Universitatea Transilvania din Braşov

**Universitatea *Transilvania* din Braşov**

# HABILITATION THESIS

**Title: MODELING FOREST MANAGEMENT AND WOOD PRODUCTS USE FROM CLIMATE CHANGE MITIGATION PERSPECTIVE**

**Domain: Forestry**

**Author: dr. ing. Viorel NB Blujdea**

**University: Transilvania University of Brasov**

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## *Cuprins*

List of abbreviations

CBM/CBM-CFS – Carbon Budget Model of the Canadian Forest Service (see reference below)

DOM – dead organic matter

EEA – European Environmental Agency

EU - European Union

FMP – forest management plan

GHG – greenhouse gases

IPCC – Intergovernmental Panel on Climate Change

LULUCF – land use, land use change and forestry

NFI – National Forest Inventory

SOC – Soil Organic Carbon

UNFCCC – United Nations Framework Convention on Climate Change

UVB - UV radiation, B fraction

## (A) Rezumat

Prima parte a tezei descrie experiența științifică a autorului în domeniul fiziologiei şi ecofiziologiei forestiere, axată pe toleranța hidrică foliară și nutriție minerală la două specii de stejari mezoxerofiţi, cer şi gârniţă. In acest domeniu am elaborat și teza de doctorat. Am demonstrat științific versatilitatea hidrică a cerului față de garniță, ce explică reziliența superioară a acestuia în condiții de secetă îndelungată. Am efectuat determinări pentru prima dată în țară si estul Europei cu un analizor în infraroșu a schimbului de gaze foliar de CO2. Am generat curbe de răspuns biologic la radiație fotosintetic activă, deficit de vapori atmosferic, temperatura frunzei si am definit cantitativ indicatorii toleranței la stres hidric de scurtă și lungă durată prin analiza eficienței de utilizare a apei (rapoarte fotosinteză/transpirație, fotosinteză /conductanță stomatală, fotosinteză/concentrație CO2 substomatal). Am efectuat determinări privind starea de hidratare tisulară prin metode mai precise respectiv prin stabilirea potențialului hidric tisular (camera de presiune Scholander). La fag expus la UVB (+25 % față de fondul normal) am demonstrat ca RUBISCO nu este direct afectat, ci este alterat doar transferul electronilor în fotosinteză ce duce la reducerea eficienței în absorbția luminii. O nouă abordare metodologică s-a realizat prin stabilirea protocolului de măsurare a fotorespirației foliare prin metoda „post illumination CO2 burst" cu un sistem „open path". Am acumulat o experiență bogată în domeniul nutriției minerale la cer şi gârniţă în cadrul tezei de doctorat care a condus la rezultate privind: 1) conținutul foliar de forme totale de macro şi micronutrienţi foliari (10 elemente), 2) dinamica sezonieră, 3) dinamica conținutului de nutrienţi în raport cu vârsta arboretelor (tinere, în maxim de creştere şi bătrâne), 4) determinarea eficienţei de utilizare a nutrienților în raport cu biomasa lemnoasă, 5) corelații între starea hidrică a ţesuturilor şi conținutul de nutrienţi (forme solubile, greu solubile şi totale), 7) translocarea nutrienţilor şi contribuția structurilor perene la aprovizionarea cu nutrienţi a structurilor noi în formare (frunze, ramuri) la cer şi stejar roşu. De asemenea, am efectuat cercetări privind alocarea carbonului și turnover-ul pentru biomasă radicelară fină la specii de arbori forestieri (stejari, molid).

Ultima parte a tezei descrie experiența din ultimul deceniu si jumătate, când am dat un sens practic preocupărilor fiziologice si eco-fiziologice prin sprijinul tehnico-științific al politicilor in domeniul schimbărilor climatice, mai precis legat de monitorizare, raportare si verificare gaze cu efect de seră în cadrul proceselor asociate Convenției Cadru a Națiunilor Unite pentru Schimbare Climatică (inclusiv Protocolul de la Kyoto și Acordul de la Paris). Contribuția efectivă este legată de sectorul folosința terenurilor, schimbarea folosinței terenurilor și forestier, precum: elaborarea de metodologii de estimare a schimbării stocului de carbon și emisiilor altor gaze cu

efect de seră din terenuri cu păduri si terenuri in conversie la/și de la pădure și pentru terenuri pășunate; utilizarea modelelor în simularea acumulării de carbon prin activități de împădurire si gospodărirea pădurii si utilizarea lemnului; realizarea planurilor de monitorizare a acumulării de carbon in depozite ecosistemice; sprijin în elaborarea inventarelor naționale ale gazelor cu efect de seră pentru sectorul folosința terenurilor și forestier, sprijin și suport științific în fundamentarea și implementarea regulilor de contabilizare pentru reduceri de emisii din gospodărirea terenurilor forestiere și neforestiere; identificarea sinergiilor mediogene, financiare și sociale asociate măsurilor de reduceri de emisii. Contribuția mea la sectorul LULUCF este fundamentată pe experiența științifică legată de alometria arborelui, modelarea și ajustarea curbelor volumului pe picior si creșterii arboretelor funcție de diverși parametrii și alocarea carbonului în componentele de biomasa la nivel de arboret, precum și elaborarea și punerea în aplicare a regulilor de contabilizare pentru sectorul folosinței terenurilor si forestier.

In final, teza descrie preocupările curente privind lipsa de cunoaștere si de date cantitative ce vor constitui fundamentul activității în viitor, si anume, preocupări atât legate de metodele de estimare și realizarea de proiecții in ce privește biomasa si fluxurile de carbon din ecosistemul forestier (inclusiv către și între depozitele de necromasă), cât și modalități de asigurare a compromisului între multiplele valențe ale lemnului in economie: volum-energie-biomasa-carbon in vederea asigurării unei contribuții adecvate a sectorului forestier la o economie neutrală climatic.

## (B) Scientific and professional achievements and the evolution and development plans for career development

## (B-i) Scientific and professional achievements

My 23 years of scientific activity include dealing with fundamental physiological and eco-physiological processes in the first part of the period, while lately, it consisted in science and technical support toward robust climate change policy and implementation (globally, EU, national). Further on, this thesis describes the evolution of my scientific career, organized on major subjects: a) water relations and mineral nutrition in forest trees, b) biomass dynamics and carbon sequestration in forest trees and forest stands, c) modeling biomass and age-structure dynamics in stands and forests and d) monitoring, estimation and verification of greenhouse gas emissions from forest sector, land use and land use change. Each subject is supported by relevant references.

### (B-i).1 Water relations and mineral nutrition in forest trees

*Relevant publications*

1. Saiz G, Byrne K, Butterbach-bahl K, Kiese R, **Blujdea V** and Farrell Ed (2006): *Stand age-related effects on soil respiration in a first rotation Sitka spruce chronosequence in central Ireland*. Global Change Biology, Volume 12, Number 6, June 2006 , pp. 1007-1020(14)
2. **Blujdea V**, Pauca-Comanescu M and Ionescu M (2003) *Mechanisms of drought tolerance in mesoxerophztic oaks*, In: Anale Seria I, vol 46, Edt. Tehnică Silvică 2003
3. **Blujdea V** and Urban O (2002) *Long-term UV-B exposure effects in early senescent leaves of Fagus sylvatica [L.] seedlings grown in vegetation pots: gas exchange analysis*, Beskydy journal (2002)
4. **Blujdea V** and Ionescu M (2001) *Studiul raportului Ca/K foliar de diferite solubilităţi ca marker fiziologic pentru toleranţa la secetă*, In: Anale, Lucrările Sesiunii Ştiinţifice din 23 martie 2001, Edt. Tehnică Silvică – Bucureşti, 2001, pp. 41-47
5. Catrina I, **Blujdea V,** Ionescu M and Voiculescu I (2001) *Încărcarea radioactiva a mediului de nutritie a arborilor cu* $^{40}K$ , In Rev Pad no 4/2001, p. 1-5
6. **Blujdea V** and Pauca-Comanescu M (2001) *Concentraţia de CO2 substomatal si semnificaţia sa ecofiziologică la Q. cerris L. si Q. frainetto Ten*, In Rev Pad 3/2001, p. 14-17
7. **Blujdea V** and Alexe A (1998) *Cercetări comparative privind eficienta de utilizare a nutrientilor minerali la arborii de cvercinee xerofiti si semixerofiti (din pãdurile Ogarca si Letca - Ocolul Silvic Ghimpati)*, Revista de Silvicultura nr.1-2/1998, p.22-26

*Theoretical contribution to science and knowledge*. Originally, I was focusing on forest physiology and ecophysiology, mainly dealing with two species of mezoxerophilic oaks, Quercus cerrir and Q. frainetto, which was also the field of my PhD disertation[1]. I made gasometric measurements of leaves CO2 gas exchnage for the first time in the country using the IR (infrared) gas analyzer in order to assess drought tolerance based on gas exchnage at leaf level (in Blujdea, Pauca et al., 2001, 2003). Measurements were performed with a range of equipments: Ciras II (UK), ADC LCA-4 (UK), or Licor 6400 (USA), both in Romania and abroad. Indicators measured reffered to net photosynthesis intensity and stomatal conductance (stomatic opening from the CO2 and H2O fluxes). Analysis included biological response curves of foliar CO2 exchnage indicators in relation to the relevant environmental factors (photosynthetic active radiation, atmospheric water vapor deficit, leaf tissue temperature). Foliar exchange allowed characterization of short and long-term water tolerance by analyzing water use efficiency (photosynthesis / transpiration, photosynthesis / stomatal conductance, photosynthesis / sub-stomataic CO2 concentration). Watre stress tolerance was also tested by tissue hydration status either by classic methods (by sampling and repeated weighing) or by determining the tissue hydric potential (scholander bomb). Further, in-depth understanding of the water tolerance in leaves was complemented by a research by Blujdea and Ionescu (2001) showing chemical interaction of Ca and K in tissues consisting in highest share of free K (water soluble) to total content in leaves tissues compared Ca.

One of the global changes associated to anthropogenic accelerated process of climate change supposed to be the change in the share of UV-B. Thus, Blujdea and Urban (2002) studied the effect of long-term exposure to UV-B[2] (+25% relative to the normal background) on foliar exchange on leaves of beech saplings. Exposure allowed conclusion that the maximum photosynthetic rate of saplings in ambient and exposed UVB (for active photosynthetic radiation of saturation and CO2 ambient) was unchanged, proved the equal intensity of “dark” respiration for seedlings from the open environment to those exposed and that exposure caused a reduction of photosynthetic capacity in exposed to UVB suggesting that RUBISCO was not directly affected, but the electron transfer in photosynthesis and light absorption efficiency were reduced. Further in Blujdea and Urban (2000000) a new methodology/protocol for photorespiration measurement “post-illumination CO2 burst” using an "open path" system. Methodology consisted in defining the Licor 6400 settings to optimize capturing the photorespiratory threshold in the post-lighting environmental evolution of foliar CO2 exchange.

[1] PhD thesis “Cercetări ecofiziologice în cerete şi gârniţete afectate de fenomenul de uscare”, Transilvania University of Brasov, 2000

[2] Research performed under a Marie Curie grant offered by then „Institute of Landscape Ecology”, today „CzechGlobe” in Brno, Czech Republic, http://www.czechglobe.cz/en/

Somehow in alternance with water tolerance research, I focussed on mineral nutrition of forest trees species in the intensive ICP Forest monitoring network, while going in very detail on Q. cerris and Q. frainetto mineral nutrition as part of my doctoral thesis. Such research were comprehensive and provide conclusions like: 1) estimates of foliar content of total forms of the macro- and micro-nutrients (10 elements), 2) their seasonal dynamics (from bud to marcescent leaves), 3) dynamics of the nutrient content in relation to the stands age (young, age associated to maximum volume increment and old stands), 5) eco-physiological correlations between the dynamics of foliar nutrient content and environmental factors, 6) correlations between the water state of the tissues and the nutrient content (soluble, heavily soluble and total forms); 7) translocation of nutrients and contribution of perennial structures of the tree to nutrient supply of the structure new shapes (leaves, branches). Further on, some research dealt with evaluation of anthropogenic radioactive cesium load of forest ecosystems: research demonstrates that Cs is actively circulating in the ecosystem along water fluxes and return to soil by foliage fall, so it is present in all biomass pools (dead or alive). Interesting was that radioactive cesium was present even in wood rings formed before Chernobyl event in 1986 bit not in wood rings formed earlier than years ’50 (thus linked to first nuclear experiments in the world).

Saiz et al. (2006) studied the effect of stand age on soil respiration and its components in a first rotation Sitka spruce chronosequence composed of 10-, 15-, 31-, and 47-year-old stands established on wet mineral gley in central Ireland. For each stand age, three forest stands with similar characteristics of soil type and site preparation were used. There were no significant differences in total soil respiration among sites of the same age, except for the case of a 15-year-old stand that had lower soil respiration rates due to its higher productivity. Soil respiration initially decreased with stand age, but levelled out in the older stands. The youngest stands had significantly higher respiration rates than more mature sites. Annual soil respiration rates were modelled by means of temperature-derived functions. My contribution dealt with developing of the method for assessment of fine roots turnovers. Our results show that stand age should be considered if simple temperature-based models to predict annual soil respiration in afforestation sites are to be used.

## (B-i).2 Biomass dynamics and carbon sequstration in forest trees and forest stands

*Relevant publications*

1. **Blujdea V,** Pilli R, Dutca I, Ciuvat L and Abrudan IV (2012) *Allometric biomass equations for young broadleaved trees in plantations in Romania*. Forest Ecology and Management (264)172-184.
2. Dutcă, I., Mather, R., **Blujdea, V.N.B.,** Ioraș, F. Olari, M., Abrudan, I.V (2018) Site-effects on biomass allometric models for early growth plantations of Norway spruce (Picea abies (L.) Karst.). Biomass and Bioenergy 2018 Vol.116, pp.8-17

*Theoretical contribution to allocation of carbon at the individual level tree.* The possibility of estimating young trees biomass is rather limited because forest yield tables are constructed starting from higher thresholds of proxy, such as diameter or height, and lack of availability of allometric equations. Power functions based on log-transformed data were applied to seven tree species (*Robinia pseudoacacia* (L.), *Quercus* sp., *Populus alba* (L.), *Gleditsia triacanthos* (L.), *Elaeagnus angustifolia* (L.), *Salix alba* (L.) and *Fraxinus excelsior* (L.)), one shrub (*R. canina* L.) and to the overall dataset with all the species pooled together (406 plants), using the diameter at collar height ($D_{ch}$), diameter at breast height ($D_{bh}$) or height ($H$) as single predictor. Parameters provided by the general equation highlighted permanent overestimation for aggregated biomass compartments and underestimation for branches or roots, but always fell into the range provided by the upper and lower values estimated for *a* and *b*. This suggests that, at least for young trees, our equation could be applied without regard for local fertility conditions or plantation management. Further contributions were looking into accuracy issues generated by model selection: a decrease of biomass estimation accuracy when ratio of powers of D and H in combined predictor D2H deviates from 2 (in Dutca et. al (2019)) compared to individual predictors. One of the most important contribution is published in Blujdea et al. (2012) shown in detail further down here. Paper was motivated the need to develop new or improved allometric functions (in a wider range of vegetation types, climate zones, and fertility classes) with associated description of the site characteristics (soil, climate, etc.) in order to make them applicable to a wider geographical area, thereby reducing error propagation effects during the scaling-up process. Also, biomass equations are needed for estimating the C stock changes in afforested areas or for verification purposes. They could also be useful in conjunction with modern remote sensing methods to measure individual trees (i.e. high resolution digital aerial photographs or laser scanning) and support the development of improved forest models (Kalliovirta et al., 2005). Brown (2002) showed that reliable carbon stocks estimates may be derived by using only diameter at breast height (Dbh) measurements and allometric relationships for broad categories of forest types and ecological zones, because Dbh alone could explain more than 95% of the variation in aboveground tropical forest carbon stocks, even in highly diverse regions. Many other studies provided reliable equations for temperate conifer and broadleaved forests, as reported in the extensive literature review by Zianis et al., 2005. Ziannis and Mencuccini (2004) compiled 279 equations, unevenly distributed on different tree species or ecological regions (i.e. 60% from North America and 23% from Australia), including young trees: for 202 out of 279 equations the minimum Dbh was less than 10 cm.

As highlighted by Parresol (1999), the relationships between tree biomass and biometric variables, such as Dbh or height (H), can be investigated by different allometric models (both linear and nonlinear), but the vast majority of equations take the simple linear form (Zianis et al., 2005; Niklas, 2004; Niklas, 2006):

$M = ax^{b}$ Eq. (1)

where the dependent variable M is the dry biomass, such as above- or belowground total biomass or individual compartments of the tree; x represents the independent variable (such as Dbh or H); *a* and *b* are the scaling coefficient and scaling exponent, respectively. Based on Eq. (1), empirical and species-specific equations were estimated by many authors for mature (Wirth et al., 2004; Joosten et al., 2004; Zianis et al, 2005) and, less frequently, young trees (Dutcă et al., 2010). Other studies suggested a different approach based on a general functional relationship between total aboveground biomass and Dbh, as was proposed by West, Brown and Enquist with the so-called WBE model (West et al., 1999; Enquist et al., 1999; Enquist et al., 2002; Simini et al., 2010). Even if this universal allometric relationship was strongly debated (Zianis and Mencuccini, 2004; Zianis and Radoglou, 2006; Fehrmann and Kleinn, 2006; Pilli et al., 2006), the application of this model on young trees was never specifically studied.

The aims of this work were: (i) to develop species-specific allometric equations for the tree species most used in afforestation in Romania, to be applied for young trees and different biomass compartments (i.e. stem, roots, branches, foliage), using different independent variables (diameter at breast height, diameter at collar height and tree height); (ii) to test the application of general equations on different species; (iii) to compare these equations against independent datasets.

***Materials and methods.*** Study area was represented by aartificial plantations realized on marginal agricultural lands in Romania, mainly on the lower Danube floodplain and hills. Former land use was generally classified as degraded and no longer suitable for arable crops or pasture, having been abandoned or under inconsistent cultivation since 1990. Soils are either sandy (wind and alluvial origin) in the western sites or chernozem, fertile and dry in the east (soils defined according to “Sistemul roman de taxonomie a solurilor”, MADR, 2003). The study focused on the four main species used for post 1990 afforestation activities (i.e., *Robinia pseudoacacia* (L.), *Quercus pedunculiflora* (L.), *Quercus cerris* (L.) and *Populus alba* (L.)), as well as *Gleditsia triacanthos* (L.), *Elaeagnus angustifolia* (L.), *Salix alba* (L.), *Fraxinus excelsior* (L.) and *Rosa canina* (L.), planted following afforestation technical norms specific to Romania.

***Sampling design and procedure.*** A non-systematic spatial sampling design was applied, as plantations are usually small plots distributed over the area concerned. One hundred and ninety-three geo-referenced plots were established based on planting statistics available from county forest authorities, while forest management plans and maps allowed precise identification of the units of afforested land. A biomass sampling plot, randomly established according predefined procedure, for each tree species was located every 200 ha of plantation, by screening the country from west to east (along the River Danube) and then from south to north (along the River Prut). Within a circular sampling plot (200 or 500 $m^2$ for older plantations), each plant was cross callipered for diameter at the collar ($D_{ch}$, in mm, measured at the soil surface after removing coarse debris) and diameter at breast height ($D_{bh}$, in mm, measured at 1.30 m height). Three to five trees having $D_{ch}$ within 1 standard deviation of the computed average were harvested, with roots larger than 2 mm in diameter being excavated. Data collection procedure was consistent with the methodology applied for the Kyoto Protocol's Joint Implementation Afforestation project currently implemented in Romania (Abrudan et al., 2003). An overview of the samples is given in Table 1.

Table 1: tree species sampled and the ranges for the independent variable datasets.

| Tree species | Number of trees | Likely range of plantation's age (years) | Average(min-max) diameter (cm) | | |
|---|---|---|---|---|---|
| | | | Dch | Dbh | H, min –max |
| *Robinia pseudoacacia (east site)* | 53 | 1-20 | 6.7(1.3-20.0) | 6(0-16.4) | 575(60-1550) |
| *Robinia pseudoacacia (west site)* | 38 | 1-20 | 4.7(0.6-16.0) | 4.5(0-15) | 334(43-1257) |
| *Quercus* sp (*Q. pedunculiflora* and *Q. cerris*) | 95 | 1-10 | 1.6(4.0-6.2) | 3(0-5.3) | 84(15-590) |
| *Gleditsia triacanthos* | 51 | 1-10 | 1.6(0.6-3.5) | 2.0 (0-3.1) | 123 (19-364) |
| *Elaeagnus angustifolia* | 24 | 1-10 | 2.4(0.8-5.9) | 2.3(0-4.1) | 184(85-410) |
| *Populus alba* | 81 | 1-12 | 4.4(0.5-12.5) | 3.4(0-10.7) | 282(75-820) |
| *Salix alba* | 19 | 1-10 | 5.1(2.1-11.0) | 4.3(0-9.1) | 282(105-540) |
| *Fraxinus excelsior* | 36 | 1-15 | 2.8(0.5-10.8) | 4.6 (0-8.1) | 236(26-910) |
| *Rosa canina* | 9 | 1-10 | 5.0(1.5-7.7) | - | 98(15-180) |
| *Overall* | *406* | *1-20* | *0.5-200* | *0-16.4* | *15-1550* |

***Allometric equations analysis.*** A general biomass equation model based on tree diameter or height, as unique predictor, was applied in Eq. (1). Even if a few authors assumed that Modeling of raw un-transformed data would render the best results (Castro, 1996), because of the heteroscedasticity of the raw data (Parresol, 1999), Eq. (1) was logarithmically transformed into linear form, as:

$$\ln M = \ln a + b \ln x \qquad \text{Eq. (2)}$$

In order to ensure a greater comparability of our results with data provided by other works and a wider practical applicability of our equations (for economic reasons, field measurements are generally limited to just one parameter such as height or diameter, Ter-Mikaelian, 1997), we based our study on the liner model defined by Eq. (2), widely applied by many authors (Zianis et al., 2005), without considering multilinear models. The *Proc Reg* procedure (SAS®) was applied to Eq. (2) considering $D_{ch}$, $D_{bh}$ and $H$ as independent variables and the individual or aggregated biomass compartments as dependent variables. The relationship between the most important biomass compartments (i.e. total aboveground and total woody aboveground) and height was also tested but, to avoid multi-collinearity implications, no second variable was included in the biomass equation (Zianis and Radoglou, 2006). However, since many authors (Zianis et al., 2005; Fehrman and Kleinn, 2006) reported a strong correlation between the three independent variables (i.e., $D_{bh}$, $D_{ch}$ and $H$), the relationship between $H$ and diameter ($D_{bh}$ and $D_{ch}$), and between $D_{bh}$ and $D_{ch}$, was also analysed through the linear model reported in Eq. (2).

The goodness of fit of each relationship was evaluated analysing the coefficient of determination $R^2$ and the distribution of the studentized residuals, i.e. the scaled version of residuals that are obtained by dividing each residual by its standard error (Sit, 1994). Because the logarithmic transformation introduces a systematic bias, a correction factor (CF) based on the standard error of the estimate (SEE) was calculated for each regression model (Sprugel, 1983):

$$CF = e^{\left(\frac{SEE^2}{2}\right)} \qquad \text{Eq. (3)}$$

In order to compare the equation estimated for each species and compartment, and to gain an idea on the uncertainty of projections, the standard error (SE) estimated by the model was also reported for both $a$ and $b$ parameters. Each compartment was then analysed by applying Eq. (2) and Eq. (3) to each species and to the overall dataset (all species pooled together). After back transformation the biomass equation was:

$$M = e^{a} X^{b} CF \quad \text{Eq. (4)}$$

where, $M$ is the dependent variable (biomass); $X$ is the independent variable ($D_{bh}$, $D_{ch}$, $H$); $a$, $b$ are the regression coefficients and $CF$ is the correction factor.

To compare our results with the values provided by other studies on the relationships between aboveground total biomass (ABGTB), $D_{ch}$ and $D_{bh}$, we also applied the reduced major axis model II regression (RMA) proposed by Niklas (1994, 2006) to the scaling exponent. Indeed, as highlighted by this author, given that $D_{bh}$ and $D_{ch}$ are subject to natural variations and measurement errors and are therefore not independent variables (Kaitaniemi, 2004), parameter $b$ should be estimated as:

$$b_{RMA} = \frac{b}{r_{yx}} \quad \text{Eq. (5)}$$

where, $b_{RMA}$ is the scaling exponent based on the RMA model, $b$ is the value estimated by the least square model I regression (OLS) applied to Eq. (2) and $r_{yx}$ is the correlation coefficient determined from least square regression (Henry and Aarssen, 1999) in Eq. (2).

***Assesment of allometric equations performance.*** Independent validation datasets were not available for all the derived equations in order to perform a thorough analysis. However, an assessment of the performance of biomass equations and independent datasets followed three different approaches, in all cases limiting the comparison only to the range of diameters available from our study (as reported in Table 1). Firstly, the general equation obtained by the same procedure as above, without any distinction between species and sites (all species pooled together), was validated against a raw dataset collected from 18 trees belonging to four different species with a range of 5 – 31 mm of $D_{ch}$ (Table 2 ).

Table 2: species and main dendrometrical parameters of the trees used to test estimated equations.

| **Datasets** | **Tree species** | **Number of trees** | **Range of plantation's age (years)** | ***Mean* and *min – max* range fo** | | |
|---|---|---|---|---|---|---|
| | | | | Dch **(cm)** | Dbh **(cm)** | H **(c** |
| Raw dataset, used for general equation | *Prunus cerasifera* Ehrh., *Quercus rubra* (L.), *Crataegus monogyna* Jacq., *Ulmus campestre* L.) | 18 | 1-15 | 2.1(0.5-3.9) | 2(0-3.1) | 137(37 |
| Species-specific dataset from Republic of Moldova (pers. com.) | *Robinia pseudoacacia* | 10 | 1-10 | 6.3(3.2-9.5) | n.a. | 575(403 |
| | *Quercus* sp | 10 | 1-10 | 6.3(3.2-9.8) | n.a. | 333(178 |
| | *Gleditsia triacanthos* | 10 | 1-10 | 5.2(3.0-7.4) | n.a. | 488(368 |

In addition, aboveground woody biomass (ABGWB) equations were validated against raw data sampled in the neighbouring Republic of Moldova for *R. pseudoacacia* (E), *Quercus* sp. and *G. triacanthos*. Sampling was done near Ţânţăreni (Anenii Noi county), close to the eastern Romania sampling sites. Biomass data were processed identically (Table 2). Tree biomass was sampled across the main slope gradient in single plots. Observed ABGWB of sampled trees was compared with values predicted by our equations. The performance of each model was tested through the relative difference (RD) between observed and predicted values, for each biomass compartment (Zianis and Mencuccini, 2004):

$$RD = \frac{|M - \widehat{M}|}{M} \quad \text{Eq. (6)}$$

where M and $\widehat{M}$ are the observed and predicted biomass, respectively. The average percentage RD ($\overline{RD}$) estimated for each species and biomass compartment was also considered.

Lastly, Romanian yield table-based and equations predicted values were further analysed based on Eq. (6). Estimates of the aboveground biomass were derived from Romanian yield tables (Giurgiu et al., 1972) by applying country specific average data of wood density (Mos, 1985). Noticeably, tree volume reported by these tables includes both stem and branches to terminal buds, with $D_{bh}$ classes of 2 cm size. No such analysis was done for *E. angustifolia* and *G. triacanthos* for which there are no yield tables in the country.

***Results. Allometric equations.*** Table 3 presents the scaling exponent (*b*) and scaling factor (reported as *ln(a)*) of the power functions for each of the predictors ($D_{ch}$, $D_{bh}$ and *H*), with the corresponding standard error (±SE), estimated for each individual compartment and for aggregated biomass compartments, for one of the species (as example, for all other species see the reference). The parameter *ln*(*a)* was negative for both *H* and $D_{ch}$ as predictors, with consistently lower values for *H* in every species. Instead, values of parameter *b* showed a positive and much greater homogeneity across all species. The coefficient of determination was generally high both for each individual species and for the general group, for either individual or aggregated biomass compartments. For foliage, $R^2$ was lower in all species with the exception of

*F. excelsior*, while for roots the goodness of regression was generally higher, with the exception of *R. canina*. $D_{bh}$ was not a good predictor for *G. triacanthos*, nor for *Quercus sp.* or *P. alba*.

Table 3: Statistics and estimates of *ln(a)* and *b* (SE = standard error) for the power function model reported in Eq. (2) distinguished by species (the General group refers to the overall dataset), predictor (Dch, H and Dbh) and biomass compartment (ABGWB = total aboveground woody biomass, including branches and stem; ABGTB = total aboveground biomass which also includes the foliage). The final sample sizes (N) are reported after exclusion of outliers.

| Species | Independent variable | Dependent variable | *ln(a)*±SE | b±SE | $R^2$ | Sample size (N) | Correcting Factor (CF) |
|---|---|---|---|---|---|---|---|
| Elaeagnus angustifolia | Dch | ABGTB | -3.9276±1.0968 | 3.1470± 0.3536 | 0.9168 | 31 | 1.1009 |
| | | ABGWB | -3.9928± 1.0575 | 3.0744± 0.3435 | 0.9149 | 33 | 1.1730 |
| | | Stem | -4.5233±0.8232 | 3.0544±0.2652 | 0.9486 | 32 | 1.0910 |
| | | Branches | -5.2852±0.8232 | 3.1704±0.4266 | 0.8848 | 32 | 1.2527 |
| | | Foliage | -4.8907±1.9919 | 2.9989±0.6459 | 0.7430 | 33 | 1.7612 |
| | | Roots | -3.3168±1.1152 | 2.5595±0.3601 | 0.8715 | 33 | 1.1882 |
| | H | ABGTB | -13.4526±2.5928 | 3.7408±0.5062 | 0.8799 | 33 | 1.2503 |
| | | ABGWB | -13.1274± 2.4517 | 3.6218± 0.4768 | 0.8892 | 32 | 1.2038 |
| | Dbh | ABGTB | 4.9209±0.6003 | 2.7844±0.6938 | 0.8190 | 18 | 1.1604 |
| | | ABGWB | 4.8291± 0.5295 | 2.5103± 0.6120 | 0.8254 | 18 | 1.7761 |
| | | Stem | 4.1759±0.5420 | 2.5932±0.6264 | 0.8280 | 18 | 1.1868 |
| | | Branches | 3.9902±0.6544 | 2.4532±0.7564 | 0.7471 | 18 | 1.2837 |
| | | Foliage | 2.3242±0.9614 | 4.0248±1.1299 | 0.7686 | 19 | 1.7648 |
| | | Roots | 3.9099±0.5733 | 2.2295±0.6738 | 0.7414 | 19 | 1.2238 |

A comparison between the scaling exponent estimated for the ABGTB compartment with the RMA model (bRMA) using Dch and Dbh as predictors (with the corresponding standard error) is tested in order to highlight possible differences for this parameter. For Dch, 5 out of 9 values were not statistically different, while for Dbh, 5 out of 8 values were not statistically different (no value was provided for R. canina). The scaling exponents estimated for the overall dataset, using the two diameters as predictors, resulted as statistically different from one another for the ABGTB.

A negative significant ($p<0.0001$) correlation, also reported by Zianis and Mencuccini (2006), was detected between the scaling factors and the scaling exponents, considering parameters estimated for all biomass compartments and species (excluding the general group) as a function of $D_{ch}$ (coefficient of correlation, $r$ = -0.83) and $D_{bh}$ (r = -0.57).

Correction factors showed a rather narrow variation, regardless of the biomass compartment. However, for foliage and branches biomass, *CF* presented a generally wider range and higher values than for the other individual or aggregated biomass compartments. As expected, we detected a strong relationship between *H* and $D_{bh}$, *H* and $D_{ch}$, and between the diameters in the two measurement positions (Table 4). The $R^2$ of the applied linear model was always significant, with the exception of the relationship between *H* and $D_{bh}$ for *G. triachantos*, probably due to the characteristics of this species in young stages.

Table 4: relationship between Dbh, Dch and H: the $R^2$ and values of parameters *ln(a)* and *b* are reported.

| SPECIES | DEPENDENT VARIABLE | INDEPENDENT VARIABLE | $R^2$ | RELATIONSHIP | |
|---|---|---|---|---|---|
| | | | | *ln(a)* | *b* |
| E. angustifolia | H | Dch | 0.96 | 2.841 | 0.744 |
| | H | Dbh | 0.79 | 3.751 | 0.561 |
| | Dch | Dbh | 0.92 | 0.723 | 0.892 |
| F. communis | H | Dch | 0.95 | 2.026 | 1.049 |
| | H | Dbh | 0.91 | 2.932 | 0.858 |
| | Dch | Dbh | 0.97 | 0.284 | 0.989 |
| G. triacanthos | H | Dch | 0.97 | 1.792 | 1.092 |
| | H | Dbh | 0.37 | 4.065 | 0.387 |
| | Dch | Dbh | 0.74 | 1.289 | 0.637 |
| P. alba | H | Dch | 0.90 | 3.430 | 0.592 |
| | H | Dbh | 0.84 | 3.733 | 0.562 |
| | Dch | Dbh | 0.92 | 0.468 | 0.958 |
| Quercus sp. | H | Dch | 0.85 | 1.841 | 0.895 |
| | H | Dbh | 0.89 | 4.003 | 0.391 |
| | Dch | Dbh | 0.75 | 1.920 | 0.533 |
| R. pseudoacacia (E) | H | Dch | 0.89 | 3.214 | 0.786 |
| | H | Dbh | 0.87 | 3.335 | 0.785 |
| | Dch | Dbh | 0.98 | 0.159 | 0.999 |
| R. pseudoacacia (W) | H | Dch | 0.95 | 2.552 | 0.877 |
| | H | Dbh | 0.93 | 3.253 | 0.726 |
| | Dch | Dbh | 0.97 | 0.735 | 0.842 |
| S. alba | H | Dch | 0.91 | 2.393 | 0.832 |
| | H | Dbh | 0.93 | 2.971 | 0.730 |
| | Dch | Dbh | 0.94 | 0.518 | 0.915 |

***Tree compartment biomass.*** Tree species showed different patterns of total biomass accumulation over the sampled diameter range (Fig. 3). The initial biomass corresponded to two-year-old trees, with the first one spent in the nursery and the second in the field at the end of the first vegetative season. Initial average total dry biomass ranged from 0.02 kg/tree in *E. angustifolia*, *R. canina*, *Gleditschia* sp., *F. excelsior* and *Quercus* sp., to 0.03 kg/tree in *P. alba* and 0.04 kg/tree in *R. pseudoacacia*.

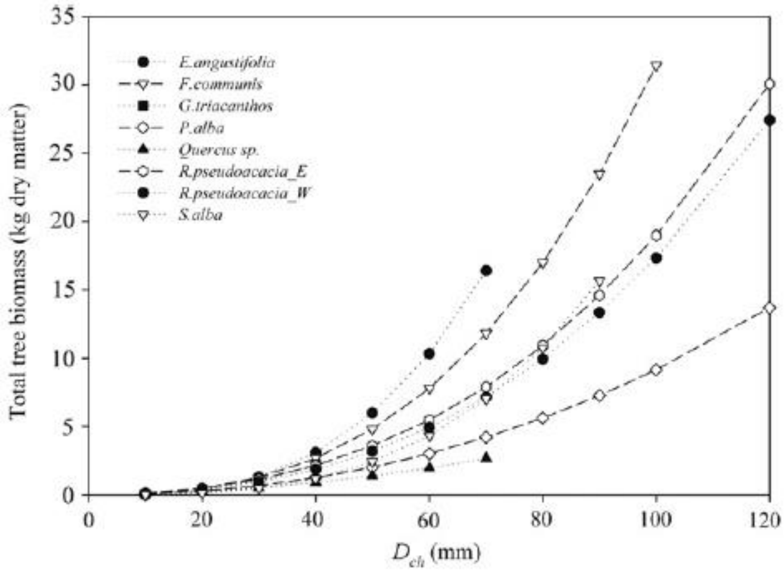



**Fig. 3.** Total tree biomass accumulation estimated for each species. $D_{ch}$ values are reported only for the measured range. Total biomass includes leaves, above and belowground woody components.

The share of compartments on the total tree biomass showed a species-specific pattern, highlighted (Fig. 4). While the percentage of stem biomass increased with $D_{bh}$ in *R. pseudoacacia*, *F. excelsior* and *Quercus* sp. (exceeding 40% of the total), it was quite stable for *P. alba* and *S. alba* (around 40%). Branches showed an increasing percentage for all species with a range between 10% in *Quercus* sp. and about 25% for other species, except *R. pseudoacacia* (E) for which the relative percentage of this compartment decreased from 25% to about 10% for $D_{bh}$>12 cm. The highest share of branch biomass occurred in *E. angustifolia* (not reported in Fig. 4), a shrub-like tree species.

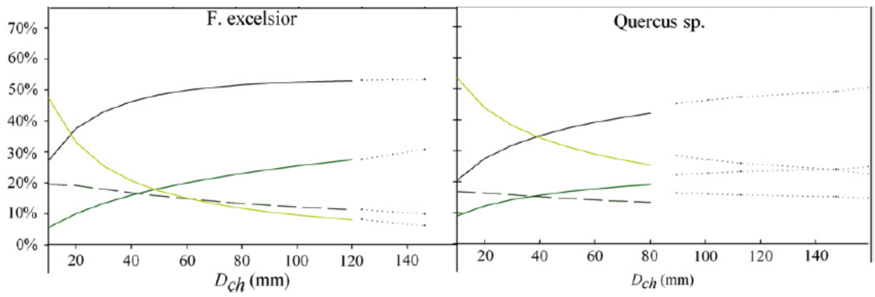



**Fig. 4.** Share of biomass compartments (out of total tree biomass, 100%) estimated by allometric equations applied to the sample dataset (the dotted lines show the likely range outside of measured collar diameters).

The share of foliage decreased with increasing $D_{bh}$ to less than 3% of total tree biomass, but higher shares of around 10% were still predicted in *F. excelsior* and *P. alba*. In *S. alba* the relative percentage of foliage increased in the range considered by our study while *E. angustifolia* showed a constant 27% foliage biomass over the entire diameter range. Biomass of roots was higher than stem biomass, under a species-specific $D_{ch}$ threshold, with the highest being in *Quercus* sp. (i.e. 40 mm). In *R. canina* roots became some 5% higher than aboveground woody biomass as soon as the $D_{ch}$ of stems passed the threshold of 20 mm.

While other species were planted in a limited range of soil types, climate and management regimes, *R. pseudoacacia* was found and sampled in two types of site. For the range of measured diameters, total tree biomass on sandy soils (western sites, W) was 20% less than on chernozem soils (eastern sites, E). More specifically, the foliage biomass was 100% and root 15% higher in the western sites. Conversely, the stem was 25% taller in eastern sites, $D_{ch}$ was around 10% larger and *H* 20% taller on average than in the other sites, if all trees with $D_{ch}$ between 100-200 mm are pooled together.

***Biomass equation performance assessment.*** The differences between the general equations and raw datasets reported in Table 2 were evaluated computing the mean percentage *RD* for each biomass compartment, estimated applying Eq. (6) to each tree (Table 5).

Table 5: comparison between observed and predicted biomass estimated by the general equations based on Dch for the raw dataset (n = 18): the difference (*D*, i.e., the average difference between observed and predicted values, either positive or negative), the mean percentage $\overline{RD}$ estimated through Eq. (5) and corresponding standard deviation are also reported.

| BIOMASS COMPARTMENT | DIFFERENCE (D) | $\overline{RD}$ | STD. DEV. of RD (%) |
|---|---|---|---|
| ABGTB | +9.86 % | 32.3 % | 32.9 % |
| ABGWB | +10.79 % | 36.7 % | 30.9 % |
| Stem | +9.04 % | 36.8 % | 25.9 % |
| Branches | -2.01 % | 45.1 % | 47.4 % |
| Foliage | +98.9 % | 108.6 % | 96.3 % |
| Roots | -18.9 % | 49.6 % | 27.5 % |

The second comparison, based on the Moldavian dataset, showed a consistently better performance (results are reported in Table 6).

Table 6: validation on the Moldavian dataset. The table reports (i) the mean percentage relative differences ($\overline{RD}$) between ABGWB estimated by allometric equations and observed values, and (ii) the difference, estimated as the average difference between predicted and observed values, either positive or negative, between ABGWB predicted by equation and reported for each tree and species in the original dataset (i.e. the negative sign shows underestimation by our equation).

| SPECIES | $\overline{RD}$ | | DIFFERENCE (%) | |
|---|---|---|---|---|
| | **f(**Dch**)** | **f(**H**)** | **f(**Dch**)** | **f(**H**)** |
| *R.pseudoacacia* | 24.2% | 42.6% | -23.7% | -15.7% |
| *Quercus sp.* | 52.0% | 42.7% | -52.0% | -41.6% |
| *G. triachantos* | 21.9% | 68.6% | -3.1% | 54.4% |

Using $D_{ch}$ as predictor for ABGWB equations and comparing the results against the values measured in Moldova, the range of $\overline{RD}$ varied between 52% (for *G. triacanthos*) and 24% (for *R. pseudoacacia*). For height the mean relative difference ranged between 42% (for *R. pseudoacacia* and *Quercus* sp.) and 68% (for *G. triacanthos*). When compared the average ABGWB per tree (estimated on the Moldavian dataset by our equations using the average values of *b* and *a*) for all species the average biomass based on field measurements (i.e., the values reported as “observed”) fell into the range predicted by equations applying the upper/lower range reported for regression parameters. The differences between observed and predicted biomass were generally lower using $D_{ch}$ as predictor rather than *H*. The range of biomass detected with *H* was considerably larger than the range detected with $D_{ch}$, above all for *R. pseudoacacia* and *G. triacanthos*.

Finally, comparing species-specific biomass equations with data derived from Romanian yield tables (Fig. 5), for *R. pseudoacacia*, *F. excelsior* and *P. alba*, the biomass predicted by our equations fell into the range estimated through the yield tables, with the upper value defined by the best fertility class and lower by the poorest fertility class. For *Quercus* sp., however, the tables apparently overestimated ABGWB for $D_{bh}< 14$ cm. Projection inaccuracy increased with the $D_{bh}$ for both *Quercus* sp. and *F. excelsior*, toward unrealistically small biomass values for high diameters.

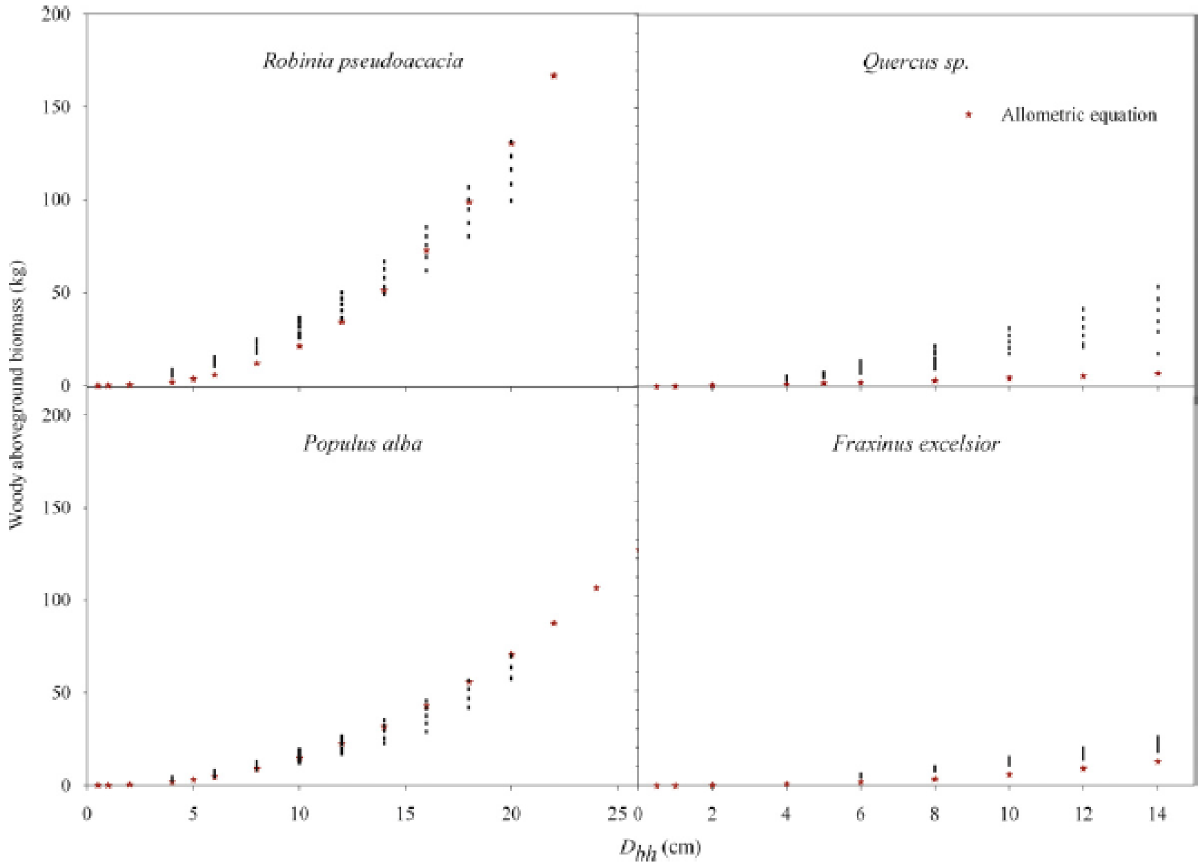



Fig. 5. Comparison between data provided by allometric equations (reported by red stars) and the ABGWB range (reported by black vertical bars) estimated applying species and country-specific data of wood density to the volume predicted by national yield tables (Giurgiu et al., 1972) for each species and five groups of fertility classes.

***Discussion. Allometric equations.*** As expected, the power function could adequately predict both individual and aggregated biomass compartments both at species-specific level and for the general group. Considering the target of this study (i.e., the early stages of tree development) the same models were applied using not only $D_{bh}$ as predictor, but also $D_{ch}$ and *H*, applying the derived equations within the recorded diameter distributions. As highlighted by the coefficient of determinations, these last variables could better predict the value of the dependent variables, both for partial and aggregate biomass compartments. Indeed, on very young trees, $D_{bh}$ showed a lower predictive capacity (i.e. for ABGTB) caused by a significant share of the crown and by trees having a “shrubby” appearance (i.e. *G. triacanthos*, *Quercus* sp.). Also, the stem is often difficult to identify either because of active branch growth and lack of dominance (i.e. *R pseudoacacia* or *P. alba*) or slow growth (i.e., *Quercus* sp.). Moreover, planting technique or damaging factors may also influence early biomass accumulation (i.e. after planting, the stem of *R. pseudoacacia* is cut to stimulate vegetative growth).

The use of $D_{ch}$ has already been suggested not only for some woodland shrub species as *Juniperus* sp. (Curtis, 2008) but also for seedlings deriving from plantations (Dutca et al., 2010) and natural regeneration processes. Geudens et al. (2004), applying this approach on young Scots pine seedlings to estimate ABGTB as a function of $D_{ch}$, detected increasing values of *b* from 2.06 to 3.36 according to seedling age (from 2 to 4 years).

A negative allometric relationship ($b < 1$) was generally detected between *H* and diameter (as independent variable) and between $D_{ch}$ and $D_{bh}$ (as independent variable). This means that, for the range considered in our study, the growth rate in height was lower than the diameter rate, and the $D_{ch}$ growth rate was lower than the detected $D_{bh}$ rate. Interestingly, we detected an isometric relationship between *H* and $D_{ch}$ only for *F. excelsior* and *G. triacanthos*, and between $D_{ch}$ and $D_{bh}$ for *R. pseudoacacia* (E). This was probably due to the diameter range investigated in our dataset.

In the overall group $b_{RMA}$ was equal to 2.75 ± 0.096 and, as highlighted by Fig.2, it was not statistically different from the values estimated for the same parameter in 4 out of 8 species. Interestingly, this value was statistically equal to the value ($b = 2.66$) predicted by West et al. (1999), based on the so-called WBE model (Enquist et al., 1999). These authors suggested that the ABGTB should scale against $D_{bh}$ according to a universal exponent ($b = 8/3$, i.e. 2.66), because the scaling exponent would depend on an optimal tree architecture. In our study, however, the value was detected using $D_{ch}$ rather than $D_{bh}$ as independent variable. The use of a general scaling exponent has been strongly debated in the literature. Zianis and Mencuccini (2004), using a world-wide list of 279 biomass allometric equations, estimated an empirical scaling exponent equal to 2.36, but they also underlined that the use of a universal value of *b*, implying that the ratio of biomass and $D_{bh}$ for trees growing in different environmental conditions should be constant, was not acceptable. On the other hand, Pilli et al. (2006) analysing 49 datasets of different species, distinguished a juvenile, an adult and a mature stage and detected three different scaling exponents, equal to 2.08 (for juvenile trees), 2.66 (for adult trees) and 2.51 (for mature trees) related to growth stages but independent of species and site. Both these studies were based on $D_{bh}$ as independent variable. However, as highlighted by Fehrmann and Keinn (2006), measuring the diameter at fixed height (i.e., 1.3 m for $D_{bh}$), regardless of the absolute tree size, we obtained a measurement of the cross-sectional area in different relative points with respect to height. To avoid this error, these authors proposed using a recalculated diameter in relative stem height and through this approach, they estimated the same exponent predicted by the WBE model (i.e., $b$ = 2.66). In our cases, using $D_{ch}$ instead of $D_{bh}$, the relative position of our independent variable with respect to the total plant height was always the same (i.e., the base of the tree), implicitly correcting the bias detected by Fehrmann and Kleinn (2006) and allowing estimation of the same exponent detected by these authors and expected by the WBE model.

The presence of very small biomass data in the dataset also seems to have a significant contribution on the $b$ value, which increases with lower $D_{ch}$. On the aggregated biomass compartments (ABGTB and ABGWB) and stem, $b$ presented similar values, likely showing that the contribution of foliage to overall biomass variability is less significant.

As highlighted in Table 3, the coefficient of determination for foliage was generally lower than the other one (except for *F. excelsior*) while $b$ varied between 4.02 for *E. angustifolia* and 0.94 for *Quercus* sp. (for this species, however, $R^2$ was equal to 0.43). Except for *E. angustifolia*, the scaling exponent was generally lower for foliage than for the other compartments, as also detected by Peichl and Arain (2007) on 2-year-old seedlings of *P. strobus*. For roots, $b$ varied between 2.55 for *E. angustifolia* and 1.50 for *Quercus* sp., while for the overall group it was equal to 2.09. For all species except *R. canina*, using $D_{ch}$ as independent variable to estimate this last compartment, $R^2$ was higher than 0.7 and always higher than the corresponding estimation performed with $D_{bh}$. This suggests that, at least for young trees, $D_{ch}$ could be a better predictor of belowground biomass than $D_{bh}$.

Using *H* as independent variable to estimate ABGTB, *b* varied between 3.7 for *E. angustifolia* and 1.4 for *R. canina*; *S. alba* and *P. alba* had values between 3.2 and 3.3; for *R. pseudoacacia* it was about 2.9 – 3.0, for the other species it was lower than 2.5. As expected in *R. canina*, a multi-stemmed shrub, the biomass predictive capacity of *H* was lower than in the tree species. In the overall group *b* was equal to 2.50. As for $D_{ch}$, the value of this parameter was generally similar for ABGWB and ABGTB. For all species except *R. canina*, $R^2$ was higher than 0.84. Geudens et al. (2004), using this parameter as predictor for ABGTB for 4-year-old seedlings of *P. sylvestris*, reported a value of *b* equal to 3.36, comparatively higher than the values detected using $D_{ch}$ as estimator of the same compartment.

The use of $D_{bh}$ as predictor for biomass has been widely reported in the literature, even if generally applied to older age (Zianis et al., 2005). Using this measurement to estimate ABGTB, *b* varied between 3.04 for *F. excelsior* and 1.22 for *Quercus* sp., but for many of our species this parameter was between 2.05 and 2.78. As highlighted by Fig.2, using $D_{bh}$ as predictor of the ABGTB the value of $b_{\mathrm{RMA}}$ for the general group ($b_{RMA}$ = 2.49 ± 0.10) was not statistically different from the values estimated for the same parameter in 5 out of 8 species. The value predicted with the least square model I regression (*b* = 2.36 ± 0.09) was instead the same as that reported by Zianis and Mencuccini (2004) as an empirical general scaling exponent, equal to 2.36. However, the $D_{bh}$ of the world-wide list of allometric equations used by these authors ranged from 0 to more than 200 cm. Empirical general equations for detecting the relationship of different biomass compartments against $D_{bh}$ for 10 tree species were also proposed by Wang et al. (2006). The scaling exponents reported by these authors applying the OLS approach varied from about 2.4 for ABGTB, stem and roots (i.e., approximately the same value estimated by our work and by Zianis and Mencuccini, 2004), to 2.85 for branches and 2.13 for foliage. Finally, the scaling exponent detected by our study with the RMA method was also not statistically different from the value predicted with the same approach by Pilli et al. (2006), being equal, for young trees, to 2.08 ± 0.4. Differently from the studies mentioned above, this value was specifically based on trees with $D_{bh}$<9.5 cm and therefore indirectly related to the effect of stand age on biomass parameters recently highlighted by Genet et al. (2011).

Moving to species level, the value detected for *E. angustifolia* (i.e., $b$ = 2.78 for the ABGTB compartment) was higher than the value ($b$ = 1.733) reported by Zhou et al. (2007) applying a power function to the same species. That study, based on older trees with a $D_{bh}$ between 7 and 31 cm collected in shelterbelts, also highlighted that trunk $D_{bh}$ and/or $H$ were satisfactory independent variables for trunk biomass prediction but insufficient for determining branch biomass, a major compartment of biomass in older trees. This also explains the lower coefficient of determination ($R^2$< 0.76) detected in our study for branches, foliage and roots of *E. angustifolia*. Interestingly, all the equations estimated for *F. excelsior* using $D_{bh}$ showed a high coefficient of determination ($R^2$ > 0.86 for all compartments). The scaling exponents detected for both ABGTB (3.04) and foliage (2.35) were higher than the values reported by Alberti et al. (2005) for the same species and biomass compartments ($b$ of 2.76 and 2.14 for ABGTB and foliage, respectively) but as in other studies reported in the literature, the parameters were estimated on older trees with a $D_{bh}$ between 6 and 25 cm. Many studies were reported by Zianis et al. (2005) for *Populus* sp., generally based on *P. tremula*. The scaling exponent detected by these authors for ABGTB varied between 2.54 and 2.60 (in our study $b$ = 2.18); for the stem $b$ was about 2.75 (in our study $b$ = 2.28), for branches it was 1.87 (in our study $b$ = 2.29) and for foliage 1.48 (in our study $b$ = 2.03). Unlike what was observed for *F. excelsior*, the scaling exponents estimated in our work, based on smaller $D_{bh}$ classes, were generally lower than values reported in other studies but the coefficient of determination was also lower than for other species ($R^2$ < 0.83 for all compartments), especially for branches and foliage.

As for *P. alba*, also equations estimated for *Quercus* sp. using $D_{bh}$ generally presented a lower $R^2$, except for ABGTB and ABGWB, which was probably related to the small number of samples (only 14 trees) and to the aggregation of different species *of Quercus* in a single group.

The samples available for *R. pseudoacacia* were split between two groups, eastern (E) and western (W), according to different climatic and soil conditions. As reported in Table 3 the scaling exponents detected for ABGTB were statistically different ($b$ = 2.46 ± 0.18 for the E group and $b$ = 2.44 ± 0.17 for the W one), as were ABGWB and stems, where the values of the eastern area were always higher than those estimated in the western one. For branches, foliage and roots no difference was highlighted (even if for foliage $R^2$ of *R. pseudoacacia* – E was 0.35). This could suggest that environmental conditions affect the aboveground woody compartments (i.e., stem) more than belowground and foliage and that, in the western sites, irrigation and fertilization significantly affect the early growth stages of the plants.

Finally, for *S. alba*, $b$ varied between 2.63 and 2.71 for ABGTB, ABGWB, stem and branches; for foliage it was 3.34 and for roots 2.40. In this species as in others (except *G. triacanthos* and *Quercus* sp), no statistical difference could be detected in the values of $b$, using $D_{bh}$ and $D_{ch}$ as independent variables.

As suggested in the literature (Niklas, 1994), we also explored the possible mathematical relationships between the scaling coefficient and scaling exponent. We detected a strong correlation ($r$ = -0.90) between the scaling coefficients and $b$, considering all equations provided to estimate biomass compartments as a function of $D_{ch}$. A linear regression could therefore be estimated between the two parameters in order to directly provide the value of the scaling exponent as a function of $b$. However, this relationship could not be estimated using $D_{bh}$ as predictor, because of the lower correlation between $ln(a)$ and $b$ (r = -0.57). It should also be pointed out that if the measurement units of the independent and/or dependent variables change then different results may be obtained for the values of parameter $a$ and its relationship to $b$ may drastically change, due to mathematical artefacts. This suggests some caution about the possible biological meanings of this relationship, also detected by other authors.

Our results differed from the results provided by Zianis and Mencuccini (2004), but the absence of a significant statistical correlation for young trees had already been reported by Pilli et al

(2006). Indeed, as suggested by many authors (Niklas, 1994; Ketterings et al., 2001; Zianis and Mencuccini, 2004; Pilli et al., 2006), the value of *a* seemed related not only to local environmental conditions but also to species-specific characteristics such as the wood density (Genet et al., 2011). However, this last parameter is likely influenced by the share of hardwood/softwood, with hardwood's contribution given by the differentiation moment (i.e. tree age) and physical properties. Analysing only fresh samples, Niklas (1997) found that in *R. pseudoacacia* the most recent sapwood layers were significantly denser than older ones, while the most recent layers of heartwood were less dense than older ones. In fact it is well-known that heartwood formation is determined by species, age of the tree, position, growth rate and silvicultural treatments (Bamber, 1976; Bamber and Fukazawa, 1985) but deeper investigation of its contribution to total biomass is needed. The larger range of the scaling exponents could therefore be related to variability of wood density. Moreover, possible comparisons with the values provided by other authors for this parameter were prevented by the mathematical meaning of *a*. Indeed, because the scaling coefficient represents the intercept of the straight line estimated by Eq. (2) on the vertical axis (i.e., the biomass of an ideal tree having $D_{bh} = 0$), this value was also related to the minimum $D_{bh}$ class considered by the sample dataset (i.e., about 1 cm), generally different from the diameter range considered in other studies.

Overall, the parameter *a* was generally either negative for $D_{ch}$ or positive for $D_{bh}$ as biomass predictor, with absolute values apparently influenced by the biomass of the initially planted tree. Interestingly, for our young trees, the ratio between the ranges of variation of the parameter *b* (i.e., the difference between minimum and maximum values) was a constant 0.27, whether of individual or aggregated biomass compartments, if all species were pooled together. Nevertheless, this ratio was smaller (value of 0.24) for biomass of foliage and higher for total biomass (value of 0.28). This may again confirm the existence of a dependency between the two parameters and that the applicability of general equations for tree biomass estimation by power functions could be explored further.

***Tree biomass compartments.*** As reported in Fig. 3 the initial total biomass estimated by allometric equations, corresponding to seedlings about 2 years old ($D_{ch}$ = 10 mm), varied between 0.02 kg and 0.04 kg/plant. Both *R. pseudoacacia* and *S. alba* showed a similar trend in the following stages, while *E. angustifolia* and *F. excelsior* showed a faster increase of biomass and *P. alba* and *Quercus* sp. a slower growth. No difference was detected for *R. pseudoacacia* between the eastern and western area. Biomass accumulation capacity and its distribution at tree level (reported in Fig. 4) markedly differ amongst species according to the intrinsic growth pattern (e.g., indeterminate in *R. pseudoacacia* or cyclic in *Quercus sp.*) and environmental pressures. As highlighted by the dotted lines reported in Fig. 4, any extrapolation of biomass equations outside the specified intervals of the independent variable should be well assessed and later validated by field measurements. The share of biomass compartments also highlighted the differences between eastern and western sites for *R. pseudoacacia* plantations. Instead, in other species no statistically significant differences in site index heights between soil types were found using a *t-test* (Johansson, 2002).

Analysing the numerical data reported in Fig. 4, we also observed that the relative increase of aggregated biomass became insignificant (< 3%) with increasing $D_{ch}$, but earlier for slow-growing species (i.e. *Quercus* sp, *E. angustifolia*, *P. alba*) and later for faster growing ones (i.e. *F. excelsior*, *S. alba* and *G. triacanthos*). This occurred at $D_{ch}$ of 128 mm for the first group and 174 mm for the second, with *R. pseudoacacia* having an intermediate position ($D_{ch}$ of 148 mm). Biomass accumulation beyond these $D_{ch}$ became practically linear, probably until very large diameters when tree growth starts to decline (likely beyond typical management cycle). This suggests that the growth of woody biomass could be defined by the equations fitted on destructively sampled young trees (max 13 cm $D_{ch}$ or 12 cm $D_{bh}$ in slow-growing trees and $D_{ch}$ 17 cm or 15 cm $D_{bh}$ in fast-growing ones). In fact, with *R. pseudoacacia* for which we had the widest dataset, parameters of the fitted power equation and the performance adjustment of the model (i.e., $R^2$) changed negligibly with increasing availability of measurements above these values. This result is consistent with the so called “small tree sampling scheme” (SSS) proposed by Ziannis and Mencuccini (2004), as far as harvesting only small trees offers considerable benefits in terms of time-saving and cost, especially when biomass data is needed for local applications.

***Biomass equation comparison.*** As reported in Table 5, the relative difference estimated applying biomass equations against an independent dataset, varied between about 30% for ABGTB, ABGWB and stems to more than 100% for foliage. As expected the equation could not adequately predict biomass of foliage, due to the environmental and local conditions which affect this compartment, but the $\overline{RD}$ detected on the most important biomass aggregations

(ABGTB and ABGWB) was satisfactory. This could support the use of such generic parameters, where no species-specific equations are available at local level. As highlighted by Fig. 5, for all species except *Quercus* sp., biomass predicted by equations fell into the range provided by the fertility classes reported by the yield tables. This suggests that, at least for young trees, our equation could be applied without regard for local fertility conditions (although these plantations were generally on quite degraded sites). For *Quercus* sp., ABGWB predicted by the equations underestimated the biomass estimated by the tables. This could be related (i) to the slower growth pattern already highlighted for this species (Fig. 3), (ii) to the grouping of different species within this group, (iii) to the low number of samples available which also affected the regression coefficient of the equation ($R^2$ = 0.87), and (iv) to the small diameter ranges of available plants. This last factor was probably the most important. Indeed, biomass equations in this study were developed for the range of diameters available in randomly sampled plantations, and could be safely applied for similar ranges.

Using the dataset provided from Moldova, we also tested the variability on the dependent variable (in this case ABGWB) related to the standard error (SE) estimated for the scaling exponent and scaling coefficient. Despite the strong difference in the average values, the range of biomass estimated for *Quercus* sp. was closer than for the other species. In any case, the average biomass calculated on the original dataset, always fell into the range provided by the upper and lower values estimated for *a* and *b*. This supported the application of our equation outside the specific area where data were collected, but the range was considerably narrower using $D_{ch}$ rather than $H$ as predictor. Therefore, as suggested by the coefficient of determinations, the first variable can probably provide a more accurate estimate when the range of variability of biomass is required for further analysis.

Finally, ABGWB equations estimated for *R. pseudoacacia* (eastern site), *Quercus* sp. and *G. triacanthos* were applied to an independent dataset including the same species. As expected, using $D_{ch}$ as predictor, the greatest differences were detected for *Quercus* sp., with $\overline{RD}$ = 52% while for *R. pseudoacacia* and *G. triacanthos* the $\overline{RD}$ was about 24%. Using $H$ as independent variable, $\overline{RD}$ ranged between 68% for *G. triacathos* and 42% for the other species. We could argue that, (i) as highlighted by previous analyses, the equations provided for *Quercus* sp. could not adequately estimate this biomass compartment, which was strongly overestimated by $D_{ch}$ and underestimated by $H$ equations; (ii) ABGWB of *G. triacanthos* could be consistently estimated using $D_{ch}$ as predictor but it was overestimated by $H$, probably because of the growth pattern of this species in the early stages; (iii) for *R. pseudoacacia* both predictors could adequately estimate ABGWB, even if it was generally underestimated. The differences regarding this last species seemed likely related to the wider planting grid used in Romania (2.0 x 1.0 m, yielding 5000 seedlings per ha) compared with Moldova (2.0 x 0.5 m, yielding 10000 seedlings per ha) which gives consistently taller trees in much denser tree-rows (Table 2).

***Conclusions.*** This study provided species–specific allometric equations to be used on young trees with $D_{bh}$ < 10 – 15 cm, including some shrub species such as *R. canina*. The equations, based on the power function, allowed all the main biomass compartments (i.e., ABGTB, ABGWB, stem, branches, foliage and roots) to be estimated as a function of three different individual predictors ($D_{ch}$, $D_{bh}$ and $H$) and were intended to be used for projection of biomass accumulation in afforestation lands or in conjunction with data sampled in national forest inventories.

Diameter at collar height resulted as being the best predictor for each compartment in such young trees, but height also proved to be a promising predictor both for individual or general equations, providing an opportunity for more practical measurements and estimations in small trees and young artificial plantations. The diameter at breast height could satisfactorily predict the main aboveground biomass compartments (i.e., ABGTB and ABGWB) of smaller trees, but generally could not adequately estimate all biomass components shrub-like trees in early stages.

General parameters were also provided for each compartment and predictor. Using $D_{ch}$ as independent variable, we observed that: (i) the value of the general scaling exponent (i.e., $b_{RMA}$ = 2.750 ± 0.096) estimated to predict ABGTB was the same as the value (= 2.66) predicted by the WBE functional model and (ii) the scaling coefficients of the equations were mathematically correlated to *b* as predicted in the literature. Using $D_{bh}$ as predictor for the general allometric equations, the resulting value of *b* estimated with the OLS method on the ABGTB compartment (=2.36) coincided with the values empirically estimated by other authors, based both on general empirical approaches and on a functional approach applied to young trees. On the other hand, this figure differed from the theoretical value predicted by the WBE model. Considering all these aspects together, we speculated that these differences could be related to stand age and the relative ratio between $D_{bh}$ and $H$, used in previous studies not only to identify different growth stages but also the relative position of the diameter with respect to height. Indeed, when we used a diameter measurement having a constant relative position with respect to the total height of the plant (i.e., $D_{ch}$) we estimated the same theoretical value as that predicted by the WBE model. Since practical and theoretical applications of the WBE model are still strongly debated these aspects should be investigated by further analyses.

## (B-i).3 Modeling biomass and age-structure dynamics in stands and forests

*Relevant publications*

1. **Blujdea** V, Marin G (2018). Obligații asumate și contribuția sectorului forestier la îndeplinirea țintelor de reducerea emisiilor de gaze cu efect de seră ale României. Bucovina Forestieră 18(1): 23-34
2. Pilli R., Grassi G, Kurz WA, Smyth CE, **Blujdea V** (2013) Application of the CBM-CFS3 model to estimate Italy's forest carbon budget, 1995–2020. Ecological Modeling 266 (2013) 144–171
3. Pilli R, Kull SJ, **Blujdea V**, Grassi G (2017) *The Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3): customization of the Archive Index Database for European Union countries*
4. Verkerk PJ, Böttcher H, Grassi G., Cianciala E, Black GK, Fortin M, Köthke M, Lehtonen A., Nabuurs GJ, Petrova L, **Blujdea V.** (2013) *What causes differences between national estimates of forest management carbon emissions and removals compared to estimates of large-scale models*?. Environmental Science & Policy 2 (33) 222–232

Over the last decades, several forest models or simulators have been developed for forests ecosystems and management. Models can be processed based (e.g. inputs as photosynthesis rates, leaf area, etc) and empiric based (inputs as field measurements of parameters regularly used in forestry: increment, standing stock and wood drain). For forestry or climate change mitigation related purposes, models representing management interventions are needed. Unlike process-based models, empiric models need a limited number of parameteres usually extracted from direct sampling available with the forest authorities or administrations (e.g. based on National Forest Inventories). For sector contribution to climate change mitigation objectives, European Commission and a variety of European countries most frequently use one of the two following forest management models: the European forest information scenario model (EFISCEN), originally set up for forest resources management and wood availability in European countries or the Carbon Budget Modeling (CBM-CFS) developed by Canadian Forest Service of Canada (Kurz et al., 2009). Nowadays, the empiric models move toward simulating increment to each individual tree level, unlike older versions which were running based on stratification of tree species stand/forest type, site index, ownership, etc. Moreover, models run either wood volume (e.g. EFISCEN) or carbon (e.g. CBM-CFS). Empiric models like CBM-CFS run data at aggregated, i.e. landscape-level, i.e. strata based on forest types, productivity, ownership.

My experience is mostly related to CBM-CFS (Kurz et al. 2009). This is an inventory-based, yield- and growth-data driven model that simulates C dynamics of above- and below-ground biomass, litter, dead wood and mineral soil pools. The CBM-CFS runs ten biomass and 11 dead organic matter C pools. In CBM-CFS, the status (e.g. C stocks) and processes (e.g. C fluxes to atmosphere, transfers among pools and to the forest products) are simulated with annual time step following IPCC/UNFCCC reporting requirements for national GHG inventories (i.e. IPCC 2006, KPS 2013). One major advantage of using predefined models vs. own built consists in that they are developed by scientists with more experience on processes and rely on extensive datasets. Thus, the key is whether envisaged models incorporate dead organic matter and soil organic matter modules on which usually there is no available information from direct measurements in many parts of the world.

CBM-CFS performs an initialization by attaching steady state stocks to each of 21 C pools to inventory user defined strata at the beginning of the year of the start year of the simulation (“0”). Initialization is done running yield table data, i.e. the standing stock volume curves until a steady state reached in mineral soils C pools. Over model run, changes in all other C pools are simulated by propagation of both area and time step dependent standing C stocks derived from cumulated curve of net annual increment of the growing stock (merchantable) volume, i.e. growth curve, and allocation of biomass to other stand biomass compartments, and transfers from living biomass pool to dead organic pool, and transfers among the dead organic matter pools and to mineral soils pool. Any silvicultural practice can be applied by CBM (i.e., thinning, clear-cuts, salvage loggings, etc.) defined by as many classifiers as used for forest inventory, e.g. as the minimum are rotation lengths for the final cut and age range for thinning. Any natural disturbance can be simulated assuming adequate data on C transfers among pools is available as a disturbance matrix attached to each type of disturbance. The model has been applied to 26 EU countries in order to estimate the EU forest C dynamic from 2000 to 2012, including the effect of natural disturbances and land use change (Pilli et al. 2016a, 2016b). Other countries are using it for scientific explorations or operational purposes (e.g. Kim et., 2016; Zamolodchikov et al. 2013).

In order to make predefined models usable in other regions they need to be tailored with local data. As such, my contribution in Pilli et al. (2017) consisted in transparent definition of stepwise/pathway for tailoring model’s original database (set for Canada’s forests) to any situations outside Canada, e.g. to other countries in the world.

As potential contribution to the estimation of “forest reference level” (FRL under Regulation (EU)841/2019)) for Romanian forestry sector, I have prepared a stepwise processing of national data tailored to CBM inputs in Blujdea et al. (2019). Fact is that running the CBM-CFS3 model with currently available data revealed major shortcomings in existing knowledge in Romanian about the carbon stock dynamics in forests. Therefore, it was necessary to make several substantial, expert guess or proxy based, assumptions: (i) the standing volume and the current annual increment for commercial timber needed by the model are generated from the whole tree volume taking into account the volumes corresponding to branches and bark (Giurgiu et al., 2004) implicitly assimilating the tree to stand; (ii) fitting of standing volume and current increment was done according to the sigmoidal model Chapman-Richards (Fekedulegn et al., 1999); (iii) the percentage of foliar biomass was derived from the original CBM-CFS3's AIDB database; (iv) conversion of the commercial timber volume into under-bark biomass was performed randomly in the range of +/- 10% of wood density (Mos et al., 1972); (iv) for decomposition parameters of the necromas all implicit values in the CBM database (Kull et al., 2017) were fully adopted. The pre-processing of input data in the model was performed in the R (R Core Team, 2017) using the *robustbase* library (Maechler et al., 2017) for the cumulative annual growth curve, the volume of commercial timber/merchantable standing wood, and dynamic equation for volume conversion to biomass. The optimization of biomass equation parameters of bark, branches and foliage in relation to commercial timber/merchantable standing wood volume was achieved by minimizing the sum of the squares of residual errors (Boudewyn et al., 2007). Processing targeted involved preparation of data in the format required as input into the model, as follows:

a) Conversion of total tree volume provided from NFI1 (mid-year 2010) to merchantable standing volume. NFI's aboveground woody volume was first converted to under-bark merchantable standing volume and to stemwood biomass (for CBM-CFS3). Conversions involved exclusion of the bark and branches from NFI estimated volume based on their proportion from Giurgiu et al. (1972) and wood density (Mos et al., 1972). Under missing national data, biomass foliage was assumed equal to values of corresponding genus in original CBM library (namely, numerator of $p_{foliage}$ ratio incorporated in CBM-CFS's original AIDB).

b) Obtain the parameters *a*, *b* and *c* by fitting Chapman Richards model of standing merchantable volume on age class of 10 years for ten major forest types in Romania, as follows:

Biomass stock = $a \times e^{-b*Age} \times (1 - e^{(-b*Age)*(c-1)}) + з$, where:

a is the maximum biomass possible to accumulate;

b is the fraction of maximum biomass still available to grow along the age;

c is the standing stock amount subject to mortality;

з is the error term reflecting model uncertainty.

An example for Fagus sylvatica is shown here (Fig. 6);

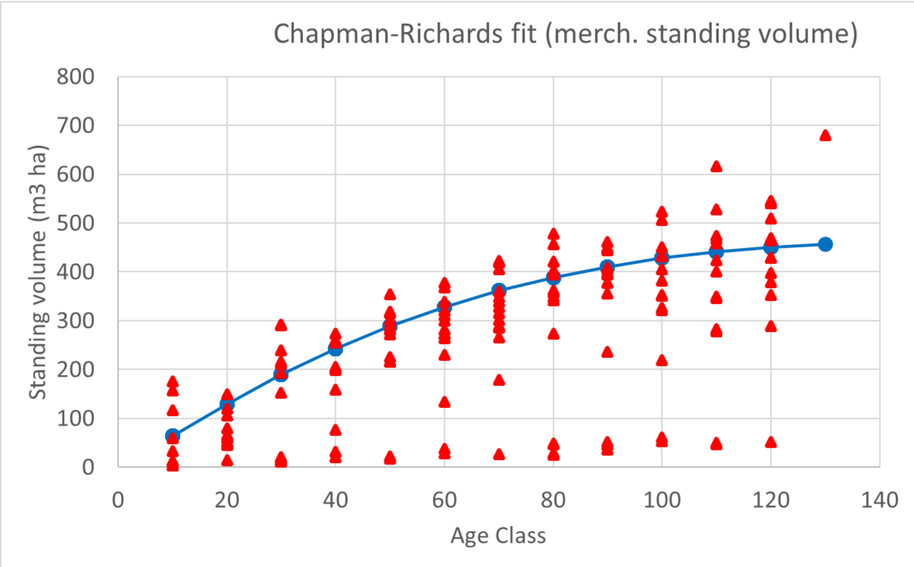



Fig 6. Age class dependent standing merchantable volume curve for *F. sylvatica* forests

c) Obtain the parameters *a*, *b* and *c* fitting Chapman Richards model of the increment of the standing merchantable volume on age class of 10 years for ten forest types. An example is shown here for *Quercus sp*. forests (Fig. 7);

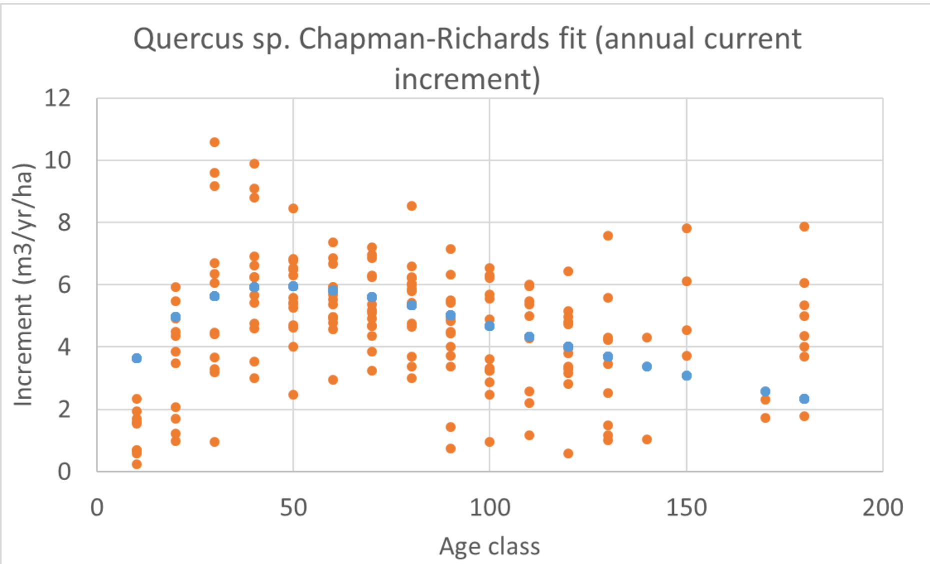
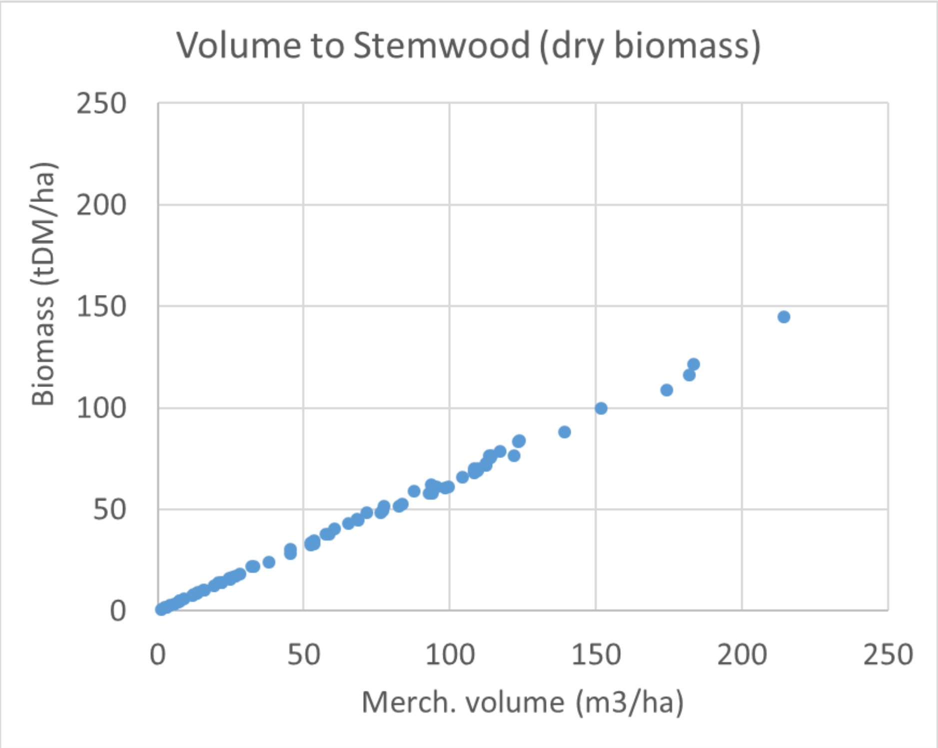



Fig 7. Age class dependent increment of the merchantable volume curve for *Quercus sp*. forests

d) Obtain the non-linear model parameters A and B fit on conversion of the merchantable/standing volume to stemwood biomass (Fig 8).



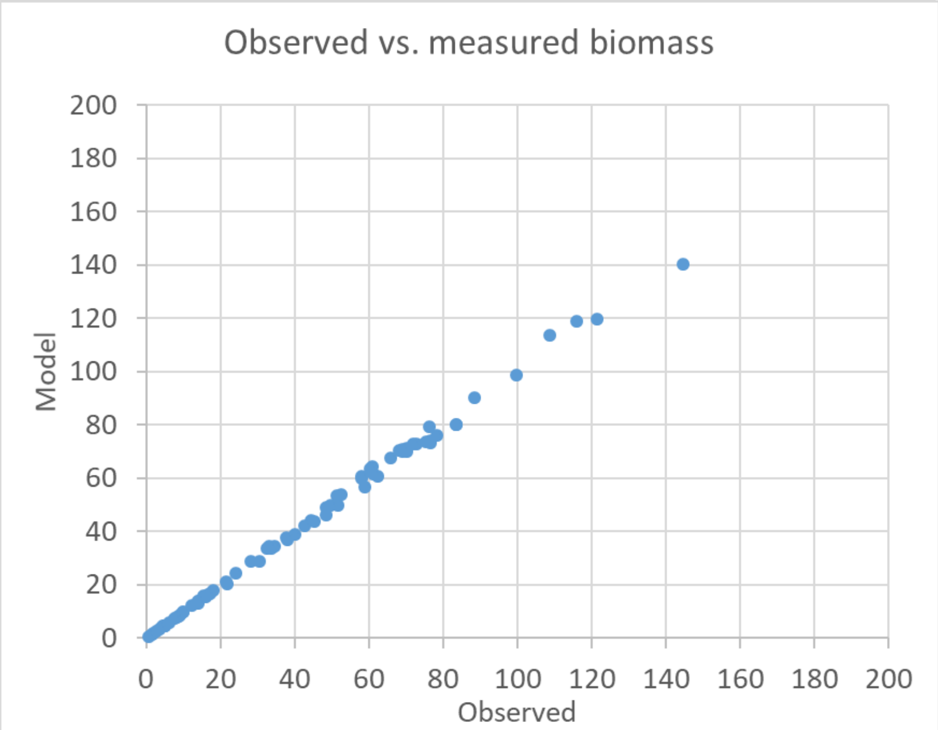




Fig 8. Conversion of merchantable volume to stemwood biomass curve (upper figure) and its validation against observed data (lower figure)

The values of the two parameters for all forest types are shown in Table 6.

Table 6. Values of parameters of exponential equation for conversion from merchantable volume to stewood biomass for 10 major forest types (AA-*Abies alba*, ConBroad – mixed of coniferous and broadleaves, FS - *Fagus sylvatica*, OB - other broadleaved, OC - other coniferous, PA – *Picea abies*, PredCon – predominantly coniferous mixed forests, PredBroad - predominantly broadleaves mixed forests, QR – *Quercus sp.* forest, RP-*Robinia pseudoacacia*)

| Parameters | AA | ConBroad | FS | OB | OC | PA | PredBroad | PredCon | QR | RP |
|---|---|---|---|---|---|---|---|---|---|---|
| **A** | 0.401728 | 0.488376 | 0.649242 | 0.638217 | 0.414060 | 0.36469 | 0.56765252 | 0.453425 | 0.708919 | 0.605874 |
| **B** | 0.997698 | 1.011117 | 0.997663 | 0.989001 | 0.995031 | 1.01623 | 1.00460649 | 1.002847 | 0.982355 | 1.014094 |

e) Obtain the non-linear model parameters *a1*, *a2*, *a3*, *b1*, *b2*, *b3*, *c1*, *c2*, *c3* fit of biomass share within total stand biomass based on standing merchantable volume as predictor, following Boudewyn et al. (2007) equation. One example is shown for *Abies alba* forests (Fig 9).

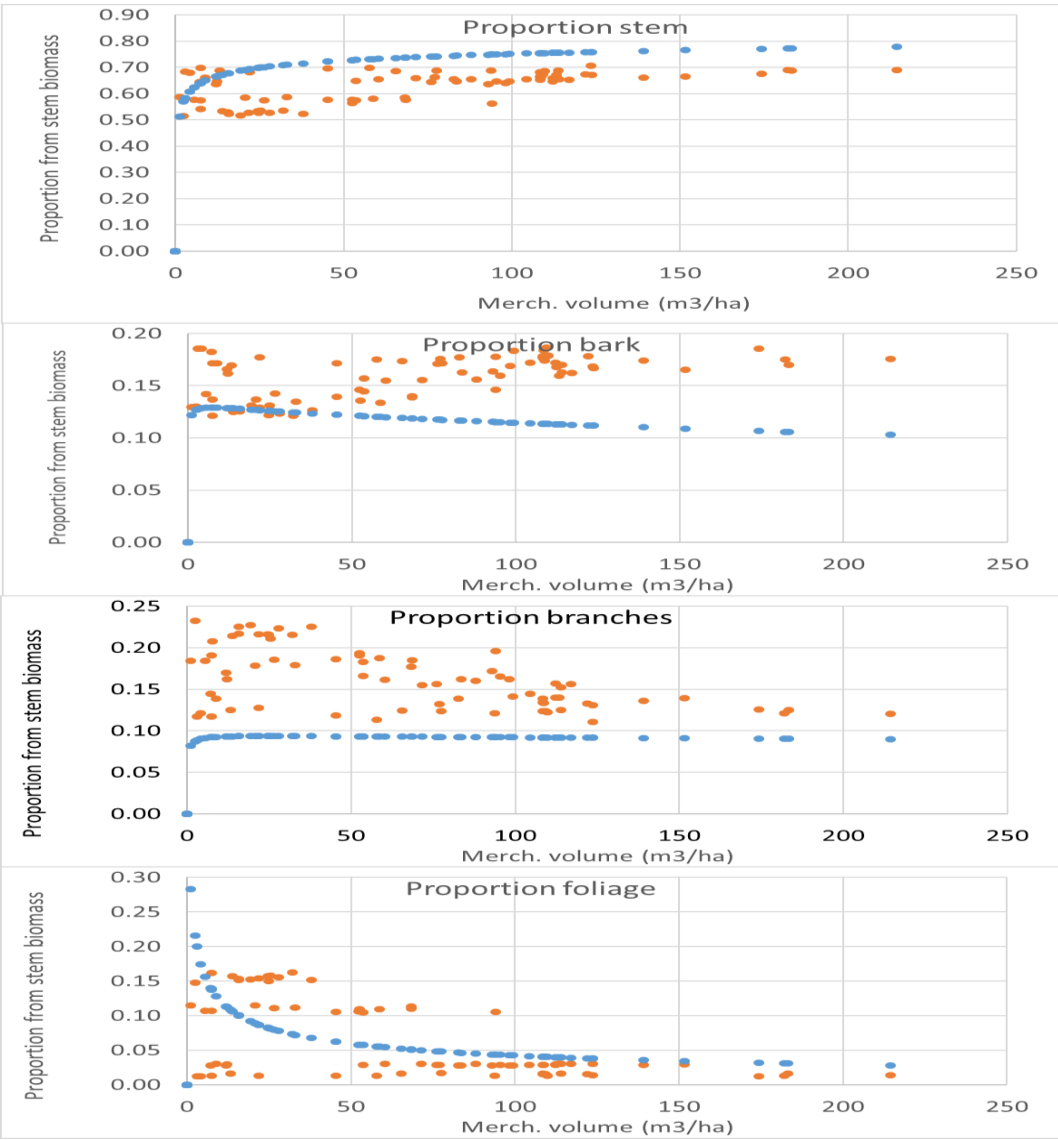



Fig 9. Simultaneous fit of biomass compartments against merchantable volume for *Abies alba* stands

Values of parameters are shown in Table 7. Under missing sampled data no statistics is presented for these parameters, as they resulted from a harmonized optimization of their values given the predefined model by Boudewyn et al. (2007).

Table 7. Values of parameters for Boudewyn equation for the ten forest types in Romanian forests

| Forest type | a1 | a2 | a3 | b1 | b2 | b3 | c1 | c2 | c3 |
|---|---|---|---|---|---|---|---|---|---|
| PredCon | -1.573653 | -0.001653 | 0.043681 | -1.917251 | -0.001318 | 0.067893 | -0.753406 | 0.005322 | -0.854548 |
| ConBroad | -1.688343 | 0.001696 | -0.255443 | -2.022535 | -0.001800 | 0.128927 | -0.722283 | 0.005140 | -1.059489 |
| AA | -1.426523 | -0.000687 | -0.083774 | -1.822640 | -0.000141 | -0.056877 | -0.522418 | -0.000518 | -0.500000 |
| OC | -1.195958 | -0.000340 | 0.044504 | -1.588882 | -0.002690 | -0.172668 | -0.888850 | -0.004805 | -0.407255 |
| PA | -1.573125 | -0.000498 | -0.022566 | -1.926263 | -0.00016 | -0.011293 | -0.870537 | -0.002046 | -0.443987 |
| FS | -1.675509 | 0.000425 | -0.153451 | -1.988408 | -0.001124 | 0.070280 | -0.796988 | 0.005713 | -1.132685 |
| PredBroad | -1.716351 | 0.000573 | -0.139975 | -2.05204 | -0.001049 | 0.055252 | -0.95141 | 0.003589 | -0.968664 |
| OB | -1.677640 | 0.000431 | -0.104280 | -1.990934 | -0.002655 | 0.119850 | -0.890889 | 0.008447 | -1.127068 |
| QR | -1.578718 | -0.002813 | 0.057617 | -1.91807 | -0.001674 | 0.076811 | -0.756822 | 0.00847 | -0.862874 |
| RP | -1.631169 | -0.008240 | 0.295419 | -1.94014 | -0.015736 | 0.303245 | -1.100035 | 0.018019 | -0.720251 |

a) Conversion of lossess from forests (i.e. wood harvest, disappeared trees) into C amounts assuming wood density (Mos et al., 1972). Losses are input into the model as roundwood originating from management interventions on forest types as extracted from the NFI1 (mid-year 2010). One rough assumption was made in that the volume were associated to thinning and final cuts according to the age when such interventions occurred following technical norms in Romanian forestry). Nevertheless, this may not always hold as final cuts may have occurred earlier than required by technical norms, which leads to overestimation of actual volume harvested from thinning and underestimation of volume from final cuts.

b) Other input data and parameters on forest status in 2010 is shown in Table 8.

Table 8. Overview of forest state parameters attached to initial year of the simulation for the simulation of forest reference level for forestry sector in Romania

| ***Forest state parameter*** | ***Values and description*** | ***Comments*** |
|---|---|---|
| **Land use (change)** | | |
| forest type areas | 6,072,260 ha ±2.199%, split on ten forest types:<br>1. Abies alba (grand fir or silver fir): 10,245 ha<br>2. Fagus sylvatica (beech): 914,359 ha<br>3. Other broadleaved: 2,303,052 ha<br>4. Other coniferous: 318,365 ha<br>5. Mixed species (Amesticuri): 527,284 ha<br>6. Picea abies >90% (Norway spruce): 674,483 ha<br>7. Quercus robur (oak species): 505,508 ha<br>8. Robinia pseudoacacia (black locust): 123,069 ha | Total area forest and other wooded lands in Romania in 2010 was 6.90 million ha (NFI-1) and in 2015 6.93 million ha (NFI-2). |

| | | |
|---|---|---|
| | 9. Predominantly broadleaved (>70%):330,923 ha<br>10. Predominantly coniferous (>70%): 364,980 ha | |
| **Forest growth** | | |
| Standing stock volume | 1,502,446,228 $m^3$ (247.43 $m^3$ ha-$^1$) | Volume of aboveground woody biomass |
| Annual net volume increment | Area weighted average value of 6.86 $m^3$ $ha^{-1}$ $yr^{-1}$ (41,632,513 $m^3$ $yr^{-1}$over total forest type area in 2010). Age-class average values were available on seven NUTS2 regions and 10 forest types | Forest area type weighted annual average volume increment of entire aboveground woody volume, excluding mortality |
| **Forest management** | | |
| Annual average felling in period 2011 -2015 | Total harvest of 28,215,945 $m^3$ $year^{-1}$ ±10.121% out of which feelings of 11,979,242 $m^3$ and thinning of 16,236,703 $m^3$ available per forest type, per type of forest owner (state; private) and per administrative region. This corresponds to 23.2 million $m^3$ per annum merchantable wood removals (excl. tops). | Average annual cut of living trees. Amounts resulted from raw split on thinning and felling according to intervention age in technical norms (e.g. early feelings may be misallocated as thinning) |
| **Non-merchantable wood parameters** | | |
| Standing dead wood stock | Standing: 53,5 million $m^3$ ±5.8%, i.e. 8.8 $m^3$ $ha^{-1}$. Laying 68,2 million $m^3$ ±5.377% | Threshold diameter for standing dead wood is 5.6 cm. |
| Annual weighted mean mortality rate | 0.96 $m^3$ $ha^{-1}$ $yr^{-1}$ ±4.6%. (from a total amount of 36.58 mil. $m^3$ or 5.2$m^3$ $ha^{-1}$ over 5 years) | Preliminary data (NFI-2) |
| Dead wood (DW) stocks | Standing DW (53.5 million $m^3$ ±5.8%), Laying DW (68.2 million $m^3$ ±5.4%) | Standing (snags) and laying dead wood |
| Annual mortality rate in period 2010-2015 | 1.12 $m^3$ $ha^{-1}$ $yr^{-1}$ ±4.7% | Preliminary data (NFI-2) |

Table 9. Definitional issues and interpretation of inputs, as well as data sources, of Romanian forest sector data to CBM in Blujdea et al. (2019).

| **Parameters** | **CBM-CFS** (Kurz et al, 2009, Li et al 2003; Boudewyn et al 2007) |
|---|---|
| **Land representation** | Initialization and simulations are organized in user defined strata resulted from combination of max. ten classifiers. Each classifier may have a non-specified number of strata. |
| **Land area at the start of simulation** | Input of area on age-class of 5, 10 or 20 years. Initialization assuming a uniform distribution of area within the age-class (i.e. equal area attached to one-year step age). |
| **Land area for land use changes** | Deforested area can be subtracted at any time step, randomly or according to pre-defined criteria (e.g. forest type, etc). New forest land can be added at any time step or age of new stands. Conversions from and to forest can be tracked for a period of 20 years. |
| **Standing volume curve** | Age-class dependent under-bark standing growing stock (merchantable) volume (i.e. yield table) required. Curve model to fit the available data is chosen by the user. Age-class can be 5, 10 or 20 years. |
| **Net annual volume increment** | Defined as gross increment (of living trees) minus mortality from self-thinning. It is required as age class-dependent cumulated curve of under-bark merchantable volume net increment. Fitting model chosen by the user. Age-class can be 5, 10 or 20 years. A growth multiplier can be applied to account for post-disturbance growth boost. |
| **Ingrowth and sub-** | Stemwood biomass for non-merchantable and sapling size trees can be added by expansion |

| | |
|---|---|
| **merchantable trees** | factors to over-bark merchantable stem wood (e.g. estimated from latest available forest inventory data) via a curve-smoothing algorithm. |
| **Specification of management interventions** | Thinning at any intensity of intervention, final cut(s) may include shelter-wood systems (2-3 interventions). |
| **Wood removals/ harvest/management interventions** | Management interventions defined by targets, eventually constrained by one to multiple combined criteria. Target can include collecting dead wood. The targets are defined as C amount in over-bark standing merchantable volume, or area, or proportion from available volume subject to an intervention (or combination amongst). It applies merchantability criteria associated to administrative boundaries classifier, i.e. proportion of non-commercial components (tops and stump in total stemwood left on site). CBM allows tracking separately the volume from deforestation or afforestation. |
| **Volume to biomass conversion and expansion procedures** | Conversion of merchantable volume-to-stemwood biomass requires the two parameters of their exponential relation. Bark, branches and foliage biomass are derived as relative to stemwood biomass from merchantable volume (see Boudewyn et al., 2007). C stock in fine and coarse roots according to general equations for softwood and hardwood species (Li et al. (2003). |
| **Natural disturbances** | Any type of natural disturbance (no matter the intensity*) can be implemented via user specified disturbance matrix attached to concerned time step and type. Disturbance matrix allows disturbance-specific transfers among the pools. No multiple disturbances are implemented in a year unless their cumulated effect is accounted in the disturbance matrix. |
| **Representation of natural processes** | Turnovers are defined for five biomass pools run individually by the model (merchantable stemwood, otherwood, foliage, coarse and fine roots). Harvesting residues defined by merchantability criteria. Annual mortality rate is defined on climatic zones for merchantable stemwood and branches, by a constant value along the simulation. |
| **Forests composition dynamics** | Transitions between various tree species, e.g. species composition change, or growth patterns as post-disturbance events, i.e. increment shift, can be implemented at any age of the stands. |
| **Information needed for initialization of standing volume** | Initial standing biomass attached user defined strata is derived from yield curve assuming one-year age distribution. |
| **Soil (submodule)** | Own decomposition model. Dead organic matter and mineral soils pools are initialized (time step "0") assuming non-equilibrium conditions, i.e. considering historical natural disturbance over past 2000 years (by default fire) and most-recent stand-replacing disturbance until less than 1% change of the aggregate amount of litter, dead wood and soil organic matter occurs in successive iterations. Temperature-dependent decay rates are defined on climatic zones. |
| **Time management** | Runs 1-year time step. A "delay" until regeneration start is possible for initialization consistent with post-harvest regeneration delay. |
| * CBM own database provides some 300 disturbance matrixes in its AIDB which can be used as a proxy for running various natural and anthropogenic disturbance events, that can be tailored by local/national data | |

Results are subject to quality control, i.e. identification of discrepancies between inputs and outputs, including any feasible calibration and indepth validation. CBM initialization of 2010 is based on empirical standing volume curves generated from NFI1 data averaged at regional scale on forest types and age-class (as far as plot data is not available for this analysis). Purpose of the calibration was to simulate an initial standing stock volume within the NFI1 confidence interval of 2.2% at aggregated level and ± 15% on forest types (error assumed by Romanian Yield tables). This was achieved by fitting Chapman-Richards model to area-weighted data (originally un-weighted). Furthermore, biomass turnover for dead wood (mortality rate) and dead wood decay (litterfall rate) were calibrated against NFI data by trial and error. Allocation of biomass in relation to merchantable volume was re-checked based on Boudewyn et al. (2007) dynamic model.

On top of this, because of predefined queries in the CBM results explorer user-interface (i.e. query limited to one combination of classifiers for every interrogation), it was performed some post-processing by querying the "results" database to extract simultaneous results across any combinations of classifiers, rather than using the interface. Own queries were confirmed against corresponding SQL clauses in the standard interface. This consisted in weighting and averaging data at the user defined strata. Further on, a back-conversion from C amount to volume was done by the inverse of volume-to-biomass equations. Results of Modeling by CBM and how such outputs may be used for policy making are presented in section *(B-i).5 Monitoring, estimation and verification of greenhouse gas emissions from forest sector, land use and land use change*, bellow.

## (B-i).4 Modeling biomass and carbon fluxes into dead organic matter and mineral soils

*Relevant publications*

1. Didion M, **Blujdea V**, Alberdi I, Jandl R, Kriiska K, Lehtonen A, Saint-Andre L (2016) *Models for reporting forest litter and soil C pools in national greenhouse gas inventories: methodological considerations and requirements*. Carbon Management (DOI: 10.1080/17583004.2016.1166457)

2. Hernández L, Jandl R, **Blujdea VNB**, Lehtonen L, Kriiska K, Alberdi I, Adermann V, Cañellas I, Marin Gh, Moreno-Fernández D, Ostonen I, Varik M, Didion M (2017) *Towards complete and harmonized assessment of soil carbon stocks and balance in forests: The ability of the Yasso07 model across a wide gradient of climatic and forest conditions in Europe*. Science of The Total Environment, Volumes 599–600, P. 1171-1180.

*Simulation of C stocks dynamic in Romanian forests.* Major requirement in climate change reporting is the monitoring and estimation of annual C stock changes rather than C stocks in a certain moment in time. C stock change was not a concern as such in the past, especially for forest soils and, if somehow approached, there were not focusing on such short period of time as currently required to report with one-year time step (under UNFCCC reporting). For this reason, data type historically available may not be useful to derive estimates such for such reporting. Reliable C stock change estimates may be derived from resampling (allowing enough period that variation of the change is less than the natural spatial variability of the stock) or modeling.

One study I was participating by Didion et al. (2016), assessed the criteria for policy application of models through meeting TACCC principles[3] from the perspective of GHG inventory reporting for six soil models widely used. Meeting TACCC was assessed from the perspective of models' ability to trade-off among *precision* (i.e. producing quantitatively precise estimates, implicitely assuming accuracy is met), *realism* (i.e. producing qualitative realistic estimates) and *generality* (i.e. representing a broad range of conditions without model modifications). Four of the models (Q, ROMUL, RothC and Yasso07) were strictly dead organic matter and mineral soil models describing C dynamics in woody and non-woody pools, and they all require external inputs of DOM production as a driving variable. Two other models were ecosystem approach models, namely CBM and CoupModel, which primarily simulate biomass growth as a driver for dead organic matter turnovers and the inputs into the soils. Soil oriented models require soil specific parameters (e.g. clay content, etc), that is not the case for ecosystem approach models which only involve simple decomposition models ran based on minimal information on climate (temperature

[3] transparency, accuracy, consistency, comparability, completeness as of UNFCCC decision 24/CP19

is always required, sometime precipitation). All models consider that the amount of soil C in mineral soils is mainly the result of a long process of biomass input from terrestrial cover and decomposition, climate and ultimately anthropogenic intervention through forest management. Most of models track decomposition as loss of dry mass (e.g. CBM) through transfers to other pools or CO2 emission to atmosphere. Among the six discussed models, the authors identified a well-defined trend toward models for providing quantitatively precise, site-specific estimates. To meet reporting needs for national GHG inventories, the authors conclude that there is a need for models producing qualitative realistic and unbiased estimates at larger scales in a transparent and comparable manner, e.g. across whole territory of member states under the EU.

Hernández et al. (2017) applied Yasso 07 over a range of European landscapes. For Romanian forests, the inputs into the model like standing volume and humus content were extracted from the forest management plan database run by ICAS/INCDS updated between 2000 and 2010, i.e. covering approximately 50% of national forests throughout the country (conversions to forest since 1990 were excluded). These data were used both to a) calculate annual biomass input to the soil, considering standing volume and, b) validate the amount of SOC stock (mineral soil and DOM) per forest type and region. The inputs and validation of the model outputs were organized by strata according to the main Romanian forest types (*P. abies, Abies alba, Fagus sylvatica, Quercus sp.*, other hardwood species, other softwood species). Yasso 07, as a process-based model tracks the decomposition of four chemical compound groups according to whether they are insoluble (N), soluble in ethanol (E), in water (W) or in acid (A) each type defined by specific mass loss rates affected by temperature and precipitation. Model was run with a ‘global’ parameter set which, in theory, can be applied anywhere to obtain accurate trends for changes in C stocks (see for example the parameterization for Nordic countries in Rantakari et al., 2012). Model performs an initialization by a spin-up procedure (cf. Liski et al., 2009) based on long-term mean annual climate and C input into the soil. This procedure ensures that the model is in equilibrium with the prevalent conditions prior to simulating scenarios of change in C inputs and/or climate. The results obtained using the Yasso07 model comprise estimates for total SOC, SOC change and CO2 flux from the soil, for example, for each sampling plot or strata in the time step selected. Parameter uncertainty at the 95% confidence interval can be assessed, although the accuracy of C input estimations is unknown. The model does not differentiate SOC by soil horizons; although SOC originating from non-woody and woody litter can be analysed separately. Turnover rates refer to the amount of C from living biomass pool that annually is transferred to dead wood pool namely from aboveground (stemwood, bark, branches, foliage, harvest residues, ground vegetation) and belowground (coarse rots, fine roots). Turnover in terms of C content of biomass ranges from 1% for branches to some 90% in case of foliage of broadleaved forests stands.

Table 10. Total average soil C stock (Mg C ha−1) and change (Mg C ha−1 yr−1) for soil, litter and deadwood estimated using the Yasso07model on three major relief forms in Romania. Period covered, spin up period and number of plots used for the application of Yasso07 (Ny) and for validation (Nv) are detailed. Standard error of themean (SEM) is also listed. Negative changes indicate losses, positive values gain (excerpt from Hernández et al. (2017).

| Country (region/Nyv) | Type of forest | Period | | SOC stock Yasso07 simulated values (±SEM) | SOC change Yasso07 simulated values (±SEM or range) | Range of observed values (2.5 & 97.5 percentile) | Observed SOC change (±SEM) |
|---|---|---|---|---|---|---|---|
| | | Period covered | Spin up period | | | | |
| *Romania ($N_v$ = 3219)* | | | | | | | |
| Plain (547) | Softwood | | | 82.29 (±1.63) | −0.10 (±0.12) | (31.7–114.4)[c] | |
| | Hardwood | | | 27.75 (±0.36) | 0.14 (±0.09) | (46–83.3)[c] | |
| | *Quercus* sp. | | | 43.19 (±0.22) | 0.07 (±0.05) | (43.2–90.2)[c] | |
| Hills (1385) | Softwood | | | 80.32 (±1.58) | −0.01 (±0.08) | (58.7–103.5)[c] | |
| | Hardwood | 2000–2010 | Steady state | 34.58 (±0.31) | 0.11 (±0.07) | (50–79.5)[c] | |
| | *Fagus sylvatica* | | | 64.19 (±0.36) | 0.09 (±0.09) | (35.4–110.6)[c] | – |
| | *Quercus* sp. | | | 46.35 (±0.11) | 0.05 (±0.03) | (41.03–80.7)[c] | |
| Mountains (1287) | *Abies alba* | | | 72.02 (±0.19) | 0.01 (±0.07) | (56–111.4)[c] | |
| | *Fagus sylvatica* | | | 65.37 (±0.18) | 0.08 (±0.03) | (56.9–98.7)[c] | |
| | *Picea abies* | | | 50.51 (±0.19) | 0.03 (±0.04) | (62.8–121.9)[c] | |

Simulated values of stocks were within the range observed from FMP database (Table 10). This research shows that most likely the forest soils in Romania behave like a sink, with exception of softwood forests which seems to be a source most likely, or even coniferous forests *Picea abies* and *Abies alba* which may be a source with lower probability.

*Contribution to forestry and resources management, and practical applications from modeling soils and biomass for GHG inventory reporting*. Emission reduction commitments require accurate estimates of GHG emission from sources or CO2 removals by sinks from all lands, especially from forestland. As far as direct measurements of gas exchanges between land and the atmosphere are still not reliable at the scale required (e.g. national or smaller), measurements related to C stocks and C stock changes in all pools are needed, e.g. for climate reporting. Resampling at required statistical optimization, either on temporal or spatial scale (e.g. national to ownership scale) may be overcame by using models. Romanian forestry is particularly hampered by old data on tree volume and old yield and increment tables, as based on sampling in years 60 -70$^{th}$ of the previous century. Discussion on the developing of biomass equations is intrinsically linked to the update of volume equations. In practice, there is a mutual interaction between forest sector development and modeling, each supporting the other in making decisions, especially for future and when decision is needed across a range of sectors of the economy. Development requires assessing future options by quantitative estimates (simulations) based on scenarios. Scenarios are prediction of certain sequence of events and descriptions of plausible futures, e.g. although with various expected likeliness to happen. For example, a “business-as-usual” or “reference”, or “baseline” scenario is the one which is expected to most likely happen under current circumstances. There are number of reasons we need modeling and scenarios in practice like: a) Modeling and scenarios help to understand complex environments and interlinked factors and complicated processes; i) models are needed to report under higher methodological tiers for quantitative estimation; ii) making sensible decisions in forestry and climate reporting (LULUCF) for example on how to a) plan regular forest management actions; b) understanding GHG risks linked to natural disturbances; c) define cost effective GHG mitigation strategy; d) integrate forest management and wood products use; e) select soil technologies and management solutions; iii) implementation of climate change policy: parties to UNFCCC are required to “formulate programmes containing measures to mitigate climate change by addressing anthropogenic emissions and removals of all greenhouse gases” and report the expected impact of implemented, adopted or planned policies (under policies and projections report to UNFCCC); v) support ex-ante analysis of policies/measures of mitigation of GHG emissions and vi) develop robust reference level for managed forest.

*Knowledge share and education.* Modeling and simulations are not only attractive for younger generations, but also required to meet reporting and emission reduction obligations under climate change commitments (e.g. Kyoto Protocol allows reporting „not a source” for C pools whose monitoring is costly, like litter, dead wood and C stock in mineral soils. In trainings or teaching I encourage and even make demonstrations on using modeling capacity.

## (B-i).5 Monitoring, estimation and verification of greenhouse gas emissions from forest sector, land use and land use change

*Relevant publications*

1 Jonsson R, **Blujdea VNB**, Fiorese G, Pilli R, Rinaldi F, Camia A (2017) *European outlook for the forest sector: supply and demand*. iForest Biogeosciences and Forestry vol. 11, pp. 315-328.

2. IPCC (2014) *Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol*. Hiraishi T., Krug T., Tanabe K., Srivastava N., Jamsranjav B., Fukuda M., Troxler T.G. (eds) Publisher IPCC Switzerland. ISBN 978-92-9169-140-1 (**Blujdea V., contributing author**)

3. **Blujdea V**., Abad-Vinas R., Federici S., Grassi G (2015) *The EU greenhouse gas inventory for LULUCF sector: I. Overview and comparative analysis of methods used by EU member states*. Carbon Management 6 (5-6) 2015, 247-259

4. **Blujdea, V.,** Marin, G., Stoichiţescu, M. (2014). *Land dataset uncertainty: effect on Romanian National Greenhouse Gas Inventory*. Annals of Forest Research DOI:10.15287/afr.2014.275

5. Cienciala E, Seufert G, **Blujdea V**, Grassi G, Exnerová Z (eds) (2010) *Harmonized methods for assessing carbon sequestration in European forests*. *Study under EEC 2152/2003 Forest Focus regulation on developing harmonized methods for assessing carbon sequestration in European forests*. ISBN 978-92-79-15319-8, 323p.

6. **Blujdea V**, Marin G, 2018. Obligații asumate și contribuția sectorului forestier la îndeplinirea țintelor de reducerea emisiilor de gaze cu efect de seră ale României. Bucovina Forestieră 18(1): 23-34.

7. **Blujdea V,** Bird DN and Robledo C (2010) *Consistency and comparability of estimation and accounting of removal by sinks in afforestation/reforestation activities*, Mitig Adapt Strateg Glob Change (2010) 15:1–18

8. Gugele et al. (**V. Blujdea** co-author) 2009, .... 2013. Annual European Union greenhouse gas inventory 1990–2011 and inventory report 201. Available at: file:///C:/Users/Viorel/Downloads/Annual%20EU%20greenhouse%20gas%20inventory%202015%20-%20Full%20report.pdf

9. Petrescu AMR, Abad-Viñas R, Janssens-Maenhout G, **Blujdea V** and Grassi G. (2012) *Global estimates of C stock changes in living forest biomass: EDGARv4.3 – 5FL1 time series from 1990 to 2010*. Biogeosciences 9, 3767-3793.

*Theoretical contribution to knowledge*. Influence of anthropogenic GHG emissions to global warming and global climate change is proven, according to IPCC reports (5th Assessment

Report)[4]. It makes full sense since land use change represents, globally, the second-largest anthropogenic source of $CO_2$ (Le Quéré et al., 2018), so it represents potentially a significant domain of reducing anthropogenic GHG emissions. Just for clarification, global climate change policy and implementation focus simultaneously on: understanding the future climate of Earth („future climate”), monitoring and reduction anthropogenic GHG emissions and removals („mitigation”) and adaptation to residual climate change („resilience”). Given my professional, scientific and technical background, my contribution focus on „mitigation” in the sector of land use and forestry activities, so called LULUCF, the short for „land use, land use change and forestry” or integrated as AFOLU or „agriculture, forestry and other land use” in the UNFCCC and its associated global negotiation and implementation processes. Specifically, for „mitigation” purpose, global and national scientific needs are underlying in:

a) monitoring GHG emissions from sources and $CO_2$ removals from all C pools from all land use categories within national territory through „national GHG inventory” to be reported by the country Parties (signatory members of United Nation Framework Convention for Climate Change, UNFCCC).

b) achieving emission reduction by specific land use and forestry activities and their „accounting” for compliance with emission reduction targets of the country;

c) implementation of emission reductions/mitigation activities by land management at project level.

All three depend on consistent and complete estimation of human-induced $CO_2$ removals by C sinks and GHG emissions from sources associated to the land use in a specific year, and across the time series required to be reported (from 1990-to date) or project lifetime.

Specifically, monitoring, reporting and estimation of GHGs at national territory requires implementation of five reporting principles defined under UNFCCC namely: transparency, accuracy, comparability, consistency and completeness (UNFCCC, 2006). Among the five, at least four are deeply rooted in scientific endeavour and technical knowledge: transparency, accuracy, consistency and completeness, as related to science practices. This is because GHG reporting is quantitative, in the sense that actual emissions or removals from atmosphere in certain period of time has to be measured and accounted.

Scientific support was needed along the way both at the setting up of GHG inventories (starting year 2002) in order to make use of historical existing data, and later on, to adjust/set up data collection systems which were able to collect parameteres relevant for GHG mitigation.

[4] https://www.ipcc.ch/report/ar5/syr/

*My small contribution to global discussion was limited to* extending the Emissions Database for Global Atmospheric Research (EDGAR). Thus, *Petrescu et al. (2010)* was calculating global forest sink by the C stock changes in living forest biomass using Tier 1 approach according to IPCC Gain-Loss method. Method consisted in using spatially coarse activity data (i.e. area, obtained combining two different global forest maps: The Global Land Cover map and the eco-zones subdivision of the GEZ Ecological Zone map) and IPCC default C stocks and C stock change factors (IPCC Tier 1 from both IPCC GPG 2003 and the IPCC AFOLU 2006). My specific support was in the methodological set up for estimation of Gains, Harvest, Net Deforestation and Losses from fires for the years 1990, 2000, 2005 and 2010. Estimates generated by using default factors from IPCC AFOLU 2006 may significantly overestimated the sink when compared to other international datasets (UNFCCC, FAO) or scientific publications. So, it was advised caution when Tier 1 method was involved in estimation.

*Contribution to integrated modeling of EU forest-based sector and GHG impact on forest by Johnsson et al. (2018).* Assessment integrates a European forest resource model (strictly linked to forest available for wood supply) and a global economic forest sector model framework by assessing biomass harvesting potentials, utilization and implications on international wood product markets and forest carbon dynamics. Basic assumption was that in a business-as-usual (BaU) scenario, EU harvest increases seven percent by 2030 compared to past levels (485 million m3 on 2000-2012 average and 517 million m3 in 2030). Alternative high mobilization scenario (HM) consisted in a harvest increase by 55% (754 million m3 in 2030) characterized by the full utilization of the potential wood supply and a doubling of EU wood pellets consumption. Increasing harvest level resulted -83% carbon-dioxide forest sequestration from the atmosphere in the medium term in 2030, compared to 2000-2012 average. My specific contribution consisted in developing the databases for CBM the forest model and running the maxim wood supply iterations. The model chosen for derivation of annual maximum wood supply was that annual harvest would equal the annual increment, assuming no change in forest management practices between the scenarios.

*GHG monitoring of mitigation at small scale projects, and fungibility of emission reductions from land toward global recognition of emission reduction from forestry and land sector.* The ambition that emission reduction generated in the LULUCF sector are of similar quality with those from non-LULUCF sectors. Today achieved, it was subject of some 15 years of debate on how to consistently account the emission reduction from LULUCF across national emission reduction target. Earlier on, *Blujdea et al. (2009)* pose the question of whether there is full estimation and accounting consistency between Annex I Party's national GHG systems and CDM projects methodologies in the LULUCF sector, in terms accuracy, completeness, levels of uncertainty and permanence risk. The Kyoto Protocol accounting system and its market mechanisms, Clean Development Mechanism (CDM) and Joint Implementation (JI), are built on the key principle that emission and emission reduction units generated by afforestation/reforestation activities under national systems and projects are fully comparable to any emission reduction from any other sector of the economy, no matter their origin. Lack of consistency in the quality of emission and emission reduction units can undermine the environmental integrity of the climate stabilization actions. To demonstrate or challenge the consistency, it was stated as crucial the understanding methodological aspects related to the applicability and practicability of using approved afforestation/reforestation CDM methodologies; estimation, reporting and accounting rules; the small pools and sources treatment, uncertainty of estimates; leakage and handling of non-permanence risk. We concluded that there is significant scope for improving the consistency of greenhouse gas emission accounting from land use activities in the post-2012 climate change agreement, between Annex I domestic and project activities. As well, we conclude that the preparation and implementation of project activities has to be made simpler by a project framework guideline, which is then adapted to any project circumstances.

*Overview of GHG estimation methods and status quo in measuring land and C stock relevant parameteres in support of climate policy making.* A systematic study of the capacity of national systems for reporting consistent and complete GHG inventory for all land use categories by the EU member states was achieved in *Blujdea et al. (2015)*. This scientific paper was part of a work supporting further inclusion of land activities into EU's emission reduction commitment for post-2020 (especially decision 529/2013/EU). Challenge in reporting emissions and removals from lands is that historical land use and conversions data is needed, for a period of time usually 20 years before the base year (which is around 1990, 1989 for Romania), i.e. thus for a period at least starting 1970. Study also analysed in a systematic way the ability across EU member states to provide GHG estimates on C stock changes in C pools (i.e. biomass, litter, dead wood, organic matter in mineral and organic soils) and non-CO2 emissions (CH4 and N2O emission factors and relevant activity data). Study revealed that EU member states generate needed data by three generic methods: a) statistical sampling NFIs designed for a continuous assessment of forests at the national level approached by 17-member states, b) stand-wise forest inventory designed for continuous FMP by eight and, c) three-member states rely on non-forest inventory data such as historical annual forestry statistics combined with yield tables. Given the national approaches of these generic methods, 23 member states were using a single data source for estimation of the entire time series 1990-2013, while five member states use a combination of several sources across time (e.g. census until 2000 combined with statistical sampling national forest inventory in Denmark, or FMPs combined with statistics sampling NFI from around 2000 for Latvia and Lithuania) or across space (FMP for former East Germany for 1990 and forest inventory for recent period), or even different regional methods (by the two of Belgium's regions: Wallonia and Flanders). Also, study showed there was no correspondence between the type of forest inventory and the method for GHG estimation for the most important contributor to inventory, the C stock change in living biomass, namely: from 17-member states using NFI data, nine applied the default „gain-loss" method. The remaining 11-member states were applying the "stock difference" method, with almost the same share among Eastern and Western member states of the EU.

*Data type and quality contributes significantly to the accuracy of a national GHG inventory*, while ignoring uncertainty and systematic errors in data result in unreliable GHG estimates. Availability of long-term land datasets is key to ensure consistent and accurate national greenhouse gas inventories for LULUCF. *Blujdea et al (2014)* has focussed on uncertainty introduced by various land datasets into the estimates from national GHG inventory. Estimation of Romania's land use and land use change removal/emissions over 1970-2010 was assessed comparatively by using land use data from National Statistics, as reference dataset, and Corine Land Cover data from whose combination resulted four additional datasets resulted by modification of the first one upon availability of independent data on forests (reflecting range of possible true events under incomplete historical data, e.g. gross data for conversions were missing). Analysis included a spreadsheet, implementing a model of following UNFCCC national greenhouse gas inventory reporting requirements, allowed estimation of both net CO2 removals and emissions and gross CO2 fluxes from 12 land use subcategories for each carbon pool for each dataset. Annual „gross" flux of CO2 was in average double to corresponding annual „net" removal of 13 TgCO2 (Fig 10).

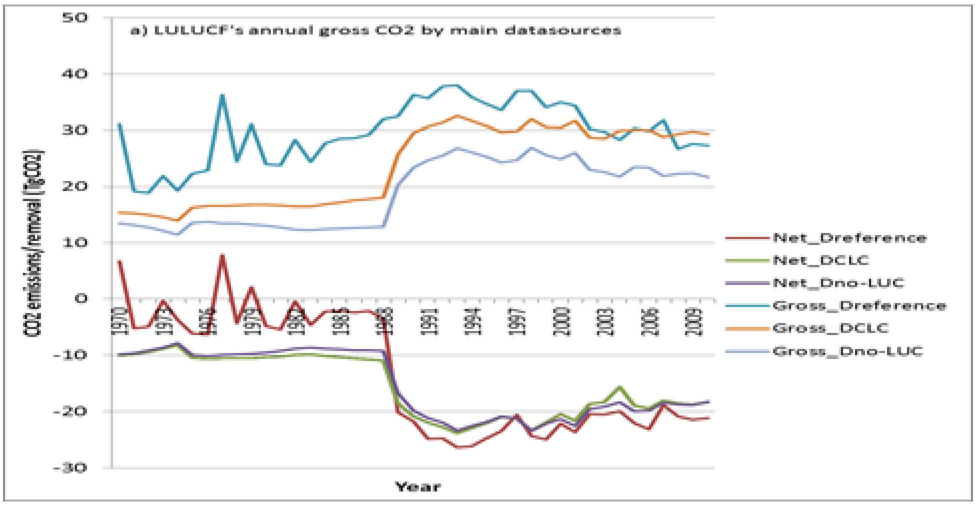



Figure 10. LULUCF annual gross (fluxes are summed up as absolute values) and net (fluxes are summed up considering their sign „negative" for removals from atmosphere and „positive" for emissions to atmosphere) estimates according to the main land datasets („reference" – INS data, CLC -Corine land cover, no-LUC – a counterfactual scenario assuming there were no land use changes from 1970 to date). Land subcategories included stands for „remaining" and „converted to", e.g. „forest remaining forest" and „cropland converted to forestland".

Overall, the hierarchy and structure of contributions of each land subcategory was actually similar in net and gross estimates and in pre- and post-1990. Land under conversions represented some 9% of the country area in pre- and only 2% in post-1990, corresponding to an annual average of 28% of gross and 6% of net CO2 estimates. Among the choice of datasets tested, the national statistics ($D_{reference}$) provides most conservative estimates for the GHG inventory and an accurate estimate for the most significant contributor the forestland, including conversions to/from forest. Other datasets ($D_{CLC}$ - Corine Land Cover and D no-LUC, the counterfactual scenario) generally overestimated both total LULUCF and its main contributor forestland. Compared to pre-1990, when annual sink was rather low, land abandonment and management extensivization in post-1990 has led to an increase of C stock in all pools, showing the relevance of political changes on land's CO2 emissions/removals. Overall trend was marked by significant increase of forest sink given the halving harvest in post 1990. Study concluded that inconsistency within available land data impairs more accurate estimation of national GHG inventory, so improved land assessment systems around National Forest Inventory is suggested as solution to implement consistent lands definitions and accurately estimate their areas in time. Uncertainty of the estimates was derived attaching a Monte Carlo simulation (by Risk6 of Palisade, USA) to the inputs for year 2010, following IPCC Tier 2 (IPCC, 2000; IPCC, 2003). Attaching a stochastic process to the reference data resulted in 31% uncertainty of the annual LULUCF net estimate for year 2010, slightly higher than 27% for the gross estimate. Lowest uncertainty was estimated for net estimates related to forest lands: 21% for 'remaining' and 10% for 'conversions to forest'. Relative uncertainty for non-forest land categories and especially conversions resulted superior to 50% for stable lands and to 100% for conversions. With CLC, the uncertainty reached 55% for total net LULUCF and 40% for forestland. Further on, sensitivity analysis showed that under reference dataset the area of "woodlands" plays a very significant role in defining the uncertainty of estimates of both forest sinks and total net/gross LULUCF estimates. Notably, LULUCF estimates were more affected by the uncertainty of the change in C pools than area of land categories.

*Implementation of GHG reporting requirements: estimating uncertainty of EU15 (referring only to old EU member states) GHG inventory under EU GHG monitoring mechanism and communication of uncertainty*. This work was carried out to support reporting of uncertainty of the EU national GHG inventory (*Gugele et. al, 2013*). In GHG inventory process, uncertainty assessment is meant to guide the improvements of the national GHG inventories, while its acceptance as a measure of accuracy of the GHG inventory estimates remains arguable, mainly from a scientific perspective. Further on, communication of uncertainty associated to estimates is main challenge. That is because of sink-source simultaneous behaviour of C pools, the expression of uncertainty in relative terms (in %) may be unpractical in certain circumstances. A message on uncertainty tailored to the user needs should also contain information on the uncertain absolute amounts concerned, as well as explicit breakdowns on each contributor, i.e. on gains and losses or pools in order to guide further development GHG inventory systems. Demonstrating LULUCF reporting difficulties to decision makers should help supporting development of national forest inventories and direct measurement methods, as well as further harmonization of GHG estimation methods (e.g. without necessary harmonizing forest parameters measurement methods among the countries) and verification.

Both stochastic and error propagation methods were used for estimating EU LULUCF inventory uncertainty. Monte Carlo assessment adds value compared to error propagation method by revealing better the contributions of each C pool from aggregated EU perspective. On top of this, Tier 2 type of error propagation enhances the ability to implement or to understand probability distribution effect in low quality input data (e.g. non-systematic sampling which is very common for C stock change in soils and dead organic matter).

In police making lack of scientific information was tested in uncertainty analysis by trials, i.e. type of distribution of parameters involved (Table 11, Fig 11) and gap filling by expert guess. Overall, living biomass dominates the uncertainty of estimates. In practice, this suggests that EU inventory uncertainty could be assessed only based on major inputs: large national inventories and large pools (i.e. the key categories).

Table 11. Statistics of the Monte Carlo distributions for EU15 aggregated CO2 emission ("+") and removal ("- ") from Forest land remaining Forest land in 2009. Selected distributions are denoted by N (normal) and logN (log-normal). Relative uncertainty is computed as half the 95% confidence interval divided by the mean. Upper and lower bounds correspond to 97.5 and 2.5 percentile respectively.

| EU 15 aggregated removal by sinks/ emissions by sources | Absolute emissions/removal (TgCO2) | | | Relative uncertainty (%, rounded to nearest integer) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean (N, logN) | Lower bound (N) | Upper bound (N) | Most expected | | Lower bound | | Upper bound | |
| | | | | N | logN | N | logN | N | logN |
| Living biomass | -264 | -300 | -228 | 13 | 13 | 12 | 12 | 16 | 16 |
| DOM | -31.6 | -40.4 | -22.8 | 28 | 28 | 22 | 22 | 39 | 37 |
| SOCmin | -49.3 | -89.9 | -9.8 | 82 | 79 | 45 | 37 | 412 | 146 |
| SOCorg | +17.3 | +7.6 | +27.3 | 56 | 56 | 35 | 36 | 126 | 125 |
| Disturbance | +1.8 | +0.7 | +3.0 | 64 | 70 | 38 | 36 | 161 | 136 |

Unlike the case when inputs are normally distributed, EU15 aggregated estimates showed asymmetric distributions especially for DOM and SOCmin when the inputs were lognormally distributed (Fig. 11). Notably, although SOCmin was reported as a sink in 2009, there were negligible chances it was a source.

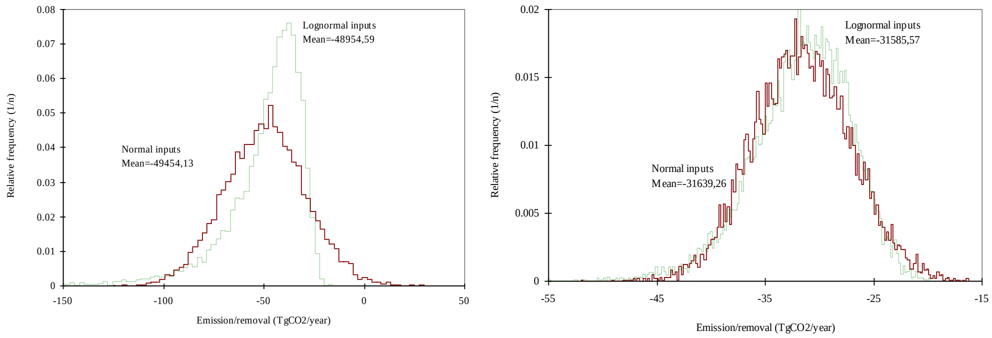



Fig. 11 Monte Carlo simulated probability density functions of EU15 aggregated CO2 removal by C stock change in soil organic matter in mineral soils (left) and dead organic matter (right). PDFs of the input variables are assumed as normal (full line) or lognormal (dotted line). Negative sign "-" marks removal of CO2.

Analysis of uncertainty propagation within EU inventory helped understanding the challenges related to bottom-up aggregations in GHG inventories (i.e. local to national, national to global) while also helped understanding any validation and comparison with other approaches, e.g. gas exchange between terrestrial and atmosphere. Uncertainty of the EU GHG inventory is driven by bottom-up aggregation, i.e. summation of the national GHG inventories. First, this means that uncertainty, as well as any error associated to member states estimates are transferred to EU's inventory. Secondly, incompleteness of member states inventories generates inaccurate EU inventory because of missing estimates or bias caused by the use of default assumptions or data.

Third, member states contributions to EU is very different, both in terms of amount and uncertainty, i.e. generally within 1-5 order of magnitude. Main conclusions and information available to decision makers were:

*Relative uncertainty of EU15 LULUCF inventory was 25%* for the scenario when member states inventories were considered fully independent, which seems to actually mostly be the case as member states use, in practice, almost exclusively country-specific data, so no reason for correlations among them.

*The uncertainty of EU net annual removals is dominated by biomass pool change of member states with largest forestland sinks*. Firstly, change in living biomass is the dominant contributor (i.e. 92%) to CO2 fluxes associated to forest subcategory which in turns contributed 67% to EU annual net CO2 removals. Secondly, its relative uncertainty is lowest compared to other pools (simple average of 31%). Thirdly, inputs of 15 out of 28-member states account for 95% of annual net removals and fourth, despite high uncertainty of typically small emissions or removals (i.e. DOM, SOCmin and SOCorg) their contribution to EU estimate is small. Additional to compensation of errors in aggregation, these explained the relatively low value of EU level uncertainty of ±25%, compared to, e.g. the simple average of the level uncertainty superior to ±50% of any land subcategory.

*Data type, quality and sampling and estimation methods affect overall uncertainty*. In the LULUCF sector no major emissions/removals was directly measured, unlike other sectors that are based on "precise physical measurements" (Winiwarter and Rypdal, 2001). Particular to LULUCF is the fact that GHG estimates are derived from multiple parameters, which are measured periodically mostly in case of forests (e.g. measured parameters in forest inventories - NFI) although often by different methods in time.

*Although national forestry sectors and agricultural soils monitoring are traditionally based on statistically sound procedures, the uncertainty estimates are not readily available to GHGI*. For forest, selection of the estimation method for GHG inventory was actually driven by the type and availability of forestry data. Consequently, the uncertainty is concerned as long as the estimation method selected requires appropriate datasets and involvement of different signs of changes in pools and amounts (i.e. very large for standing biomass C stocks or comparatively much smaller for annual gains and losses). Overall, the larger the difference between amounts involved in estimation, the smaller the relative uncertainty of the sink (e.g. IPCC, 2006; Tabacchi, 2010). Gain-loss can easily involve overestimated parameters for sink and underestimates for sources especially when expert judgment is involved in selection of parameters or because of the spatialization method under lower tiers (multiplication of area with an emission factor). Also "gain-loss" apparently yields less uncertain removal estimate, although the risk of unaccounted uncertainty is much larger than for „stock difference" method because of heterogeneous data inputs, e.g. different methods to estimate gains and losses and the bias especially in non-NFI harvest statistics. Actually, wood harvest remains one of the most uncertain datasets because of usually unreliable statistics (US Geological Survey, 2005; Corona et al., 2007; Mantau et al., 2007). Disturbances, e.g. fire statistics are also a major source of uncertainty in terms of activity data (Goldammer, 2003; FAO, 2007; Holmes et al., 2008), but their contribution to overall EU uncertainty is likely insignificant under small annual emissions, despite being a major factor in some national GHG inventories (e.g. in Mediterranean countries; EEA, 2012).

*Relative uncertainty of C stock changes in C pools at national level, provided by national reports, can be assumed as a composite parameter from a statistical point of view*. For example, among the factors needed to estimate change in biomass pools for forests, the standing stock volume or current annual increment, sometime harvest and dead wood, are reported as a mean and its confidence interval computed as sampling error of the mean from systematic sampling national forest inventories (assumed normally distributed under Central Limit Theorem). Further on, most likely increment and harvest are asymmetric distributions (presumable log-normal), the sink also distributes normally, applying CLT to summation of uncertain quantitates. Consequently, the uncertainty transferred to GHG inventories is dominated by random errors while risk of systematic errors is lower under such random approach and multiple checks (both attached to NFIs and GHG inventories). Other needed parameters are generally provided from non-representative and non-systematic samplings, which can be reasonable assumed only as population descriptors (as mean and 95% probability range) reflecting the overall variability, i.e. on geographical scale. In this case the whole variability is assumed as uncertainty while parameters show naturally asymmetric distributions. This is the case for default or expert judgment-based selection of parameters: expansion factors or root-to-shoot ratio for biomass pools, as well as for soils related pools (White, 1978; IPCC, 2006; Monni, 2005; Lehtonen et al., 2007; Tsutsumi et al., 2007), distribution of C stock in mineral soils (Dinca et. al., 2012). Overall, use of such factors induce systematic errors and likely bias in the GHG inventories, with their effect diminished by application of reporting rules (i.e. reporting "no change" instead of a demonstrated sink) and time improvements (replacing default factors with dynamic models, like BEF with age dependent equations).

*Versatility of SOC and DOM pools does not affect significantly the EU uncertainty*. Contrary to other national GHG inventory sectors entirely composed by sources, LULUCF includes pools that behave either as sink or source depending upon management approaches and environmental conditions. Inherently, C stock change in these pools has a strictly natural component, an inter-annual variability, which cannot be easily discriminated from the anthropogenic one, thus the entire change is conservatively assumed to be directly human induced by land management (Gupta et al., 2003). Characteristically, they make a relatively small contribution to both GHG inventory accuracy and uncertainty, with contribution to accuracy, i.e. the estimate closer to true anthropogenic net removal, being more important as a tool to prioritize improvements of the GHG inventory. From a scientifically perspective, the accuracy and uncertainty of such estimates may be underestimated under reporting rules of GHG inventory, when notation keys are reported instead of actual estimates, as 'not occurring'. EU level uncertainty increased by 300% when uncertainty value was gap filling to pools reported as "no change", but the trend range tends to decrease by some 30% because of time correlations. The fact is that current knowledge does not support higher confidence in the inventories of these pools (e.g. Baritz, 2010). With the requirement of an annual GHG inventory, various pragmatic solutions were suggested: allowing more time for emissions/removals to materialize and increased measurability (Jonas et al., 2010), while greater resources are needed both for reporting and verification of the inventories (Monni et al., 2004).

*Under lack of data, common use of default parameters or assumptions affect uncertainty level but brings negligible dependency among member states estimates*. Reasons for correlations among member states or even Annex I countries inventories have become negligible, while correlations within inventories become very important. Any approximation of correlation coefficients among national estimates seems to significantly overestimate the EU uncertainty (i.e. four times increase from 25% to 113%), thus accounting correlations at the level they occur is crucial. Such correlation would occur in case when a European wide natural resource inventory would be developed, where unbiased sampling error would be aggregated across the whole sampling network, e.g. very useful for detecting cost effective change in mineral soils or grass vegetation under management. Most likely, nationally available datasets may not be time and spatially independent, by pool or among pools. National GHG inventories have to provide annual estimates, but underlying data is periodically assessed (i.e. forest and soils inventories, land use/cover survey) in identic frameworks. Annual estimates for non-measured years are back/upward extra/interpolated or simple/weighted averaged (Heikkinen et. al, 2012, EEA, 2012). Re-measuring same trees and plots (as in NFIs) or use of same conversion to biomass method (i.e. BEF or biomass equations) generates time and spatial dependent data not only among estimates of same pool but among estimates of different pools. Overall, correlations are assumed decreasing with the increase in time span between successive measurements (Winiwarter and Rypdal, 2001). Correlation extends not only pools change estimated within NFI cycle, but also among consecutive cycles NFI, so more relevant for trend uncertainty.

*Because datasets are not independent in time, the real trend is also uncertain*. Trend and its uncertainty are also dominated by living biomass. While broaden the range for level uncertainty, the correlations keep the overall EU trend uncertainty at lower level because of error compensation in aggregation (e.g. Monni et. al., 2004). Trend is more difficult to explain when management changes are implemented. Time correlation tends to reduce the range of uncertainty in the trend, while gap filling magnifies it substantially.

My early work related to GHG inventories focused on *methods for deriving and estimation of biomass expansion factors for forests from historical database* available within the countries, e.g. quantitative relation of merchantable volume and biomass components of the trees (aboveground and belowground biomass) (Cienciala et al., 2011 (eds)). Unlike other countries which report volume of growing stock in their forestry records, Romanian forestry databases records total tree volume (for broadleaved at least), excluding foliage. Methods for estimation of removals/emissions from forests management and from *land conversions from* and *to forest* needed refinement and improvements in order to accurately estimate the emissions/removals and to avoid double counting of emissions across land categories. Solutions were described in detail under section *(B-i).3 Modeling biomass and age-structure dynamics in stands and forests* of this thesis.

IPCC recommended generic methods for estimation of annual C stock changes were subject to testing in practice: gain-loss and stock difference. Practical applications referred from using historical data (e.g. share of branches, bark, belowground) to development of complete and adequate data sampling (e.g. over LULUCF workshops). For forest, there were technical support for clarifications with regards to C pool and their link from dynamic CO2 fluxes to/from atmosphere: e.g. avoid double counting of foliage biomass under low methodological effort (Tier 1) among successive years, or between foliage and litter, or in case of dead organic pools in land conversions, as defined by IPCC Guidelines (GPG for LULUCF 2003, 2006 Guidelines, 2013 KP Supplement).

As a *contributor author*, invited by the authors of the *IPCC's KPS2013 Supplement* for Section 2.5–2.7(Afforestation/Reforestation, Deforestation, Forest Management), I was involved in providing specific knowledge and expertise, as well as on interpreting, processing and integrating inputs from globally consulted experts and scientific community into the guidance on "accounting" of emissions reductions from forest-related eligible LULUCF activities:

deforestation, afforestation/reforestation and forest management. Purpose of the "accounting" is to detect additional emission or removals from management activities, which then count against national target. Several types of accounting rules are used, e.g. "gross-net" for afforestation and deforestation, or "net-net" for revegetation. KPS guideline was used to provide the methodological steps in estimating the amount of net GHG emissions or removals from atmosphere for each type of eligible activity. In order to account net emissions or removals to the atmosphere, a new concept was introduced for land sector and specifically for forest management, namely an accounting based on a "forest management reference level" (FMRL). RL is a projection of a "counterfactual" scenario, e.g. projection of expected sink, against which actual net emissions reductions achievements are recorded over the compliance period. FMRL evolved in FRL applicable for 2020-2030 under EU LULCF Regulation which strives to exclude the impact of policies generating future impact on sinks or sources related to managed forests (e.g. higher harvest for bio economy, or bioenergy purpose).

*Further support in climate change policy consists in preparing forestry sector for compliance with commitments and further GHG emission reductions.* This requires quantification and accounting of emissions and removals given various measures and policies with impact on sink or sources. In *Blujdea et al. (2018)* such scientifically based support is revealed by using empiric models for projections for conversion to forest and forest management (e.g. CBM-CFS, Efiscen, Yasso 07/15, CO2fix) to which is attached the estimate on changes in C stocks in harvested wood products (i.e. IPCC's Tier 1 based spreadsheets). Projections in support of then ongoing negotiations under LULUCF regulation ((EU) 2018/841, (EU) 2018/842) published in *Blujdea et al (2018)* is shown in Fig 12 for afforestation and Fig 13 for managed forest. A maximal scenario was defined targeting the full benefit from using of "flexibility" amount provided in Art.7 and Annex III of (EU)2018/842.

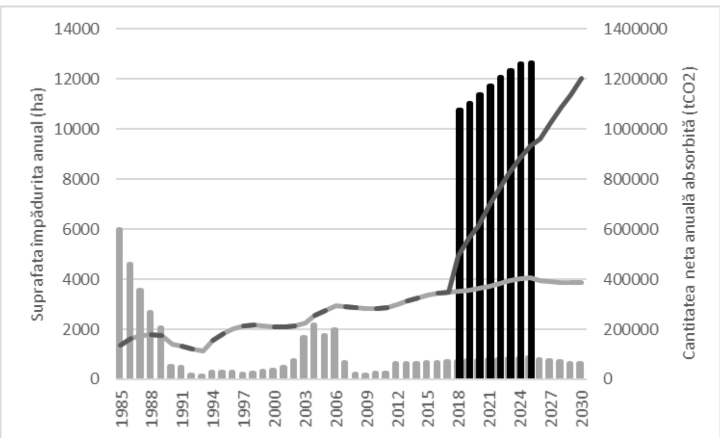


Figure 12. Over left-Y, bars represent afforestation area over 1985-2016 (gri) combined a) business as usual afforestation area (average corresponding to historical rates over previous 10 years, in grey) or maximal scenario (annual area x12, in black) over 2018-2030. Over right-Y, line represents annual amount of CO2 removals associated to afforestation rate scenarios assuming 20 years transition period (available at: http://www.bucovina-forestiera.ro/article/02_blujdea_23-34/). Projections by CBM.

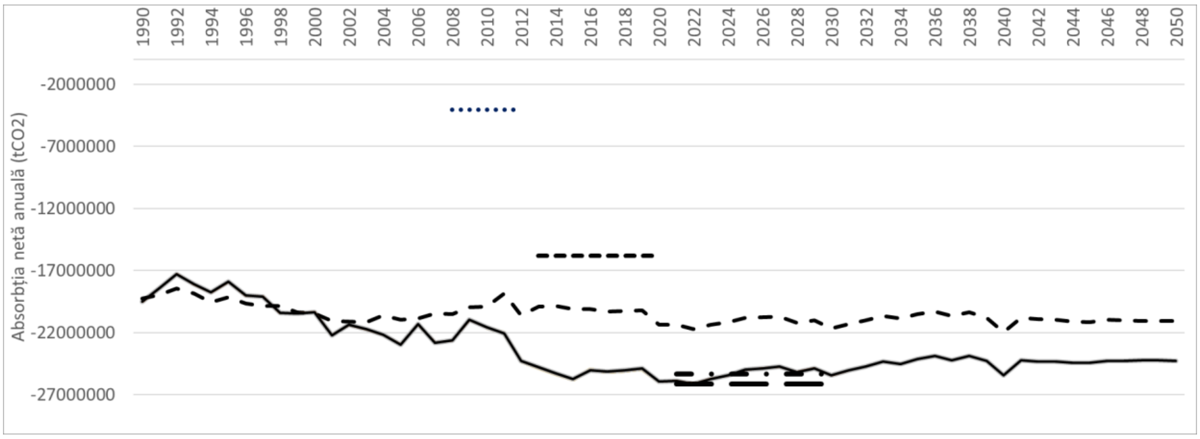



Figure 13 History and forthcoming GHG accounting parameteres reflecting net CO2 removals from managed forests (removals count as "-") until 2050. HWP is included (full line) or excluded (dotted line). Accounting parameters are represented by horizontal lines corresponding to successive commitment periods/compliance frameworks: "FM cap" (2008-2012), "FMRL" (2013-2020), "FRL" (line evenly discontinued for 2021-2030), as well as the average assuming identical management practices as in the reference period 2000-2009 (line-dot over 2021-2030) (available at: http://www.bucovina-forestiera.ro/article/02_blujdea_23-34/). Projections by CBM-CFS.

Simulations account for change in forest management practices given increased share of biomass used for energy purposes, production, import and export of roundwood, and share of Roundwood in future harvest level assuming restrictions of intensity from reference period.

Consequent *contribution to forestry and natural resources management and other practical applications*, are spelled out here:

- Contributing author to the IPCC's supplementary Methods and Good Practice Guidance for accounting under the 2nd commitment period (2013-2020) of the Kyoto Protocol;
- Development of methodologies for estimation of C sequestration in C pools in degraded and agriculturally marginal lands afforestation projects (living biomass, litter, dead wood and organic matter in mineral soils) for commercial transactions of emission reduction (JI[5], CDM[6],[7]);

[5] JI Romania - Afforestation of Degraded Agricultural Lands Project (http://documents.worldbank.org/curated/en/659041468758956310/Romania-Afforestation-of-Degraded-Agricultural-Land-Project)

[6] CDM Moldova (http://documents.worldbank.org/curated/en/570801468062645412/Moldova-Soil-Conservation-Project)

[7] Second verification of the CDM A/R project "Assisted Natural Regeneration of Degraded Lands in Albania" (https://cdm.unfccc.int/PRCContainer/DB/prcp248748406/view)

- development of methodologies for estimation of C sequestration in C pools in pastureland projects[8];
- Support and technical advice to national and international authorities on simulation of C stocks and C stock changes in forest C pools in the context of National Forestry Accounting Plans or National Communication/Biennial Reports due to UNFCCC (e.g. European Commission[9], Ireland[10], Montenegro[11]);
- contribution to scientific-technical background of legislation, e.g.
  - COMMISSION DECISION of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC (notified under document C (2010) 3751) (2010/335/EU)
  - REGULATION (EU) No 525/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC Decision No 529/2013/EU of the European Parliament and of the Council of 21 May 2013 on accounting rules on greenhouse gas emissions and removals resulting from activities relating to land use, land-use change and forestry and on information concerning actions relating to those activities;
- Independent expert in LULUCF Expert Group established by the DG Clima of the European Commission in support of the implementation of LULUCF Regulation 841/2013(EU).

*Contribution to education and knowledge sharing.* I was an invited speaker to various workshops[12] with the purpose to communicate to stakeholders the impact, or the past and potential contribution in the future, or the uncertainty of the estimates, related to forest and forestry sector contribution GHG mitigation under the climate change process and commitments.

[8] Viorel N.B. Blujdea (2016) Report on best available practices and methodological approaches, including recommendations related to carbon stock assessment and monitoring in mountain ecosystems, for the LULUCF sector of the national GHG inventory and mitigation activities, in Armenia. Final report, contribution to "Clima East Pilot Project - Sustainable management of pastures and forest in Armenia to demonstrate climate change mitigation and adaptation benefits and dividends for local communities" of UNDP/EU (reference at: https://erc.undp.org/evaluation/documents/download/12044)

[9] 'Forest carbon databases and modeling' for the Joint Research Center of the European Commission's mandate on the provision of data and analysis on biomass (ESP DESIS III). 2014-2016. Sub-contract to Engeneering SpA, Italy.

[10] Alternative modeling by CBM-CFS of Irish Forest for the Ministry of Agriculture, Ireland (2018). Subcontracted by FERS Ltd, Ireland.

[11] UNDP RFP 03-2019 Development of Mitigation Chapter for the Third National Communication (TNC) of Montenegro. Sub-contract by Aether Limited, United Kingdom.

[12] e.g. EUSTAFOR, see https://eustafor.eu/lulucf-practical-consequences-for-the-forest-based-sector-follow-up-materials/

As a scientific/technical officer working for the Joint Research Center of the European Commission I was one of the main organizers of several technical workshops related to LULUCF[13] where the purpose was to advance the harmonization of the understanding, interpretation and practices regarding the rules and methodologies for GHG estimation by the EU member states.

Over last decade, I was a trainer or international experts on IPCC GHG estimation methodologies and UNFCCC/Kyoto Protocol reporting requirements for national GHG inventories.

Finally, I am an accredited reviewer (nominated by Romania) of national GHG inventories and other official reports due by the countries to UNFCCC.

[13] https://forest.jrc.ec.europa.eu/en/activities/lulucf/workshops/

## (B-ii) The evolution and development plan for career development

### B-ii.1 Modeling biomass accumulation processess in trees and forests

*Scientific drivers and societal needs.* As some other countries in East Europe, or around the world, Romania still lacks data regarding biomass and carbon poos and dynamic (i.e. stocks, transfers among pools including to atmosphere). Additionally, Romania lacks updated data on trees and stand volume yield tables or equations. Such data is most needed for GHG inventories and GHG mitigation activities. Further clarification and transparency, and updated approaches, are needed on definitions, sampling and processing methodologies on what is merchantable volume and volume increment, biomass and biomass growth. A meaningful approach would be the sampling in a systematic network (e.g. National Forest Inventory), data which would serve simultaneously to develop models and construct equations for all relevant parameters related to volume and biomass. For example, volume which refers to each of parameters: „increment" „standing volume" and „harvested volume" need a redefinition of which part of the tree it actually represents, total tree or merchantable part, etc in order to avoid under/overestimation of biomass.

Further on, there is also a priority to link models and equations to environmental (e.g. climate), biological cycles (e.g. turnovers, share of biomass or dead organic matter components according their life time), geochemical cycles (e.g. C cycles) or economic processes (e.g. management interventions, evaluation of standing merchantable wood instead of total tree aboveground volume).

Compared to living trees, there is even more pronounced lack of systematically sampled data related for dead organic matters: litter, dead wood and soil organic carbon in mineral soils.

On short term, a surrogate solution valid from scientific and statistic point of view, consists in selection of equations used elsewhere e.g. CBM default (in fact defined for Canada) parameters are provided in model's database (Pilli et al., 2018).

*State of the art.* Both ground-based and remote sensing measurements are more and more available for estimation of both volume and biomass estimation. Typically, conversion of tree volume to biomass, and further to C content, requires two parameters of their exponential relation (easy assimilated with linear relation whose slope corresponding to wood density, and nil interception). In case of stands additional parameteres may be needed to secure accurate estimates, as basal area of the stand. Most advanced understanding of biomass compartmentation assumes additional restriction that for any independent variable the dependent variables satisfy the empiric sum of all biomass components. Best practical example is shown by Boudewyn et al.

(2007) whose model ensures derivation of relative shares of bark, branches, foliage and stemwood biomass as function of merchantable standing volume at stand level. Nord-Larsen et al (2017) imposes similar restriction on fitting biomass equations. Belowground biomass, fine and coarse roots, is even poorer given limited underlying empiric data, e.g. general equations are used (e.g. Li et al., 2003).

*Challenges.* Major information missing or no-updated that prevents running tree-by-tree or large-scale models in Romania on which I would focus are:

- equations for standing stocks and growth of biomass of forest trees and non-forest woody individual plants;
- biomass equations for merchantable share of stands for forest, woody crops or non-forest woody plants, embedding biological relevant processes (e.g. maximum biomass reachable, current growth, mortality), as well as other characteristics (e.g. environmental parameters, basal area);
- modeling and development of equations for conversion of volume of merchantable stock to stem wood biomass, bark, branches, foliage biomass, as well as coarse and fine roots, as well as corresponding values for volume increment;
- development of turnovers values or equations for biomass compartments for major types of forest on climate regions of the country;
- developing calibration and validation methods for models of biomass and dead organic matter pools (litter, dead wood, organic matter in mineral soils) in land conversions from and to forests;
- anticipating the technological properties of wood for the tree species which become more relevant under climate change at various geographical scales or toward diversification of their use;
- modeling GHG at landscape scale as a tool for integrated solutions supporting climate neutrality of sub-national administrative units;
- advanced understanding and quantitative convergence of the IPCC methods for estimation of C stock change in carbon pools (Gain-Loss, Stock Difference) and define criteria for selection of one method over another for the purpose of the national GHG inventory or models use (development, calibration, verification).

### B-ii.2 Modeling the fluxes of „the four forms of wood: volume, energy, biomass and carbon” through forestry sector and economy

*Relevant publications*

1. *EIP-AGRI Focus Group Forest Practices & Climate Change. MINIPAPER 9: Innovative Wood-based Value Chains - “shift to smart wood” 20.12.2017. Authors:* ***Viorel N.B. Blujdea (Coord.)****, Gunilla Holmberg, Juan Picos*

2. Jonsson R, **Blujdea VNB**, Fiorese G, Pilli R, Rinaldi F, Camia A (2017) *European outlook for the forest sector: supply and demand*. iForest Biogeosciences and Forestry vol. 11, pp. 315-328.

*Background, scientific drivers and societal needs*. Wood is traditionally used as a construction material and as an energy source, with broad range of applications across all life aspects: individual, commercial and industrial constructions. It is a raw material for other products (celluloses, fibres, etc) and fuel (e.g. firewood, pellets). In the EU-28, around 25% of total biomass supply of terrestrial origin is wood. Although recognized as highly uncertain, in the EU, some 100 mil/m3 or 28% of annual roundwood production is used for different energy purposes (http://ec.europa.eu/eurostat). Overall, fuelwood consumption remains rather constant in time, although there is an increase of the share of densified wood-based fuels such as pellets and briquettes.

Under global anthropogenic pressure on natural resources and need to move towards neutral GHG emission economies there is expected an *intensified use of wood. This represents a major opportunity* by: a) enhancing wood products characteristics toward use in traditional applications (e.g. buildings, wood fuel) b) substitution of non-renewable, or energy-, or water-, or carbon-intensive materials (e.g. in construction, textile), c) development of new products from tree parts traditionally not used (e.g. for food, pharmaceuticals), as well as by d) supplementing non-woody biomass supply to economy (e.g. agricultural, marine). Thus, given sustainability restrictions for forest resources use, wood has to be integrated into analysis of the forest’s sustainability and its contribution to society, so considering the four forms of wood: volume, energy, biomass and carbon. Within this forestry sustainability concept, wood has even more to provide when it is about societal needs, so my focus would be on contribution of C exchange with the atmosphere from using wood as a material and energy. Concept is based on the four fundamental dimensions/pathways of wood:

> *volume* of matter as the primary/classic product of forest management used in the natural or technologically improved form (includes aesthetic and technological properties). Notably, shape is a dominant characteristic of this wood dimension;

*energy* source qualified as being of renewable origin, in comparison to many other types of energy sources available, although science warns that not all fuelwood contributes to climate neutrality,

*biomass* or matter amount used for non-energy purposes, to supply the forthcoming bio economy future. Notably, shape does not matter, instead amount does, and

*carbon* content – wood and wood products are deposits of carbon on various time frames, thus contributing to the global effort to mitigate the climate change.

Each of this pathway adds value to wood and forests. Nevertheless, wood use versatility will most likely be escalating in a strong competition among the four forms (additional to the challenge to forest services related to forestland). If in the past, the volume dimension was dominating (e.g. size and shape of roundwood, or aesthetics), future seems to favour biomass use (e.g. fibre content, accessibility, easiness of supply).

*State of the art.* Higher wood demand would also increase the impact on forest ecosystems and forest sector capacity while also bring favourable benefits (e.g. increased harvesting rates, advanced processing of wood), to rural areas and to society, in general (e.g. more and diversified environmentally-friendly products, downstream forest related jobs and less workforce migration, lower GHG emissions). Sustainably harvested wood is a renewable, but limited, resource. Forestry relies on sustainable forest management approach which gives due consideration to all societal and environmental concerns. The overarching principle underlying the sustainability of forest resources is the indefinite continuity of wood supply. This principle is implemented through technical norms and guidelines materialized most often in planning of forest interventions on short run (thus providing for the expected amounts and quality of wood available). Moreover, using wood has a global sustainability dimension as wood market and commerce exercise a rather strong pressure on global forests harvesting. Increasing the availability of wood from sustainable managed forest is the main concern of forestry from all the times. Under last half a century lower demand than availability, measures to actual increase of productivity of existing forests might just have had localized impact (e.g. improved and active silviculture, through genetic improvement or fertilization, or active post-disturbances interventions).

Wood harvesting follows national circumstances and traditional forestry rules and practices. *First*, national circumstances are very relevant in defining harvest amount (i.e. rotation cycles, age-structure, natural disturbance pattern, management/intervention approaches, afforestation rate over last decades). In Europe, over the last half century there has been an overall under-utilization of the available wood at national scale. Among most notable under-utilized resource is the so called “small wood”, i.e. from stems and branches, both because forest operations costs of early thinning are simply not cost-efficient and market prices are too low for these such assortments. Another notable under-utilized resource are hardwoods because of lack of demand especially for mature broadleaved forests. *Secondly*, actual use of wood may not be always optimal according to the size and the potential use in long life products or low emissions paths, e.g. roundwood is used as firewood. *Third*, significant woody biomass remains currently not harvested (e.g. branches, roots, stumps, etc) but left as residues on forest ground. *Forth*, non-forestland wood resources are generally not considered by countries in terms of their actual contribution with industrial wood and biomass, although such amounts seem to be significant (i.e. 87 mil m3 in 2010 according to Mantau et al., 2010) with some 50% used as fuel. *Fifth*, forests are subject to unpredictable events, natural disturbances may have significant impact on management, e.g. age structure, and wood processing, e.g. suddenly make available locally unplanned large quantities of wood, in many cases of lower quality due to damages.

*Scientific challenges.* I would focus on forestry as service delivery to society and economy through several interconnecting pathways around the four dimensions of wood. Research and modeling tools and exercises are needed to understand challenges and prepare forestry sector to face future challenges related to bio economy and climate change, and societal behaviours change:

- early understanding of the future challenges and opportunities for the forestry sector, e.g. for forest management, for wood processing industry and for competition for wood, and how to contribute to future challenges of the society (e.g. climate targets, bio economy, migration);
- identification of climate friendly pathways by incorporation of re-use and recycling of wood (cascading use, e.g. with final step as a product dedicated to soil fertility improvement);
- early undrstanding of the volume-energy-biomass-carbon competition along land-energy nexus, at local and regional/national scales, in relation to wood availability and sustinability of wood and non-wood resources. This means advanceing understanding of the evolving competition between a) energy and material use, b) wood assortments (by-products of high value-added products, raw dimensions or biomass, recycled), c) among wood from various forest interventions and d) wood and other non-woody biomass types. This also includes, interdisciplinary research for more efficient burning installations and diminishing wood use by alternative forms of energy. Further question is if an energy

mix with minimum contribution of firewood is realistic, can wood be phased out in the future?;

- focus toward development of reliable tools for forecasting of wood harvest and biomass availability mid- and long-term planning at micro and macro-scale, i.e. integrating forest management and practices with harvested wood use;
- understanding forest management practices and interventions needed to maximize wood supply toward long life wood products and bio-economy needs;
- support for the development of the scientfic basis for economic/fiscal/subsidies stimulus of enhanced harvesting wood biomass and use. e.g. shift to new wood processing technologies;
- substantiate further the science if sustainable wood is one of the candidates for next generation of climatic neutral sources of materials and chemicals, and what is neded to stimulate such potential, e.g. by adequate support of research and innovation;
- study how small wood from hardwoods can be further used, knowing current trend in expanding broadleaved tree species in Europe as response to climate change impacts (e.g. given the climate conditions in Romania);
- development of end-user/practitioner friendly tools for integrated modeling of forest productivity and C dynamics in forest C pools, GHG emissions/CO2 removals and wood products chain, which necessary must incorporate economic module;
- research effort to accurately estimate the duration of C residence/lifespan of wood products for all significant wood products for each country or region, e.g. life time and decomposition pattern;
- understand the triggers for more use of wood in non-energy applications by various users and design funding opportunities and stimulus for supporting enhanced wood use and economically viable solutions;
- contribute to definition of principles and criterias defining wood as a renewable source of energy or materials;
- understand whch are the drivers and expected trend in wood resource efficiency and recycling. Are harvesting residues and old wood products recycled instead of deposited in landfills or left in forests?
- study which is the impact of demand by industrial and non-industrial consumers on the quantity and quality of harvest? Whar are regional patterns and trends of technologies and tradition in use and processeing wood, e.g. related to particularities of forest stands (species) and historical investments in wood industry;

- study which are land use based solutions to ensure increasing the availability of roundwood and woody biomass? Are still feasible old methods as expansion of forest, woody biomass plantations and non-forest lands by improving presence of woody species plantations and forest stands within landscape?
- study which may be the economic stimulus for using more wood or enhancing cost-efficiency of low income forest interventions, and further understand how to stimulate the apetite of consumers to innovative wood materials, like: high-strength engineered wood product as material for permanent structural applications, cross-laminated timber and various boards are increasingly used to pre-fabricate building elements. Small wood, wood residues and recycled wood products receive interest in non-traditional applications, e.g. ultra-lights particleboards, wood pulp-based fibres as substitutes of synthetic textiles and plastics, metallurgical charcoal (biocoke) or packaging. Novel uses are emerging though, e.g. chemicals contained in various parts of trees, like stumps and roots of resinous species, have pharmaceuticals, dietary and cosmetics applications, or, new insulation materials like cellulose compressed into boards or blown-in loose-fill insulation cellulose wool instead of stonewool;
- understand the competitivity around wood use, especially as energy source, especially for rural areas where the use efficiency is very small, e.g. using biomass emits more carbon per unit of energy than most fossil fuels;
- understand "zero rating" of using biomass as bioenergy impact in the GHG inventory, the accounting framework related to Energy Union, and which are practical solutions to avoid non-compliance in the future climate commitments or other obligations related to sustenability of natural resources;
- identification and support for promotion of biomass applications in bio-economy-based-society in order to create additional demand for wood and optimize competition among wood uses, e.g. one of most likely challenge regards the availability of fuelwood facing strong competition from high-income novel uses (e.g. food industry, medicine);
- which are the trends and which is the impact of technology innovation and industry standards on diversifying management/practices and type of wood or woody biomass needed. Effort focuses on enhancing resource availability, minimization of environmental impacts, development of machineries and technology base, as well as instruments for economic analysis to ensure highest investment returns of using any of, or both, wood (i.e. for innovative wood products) and woody biomass (as raw bark, branches, stumps and roots, etc). Innovation in forest operations is limited especially by the operation costs and labour demand.

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