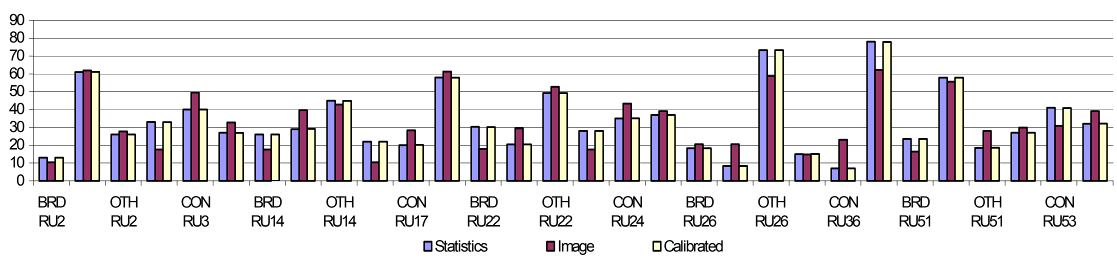


**Figure 19.** Comparison of sub-country level statistics and the forest cover estimates derived from the AVHRR mosaic for coniferous and broad-leaved forest classes in the European part of Russia (extract of 10 Oblasts).

17 countries were calibrated at the country level based on the data of the TBFRA 2000. In general the results were satisfactory and the forest statistics and the forest cover estimates derived from the AVHRR mosaic showed similar proportions for the three classes (see example Romania: Table 11 and Figure 20). Two striking exceptions, however, were identified. In the case of Albania the calibrated

forest forest database showed a considerably higher proportion of forest both for coniferous and broadleaved class (Statistics: 29 % broadleaved, 7% coniferous AVHRR classification: 12% and 3%).

**Table 11.** Comparison of national statistics and the forest cover estimates derived from the AVHRR mosaic for coniferous and broad-leaved forest classes Romania.

| NUTS | CLASS | Statistics | AVHRR classification | Calibrated classification | Iterations |
|---|---|---|---|---|---|
| RO0 | BRD | 19 | 16.96 | 18.91 | 4 |
| RO0 | CON | 8 | 4.88 | 7.96 | |
| RO0 | OTH | 73 | 78.16 | 73.13 | |

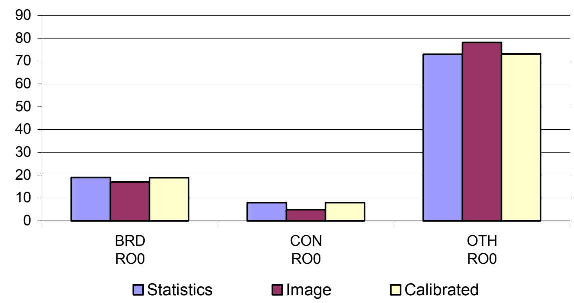


**Figure 20.** Comparison of national statistics and the forest cover estimates derived from the AVHRR mosaic for coniferous and broad-leaved forest classes Romania.

A similar observation was made for Iceland, where the forest proportion was strongly overestimated within the non-calibrated AVHRR forest mosaic as compared to the statistics available from the TBFRA 2000 (Table 12).

**Table 12.** Comparison of national statistics and the forest cover estimates derived from the AVHRR mosaic for coniferous and broad-leaved forest classes for Albania and Iceland.

| NUTS | CLASS | Statistics | AVHRR classification | Calibrated classification | Iterations |
|---|---|---|---|---|---|
| AL0 | BRD | 30 | 11.78 | 29.91 | 3 |
| AL0 | CON | 7 | 3.05 | 6.96 | |
| AL0 | OTH | 63 | 85.17 | 63.13 | |
| IS0 | BRD | 0.001 | 8.08 | 0.001 | 1 |
| IS0 | CON | 0.001 | 15.09 | 0.001 | |
| IS0 | OTH | 99.99 | 76.83 | 99.99 | |

*Experimental stratification*

To reduce the underestimation of coniferous forest in the Atlantic stratum derived from the NOAA-AVHRR mosaic, an additional stratification had been experimentally applied. In the alternative, the Atlantic stratum included only the British Isles and Iceland. Continental Europe that formerly belonged to the Atlantic stratum was included in the temperate and boreal stratum (see Chapter 0). The results of both approaches are presented in Table 13 and Figure 21. An increase of the proportion of the coniferous class can be observed in the polygons FR51, FR52, FR53 and FR61 (Pays de la Loire, Bretagne, Poitou-Charentes and Aquitaine). The polygons are situated along the Atlantic coast. The proportions of the coniferous class resulting from the experimental stratification correspond more closely with those of the forest statistics. In other regions the differences increased between the statistics and the results from the experimental stratification (e.g. FR41 Lorraine, FR42 Alsace and FR43 Franche-Comté).

**Table 13.** Comparison of national forest statistics and the forest cover estimates derived from the AVHRR mosaic for coniferous and broad-leaved forest classes in France by regions (experimental stratification).

| Nuts | Class | Statistics | AVHRR classification | | Difference in % units |
|---|---|---|---|---|---|
| | | | original | experimental | experimental/ traditional |
| FR1 | CON | 2.5 | 1.99 | 2.02 | 0.03 |
| FR21 | CON | 4.4 | 2.75 | 2.35 | -0.40 |
| FR22 | CON | 1 | 1.14 | 1.58 | 0.44 |
| FR23 | CON | 3 | 1.21 | 1.90 | 0.69 |
| FR24 | CON | 5 | 1.94 | 1.95 | 0.01 |
| FR25 | CON | 2 | 1.56 | 2.72 | 1.16 |
| FR26 | CON | 5 | 2.09 | 2.19 | 0.09 |
| FR3 | CON | 0.001 | 0.70 | 1.55 | 0.86 |
| FR41 | CON | 11 | 7.52 | 5.58 | -1.94 |
| FR42 | CON | 16 | 13.39 | 9.06 | -4.33 |
| FR43 | CON | 13 | 6.83 | 4.99 | -1.84 |
| FR51 | CON | 3 | 1.17 | 1.91 | 0.74 |
| FR52 | CON | 5 | 3.01 | 3.74 | 0.73 |
| FR53 | CON | 3 | 1.07 | 1.73 | 0.66 |
| FR61 | CON | 27 | 13.69 | 15.33 | 1.65 |
| FR62 | CON | 4.3 | 5.27 | 5.02 | -0.26 |
| FR63 | CON | 11 | 6.93 | 5.31 | -1.63 |
| FR71 | CON | 17 | 8.96 | 7.38 | -1.58 |
| FR72 | CON | 14 | 6.27 | 5.36 | -0.91 |
| FR81 | CON | 15.6 | 11.93 | 12.24 | 0.30 |
| FR82 | CON | 23 | 10.77 | 9.51 | -1.26 |
| FR83 | CON | 8.6 | 16.98 | 13.30 | -3.67 |

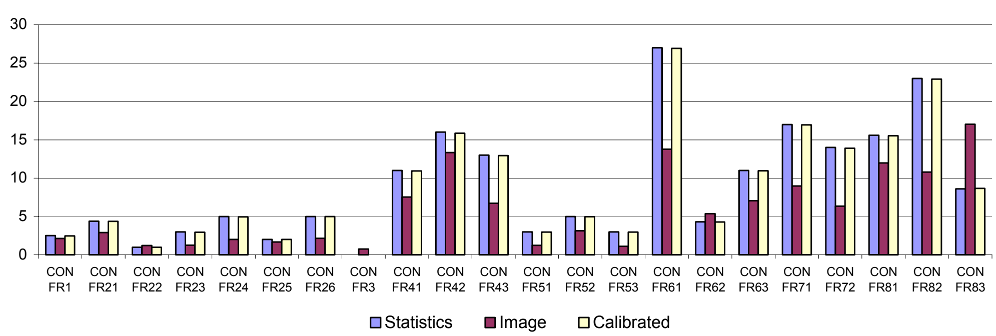


**Figure 21.** Comparison of national forest statistics and the forest cover estimates derived from the AVHRR mosaic for coniferous and broad-leaved forest classes in France by regions (experimental stratification).

## 3.4 VALIDATION OF THE CALIBRATION RESULTS

### 3.4.1 Validation based on a questionnaire

A questionnaire was prepared by the European Forest Institute in the summer of 2002 and sent to 23 countries (Annex 5). It was seen as important to consult national inventory and remote sensing specialists to give their expert opinion on the quality and accuracy of the forest map (including coniferous and broadleaved maps) as compared to their expertise and national mapping activities.

To date (31. October 2002) the European Forest Institute has received 10 replies from 8 countries (Table 14). The process of collecting feedback is presently still ongoing.

**Table 14.** Questionnaire replies (summary of main comments and suggestions).

| Country | No. of replies | Assessment of data used | Assessment of calibrated map image | Assessment of timberline |
|---|---|---|---|---|
| Austria | 1 | Best available data were used | Overestimate of coniferous class in particular along rivers | References to more detailed literature given |
| Germany | 2 | Acceptable data were used for given purpose (reference to further data sources) | Overall forest intensity is ok.<br>total and coniferous forest is too low in the border region Saxony and Severocesky (Czech R.)<br>Depending on underlying data, it may be necessary to reduce forest intensity (e.g. storm events) | Timberline only secondary |
| Slovakia | 1 | Latest data provided for national level for coniferous and broadleaved forest (TBFRA 2000 data were used) | Forest is overestimated in the south-western and in the north-eastern parts of the country. | Not relevant |
| Switzerland | 2 | Best available data were used | Maps good quality (some slight over- and underestimation was observed for certain regions) | References to more detailed literature given |
| Lithuania | 1 | Latest forest data were not used<br>(TBFRA 2000 data applied) difference in forest definition FAO/national | Map result acceptable for given purpose<br>Overall underestimation; too little forest along rivers | Not relevant |
| Czech Republic | 1 | Data uses acceptable; new data becoming available soon | - | - |
| Belgium | 1 | Best available data were used; new data for Wallonne region becoming available soon | most eastern part of Wallonne forest show overestimates broadleaved forest | Not relevant |
| Italy | 1 | Issue of other wooded land was raised however concerning forest data used are acceptable | In principle correct and good. Evident errors: Po Valley (probably misclassification of rice fields), southern Latinum (too much forest in the planes), and northern Sicily (where there are some conifer plantations). | More information provided |

Overall the responses from experts were very positive and constructive towards improving and developing the calibrated forest map. The map results were considered as good especially regarding the scale and coverage of the pan-European area. Especially helpful comments were made towards improving the input data and refining the timberline. Also the experts pointed out inconsistencies of the map with national mapping activities. One particular point of interest were the placement of forests along large rivers.

Further to the assessment of the map the expert expressed options to improve the map output. The related to apply a more detailed classification (more classes than currently 6), including layer for rivers, roads and cities and use a more distinct colour coding. Also the request was made to use finer resolution (e.g. 1ha) so the map could be used directly for management planning purposes.

### 3.4.2 Quantitative analysis of the calibrated forest map on a pixel by pixel basis

The AVHRR input grid was calibrated on a percentage basis. The calculation of the percentage land cover for each class was based on the land and forest cover area from inventory statistics. The respective areas have been calculated from the grid and compared to the initial absolute land cover data. The approach for the quantitative analysis of the forest map was based on a pixel-by-pixel approach (Figure 22).

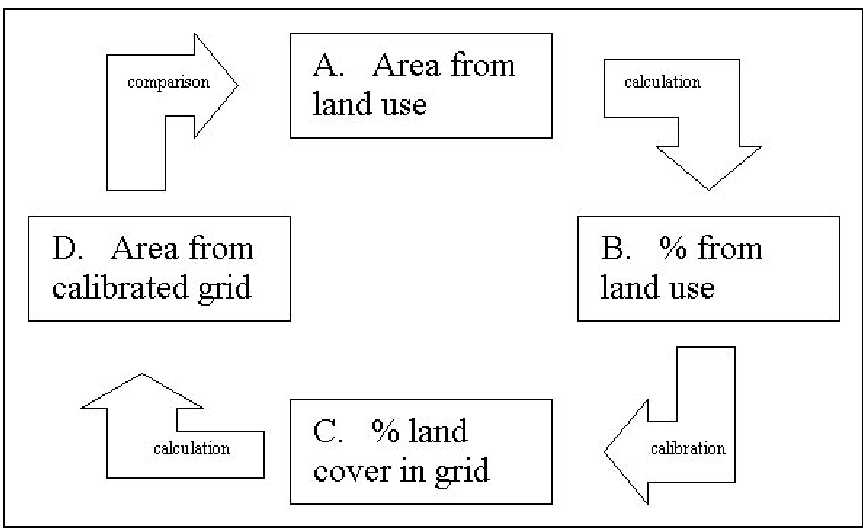


**Figure 22.** Approach for the quantitative analysis.

In a first phase the land area (excluding inland water) of the grid was compared to the land area given by the statistics. This was done in order to examine the match/mismatch of land area from both sources. Figure 23 illustrates the result of this exercise. It shows the land area from the grid minus the land area from the statistics relative to the statistics.

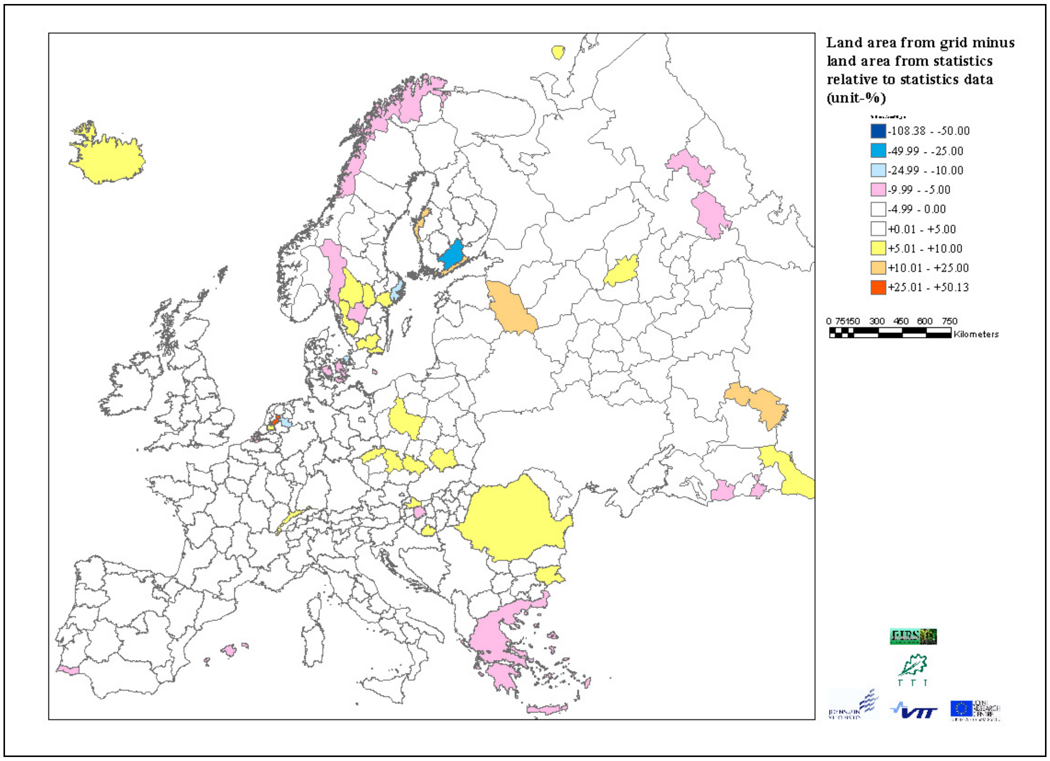


**Figure 23.** Land area from the grid minus the land area from the statistics relative to the statistics. Blue to magenta: land area from grid is lower than that from the statistics; Yellow to red: land area from the grid is higher than that of the statistics.

Overall the difference is not very high and mainly situated between –5 and +5 unit-%. However in a number of cases the land area is considerably higher or lower in the statistics as compared to the grid. This observation was made mainly in areas with a very extensive coastline and areas with a large amount of islands (e.g. Greece, Norway, Denmark, Finland and Iceland. Such differences may be caused to some extent by land area that is not captured by the grid or where the grid expands into water bodies (Figure 24).

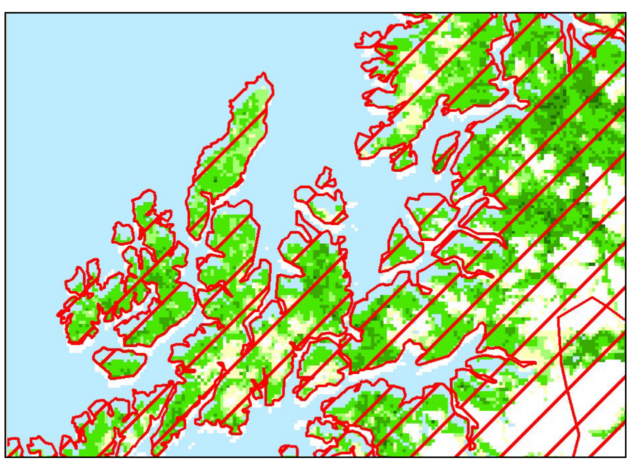

**Figure 24.** Image of the Norwegian coastline at Lofoten, showing a crude match between the polygon coverage and the image. Areas hatched in red are within the polygon coverage.

Generalising, the factors that may contribute to the difference between the 'official' land area statistics and the land area as calculated from the grid, are considered to be the following:

- Rectification of the original satellite images;
- Misplacement of polygon coverage over the grid image;
- (Partial) mismatch between the polygon coverage and the grid image;
- Incomplete polygon coverage, e.g. excluding some (smaller) islands;
- Accuracy or source of land area statistics;
- Missing data on inland water area;
- Accuracy or source of forest area statistics

These effects are then visible when analysing the calibrated forest map on a pixel-by-pixel basis and comparing the result to the actual statistics used as input data to the calibration. In the ideal case the result from this exercise should yield the same figure as from the statistics. As Figure 25 shows, this is not necessarily the case.

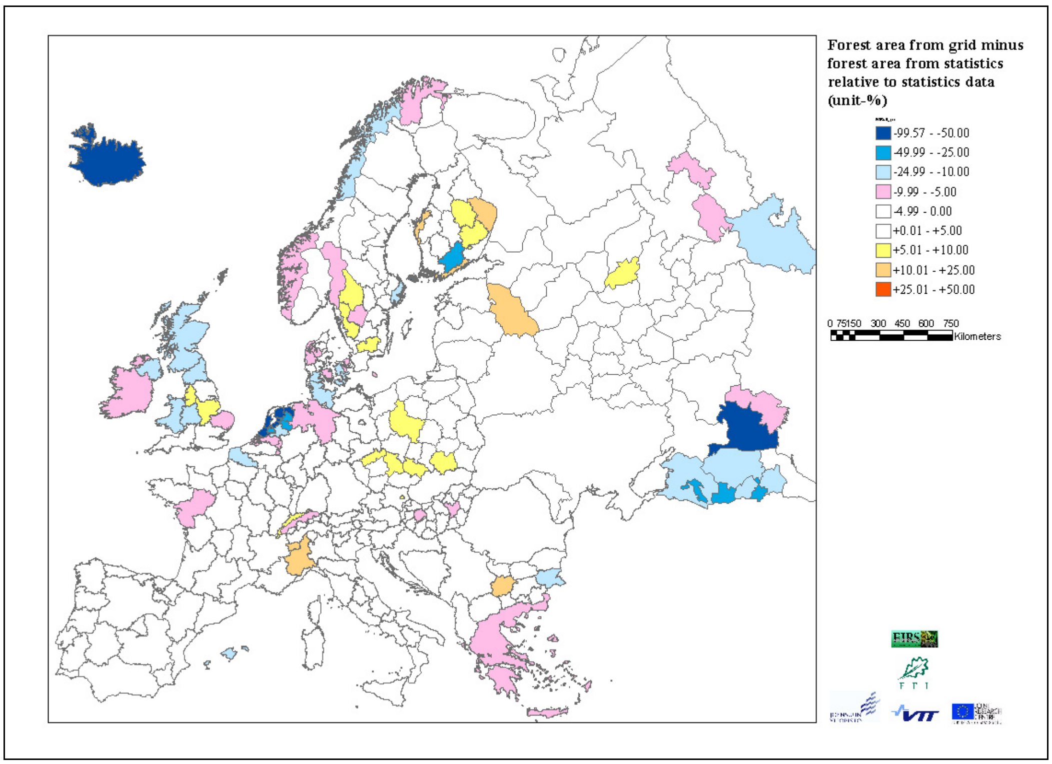


**Figure 25**. Unit-percent difference between forest statistics and the pixel-wise analysis for the forest class compared to the forest statistics. Blue to magenta: forest area from grid is lower than that from the statistics; Yellow to red: forest area from the grid is higher than that of the statistics.

Errors in land area in the grid or from the statistics can have an immediate effect on the absolute values of the forest area within a polygon, as the calibration is based on land cover percentages. Problem areas shown in Figure 23 are in many cases identical with those in Figure 25.

In addition to the factors that influence the absolute land area statistics, the accuracy or source of forest area statistics can contribute to the error.

A more detailed investigation into these inconsistencies is necessary. However such activities were not within the scope of this project and will need to be looked into in a follow-up project.

# 4 DISCUSSION

## 4.1 NOAA-AVHRR MOSAIC

The geometry of the AVHRR mosaic was improved by utilising the GTOPO30 digital terrain model. The model showed to be a useful map database for the geometric corrections. Within the project a new method for image mosaic compilation was developed, aiming at automatically excluding the cloudy pixels, eliminating the pixels with cloud shadow, and including all the pixels with good data. Comparing the results from this exercise with the spectral characteristics of the previous mosaic showed that the radiometry in the new mosaic was not significantly changed. This suggests the automatic method being successful.

The Atlantic stratum was problematic in the variables estimation because the forest area particularly in France was obviously underestimated and the border between the estimates in the Atlantic and temperate strata was distinct (Häme et al 2001). Therefore another additional output was compiled in which the continental parts of the Atlantic stratum were estimated using the model for the temperate forest. If the experimental stratification appears to be better than the original in the further evaluation of the estimation results, the original stratification should be re-considered.

## 4.2 STATISTICAL DATA

The statistical data proved to be sufficient although they were not in all cases available in a format that was required for the project. Difficulties occurred in compiling reliable data on the mixed forest class. Only a limited number of countries allowed distinguishing that class and if it was available in the statistics there were differences in the definitions of the mixed class. Due to that reason the mixed class was not used in the calibration process.

In the case of the classes ‘coniferous’ and ‘broadleaved’ it was not possible in many cases to the total forest but to production forest only. Other forest areas that were not specified by these classes then were proportionally divided to the two classes either at the national or sub-country level.

The above observations constitute weakness of the statistical data, as they did not necessarily specify explicitly all forested areas at the level of detail needed within this study. The area of production forest can be assumed as rather accurate and the level of detail may reach down to distinguishing individual species (implementation of national forest inventories). A further problem area that causes difficulties is the differences in definitions of forest between European countries. The UN-ECE/FAO provides within its TBFRA 2000 a harmonised set of forest data in which the countries have adjusted their national data to conform to the definition given by the UN-ECE/FAO. This data is however is only available at the country level.

## 4.3 POLYGONS

Digitising was necessary to receive a complete borderline map of all countries with their respective regions. The map comprises of NUTS level boundaries (NUTS V Version, Eurostat/GISCO) for the 15 EU countries, ESRI 2001. ESRI DATA & MAPS - Media Kit. Redlands and newly digitised countries at the sub-national level. The different sources were drawn together and no major obstacles were encountered. The result is a complete borderline map in reference to the calibrated data.

## 4.4 Timberline

The identification of timberlines both Arctic timberline and elevation timberline showed more difficult than expected. Expert consultations were implemented in order to receive a reliable indicator of timberlines in different European mountain ranges. The most difficulties were encountered for identifying the timberline the Fenno-Scandia region (Sweden and Norway). For future activities it could be suggested to test the potential vegetation map as a supportive tool to derive the timberline.
The elevation model GTOPO30 and the timberline information were included to the calibration process. No major problems occurred.

## 4.5 Calibration

The calibration procedure has worked satisfactory for all countries at different levels of detail (national, sub-national). The calibration method was changed to allow setting three different constraints:

- Maximum number of rounds (1-n)
- Threshold for stopping calibration process
- Criteria for last rounds (in case of same value calibration stops)

The method worked very well and showed to be flexible in responding to the number of iterations. The number of rounds ranged from 1 to a maximum of 10. An average number of iterations was 3.

The results of the calibration process were overall satisfactory. The central and northern European countries showed good results after applying the calibration. Statistics for forest area in countries such as e.g. Germany, France, Austria, Poland, Switzerland, Finland and Sweden are mainly managed forests and therefore detailed information is available. Less information from official statistics was available for unmanaged forests or alike. In parts of France, the small area of high forest proportion causes an underestimate to the total forest area.

A general observation has been that the AVHRR image is of high accuracy and that there in general is a good match between the ground inventory and the satellite imagery data. The largest discrepancies were found in Northern Europe were the inventory data showed less forest than the image data and in Southern Europe where the inventory data showed more forest than the image data.

## 4.6 Assessment of the Project Results

### 4.6.1 Questionnaire feedback

Additional information was collected via a questionnaire to inventory and remote sensing experts who were asked to – qualitatively – not quantitatively- assess the quality of the data that were used, the map output and the applied timberline. This activity is currently still ongoing. Overall the replies available to date were positive giving details on how to enhance the current result. Issues which were identified were the actuality of data, definitional aspects, and local over- and underestimation of either coniferous or broadleaved forest. One particular comment that appeared in a number of replies was the underestimation of broadleaved forest along river bodies. This may be due to the spectral reflectance of broadleaved forest in combination with that of water resembling quite closely the spectral reflectance of coniferous forest. Further good feedback was given on how to refine the both the arctic and elevation timberline. When revisiting the map the comments from the experts will be utilised for updating the current map product.

### 4.6.2 Quantitative analysis

The absolute land area and forest area data that were used to calculate the land use ratios, were compared to the calibrated polygon area that was calculated as a pixel-by-pixel sum. The calculation overall showed a good result for most of the polygons. There were however areas that deviated between 5 and 10 % - some even higher.

It remains difficult to verify the result of the calibration to the level of a pixel without the possibility to link the output with additional ground-truth data. It has shown possible to analyse the quality of the maps to a certain extent by coupling the forest area statistics (input) to the calibrated grid data (output).

## 4.7 NEW CHALLENGES

As a result of the project a number of new challenges for applying the developed methodology have emerged during the project both addressing the improvement of the current forest area maps and other possible applications.

One important issue worth pursuing further is the adjustment of forest area definitions of individual countries to reach conformity with the international definitions of UN-FAO and UN-ECE/FAO. This procedure could then be applied to regionally available statistics.

Many activities in relation to climate change, carbon sequestration and biodiversity issues are in need of individual tree species or tree species group maps at the European scale including however also the regional dimension. Applying the developed calibration method for the elaboration of tree species based maps (major tree species) or tree species groups therefore seems a timely activity.

Further the production of maps based on other parameters such as for example standing volume, woody biomass, age class distribution in European forests are needed within research.

Following a short article on the project that had been published in the EFI News (No. 1, Vol 19 2002) EFI received a wide variety of responses, questions on availability of the forest map and requests for concrete applications within ongoing research activities. Also the questionnaire yielded proposal for further enhancement. The replies contained besides some of the above-mentioned proposals for development suggestions for including additional layers (e.g. rivers, roads and cities), the use a more extensive colour coding. Also the request was made for using a finer resolution (e.g. 1ha or even smaller) so the map could actually be used for management planning at regional/local level.

The aim of the project was to calibrate forest maps on a relative (percentage) basis. By linking the output of the pixel-by-pixel analysis back to the original forest area statistics, it would be possible to calibrate the maps on an absolute area basis. This could be investigated in a further study.

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