Spatial distribution of regional whole tree carbon stocks and fluxes of forests in Europe

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ABSTRACT

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Keywords: forest carbon stock, forest carbon flux, Europe, greenhouse gasses, carbon sequestration

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Contents

Preface

This project was carried out through funds made available under the framework of the Dutch National Research Programme on Global Air Pollution and Climate Change (NOP-MLK), registered under nr: 958254. Additional funds were provided by the 'Climate Programme' of the Agricultural Research Department (DLO). We like to thank the country data correspondents who supplied their national forest inventory data in 1996 for the European Scenario Studies, carried out by the European Forest Institute and Alterra: Prof. Dr. A. Postoli & Mr. F. Hoxha, Albania; Hr. D.I. K. Schieler, Austria; Prof. Dr. J. Rondeux & Mr. W. Buysse, Belgium; Dr. I. Angelov, Bulgaria; Prof. Dr. M. Harapin, Croatia; Mr. M. Kraus, Czech Republic; Dr. P. Munkplum, Denmark; Prof. E. Tomppo, Finland; Dr. G. Pignard, France; Dipl. Ing. H. Englert & Dr. V. Sasse, Germany; Dr. I Meliadis, Greece; Mr. P. Csoka, Hungary; Dr. P. Dodd, Ireland; Dr. F. Cozza, Italy; Mr. M. Wagner, Luxembourg; Ir. H. Schoonderwoerd, The Netherlands; Mr. S.M. Tomter, Norway; Dr. Glaz & Dr. J. Wawrzoniak, Poland; Prof. Dr. J. Borges & Mr. A. Leite, Portugal; Mr. T. Tudor & Mr. I Ciurea, Romania; Dr. I. Luptak, Slovak Republic; Dr. Hocefar, Slovenia; Dr. J.A. Villanueva, Spain; Dr. U. Söderberg, Sweden; Dr. U.-B. Brändli, Switzerland; Mr T. Otrakçýer, Turkey; Dr. R. Coppock, United Kingdom.

Summary

This report is part of the project 'Interactions between land use, atmospheric concentration of greenhouse gasses and climate in Western Europe and their consequences for post-Kyoto policy options'. The project aims to investigate the role of land use and land use change in the climate system and to quantify the consequences of, and a potential for land use options in relation to "post-Kyoto" emission reduction and climate policies in North Western Europe.

This report presents carbon stocks and fluxes of the whole tree biomass of European forests and other wooded land, distinguished by coniferous, deciduous and mixed forests. The results are presented at European, national and (where possible) regional level. Results concerning carbon stock, NEP and NBP for the whole tree biomass were derived from a detailed European forest resource database and converted to carbon using biomass expansion factors. Uncertainties and differences with other estimates are discussed.

Based on these detailed national forest inventory data, the estimated carbon stock in whole tree biomass for the European forest, excluding Russia and the Newly Independent States, amounts to 6.15 Pg C. The annual flux before harvest is estimated at 217 Tg C and the annual flux after harvest is estimated at 77 Tg C. The variation in stocks and fluxes throughout Europe are large, with the highest carbon stocks per hectare in Central Europe and the highest fluxes in regions with abundant precipitation and a not too extreme temperature regime. At the moment there are no indications that the current carbon sink will saturate.

1 Introduction

The global carbon cycle is heavily perturbed by human activities, especially by emissions of carbon dioxide from the combustion of fossil fuels and changes in land use. Of all the carbon dioxide emitted, only about half remains in the atmosphere. The rest is absorbed in oceans or stored, at least temporarily, in the terrestrial biosphere. Carbon sequestration by terrestrial ecosystems, in living biomass and dead organic matter (including soils), plays a critical role in the global carbon cycle. The fluxes of carbon dioxide in photosynthesis and respiration are approximately ten times larger than the emissions from the use of fossil fuels and land use change. Therefore, a small relative imbalance between carbon fixation through photosynthesis and loss through respiration can produce a net source or sink that is a sizeable fraction of the anthropogenic emissions. Humans influence the fluxes of carbon between the terrestrial pools and the atmosphere both indirectly, through impacts on atmospheric CO_2 and climate, and directly, through land use and land use change, e.g. through forestry activities and deforestation.

During the 1980s, the estimated amount of carbon stored in terrestrial ecosystems increased by about 0.2 Pg C y^{-1}, based on the residual from human emissions, the atmospheric increase, and oceanic uptake. This is the difference between a net emission of about 2 Pg C y^{-1} from land use changes, primarily in the tropics, and uptake of about 2.2 Pg C y^{-1} (Watson and Verardo 2000, Tans et al 1990, Ciais et al. 1995, Keeling et al. 1996). It is this latter terrestrial carbon uptake that is the subject of ongoing debate. Is it in the Northern Hemisphere north of 30°N, or primarily in tropical rain forest (Grace et al. 1995, Philips et al. 1998)? If it is in the Northern Hemisphere, what is the longitudinal distribution (Fan et al. 1999)?

The debate has concentrated on the role of the North American continent. Using inverse modelling techniques based on the atmospheric CO_2 sampling network, Fan et al. (Fan et al. 1999) estimated a North American carbon sink of 1.7 ± 0.5 Pg C y^{-1}, largely south of 51°N. However, Houghton et al. (1999), using historical land-use data for the USA, and Schimel et al. (2000), using biogeochemical models for the conterminous USA, estimated the 1990 carbon sink to be an order of magnitude smaller. A comparable magnitude of uncertainty also surrounds the estimates for the European terrestrial biospheric sinks (Valentini et al. 2000).

In the midst of this uncertainty lies the current effort of the 174 nations, who negotiated the Kyoto protocol, to develop a set of consistent regulations to monitor the net reductions in CO_2 emissions. Articles 3.3 and 3.4 of the Kyoto protocol allow for Annex I nations to partially offset their emissions of CO_2 by carbon accumulated due to forest management and “additional human-induced” land-use change. In both cases the Annex I countries are committed to report the related sources and sinks of greenhouse gases in a “transparent and verifiable manner”.

Disagreements centring on these “Kyoto sinks” were arguable responsible for the failure of the 6th Conference of the Parties (The Hague, Nov 2000). Differing opinions regarding the utility of managed land to offset emissions are indicative of uncertainties over the processes governing the spatial and temporal variation of current sources and sinks of CO_2. It is therefore vitally important to address the scientific questions about the spatial and temporal evolution of the terrestrial carbon sink in the European terrestrial biosphere, its causes and persistence.

To deal with these questions the project ‘Interactions between land use, atmospheric concentration of greenhouse gasses and climate in Western Europe and their consequences for post-Kyoto policy options’ was formulated. The project aims to investigate the role of land use and land use change in the climate system and to quantify the consequences of, and a potential for land use options in relation to “post-Kyoto” emission reduction and climate policies in North Western Europe. It was proposed to use, and where needed, to adapt existing state-of-the-art modelling tools in combination with socio-economic analysis and supported by available pan-European data to achieve this aim. Stand- and landscape scale biogeochemical, carbon and vegetation growth models, a regional atmospheric modelling system, a global climate model and an integrated assessment model have been used in this project.

The underlying report is part of the first subproject ‘inventory of greenhouse budgets’ which as a whole has the aim to make a detailed budget of trace gas exchange for European land cover, by combining state of the art land use/cover and soil data sets, with vegetation and soil class specific source/sink strengths. This report focuses within that framework on the conversion of forest inventory data to carbon stocks and fluxes.

2 Methods and data

2.1 Introduction

A managed forest ecosystem consists of three main carbon stocks. The living tree biomass, soils and wood products. Carbon is exchanged between these pools and the atmosphere through photosynthesis and both autotrophic and heterotrophic respiration (Figure 2.1).

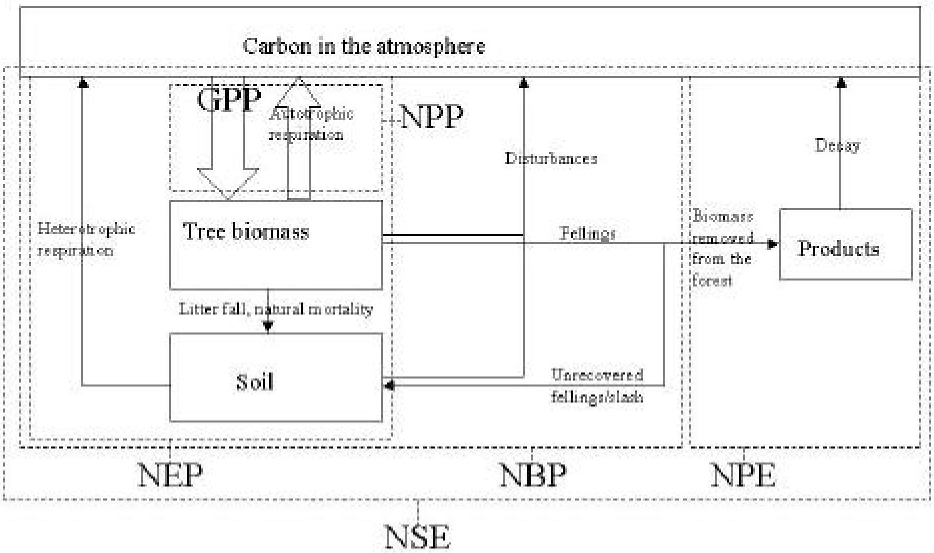

*Figure 2.1. The full forest sector carbon cycle (*Note: the size of the boxes does not represent the absolute size of the carbon stock*). GPP=Gross Primary Production, NPP=Net Primary Production, NEP=Net Ecosystem Production, NBP=Net Biome Production, NPE=Net Product Exchange, NSE=Net Sector Exchange.*

Many methods are available to quantify (parts of) this system at various scales. These include biogeochemical modelling, inversion techniques and inventory based carbon budgeting. Here, the latter is employed, but only for the whole tree biomass compartment. In most European countries one or more forest inventories have been carried out (EFICS 1997). In such inventories the focus is on characteristics like forest area, standing stemwood volume and stemwood volume increment, although currently more attention is paid to other values, like nature conservation and recreational aspects. These inventories provide a good basis for estimates of the carbon sequestration of the tree biomass, since the wood volumes can be converted to carbon quantities by using conversion factors. Several steps are required to convert inventory measurements to a full forest sector carbon balance. Timber stocks and growth are nearly always reported in terms of growing stock volume, which is the volume of the bole portion of living trees that exceed a threshold diameter. To convert from growing stock volume to estimates of the carbon content of the whole tree biomass, species- and region-specific conversion factors or regression equations have been developed from measurements of plant biomass, carbon content, and allometry. Improved and more detailed conversion factors have substantially refined previous estimates of forest carbon stocks and changes (UN-ECE 2000). These latter conversion factors have been used in this study as well (Annex 1) for both converting standing volume and volume increment (see also the discussion).

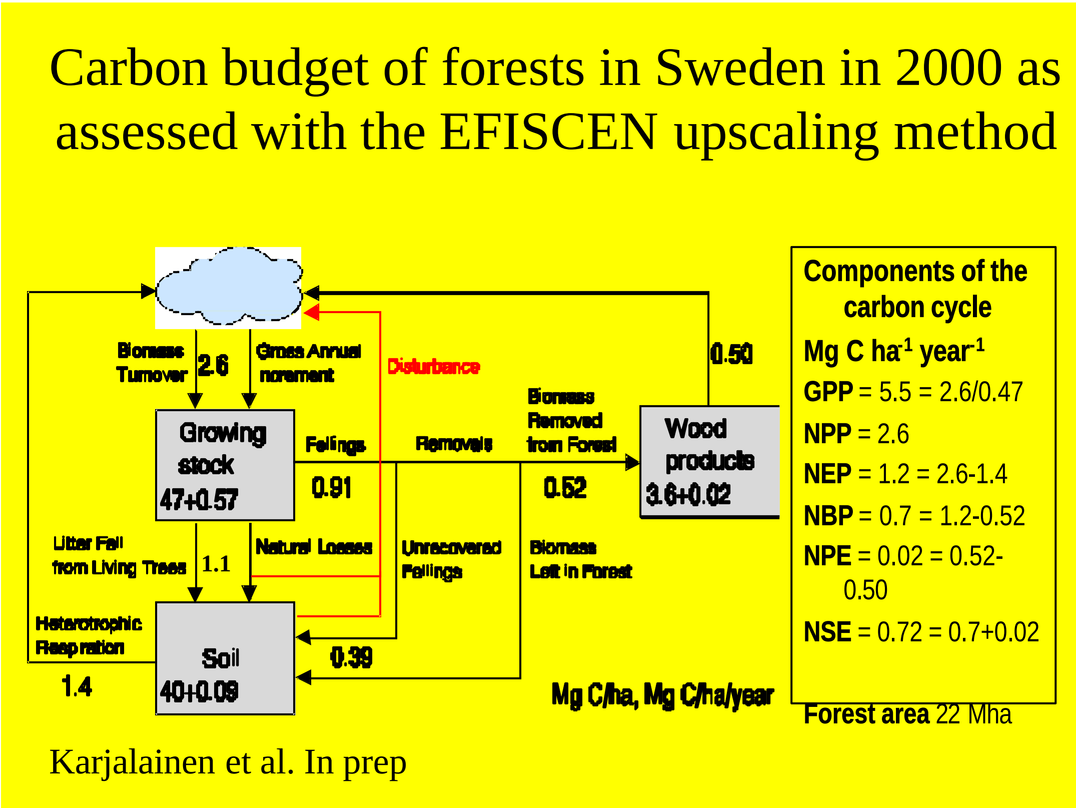

Figure 2.2. A typical full forest sector carbon budget for a Swedish stand (all values at hectare scale). The current report deals with the variables (NEP and NBP) only for the growing stock (= whole tree) compartment. See figure 1 for an explanation on the abbreviations.

In a full forest sector carbon balance study such whole tree carbon information would be used to model litterfall and addition to soils etc. Here we assume that the input and output of the soil carbon is in balance. Furthermore in a full forest sector carbon balance the management would be included through felling statistics and a wood products compartment. Here it was assumed that all harvested wood decays in the year of harvest, and therefore only the carbon sink in the forest before (Net Ecosystem Production, NEP) and after harvest (Net Biome Production, NBP) is presented.

2.2 Forest land

The data on which the calculations are based were gathered in the European Forest Scenario Modelling Project of the European Forest Institute (EFI). From all European countries[1] detailed results of their forest inventories were gathered, separated into forest types, where forest types could be distinguished by region, owner class, site class and tree species, dependent on the level of detail of the inventory. Per forest type the area, standing volume and current annual increment were given, separated into age classes. An electronic database containing all these data (EFISCEN's European Forest Resource (EEFR) database) has been compiled and is available on the internet (Schelhaas et al 1999). In order to comply with the format of the available landuse maps, the data were aggregated over all age classes, site classes and owner classes into the groups conifers, broadleaves and mixed forest. The EEFR database represents the situation in European forests for the period mid 1980s to mid 1990s.

In the Temperate and Boreal Forest Resource Assessment 2000 (UN-ECE/FAO 2000), conversion factors are given per country and tree species group (conifers/broadleaves) for conversion from wood volume to above stump dry woody biomass (see Annex 1, column 1 and 2). For the below stump woody biomass a conversion factor is given for conifers and broadleaves together per country (see Annex 1, column 3). When these conversion factors are put together, a conversion factor from wood volume to whole tree biomass is obtained. In concordance with UN-ECE/FAO 2000, we assumed a carbon content of 50% of dry woody biomass. The standing volume and increment figures per tree species group and region were converted to carbon using the above mentioned method, yielding estimates of total tree carbon stock and total tree carbon flux before harvest, equal to the Net Ecosystem Production (NEP).

UN-ECE/FAO 2000 also provides data on the ratio between fellings and increment per country and tree species group. By combining these ratios with the aforementioned carbon flux before harvest, the total tree carbon flux after harvest was calculated, which is equal to the Net Biome Production (NBP).

2.3 Other wooded land

Because the interest of many countries was usually aimed at the wood production function of forests, data on other wooded land is usually scarce. In UN-ECE/FAO (2000), countries were asked to submit data on other wooded land as well, but only few countries actually submitted data. For the countries where enough data were

1 The EEFR database covers the countries: Albania, Austria, Belgium, Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Leningrad region (part of the Russian Federation), Luxembourg, Macedonia, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and Yugoslavia

available, the following procedure is applied: Estimates of total above stump woody carbon biomass were given for the categories forest land, and forest and other wooded land, including trees outside the forest. The difference is the total above stump woody carbon biomass at other wooded land and trees outside the forest. Total gross increment is given for trees outside the forest and other wooded land separately. The ratio between these is used to divide the above stump woody carbon biomass over trees outside the forest and other wooded land. The resulting above stump woody carbon biomass on other wooded land is divided by the area of other wooded land to arrive at an estimate per hectare. Stump and root carbon biomass is only given for the category forest and other wooded land. By dividing this figure by the total area of forest and other wooded land, an estimate per hectare was obtained. It was assumed that the amount of stump and root biomass was the same on forest land as on other wooded land. Together with the above stump woody carbon biomass as calculated above this yielded an estimate of total carbon stock in woody biomass on other wooded land.

For the estimation of carbon flux before harvest, net volume increment on other wooded land was converted to carbon using the same conversion factors as on forest land. Not for all countries increment figures were available, for the other countries the weighted average of all available countries was taken. The carbon flux after harvest was calculated using the same ratio of harvest/net annual increment as for forest land.

3 Results

3.1 Country level results for 'forest land'

The total amount of carbon in the European whole tree biomass as derived from the EEFR database (135.8 million ha of forest) amounted to 6.15 Pg C. The total whole tree NEP for European forests amounted to 216 Tg C y^{-1}, the NBP amounted to 76.7 Tg C y^{-1}.

Table 3.1 Total whole tree carbon stock and fluxes before and after harvest for all tree species per country and total whole tree carbon stock and flux after harvest as given by UN-ECE/FAO (2000).

Country	Total whole tree carbon stock (Tg C)	Total whole tree carbon flux before harvest (Tg C/yr) (=NEP)	Total whole tree carbon flux after harvest Tg C/yr) (=NBP)	UN-ECE/FAO total whole tree carbon stock (Tg C)	UN-ECE/FAO total whole tree carbon flux after harvest (Tg C/yr)
Albania	23.14	0.92	0.20	34.37	0.12
Austria	500.07	15.87	4.54	573.71	5.15
Belgium	30.05	1.23	0.13	38.92	0.22
Bosnia Herzegovina	15.00	0.59	0.29	86.80	1.37
Bulgaria	120.80	4.39	2.14	160.57	2.65
Croatia	49.26	1.50	0.57	109.75	1.12
Czech Republic	186.71	2.68	0.63	207.00	2.13
Denmark	20.25	1.18	0.37	16.97	0.30
Finland	587.96	22.76	5.49	634.49	6.64
France	520.15	21.11	7.37	794.27	9.92
Germany	849.78	26.66	12.05	920.00	14.02
Greece	34.21	0.90	0.39	46.70	0.59
Hungary	119.55	4.37	1.77	123.05	1.91
Ireland	10.60	1.36	0.44	8.70	0.35
Italy	232.96	9.94	5.03	382.45	6.95
Norway	201.24	6.10	2.85	240.23	4.56
Luxembourg	8.11	0.26	0.05	6.49	0.09
Macedonia	16.30	0.81	0.40	20.32	0.00
Poland	335.60	9.92	1.96	487.80	5.49
Portugal	45.70	2.79	0.46	88.96	1.45
Romania	386.79	17.49	7.48	468.95	7.35
Slovak Republic	130.41	3.10	1.33	164.00	3.43
Slovenia	100.87	2.08	1.33	110.85	1.89
Spain	186.83	10.63	6.55	175.41	4.49
Sweden	926.73	31.59	6.74	1007.00	10.85
Switzerland	121.41	3.08	0.44	131.25	0.71
The Netherlands	23.34	1.07	0.35	25.47	0.40
Turkey	246.18	5.32	2.51	399.78	7.93
United Kingdom	74.51	4.76	1.66	115.82	1.79
Yugoslavia	43.77	2.07	1.20	50.13	1.32
Subtotal	**6148.28**	**216.5**	**76.7**	**7630.21**	**105.19**

Country	Total whole tree carbon stock (Tg C)	Total whole tree carbon flux before harvest (Tg C/yr) (=NEP)	Total whole tree carbon flux after harvest Tg C/yr) (=NBP)	UN-ECE/FAO total whole tree carbon stock (Tg C)	UN-ECE/FAO total whole tree carbon flux after harvest (Tg C/yr)
Cyprus				1.52	0.01
Estonia				100.37	1.23
Iceland				0.37	0.02
Israel				2.01	0.10
Latvia				176.41	2.52
Liechtenstein				0.51	0.00
Lithuania				117.71	1.96
Malta				0.06	
Armenia				13.02	0.07
Azerbaijan				57.45	0.64
Belarus				372.39	5.65
Georgia				167.20	1.37
Kazakhstan				101.19	1.54
Kyrgyzstan				7.76	
Republic of Moldova				12.28	0.23
Russian Federation				38901.34	428.79
Tajikistan				2.16	0.03
Turkmenistan				6.06	0.05
Ukraine				545.47	7.36
Uzbekistan				4.12	

Some analyses of the results at the country level are presented below. Figure 3.1. shows that the total carbon stock in European forests is concentrated in five large forestry countries in Europe namely Austria, Finland, France, Germany and Sweden). These five together represent 55% of the total carbon stock. Figure 3.2. then shows an almost perfect linear relation between the national level tree C stock and the C sink in the country. This indicates that countries with a large stock do not show any signs of saturation of the sink.

Due to regular management of thinning and final fellings, approximately 60 to 70 % of the increment is annually harvested, depending on the country. This is clearly shown in Figure 3.3. which gives the relation between NEP and NBP for the European countries.

Estimates of NBP as presented in UN-ECE/FAO (2000) and as presented in this study are compared in Figure 3.4. Even though the same conversion factors were used, the UN-ECE/FAO estimates are usually higher, which is caused by the fact that the EEFR data mostly only cover the productive forests.

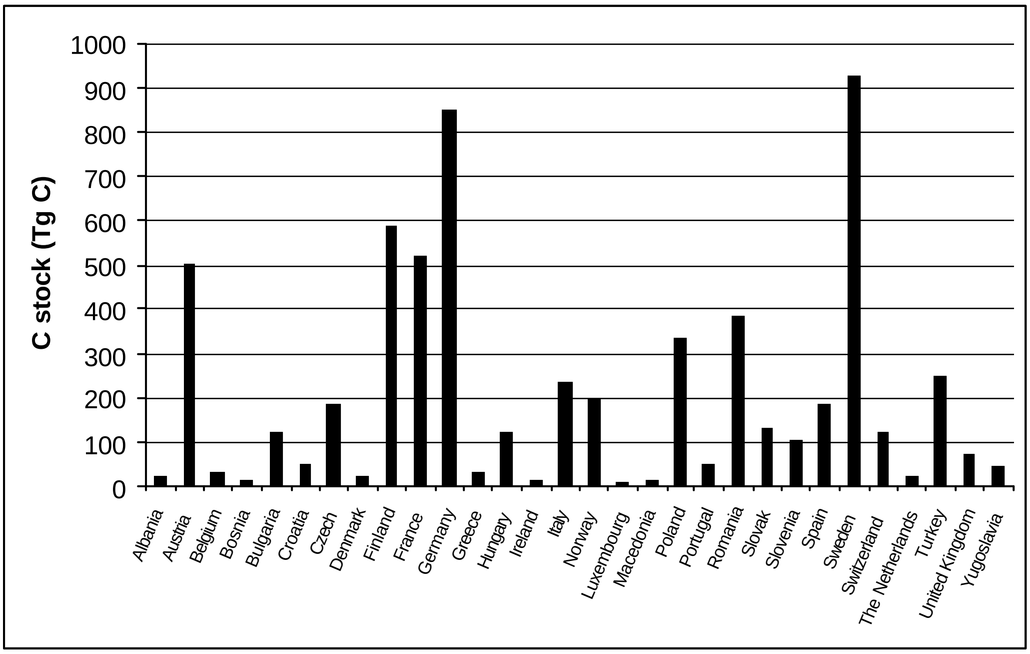

Figure 3.1 Carbon stock in whole tree biomass per country

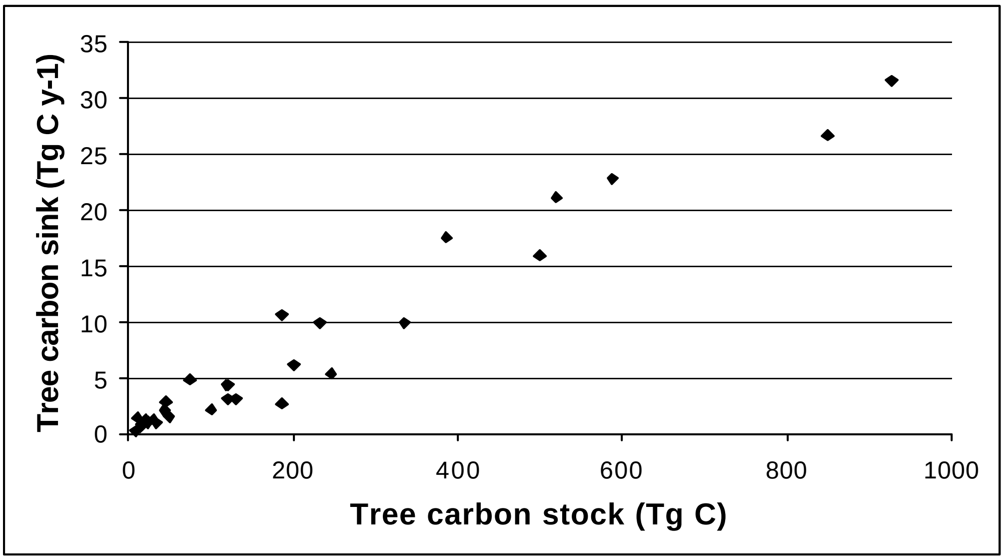

Figure 3.2. Relation between total C stock in tree biomass per country and the total tree biomass sink before harvest in the same country.

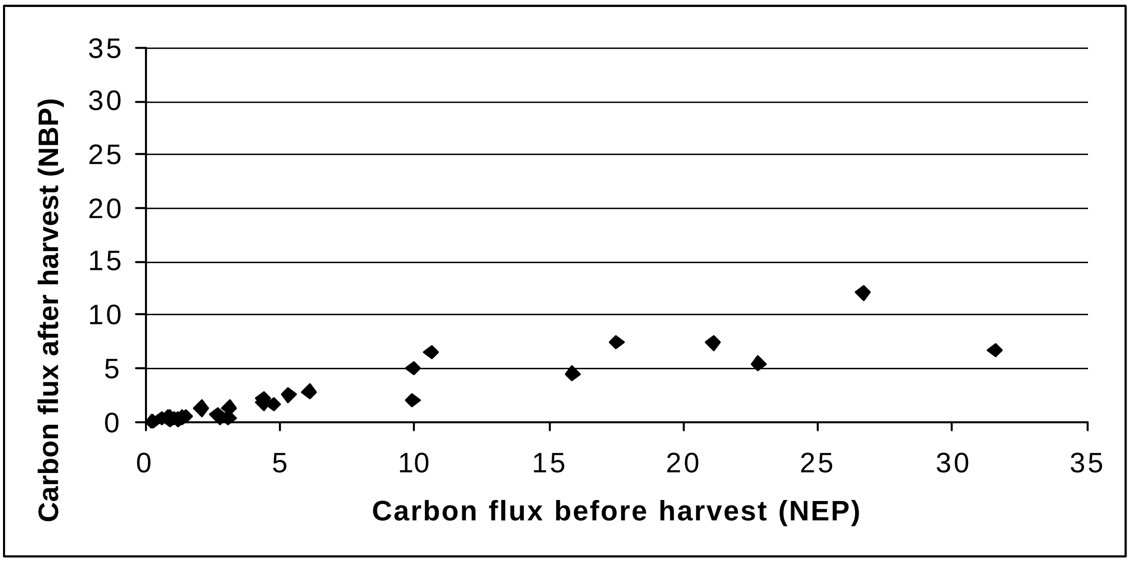

Figure 3.3. Relation between NEP and NBP at the country level for Europe (y=0.3305x).

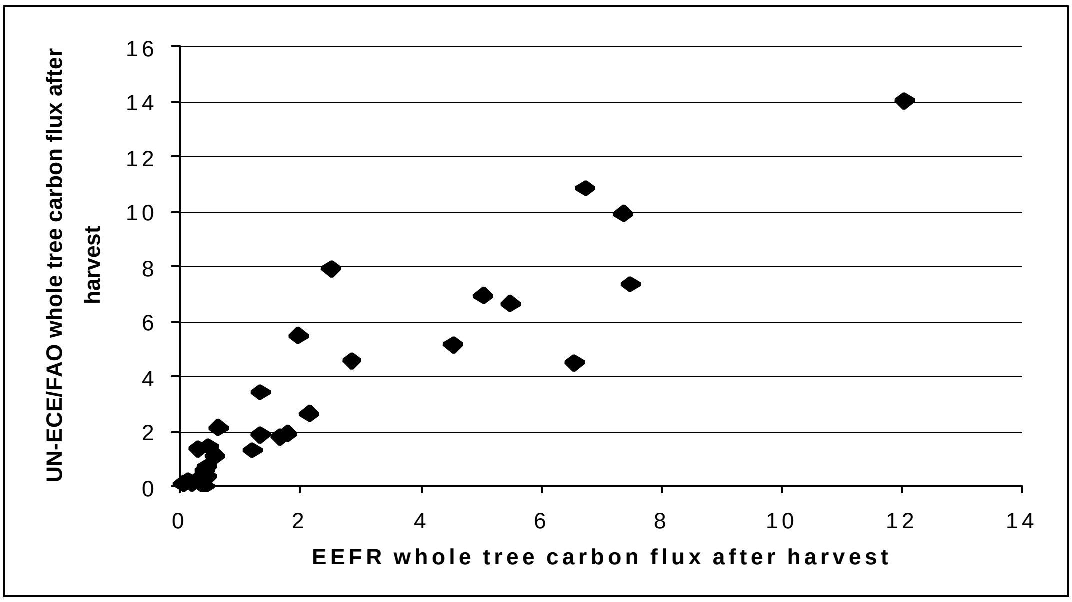

Figure 3.4 Estimates of whole tree carbon flux (NBP) (Tg C y[1] per country) as presented in UN-ECE/FAO (2000) and as presented in this study

3.2 Country level results for 'other wooded land'

Table 3.2. presents the carbon stock and fluxes for other wooded land. Only for a few countries enough data were available to calculate the desired values (see methods). Furthermore, the definitions for 'other wooded land' differs very much between countries. Therefore analyses as presented in section 3.1. provided a far

wider scatter. It is clear that the uncertainty in this land use type is far larger than in the 'forest land' land use type.

Table 3.2. Whole tree carbon stock and fluxes before and after harvest for other wooded land.

Country	Whole tree carbon stock per ha (Mg/ha)	Whole tree carbon flux per ha before harvest (Mg/ha/yr)	Whole tree carbon flux per ha after harvest (Mg/ha)
Albania*	3.93	0.04	0.01
Bosnia*	5.66	0.04	0.02
Bulgaria*	6.98	0.04	0.02
Croatia	16.74	0.10	0.04
France*	24.16	0.03	0.01
Greece	24.16	0.01	0.00
Italy*	27.24	0.03	0.02
Macedonia*	3.93	0.04	0.02
Portugal	27.57	0.98	0.13
Romania*	11.37	0.04	0.02
Slovenia	83.22	0.25	0.15
Spain	0.90	0.00	0.00
Switzerland	145.70	1.62	0.21
Turkey	4.84	0.12	0.06
Yugoslavia	5.78	0.00	0.00
United Kingdom	15.74	0.09	0.03
Russia	62.16	0.79	0.65
Ukraine	11.19	0.10	0.06

* For Albania, Bosnia, Bulgaria, France, Italy, Macedonia and Romania the weighted average of the rest of the countries was taken for the net annual increment

3.3 Regional level results for 'forest land'

The data of the 273 data points at the regional level within Europe are given in Annex 2 (distinguished by coniferous, deciduous and mixed forests) and are presented graphically in figure 3.5 for these three forest groupings mixed. In order to complete the overview in Annex 2, data for the countries not included in the EEFR database are added from the UN-ECE/FAO (2000). Figure 3.5 shows that despite the often mentioned large uncertainty in conversion coefficients, and the actual differences that are also given in this report in Annex 1, the relation between standing stock and total C in the trees still gives a very good fit.

Figure 3.6 shows a clear relation between whole tree C stock and whole tree C sink at the regional level. This can mean two things: 1) the European forests are still young and can still move a long way along the regression line (thus the sink is by far not saturated), or 2) it simply shows that provinces with forests with high growing stocks are also the locations with the best growing conditions and the increment (and thus the sinks) are the largest there too.

Figures 3.7 till 3.9 show the regional distribution of the total carbon stock (figure 3.7), NEP (figure 3.8) and NBP (figure 3.9). From these figures it is clear that the largest carbon stocks can be found in Central Europe. The area with the largest fluxes seem to coincide with areas with most precipitation and moderate temperatures.

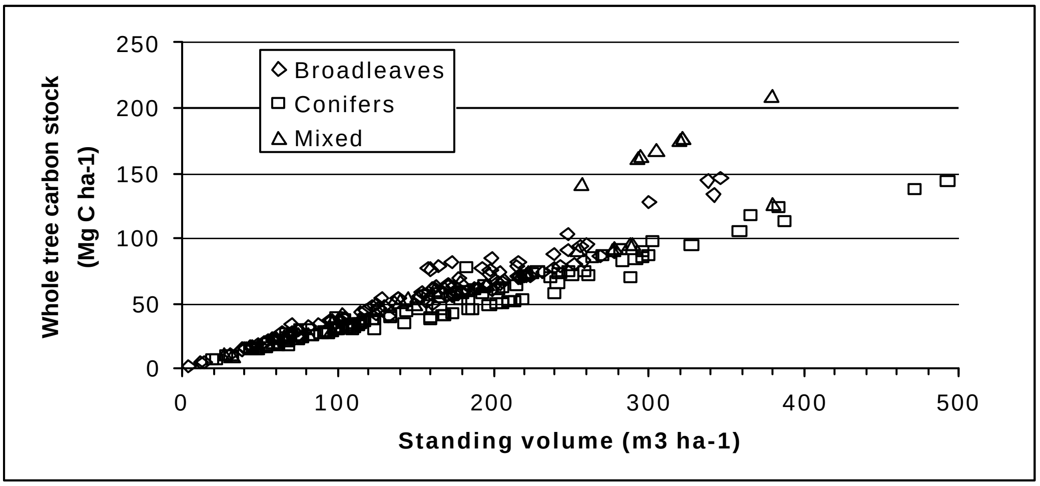

Figure 3.5 Relation between standing volume and carbon stock per hectare

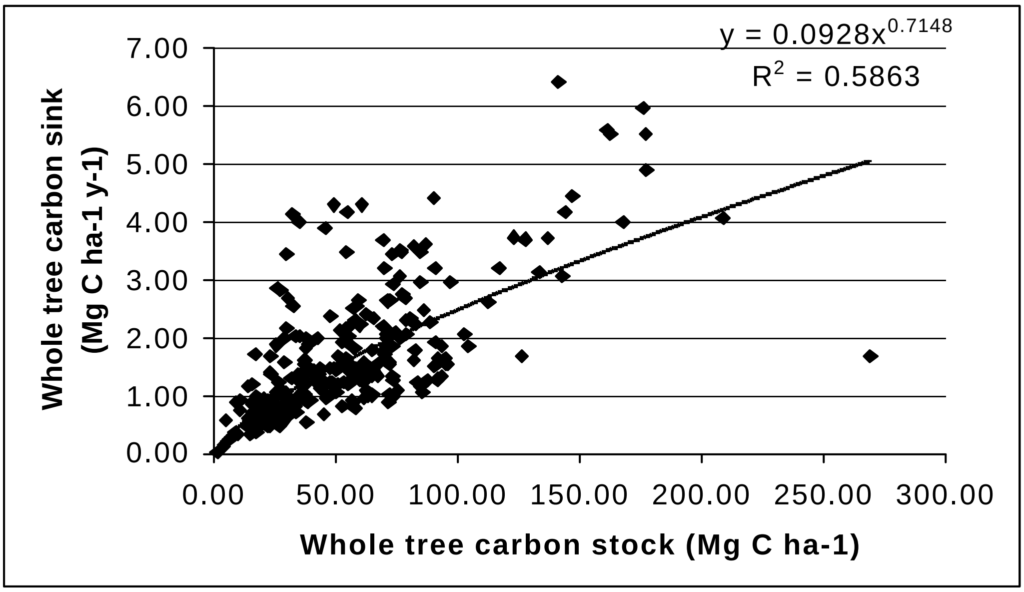

Figure 3.6 Relation between carbon stock and sink (before harvest) at regional level in Europe

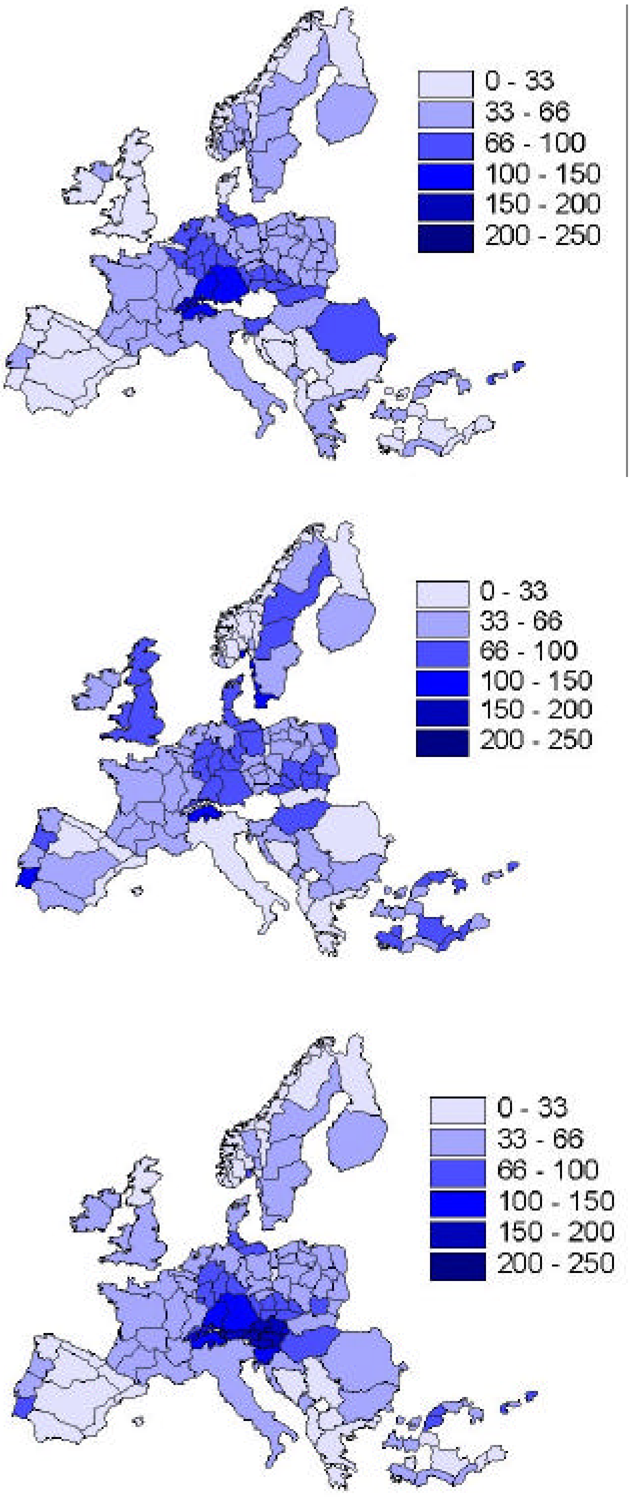

Figure 3.7 Maps of regional whole tree carbon stock per hectare (Mg C ha^{-1}) for conifers (top), broadleaves (middle) and all species (bottom)

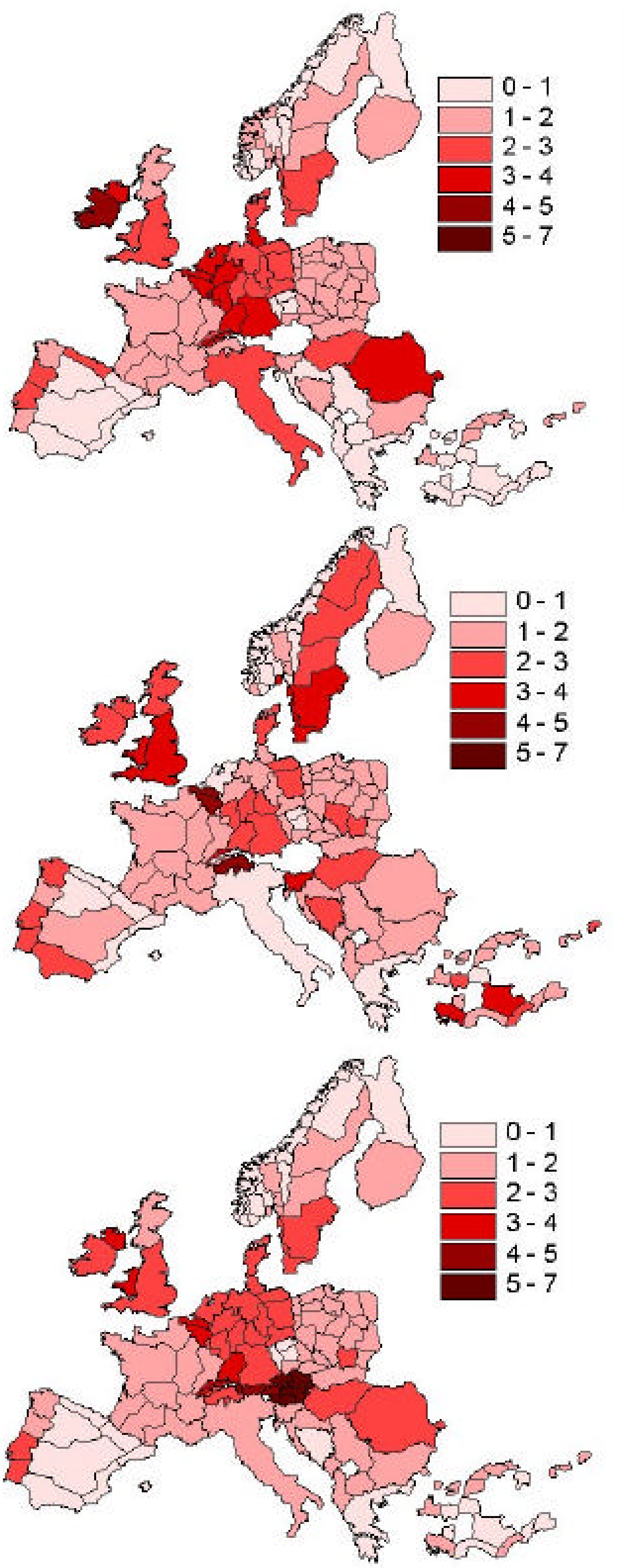

Figure 3.8 Whole tree carbon flux before harvest (NEP) per hectare (Mg C ha^{-1} year^{-1}) for conifers (top), broadleaves (middle) and all species (bottom)

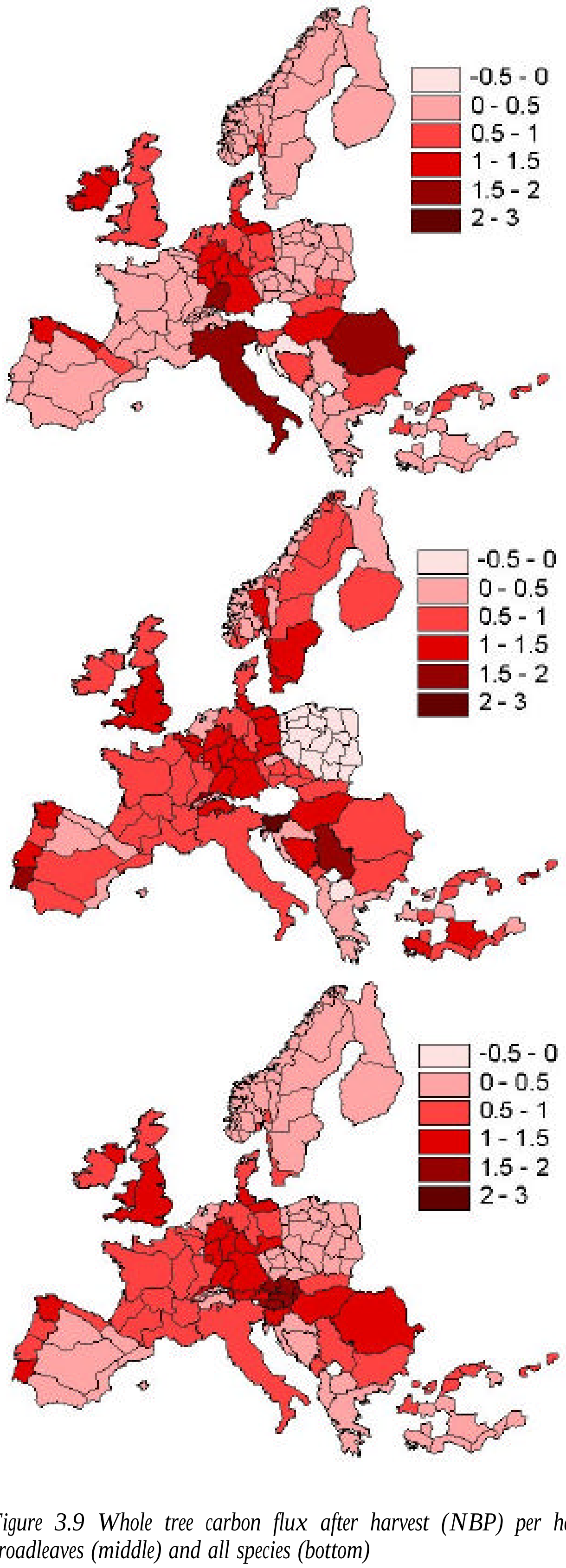

Figure 3.9 Whole tree carbon flux after harvest (NBP) per hectare (Mg C ha^{-1} $year^{-1}$) for conifers (top), broadleaves (middle) and all species (bottom)

4 Discussion

The accuracy of the presented results depends on several factors. The first factor is the quality of the results of the national forest inventories. For Finland, a very high accuracy is reported, with standard errors of 0.1 for forest area, 0.4 for standing volume and 1.1 for increment (Tomppo 1996). On the other hand, several European countries will have a less accurate forest inventory (e.g. Portugal and the Balkan region). Moreover, for increment a combination of (sometimes outdated) growth models with actual measurements is used. Also the year of the latest inventory differs per country, and differences in definitions occur between countries.

Data on other wooded land are scarce and probably not very accurate, which can be demonstrated by the fact that some countries give inconsistent data. Some countries give for the classes 'forest land' and 'forest and other wooded land' the same area, indicating that they have no other wooded land, but at the same time they do provide estimates for increment on other wooded land. The results presented here for other wooded land must therefore be handled with caution and must be regarded as merely indicative.

When we compare the total carbon stock and flux after harvest with the values given by UN-ECE/FAO (2000), we see that our results are lower. As already mentioned, the EEFR database mostly covers productive forest only. The total forest area covered by the EEFR database is 135.8 million ha, while the UN-ECE/FAO gives for the same countries a total area of forest land of 168.7 million ha. So, EEFR covers about 80% of the total forest land area, which matches quite well with the ratio of the total carbon stock of the EEFR data and the total carbon stock as given by UN-ECE/FAO.

Another factor is the difference in conversion factors between countries. The reported conversion factors for conifers range from 0.47 tn/m^3 to 1.02 tn/m^3 and for broadleaves from 0.6 to 1.18 tn/m^3. The reported conversion factors can also differ remarkably between neighbouring countries. For example, Austria reports for conifers a conversion factor of 1.02 while Switzerland reports a value of 0.58 tn/m^3, whereas both countries have mountainous growing conditions. Different age class structures could cause some of the observed difference, but is probably not enough to explain the difference. An indication of differences in conversion factors per country is that from the maps country borders are still clearly visible

Furthermore, we used the same conversion coefficients for upscaling both standing volume as well as increment (consistent with UN-ECE/FAO 2000). This is probably not correct. Namely conversion coefficients should be distinguished between converting for standing stock, NPP or NEP. In case of converting for NEP the real net increase in other compartments (see Figure 4.1.) is very small after a certain age. Upscaling bole dry weight to whole tree dry weight may therefore not be necessary at all, or just a very small fraction. In the past these different conversion have often been confused.

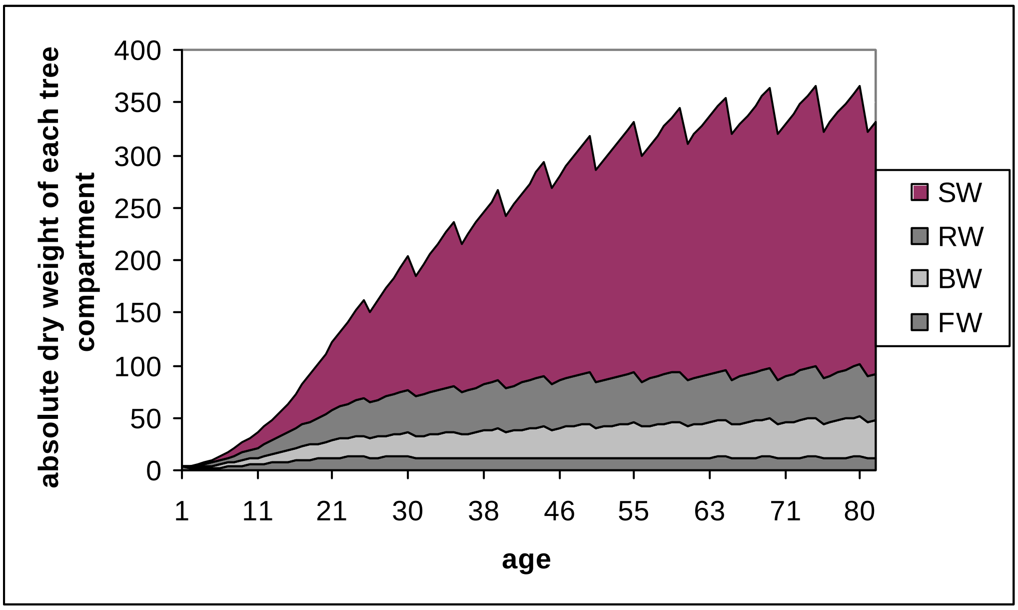

Figure 4.1 Absolute amount of dry biomass in each tree compartment of a spruce stand through time. SW = stem weight, RW = root weight, BW = branch weight, FW = foliage weight

5 Conclusion

Based on detailed national forest inventory data, collected in the EFISCEN's European Forest Resource Database, we estimate that the carbon stock in whole tree biomass for the European forest, excluding Russia and the Newly Independent States, amounts to 6.15 Pg C. The annual flux before harvest is estimated at 217 Tg C and the annual flux after harvest is estimated at 77 Tg C. This indicates that on a European scale about 66% of the increment is harvested. Since the forest inventory data mostly only cover the productive forest per country, the presented total stocks and fluxes are likely underestimated.

The variation in stocks and fluxes throughout Europe are large. The highest carbon stocks per hectare can be found in Central Europe, whereas the highest fluxes can be found in regions with abundant precipitation and a not too extreme temperature regime. At the moment there are no indications that the current carbon sink will saturate.

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Appendix 1 Conversion factors

Table Appendix 1. Factors for converting stemwood volume to whole tree dry woody biomass per country (UN-ECE 2000, Annex 3B.1). These conversion factors are a combination of Biomass Expansion Factor (BEF) times basic wood density of wood.

Country	Above stump dry woody biomass of conifers, (tonnes biomass per m3 stem wood)	Above stump dry woody biomass of broadleaves (tonnes biomass per m3 stem wood)	Stump and root biomass of conifers and broadleaves (tonnes biomass per m3 stem wood)
Albania	0.6	0.75	0.11
Austria	0.85	1.01	0.17
Belgium	0.39	0.52	0.09
Bosnia and Herzegovina	0.52	0.66	0.12
Bulgaria	0.45	0.67	0.12
Croatia	0.4	0.55	0.1
Cyprus	0.5	0.5	0.12
Czech Republic	0.45	0.64	0.12
Denmark	0.4	0.55	0.17
Estonia	0.51	0.6	0.08
Finland	0.53	0.64	0.1
France	0.4	0.53	0.07
Germany	0.5	0.5	0.14
Greece	0.46	0.68	0.11
Hungary	0.5	0.67	0.13
Iceland	0.54	0.65	0.13
Ireland	0.52	0.65	0.07
Israel	0.52	0.66	0.12
Italy	0.42	0.56	0.12
Latvia	0.48	0.62	0.12
Liechtenstein	0.4	0.67	0.11
Lithuania	0.48	0.63	0.09
Luxembourg	0.52	0.66	0.12
Malta	0.52	0.66	0.19
Netherlands	0.61	0.74	0.23
Norway	0.51	0.69	0.09
Poland	0.41	0.58	0.07
Portugal	0.52	0.55	0.24
Romania	0.47	0.65	0.12
Slovakia	0.46	0.65	0.08
Slovenia	0.51	0.74	0.09
Spain	0.51	0.61	0.08
Sweden	0.58	0.67	0.11
Switzerland	0.41	0.68	0.17
The FYR of Macedonia	0.52	0.66	0.12
Turkey	0.5	0.64	0.09
United Kingdom	0.43	0.83	0.12
Yugoslavia	0.52	0.66	0.12

Table Appendix 1. (continued)

Armenia	0.52	0.51	0.09
Azerbijan	0.75	0.77	0.14
Belarus	0.49	0.62	0.11
Georgia	0.6	0.7	0.1
Kazakhstan	0.47	0.55	0.08
Kyrgyzstan	0.52	0.66	0.12
Republic of Moldova	0.5	0.5	0.08
Russian Federation	0.54	0.51	0.21
Tajikistan	0.54	0.89	0.14
Turkmenistan	0.6	0.7	0.15
Ukraine	0.52	0.66	0.12
Uzbekistan	0.52	0.66	0.12

Appendix 2 Regional level results on carbon stocks and fluxes for forest land in Europe

Table Appendix 2.1. Whole tree carbon stock and fluxes before and after harvest for coniferous species, per hectare per region or country.

Country	Region	Whole tree carbon stock per ha (Mg/ha)	Whole tree carbon flux per ha before harvest (Mg/ha/yr)	Whole tree carbon flux per ha after harvest (Mg/ha)
Albania		29.12	0.72	0.42
Belgium	Flanders/ Brussels	29.74	3.45	0.21
Belgium	Wallony	69.26	3.68	0.23
Bosnia Hercegovina		14.15	1.17	0.53
Bulgaria		31.62	1.31	0.85
Croatia		17.31	0.38	-0.06
Czech Republic	Central Bohemian	73.79	0.99	0.13
Czech Republic	East Bohemian	83.35	1.23	0.16
Czech Republic	North Bohemian	52.69	0.83	0.11
Czech Republic	North Moravian	93.35	1.34	0.18
Czech Republic	South Bohemian	85.50	1.06	0.14
Czech Republic	South Moravian	84.54	1.19	0.16
Czech Republic	West Bohemian	71.46	0.89	0.12
Denmark		32.56	2.54	0.85
Finland	North Finland	19.49	0.57	0.13
Finland	South Finland	37.15	1.54	0.36
France		37.64	1.83	0.39
Germany	Baden-Württemberg	122.87	3.74	1.55
Germany	Bayern	117.13	3.21	1.33
Germany	Brandenburg	60.11	2.24	0.93
Germany	Hessen	96.90	2.96	1.23
Germany	Mecklenburg-Vorpommern	72.47	2.67	1.11
Germany	Niedersachsen	57.94	2.33	0.97
Germany	Nordrhein-Westfalen	86.76	3.62	1.50
Germany	Rheinland-Pfalz	90.58	3.22	1.33
Germany	Saarland	84.51	3.48	1.44
Germany	Sachsen	62.25	2.42	1.00
Germany	Sachsen-Anhalt	62.38	2.41	1.00
Germany	Schleswig-Holstein	73.21	3.46	1.43
Germany	Thüringen	70.91	2.64	1.09
Greece		38.18	0.89	0.42
Hungary		58.36	2.56	1.29
Ireland		32.23	4.13	1.34
Italy		65.38	2.33	1.64
Norway	Aust-Agder	33.38	0.82	0.34
Norway	Buskerud	36.99	1.04	0.43
Norway	Hedmark	29.53	0.95	0.39
Norway	Hordaland	27.71	1.08	0.45
Norway	More og Ronsdal	27.92	1.02	0.42
Norway	Nordland	20.83	0.65	0.27
Norway	Nord-Trondelag	25.08	0.58	0.24

Norway	Oppland	34.41	0.99	0.41
Norway	Oslo-Akershus	37.32	1.43	0.59
Norway	Ostfold	35.32	1.23	0.51
Norway	Rogaland	25.26	1.00	0.41
Norway	Sogn og Fjordane	30.35	1.01	0.41
Norway	Sör-Tröndelag	31.09	0.73	0.30
Norway	Telemark	34.23	0.95	0.39
Norway	Troms	13.58	0.49	0.20
Norway	Vest-Agder	30.10	0.85	0.35
Norway	Vestfold	36.52	1.36	0.56
Luxembourg		90.19	4.44	0.28
Macedonia		17.86	0.63	0.29
Poland	Bialystok	51.37	1.53	0.45
Poland	Gdansk	47.60	1.47	0.44
Poland	Katowice	50.30	1.43	0.43
Poland	Krakow	52.59	1.92	0.57
Poland	Krosno	57.63	1.84	0.55
Poland	Lodz	44.86	1.18	0.35
Poland	Lublin	50.71	1.21	0.36
Poland	Olsztyn	49.36	1.48	0.44
Poland	Pila	38.49	1.41	0.42
Poland	Poznan	41.76	1.26	0.37
Poland	Radom	48.66	1.25	0.37
Poland	Szczecin	40.30	1.43	0.42
Poland	Szczecinek	40.58	1.43	0.42
Poland	Torun	40.60	1.40	0.42
Poland	Warszawa	44.46	1.27	0.38
Poland	Wroclaw	51.24	1.67	0.50
Poland	Zielona Gorara	34.34	1.28	0.38
Portugal	Central Portugal	37.93	2.01	0.43
Portugal	North Portugal	28.89	2.01	0.43
Portugal	South Portugal	25.52	1.88	0.40
Romania		69.80	3.20	1.61
Slovak Republic		70.86	1.86	0.52
Slovenia		269.05	1.69	0.82
Spain	North-east Mediterranean	14.28	0.62	0.37
Spain	Pyrenees	22.24	0.84	0.51
Spain	Galicia	23.04	1.69	1.03
Spain	Islands	20.10	0.56	0.34
Spain	South-east Mediterranean	5.97	0.25	0.15
Sweden	North west Sweden	23.45	0.64	0.13
Sweden	Northern part of central Sweden and North east Sweden	36.36	1.05	0.21
Sweden	Southern part of central Sweden	43.85	1.48	0.29
Sweden	South Sweden, except south west coast	55.01	2.04	0.41
Sweden	South west coast and islands	56.95	2.53	0.50
Switzerland	Alpen	104.18	1.88	0.08
Switzerland	Alpensued	82.50	1.78	0.07

Switzerland	Jura	112.52	2.63	0.11
Switzerland	Mittelland	136.85	3.72	0.15
Switzerland	Voralpen	143.03	3.07	0.13
The Netherlands		76.87	3.50	0.55
Turkey	Adana (South Anatolian)	31.15	0.68	0.34
Turkey	Adapazari (North West Anatolian)	20.43	0.95	0.48
Turkey	Amasya (North Anatolian)	33.69	0.70	0.35
Turkey	Antalya (South Anatolian)	57.31	0.89	0.44
Turkey	Artvin (North Anatolian)	73.39	1.27	0.64
Turkey	Balikesir (North Anatolian)	45.03	1.08	0.54
Turkey	Bolu (North Anatolian)	61.12	1.24	0.62
Turkey	Denizli (West Anatolian)	26.49	0.60	0.30
Turkey	Eskisehir (Middle Anatolian)	31.34	0.69	0.35
Turkey	Giresun (North Anatolian)	71.83	1.56	0.78
Turkey	Istanbul (North West Anatolian)	6.52	0.29	0.14
Turkey	K.Maras (South East Anatolian)	24.90	0.60	0.30
Turkey	Kastamonu (North Anatolian)	63.33	1.52	0.76
Turkey	Konya(Middle Anatolian)	22.87	0.47	0.24
Turkey	Kutahya (Middle Anatolian)	39.55	0.93	0.46
Turkey	Mersin (South Anatolian)	29.42	0.60	0.30
Turkey	Mugla (West Anatolian)	31.75	0.72	0.36
Turkey	Sinop (North Anatolian)	52.87	1.23	0.61
Turkey	Trabzon (North Anatolian)	60.13	1.26	0.63
Turkey	Zonguldak (North Anatolian)	42.68	1.37	0.68
United Kingdom	England	30.25	2.71	0.94
United Kingdom	Northern Ireland	45.67	3.89	1.36
United Kingdom	Scotland	17.01	1.71	0.60
United Kingdom	Wales	25.78	2.86	1.00
Yugoslavia	Monte Negro	58.05	0.79	0.36
Yugoslavia	Serbia	17.79	0.81	0.37

Table Appendix 2.2. Whole tree carbon stock and fluxes before and after harvest for broadleaved species, per hectare per region or country.

Country	Region	Whole tree carbon stock per ha (Mg/ha)	Whole tree carbon flux per ha before harvest (Mg/ha/yr)	Whole tree carbon flux per ha after harvest (Mg/ha)
Albania		27.71	1.12	0.16
Belgium	Flanders/ Brussels	60.76	4.30	1.28
Belgium	Wallony	49.17	4.30	1.28
Bosnia and Herzegovina		27.15	2.84	1.44
Bulgaria		40.88	1.40	0.57
Croatia		55.34	1.21	0.49
Czech Republic	Central Bohemian	61.50	0.95	0.55
Czech Republic	East Bohemian	64.96	1.02	0.58
Czech Republic	North Bohemian	44.98	0.70	0.40
Czech Republic	North Moravian	81.97	1.63	0.94
Czech Republic	South Bohemian	61.12	1.52	0.87
Czech Republic	South Moravian	75.46	1.09	0.63
Czech Republic	West Bohemian	43.79	1.13	0.65
Denmark		73.46	2.92	0.80
Finland	North Finland	21.64	0.92	0.29
Finland	South Finland	38.60	1.90	0.60
France		39.87	1.45	0.65
Germany	Baden-Württemberg	86.14	2.49	1.38
Germany	Bayern	74.34	2.09	1.15
Germany	Brandenburg	70.54	2.06	1.14
Germany	Hessen	88.92	2.28	1.26
Germany	Mecklenburg-Vorpommern	80.59	2.35	1.30
Germany	Niedersachsen	65.14	1.79	0.99
Germany	Nordrhein-Westfalen	70.77	2.00	1.11
Germany	Rheinland-Pfalz	71.57	2.07	1.14
Germany	Saarland	69.90	1.74	0.96
Germany	Sachsen	55.60	1.89	1.04
Germany	Sachsen-Anhalt	70.55	1.82	1.00
Germany	Schleswig-Holstein	76.60	1.99	1.10
Germany	Thüringen	82.50	2.25	1.24
Greece		29.75	0.86	0.35
Hungary		77.20	2.75	1.07
Italy		42.27	2.01	0.90
Norway	Aust-Agder	27.98	0.73	0.52
Norway	Buskerud	17.66	0.81	0.57
Norway	Hedmark	14.66	0.57	0.40
Norway	Hordaland	21.29	0.64	0.45
Norway	More og Ronsdal	23.24	0.66	0.47
Norway	Nordland	14.79	0.35	0.25
Norway	Nord-Trondelag	17.16	0.62	0.44
Norway	Oppland	16.07	0.50	0.35
Norway	Oslo-Akershus	28.92	1.58	1.11
Norway	Ostfold	37.53	1.61	1.13
Norway	Rogaland	20.62	0.69	0.48

Norway	Sogn og Fjordane	23.02	0.57	0.40
Norway	Sör-Tröndelag	20.53	0.57	0.40
Norway	Telemark	22.54	0.77	0.54
Norway	Troms	18.68	0.48	0.34
Norway	Vest-Agder	31.69	0.85	0.60
Norway	Vestfold	34.44	1.38	0.97
Luxembourg		133.21	3.14	0.93
The FYR of Macedonia		48.78	1.17	0.59
Poland	Bialystok	58.60	1.43	-0.21
Poland	Gdansk	70.40	1.65	-0.24
Poland	Katowice	51.07	1.21	-0.18
Poland	Krakow	70.13	2.16	-0.32
Poland	Krosno	78.81	2.08	-0.30
Poland	Lodz	67.21	1.36	-0.20
Poland	Lublin	55.29	1.43	-0.21
Poland	Olsztyn	58.40	1.40	-0.20
Poland	Pila	63.22	1.50	-0.22
Poland	Poznan	61.59	1.40	-0.20
Poland	Radom	56.74	1.53	-0.22
Poland	Szczecin	66.86	1.56	-0.23
Poland	Szczecinek	62.12	1.53	-0.22
Poland	Torun	57.58	1.48	-0.22
Poland	Warszawa	58.11	1.46	-0.21
Poland	Wroclaw	65.96	1.53	-0.22
Poland	Zielona Gorara	61.03	1.44	-0.21
Portugal	All	15.90	1.21	0.00
Romania		59.10	2.65	1.03
Slovak Republic		72.05	1.59	0.88
Slovenia		102.82	2.06	1.55
Spain	North-east Mediterranean	22.91	1.41	0.89
Spain	Pyrenees	25.54	1.06	0.66
Spain	Galicia	35.04	4.00	2.50
Spain	Islands	15.42	0.89	0.56
Spain	South-east Mediterranean	1.39	0.04	0.03
Sweden	North west Sweden	20.41	0.73	0.27
Sweden	Northern part of central Sweden and North east Sweden	36.93	1.62	0.59
Sweden	Southern part of central Sweden	47.70	2.38	0.87
Sweden	South Sweden, except south west coast	54.36	2.17	0.79
Sweden	South west coast and islands	69.44	2.19	0.80
Switzerland	Alpen	84.55	2.96	0.90
Switzerland	Alpensued	54.39	3.49	1.06
Switzerland	Jura	127.64	3.71	1.13
Switzerland	Mittelland	146.88	4.45	1.36
Switzerland	Voralpen	143.85	4.17	1.27
The Netherlands		76.42	3.53	1.93
Turkey	Adana (South Anatolian)	26.02	0.83	0.34

Turkey	Adapazari (North West Anatolian)	55.87	1.28	0.53
Turkey	Amasya (North Anatolian)	46.11	0.97	0.40
Turkey	Artvin (North Anatolian)	87.37	1.27	0.52
Turkey	Balikesir (North Anatolian)	62.49	1.08	0.45
Turkey	Bolu (North Anatolian)	90.37	1.52	0.63
Turkey	Giresun (North Anatolian)	65.50	1.43	0.59
Turkey	Istanbul (North West Anatolian)	78.58	2.32	0.96
Turkey	K.Maras (South East Anatolian)	37.37	1.20	0.50
Turkey	Kastamonu (North Anatolian)	61.49	1.57	0.65
Turkey	Kutahya (Middle Anatolian)	93.34	1.87	0.77
Turkey	Mersin (South Anatolian)	56.46	0.91	0.38
Turkey	Mugla (West Anatolian)	47.43	1.25	0.52
Turkey	Sinop (North Anatolian)	63.73	1.37	0.57
Turkey	Trabzon (North Anatolian)	50.12	1.06	0.44
Turkey	Zonguldak (North Anatolian)	94.78	1.64	0.68
UK	England	76.15	3.08	1.08
UK	Northern Ireland	33.46	2.04	0.72
UK	Scotland	78.50	2.68	0.94
UK	Wales	82.04	3.59	1.26
Yugoslavia	Monte Negro	63.38	1.02	0.65
Yugoslavia	Serbia	54.21	1.65	1.65

Table Appendix 2.3. Whole tree carbon stock and fluxes before and after harvest for mixed forest, per hectare per region or country.

Country	Region	Whole tree carbon stock per ha (Mg/ha)	Whole tree carbon flux per ha before harvest (Mg/ha/yr)	Whole tree carbon flux per ha after harvest (Mg/ha)
Albania		10.70	0.94	0.23
Austria	Burgenland	141.26	6.43	1.84
Austria	Kärnten	162.40	5.51	1.58
Austria	Nieder-österreich	161.13	5.60	1.60
Austria	Ober-österreich	176.10	5.99	1.71
Austria	Salzburg	177.34	4.90	1.40
Austria	Steiermark	177.09	5.52	1.58
Austria	Tirol	167.87	4.01	1.15
Austria	Vorarlberg	208.69	4.09	1.17
Bosnia Hercegovina		20.63	0.79	0.39
Croatia		9.15	0.89	0.32
Italy		29.16	1.06	0.57
Macedonia		17.36	1.01	0.50
Slovenia		90.64	1.94	1.21
Sweden	North west Sweden	24.30	0.79	0.18
Sweden	Northern part of central Sweden and North east Sweden	35.34	1.27	0.29
Sweden	Southern part of central Sweden	51.59	2.13	0.48
Sweden	South Sweden, except south west coast	55.50	2.22	0.50
Sweden	South west coast and islands	59.48	2.22	0.50
Turkey	Adana (South Anatolian)	26.77	26.77	12.48
Turkey	Adapazari (North West Anatolian)	71.83	71.83	33.47
Turkey	Amasya (North Anatolian)	49.05	49.05	22.86
Turkey	Antalya (South Anatolian)	37.77	37.77	17.60
Turkey	Artvin (North Anatolian)	126.22	126.22	58.82
Turkey	Balikesir (North Anatolian)	57.15	57.15	26.63
Turkey	Bolu (North Anatolian)	95.74	95.74	44.61
Turkey	Eskisehir (Middle Anatolian)	64.64	64.64	30.12
Turkey	Giresun (North Anatolian)	73.32	73.32	34.17
Turkey	Istanbul (North West Anatolian)	15.88	15.88	7.40
Turkey	K.Maras (South East Anatolian)	21.69	21.69	10.11
Turkey	Kastamonu (North Anatolian)	73.00	73.00	34.02
Turkey	Sinop (North Anatolian)	91.86	91.86	42.81
Turkey	Trabzon (North Anatolian)	91.40	91.40	42.59
Turkey	Zonguldak (North	95.03	95.03	44.29

	Anatolian)			
UK	Northern Ireland	54.51	4.18	1.46
Yugoslavia	Monte Negro	26.56	1.23	0.61
Yugoslavia	Serbia	23.37	1.39	0.69
Cyprus		6.1	0.11	0.04
Estonia		46.8	1.12	0.57
Iceland		3.2	0.18	0.18
Israel		12.4	0.84	0.60
Latvia		59.3	1.58	0.84
Liechtenstein		68.9	1.03	0.40
Lithuania		57.7	1.58	0.96
Malta		162.8		
Armenia		34	0.32	0.17
Azerbaijan		58.5	0.66	0.65
Belarus		42.5	0.88	0.63
Georgia		55.9	0.52	0.46
Kazakhstan		6.4	0.11	0.09
Kyrgyzstan		9.9		
Republic of Moldova		35	0.89	0.65
Russian Federation		44.7	0.54	0.48
Tajikistan		3.2	0.05	0.05
Turkmenistan		1.6	0.01	0.01
Ukraine		57.5	1.10	0.78
Uzbekistan		1.9		

Appendix 3 Comparison of forest area as given in various forest statistics.

	UN-ECE/FAO 2000	UN-ECE/FAO 1992		**EEFR database**
Country	Forest area (1000 ha)	Forest area (1000 ha)	Exploitable forest area (1000 ha)	Area (1000 ha)
Albania	1030	1046	910	898
Austria	3840	3877	3330	2942
Belgium	646	620	620	531
Bosnia-Hercegovina	2276			733
Bulgaria	3590	3386	3222	3202
Croatia	1775			1443
Czech Republic	2630			2584
Denmark	445	466	466	442
Finland	21720	20112	19511	19752
France	15156	14230	12460	13318
Germany	10740	10490	9852	9979
Greece	3359	2512	2289	3252
Hungary	1811	1675	1324	1609
Ireland	591	396	394	329
Italy	9857	6750	4387	5757
Luxembourg	86	85	82	71
The FYR of Macedonia	906			653
Netherlands	339	334	331	301
Norway	8710	8697	6638	7145
Poland	8942	8672	8460	8703
Portugal	3383	2755	2346	1613
Romania	6301	6190	5413	6211
Slovak Republic	2016			1823
Slovenia	1099			1077
Spain	13509	8388	6506	13905
Sweden	27264	24437	22048	22175
Switzerland	1173	1130	1093	1044
Turkey	9954	8856	6642	5466
United Kingdom	2469	2207	2207	1930
Yugoslavia, Fed state of	2894			1511

*EEFR represents the exploitable forest area as given in UN-ECE/FAO 1992