

JRC SCIENTIFIC AND POLICY REPORTS

A European map of living forest biomass and carbon stock

Executive report

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2012



European Commission
Joint Research Centre
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JRC-IES

EUR 25730 EN

ISBN 978-92-79-28133-4 (pdf)

ISSN 1831-9424 (online)

doi: 10.2788/780

Luxembourg: Publications Office of the European Union, 2012

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Abstract

Forest ecosystems have a key role in the global carbon cycle and are considered large and persistent carbon sinks. The CO₂ fixed by photosynthesis is one of the most important components of the carbon cycle, and forests play a determinant role in this process. Therefore, spatially explicit data and assessments of forest biomass and carbon is of paramount importance for the design and implementation of effective sustainable forest management options and forest related policies at the European level.

The aim of this report is to present a summary of early results of the FOREST Action activities on forest biomass and carbon stock in Europe. In this report we present European-wide maps of forest biomass and carbon stock at IPCC Tier 1 level. Maps of forest biomass and carbon stock are relevant for quantifying terrestrial carbon storage and carbon sinks as well as for estimating potential emissions from land cover changes (afforestation, deforestation, reforestation), forest fragmentation and biotic (pests) and abiotic (e.g. forest fires, windstorms) disturbances. We describe the input data and approach, then present a summary examining the potential of the approach and further work as well as data needs in this field.

The maps presented, implemented following the IPCC methodology, represent spatially explicit biomass and carbon stock on forested land disaggregated at 1 km x 1 km grid cells. The resulting maps represent the biomass and carbon at continental level, accounting for around 90% of the total continental amounts of biomass and carbon reported in the FAO's Global Forest Resource Assessment (FRA) and State of Europe's Forest report from the Ministerial Conference on the Protection of Forest in Europe (MCPFE). To account for regional discrepancies the maps were then adjusted to match FRA amounts of biomass and carbon at the country level. This report will be followed by an extended report including methodological details of the approach implemented.

1. Forest biomass and carbon stock

1.1 Background

The focus of the Forest Resources and Climate Unit¹ is analysing the role that forests play in providing economic (e.g. timber, biomass for renewable energy, etc.) and ecological services (biodiversity and soil protection, water supply, etc.), supporting the EU eco-industry and bio-economy in a transition to a greener Europe.

Enhancing forest biodiversity is one of the main objectives of the EU Forest Strategy. Moreover, the EU has set targets to assess and halt biodiversity loss in its Biodiversity Strategy 2020. In this context, the FOREST activities on forest ecosystem services² aim at mapping, assessing, modelling and valuing forest ecosystem goods and services under natural and anthropic threats and from multiple policy perspectives.

Forest ecosystems play a key role in the global carbon cycle (Pan et al., 2011). European forests sequester increasing amounts of carbon in tree biomass. Each year about 430 million tonnes of CO₂ (MCPFE, 2011), or around 10% of total greenhouse gas emissions, are removed from the atmosphere by photosynthesis and tree biomass growth in EU countries. In these countries total carbon stock in forest biomass amounts to ~9900 million tonnes (MCPFE, 2011). Therefore spatially explicit maps of forest biomass and carbon stock are relevant for quantifying terrestrial carbon storage and carbon sinks as well as for estimating potential emissions from land cover changes (deforestation, reforestation, afforestation), forest fragmentation and biotic (pests) and abiotic (e.g. forest fires, windstorms) disturbances.

The aim of this report is to present a summary of early results of the FOREST activities on forest biomass and carbon stock in Europe. The report is organised in three sections. The current section describes the rationale, data and approach for assessing forest biomass and carbon stock. Section 2 shows preliminary results and biomass and carbon maps. This is followed by a summary section examining the potential of the approach and further work in this field.

1.2 Data and approach

Despite the relevance of baseline biomass and carbon information and maps for policy discussions on climate change, forest management, carbon storage and for assessing the economic value of forest services and products, information on forest biomass is not usually easily accessible. FAO's Forest Resource Assessment –FRA– (FAO, 2010) is a regularly updated database on forest biomass and carbon at the country level. At subnational level, publicly available biomass data from National Forest Inventories (NFI) (Tomppo et al., 2010) is not available for most European countries. Nevertheless, as mentioned above, updated gridded maps of forest biomass are necessary for several purposes.

In this study the IPCC Tier 1 method (IPCC, 2006; Ruesch & Gibbs, 2008) was used for implementing gridded biomass and carbon stock maps. The Tier 1 method is a cost-effective approach for biomass and carbon mapping over large geographical regions where gaps in accurate biomass information exist. This method is considered appropriate for continental or global studies. For assessments at higher spatial scales more accurate procedures are deemed necessary. In total four maps at 1 km grid size were implemented covering the

¹ <http://ies.jrc.ec.europa.eu/the-institute/units/forest-resources-and-climate.html>

² <http://forest.jrc.ec.europa.eu/forest-ecosystem-services>

European continent: i.e. above ground and total (above and below ground) living forest biomass and above ground and total carbon stock in living forest biomass.

IPCC Tier 1 method applied to forest biomass requires two types of data input. First, maps of forest types (coniferous and broadleaved) and the map of Global Ecological Zones for the Global Forest (FAO, 2001) (Figure 1). Secondly, several average amounts and factors sourced from the IPCC report on Guidelines for National Greenhouse Gas Inventories (IPCC, 2006): average amount of biomass in forest per ecological zone, ratio of below ground biomass to above ground biomass per ecological zone and carbon fraction of forest biomass.

The maps accounting for the area of coniferous and broadleaved forest types were sourced from CORINE land cover data (EEA, 1993; EEA, 2000) of 2006³ at 100 m grid size. CORINE data at 100 m grid size were converted to 1 km grid size maps of coniferous (Figure 2) and broadleaved forest (Figure 3). Three CORINE land cover classes were considered for computing the area of each forest type: broad-leaved forest, coniferous forest and mixed forest. This last category was assumed to contain 50% broadleaved and 50% coniferous forest.

At the grid cell level the method computes forest biomass by the product of forest area and the average amount of biomass in the forest in the corresponding ecological zone. Then ratios are applied for computing the proportion of above/below ground forest biomass and carbon fraction. An additional step was implemented for adjusting the biomass and carbon amounts computed in the maps with data from the FAO's FRA (FAO, 2010). The maps are then adjusted at the country level, therefore matching amounts of biomass and carbon as presented in FRA.

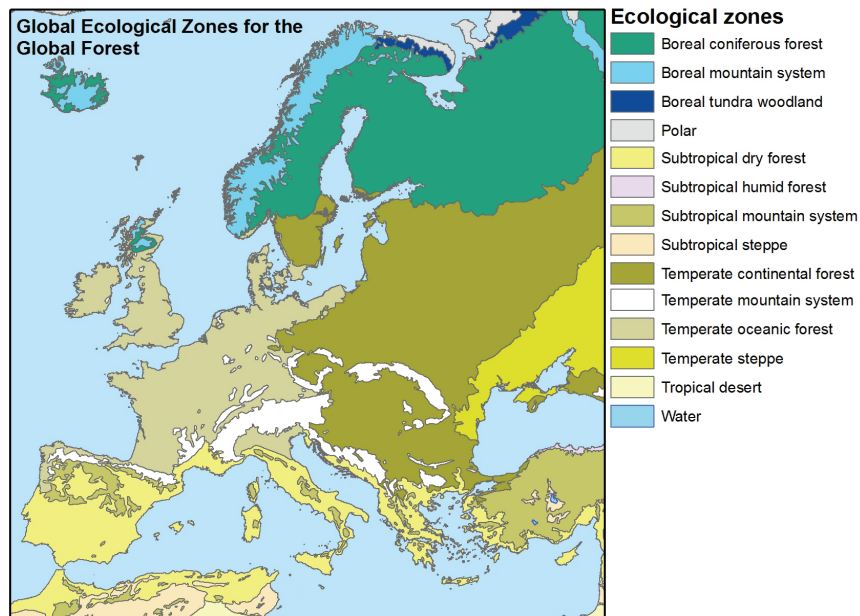


Figure 1. Map of Global Ecological Zones for the Global Forest. Source: FAO (2001).

³ <http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-clc2006-100-m-version-12-2009>

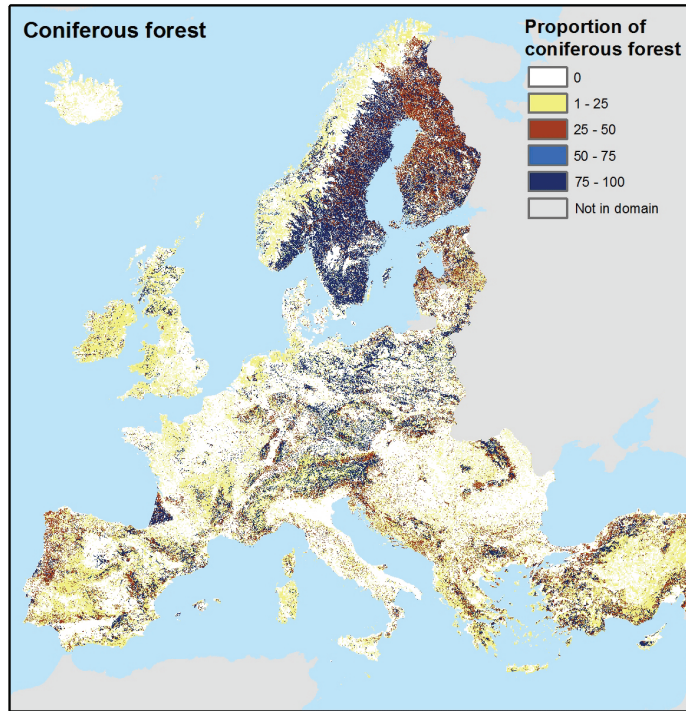


Figure 2. Coniferous forest map of Europe. Baseline data from CORINE land cover.

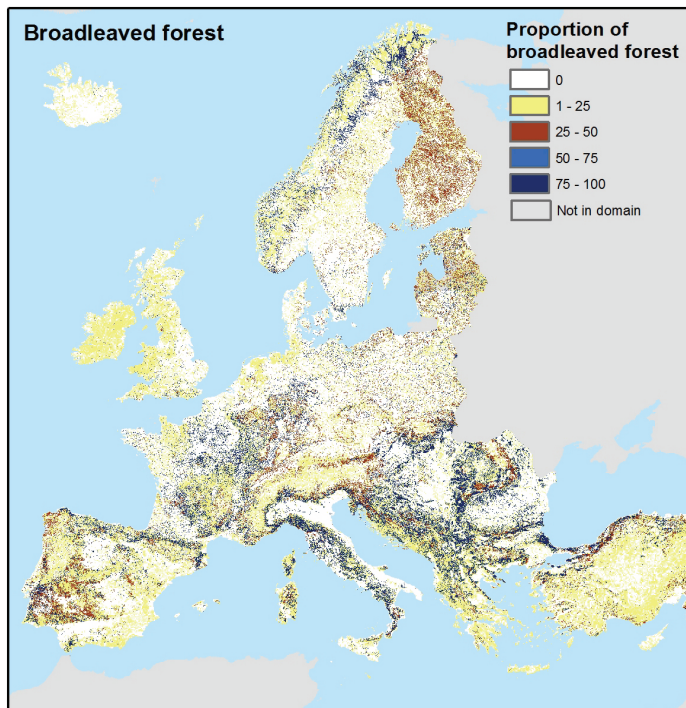


Figure 3. Broadleaved forest map of Europe. Baseline data from CORINE land cover.

2. Main preliminary results

The most salient results of this study are gridded maps of above ground and total forest biomass and carbon stock in forest biomass in Europe. Overall accuracy of the maps was assessed comparing, at country level, the maps with biomass and carbon amounts reported in FRA 2010 (FAO, 2010). Despite a general tendency towards underestimation, results of this assessment indicate that the maps represent reasonably well the biomass and carbon at continental level. The maps account for around 90% of the total continental amounts of biomass and carbon reported in FRA. Additionally we regressed amounts of biomass and carbon at country level from the maps with FRA data obtaining statistically significant R^2 values ≥ 0.87 (Table 1).

	Above ground forest biomass	Total forest biomass	Carbon in above ground forest biomass	Carbon in total forest biomass
Overall accuracy (%)	89	91	90	94
R^2	0.87*	0.87*	0.88*	0.88*
Total in map (10⁶ tonnes d.m.)	17,252	22,130	8,471	11,153
Total in FRA (10⁶ tonnes d.m.)	19,307	24,276	9,454	11,884

Table 1. Accuracy assessment of the biomass and carbon maps, comparison at country level with data from the Global Forest Resource Assessment –FRA– (FAO, 2010). Overall accuracy: indicates the proportion of biomass/carbon computed in the maps in relation to FRA at continental level. R^2 is the coefficient of determination i.e. the proportion of variability explained by the regression model (see text); (*) statistically significant at 5% ($\alpha=0.05$). Total in maps and in FRA are the amounts computed from the maps and reported in FRA respectively at continental level.

Despite good agreement between the maps and FRA at continental level, a closer look at country level reveals higher discrepancies. In some cases the amounts in the maps are reasonably in line with FRA ($\pm 10\%$), while in other cases there is a larger discrepancy. To mitigate these discrepancies the maps were adjusted using biomass and carbon data from FRA. An adjusting ratio was computed for each country and applied on each grid cell to create adjusted biomass and carbon maps. The adjusted maps are in line with reported biomass and carbon in FRA at country level and therefore at continental level. The map in Figure 4 represents amounts of biomass on forested land disaggregated at 1 km grid cells. In addition to the areas shown in the maps, the spatial domain also includes the Canary Islands and Turkey (not totally shown in the figures for better readability of the maps). The carbon map (not shown) was implemented from the biomass map using the carbon fraction of forest biomass (~ 0.5).

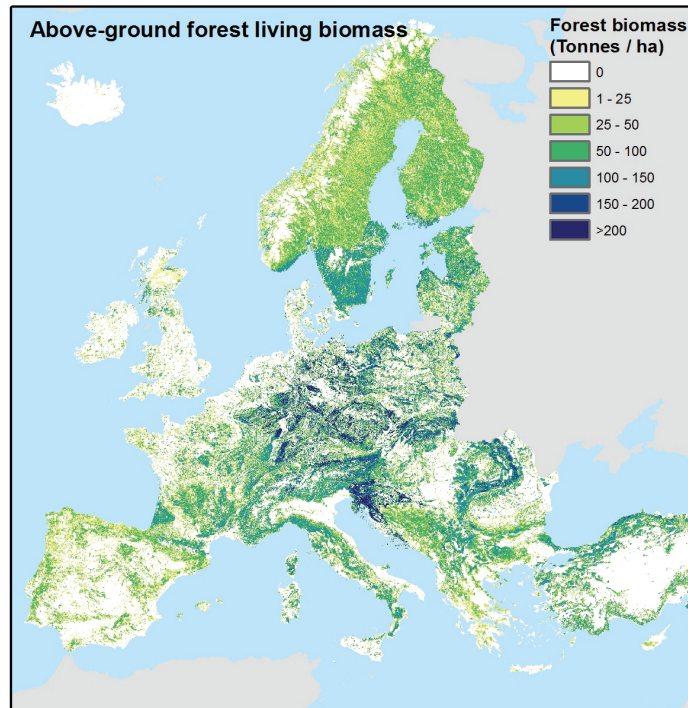


Figure 4. Map of above ground forest living biomass at 1 km grid size. Map implemented using IPCC TIER 1 methodology and adjusted with data from FAO's FRA.

Figures 5 and 6 show amounts of biomass and carbon aggregated at NUTS-2 level⁴. These maps result from adding amounts of biomass and carbon of all grid cells corresponding to each NUTS-2 region. Table 2 shows estimated amounts of above ground forest biomass and carbon in a sample of six NUTS-2 regions. The aggregated maps provide an overview of the geographical distribution of forest biomass and carbon stock. Nevertheless, two issues should be considered regarding these maps. First, that the maps have been verified at the continental level and then adjusted at the country level; however the maps are not validated with field data. And second, size differences of the NUTS-2 regions may introduce distortions in the perception of the distribution of biomass and carbon stock.

A preliminary accuracy assessment of the maps at NUTS-2 level was implemented using available biomass data from the NFIs of Spain⁵, Portugal⁶, Sweden⁷ and Italy⁸. Data on total biomass at NUTS-2 is available for the first three countries and above ground biomass for Italy. Despite the expected reliability of NFI data, a degree of uncertainty is introduced in the accuracy assessment due to different definitions used in NFI, something that could introduce some distortion regarding the comparability of the biomass and carbon amounts included in the different NFIs.

⁴ A description of the NUTS system is available at:

http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction

⁵ http://www.magrama.gob.es/en/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/tablas_resumen_IFN3.aspx

⁶ <http://www.icnf.pt/portal/florestas/ifn/ifn5/relatorio-final-ifn5-florestat-1>

⁷ <http://www.slu.se/en/webbtjanster-miljoanalys/forest-statistics>

⁸ http://www.sian.it/inventarioforestale/jsp/dati_carquant_tab.jsp

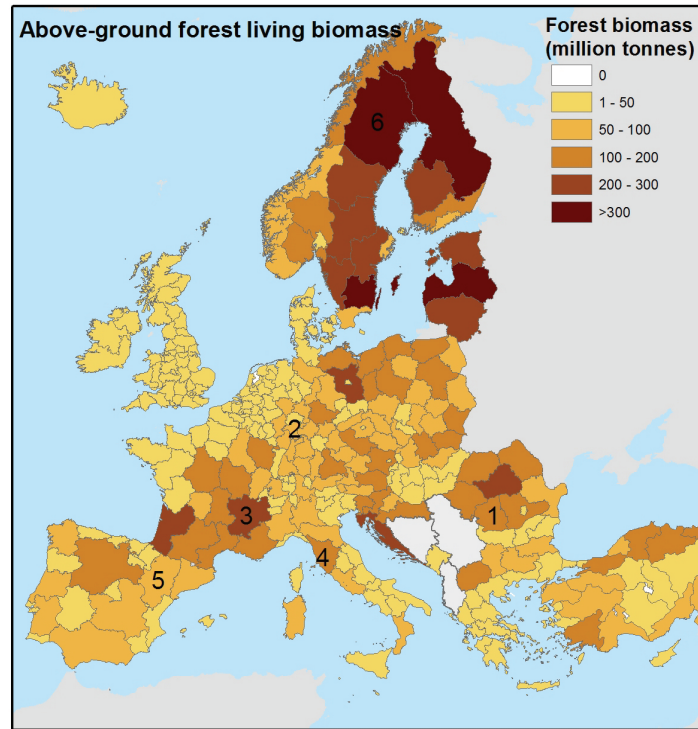


Figure 5. Map of above ground forest living biomass aggregated at NUTS-2 level. Baseline map implemented using IPCC Tier 1 methodology and adjusted with data from FAO's FRA. Numbers in the map link with Table 2. © EuroGeographics for the administrative boundaries.

Reference number in maps of Fig. 5 and 6	NUTS-2 code	NUTS-2 name	Estimated above ground forest biomass (10 ⁶ tonnes d.m.)	Estimated carbon in above ground forest biomass (10 ⁶ tonnes d.m.)
1	RO41	Sud-Vest Oltenia	131	61
2	DE71	Darmstadt	63	31
3	FR71	Rhône-Alpes	230	109
4	IT11	Toscana	126	58
5	ES24	Aragón	67	32
6	SE33	Övre Norrland	469	235

Table 2. Estimated above ground forest biomass and carbon in a sample of NUTS-2 regions. The reference number identifies the regions in the maps of figure 5 and 6.

Three measures of accuracy were computed (Table 3). First, we regressed amounts of biomass at NUTS-2 level from the maps with NFI data obtaining statistically significant R^2 values of 0.89 and 0.84 for the group of three countries and Italy respectively. Therefore, the computed biomass explains respectively 89% and 84% of the variability of the data from the NFIs. Second, the absolute accuracy of the total amount (all NUTS regions) of biomass computed in the group of tree countries and Italy is 99% and 86% respectively. Finally, mean absolute error (MAE) (Willmott & Matsuura, 2005) indicates that 68% of the residuals of the regression fall between ± 35 and ± 10 million tonnes of biomass in the group of three countries and Italy respectively (Figure 7). These results suggest that despite the limitations

of the approach and data used for mapping biomass and carbon, the maps at NUTS-2 level represent faithfully the amounts of biomass and carbon as reported in the NFI.

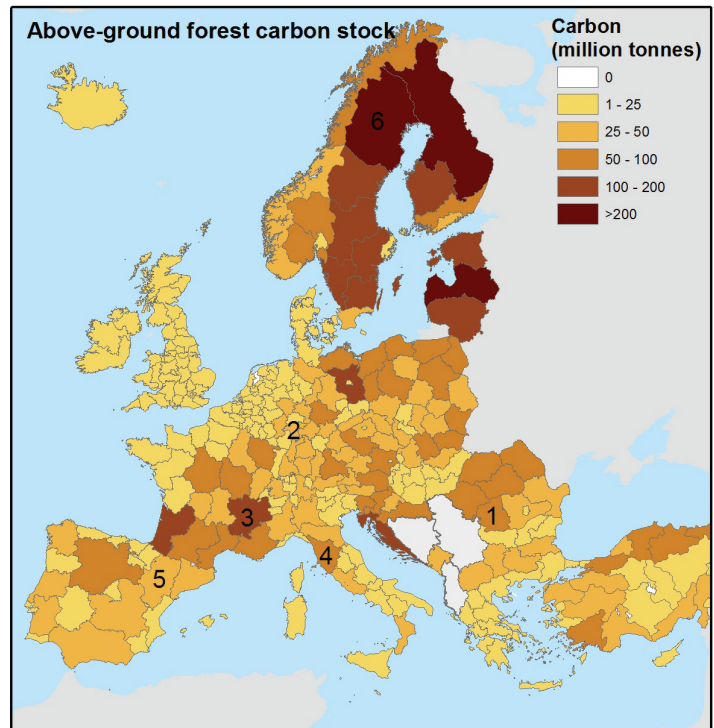


Figure 6. Map of above ground forest carbon stock aggregated at NUTS-2 level. Baseline map implemented using IPCC Tier 1 methodology and adjusted with data from FAO's FRA. Numbers in the map link with Table 2. © EuroGeographics for the administrative boundaries.

3. Summary

Preliminary results of this study are the Tier 1 maps of biomass and carbon stock for Europe. The maps are a faithful representation of the amounts of forest biomass and carbon at the continental level. The approach used, first implemented by Ruesch and Gibbs (2008), has many advantages. It is simple, transparent and a cost-effective option for biomass mapping over large areas. In addition this approach uses the standard and widely accepted IPCC (2006) Tier 1 method for carbon stock estimation. Nevertheless our resulting maps are subject to a number of constraints. Among the constraints the first is that the maps were not validated using ground level data on biomass. Second, the Tier 1 approach using the FAO's Map of Global Ecological Zones may create abrupt changes between ecological zones. The same effect may be observed in the adjusted maps in country borders. Despite these limitations the maps represent baseline information for further assessments regarding forest biomass and carbon stock at pan-European level.

	Total biomass	Above ground biomass
Countries assessed	Spain, Portugal and Sweden	Italy
Number of NUTS-2 regions	30	21
Total in NFIs (10⁶ tonnes d.m.)	3,604	874
Total in maps (10⁶ tonnes d.m.)	3,640	998
Absolute accuracy of total amount (%)	99	86
R²	0.89*	0.84*
MAE (10⁶ tonnes d.m.)	35	10

Table 3. Accuracy assessment of the biomass map, comparison at NUTS-2 level with data from National Forest Inventories (NFI). R^2 is the coefficient of determination i.e. the proportion of variability explained by the regression; (*) statistically significant at 5% ($\alpha=0.05$). MAE is the mean absolute error.

Other studies mapping forest biomass either at the continental or global scale share some common limitations with this study regarding lack of biomass field data for model fitting and/or validation. Kindermann et al. (2008) produced a global study mapping biomass at half degree resolution using net primary productivity (NPP), human impact and FRA data at country level as independent variables. Their approach consisted of downscaling the country-level data of FRA at half-degree grid cells. Ruesch and Gibbs (2008) implemented a global biomass carbon map at the 1 km grid size using IPCC Tier 1 method (the method used in this report). Also in this case, the method was not validated with field data. At pan-European level Kindermann et al. (2009) presented a 1 km grid size map of forest biomass using NPP, species-specific yield tables and land cover data. Although the resulting map is at pan-European scale it was validated for one Austrian region using Lidar data as a proxy for above ground biomass. In summary, lack of accessible biomass field data limits the implementation of accurate maps of biomass and their validation.

Assessments with high accuracy at sub-national level would demand methods and data applicable at higher spatial resolutions for improving the accuracy of the maps and reducing uncertainty, but the complexity and resources required also increases. For instance, ideally a consistent number of field data (samples at plot level) on canopy height, basal area, growing stock and biomass would be used in model development, fitting and validation. Integration of this information with environmental predictors of forest biomass would produce more reliable and validated continental-wide maps of forest biomass and carbon stock. Additionally, harmonised biomass data at NUT2/3 levels for the countries covering the spatial domain would allow a more robust accuracy assessment of the maps.

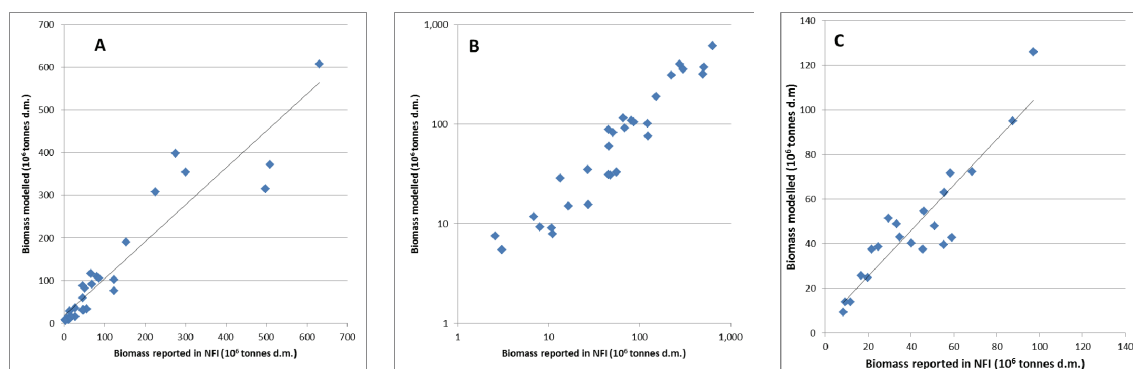


Figure 7. Regression of the computed biomass at NUTS-2 level with biomass data from National Forest Inventories. A) Total biomass in Spain, Portugal and Sweden; B) same as A but with logarithmic scale in X and Y axes; C) Above ground biomass in Italy.

The maps presented are a spatially explicit representation of the amount of biomass/carbon on each grid cell, thus providing information on where the biomass is located within each country. This allows biomass/carbon estimates at subnational NUTS level. The adjusted maps provide information in line with FRA and the Ministerial Conference on the Protection of Forest in Europe (MCPFE) and are in reasonable good agreement with subnational data from NFI. Therefore, the maps are useful for estimating potential emissions from spatial forest dynamics such as deforestation, afforestation, forest fragmentation and disturbances. Furthermore the maps provide baseline information for assessing the value of forest ecosystem goods and services at pan-European level.

The CO₂ fixed by photosynthesis is one of the most important components of the carbon cycle, where forests play a determinant role, being thus considered as large and persistent carbon sinks (Pan et al., 2011). Forest ecosystem services constitute the direct and indirect contributions of forest to human wellbeing. Therefore, baseline information and assessments of forest functions and services is of paramount importance for the design and implementation of effective sustainable forest management options and forest related policies at the European level.

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European Commission

EUR 25730 EN – Joint Research Centre – Institute for Environment and Sustainability

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Luxembourg: Publications Office of the European Union

2012 – 12 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series

ISSN 1831-9424 (online)

ISBN 978-92-79-28133-4 (pdf)

doi: 10.2788/780

Abstract

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