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Local Authorities, such as Mountain Communities, can be supported in sustainable forest planning and management by providing specific models in which the reference unit is the same as the one reported in the Forest Management Plans (FMPs), i.e. the forest stand. In the Lombardy Region (Northern Italy), few studies were performed to assess WB and forest C stocks, and they were generally based on data coming from regional—or national—forest inventory and remote sensing, without taking into account data collected in the FMPs. For this study, the first version of the stand-level model "WOody biomass and Carbon ASsessment" (WOCAS) for WB and C stocks calculation was improved into a second version (WOCAS v2) and preliminary results about its first application to 2019 forest stands of Valle Camonica District (Lombardy Region) are presented. Since the model WOCAS uses the growing stock as the main driver for the calculation, it can be applied in any other forest area where the same input data are available.

Keywords Forest modelling - Woody biomass - Carbon stock - Forest management plan - Site-specific primary data - Climate change mitigation

Assessment of Forest Biomass and Carbon Stocks at Stand Level Using Site-Specific Primary Data to Support Forest Management

Luca Nonini, Calogero Schillaci and Marco Fiala

Abstract To quantify and map woody biomass (WB) and forest carbon (C) stocks, several models were developed. They differ in terms of scale of application, details related to the input data required and outputs provided. Local Authorities, such as Mountain Communities, can be supported in sustainable forest planning and management by providing specific models in which the reference unit is the same as the one reported in the Forest Management Plans (FMPs), i.e. the forest stand. In the Lombardy Region (Northern Italy), few studies were performed to assess WB and forest C stocks, and they were generally based on data coming from regional—or national—forest inventory and remote sensing, without taking into account data collected in the FMPs. For this study, the first version of the stand-level model "WOody biomass and Carbon ASsessment" (WOCAS) for WB and C stocks calculation was improved into a second version (WOCAS v2) and preliminary results about its first application to 2019 forest stands of Valle Camonica District (Lombardy Region) are presented. Since the model WOCAS uses the growing stock as the main driver for the calculation, it can be applied in any other forest area where the same input data are available.

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1 Introduction

Forests provide several Ecosystem Services (ESs), commonly classified as: (i) regulating, (ii) provisioning and (iii) cultural (Costanza et al. 1997; Bennett et al. 2009; Krieger 2011). The quantification of the demand (human society) and the supply (environment) of ESs is a key challenge to define the effective environmental management practices and to identify the best institutional scale for the decision-making

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processes (Daily and Matson 2008; Swetnam et al. 2011; Kroll et al. 2012; Marchetti et al. 2012; Garcia-Gonzalo et al. 2015). In the context of the current climate change scenario, the most important forest ESs are: (i) woody biomass (WB) supply and (ii) carbon (C) stock (Nabuurs et al. 2008; Ekholm 2016; Gren and Zeleke 2016). WB and C stock are indicators of provisioning and regulating services, respectively, and they are competing, as an increase in WB supply generally causes a reduction of C stock in the forest (Bottalico et al. 2016). To quantify and map these two ESs, several models were developed; they differ in terms of scale of application (single-tree, whole stand, regional or continental level), details related to the input data required and outputs provided (Vanclay 1994; Pretzsch et al. 2009; Klein et al. 2013; Pilli et al. 2013). In the alpine forestry region, Mountain Communities are the main Local Authorities having a key role in forest planning and management (Cantiani 2012). At this purpose, stand-level models are particularly important because stands represent the reference unit of the Forest Management Plans (FMPs). FMPs make available a wide range of primary (measured) data that can be used to estimate the current WB (and the corresponding aboveground and belowground C stock), the mass harvested and their variation over time. In the Lombardy Region (Northern Italy) only a few studies were performed to assess WB and forest C stocks, and they were generally based on data coming from regional—or national—forest inventory and remote sensing (Federici et al. 2008; Colombo et al. 2009). None of these studies took into account primary data collected in the FMPs. Considering all of these elements, the aims of this study were: (i) to develop a model—based on site-specific primary data—to calculate WB and C stocks at the stand level, (ii) to test the model for the Valle Camonica District (Lombardy Region) and (iii) to map the spatial distribution of these stocks at different levels (from the stand, to the municipality and to the whole forest area under assessment).

2 Materials and Methods

2.1 *The Model WOCAS*

A first version of an empirical stand-level model called "WOody biomass and Carbon ASsessment" (WOCAS) was developed to calculate the annual WB and C stocks in different forest pools. This model was recently improved into a second version (WOCAS v2) by: (i) adding new information (FMPs new data), (ii) defining more accurate calculation methods and (iii) improving the general structure to increase the model's reliability and flexibility. For a generic (j) forest stand, for the year n, calculations are performed in the following pools: (i) aboveground woody biomass ($AWB_{n(j)}$), (ii) belowground woody biomass ($BWB_{n(j)}$) and (iii) dead organic matter ($DOM_{n(j)}$; dead woody biomass + litter) by applying a mass balance based on a "gain-loss" approach consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006; Federici et al. 2008).

For each j-stand, the input data required are: (i) starting ($YR_{S(j)}$) and final ($YR_{F(j)}$) year of the FMP, (ii) forest typology, (iii) forest function (e.g. production, environmental protection, recreational), (iv) forest structure (i.e. coppice, high forest), (v) area ($A_{(j)}$; ha), (vi) growing stock at $YR_{S(j)}$ ($GS_{(j)}$; t year^{-1} dry matter, hereafter DM) and (vii) growing stock harvested over time ($H_{n(j)}$; t year^{-1} DM).

For each harvesting operation, the corresponding woody residues ($HR_{n(j)}$; t year^{-1} DM)—consisting in tree stumps, tops, branches, twigs and non-commercial parts—are also calculated (IPCC 2006). Woody residues represent a loss from the living $AWB_{n(j)}$ and $BWB_{n(j)}$ pools, and—if they are left on the ground and are not extracted from the stand—a gain for the $DOM_{n(j)}$ pool.

For each j-stand, for the year n, starting from the growing stock of the previous year ($GS_{n\text{-}1(j)}$; t year^{-1} DM), the gross annual increment ($GAI_{n(j)}$; t year^{-1} DM) is calculated by applying the first derivative of the Richards growth function (Richards 1959; Pienaar and Turnbull 1973; Birch 1999; Federici et al. 2008). Then, the net annual increment ($NAI_{n(j)}$; t year^{-1} DM)—defined as $GAI_{n(j)}$ minus growing stock losses within the same period of time due to natural mortality (UNECE/FAO 2011)—is quantified.

Two types of natural mortality are considered: (i) regular (RM), due to senescence, competition for light, water, nutrient and from the normal incidence of pests, diseases, and weather phenomena, and (ii) irregular (IM), due to wildfire, windstorm, avalanche, insect's outbreaks or other disturbances (Vanclay 1994; Alenius et al. 2003). Regarding the former, it is assumed that the growing stock losses ($GS_{RMn(j)}$; t year^{-1} DM) occur each year, whereas, regarding the latter, information about: (i) year of occurrence, (ii) type of disturbance and (iii) growing stock losses ($GS_{IMn(j)}$; t year^{-1} DM) has to be defined by the user. As well as for the woody residues, natural mortality represents a loss from the living $AWB_{n(j)}$ and $BWB_{n(j)}$ pools, and a gain for the $DOM_{n(j)}$ pool. In more detail, for the regular mortality, it is assumed that all the $GS_{RMn(j)}$ are transferred to the $DOM_{n(j)}$ pool, whereas, for the irregular mortality, the WOCAS model calculates the fraction of the $GS_{IMn(j)}$ transferred to the $DOM_{n(j)}$ pool according to the type of disturbance.

The growing stock in the year n ($GS_{n(j)}$; t year^{-1} DM) is then calculated starting from the $GS_{n\text{-}1(j)}$, (t year^{-1} DM), adding the $NAI_{n(j)}$ (t year^{-1} DM) and subtracting losses due to the growing stock harvested, $H_{n(j)}$ (t year^{-1} DM). The living $AWB_{n(j)}$ and $BWB_{n(j)}$ (t year^{-1} DM) stocks are calculated by multiplying the $GS_{n(j)}$ for specific coefficients (Somogyi et al. 2007; Federici et al. 2008) defined according to the stand's characteristics.

The $DOM_{n(j)}$ in the year n is calculated by taking into account, as inputs: (i) $GS_{RMn(j)}$, (ii) $GS_{IMn(j)}$ and (iii) $HR_{n(j)}$, and as output, the $DOM_{n(j)}$ decomposition, by using specific decay rates (Harmon et al. 1986; Melin et al. 2009) defined according to the stand's characteristics.

Finally, the carbon stocks in: (i) $AWB_{n(j)}$ ($C_{AWBn(j)}$, t year^{-1} C), (ii) $BWB_{n(j)}$ ($C_{BWBn(j)}$, t year^{-1} C) and (iii) $DOM_{n(j)}$ ($C_{DOMn(j)}$, t year^{-1} C) are calculated by multiplying the WB of each pool for the corresponding carbon fraction , k_C ($k_{C\_AWB(j)}$;

$k_{C\_BWB(j)}$; $k_{C\_DOM(j)}$). By summing up: (i) $C_{AWBn(j)}$, (ii) $C_{BWBn(j)}$ and (iii) $C_{DOMn(j)}$, the total carbon content of the j-stand—and of the whole forest area under assessment—can be calculated.

2.2 *Case Study*

The model WOCAS was applied to the Valle Camonica District to estimate WB and C stocks of the public forests. The total forest area is equal to 6.5 × 10^4 ha (52% of the total area); the public forests (managed thorough FMPs) cover 4.2 × 10^4 ha, whereas the private forests (not managed thorough FMPs) cover the remaining 2.3 × 10^4 ha. Among the coniferous, the main species are *Picea abies* L. and *Larix decidua* Mill. (30% and 20%, respectively), whereas, among the broadleaves, the main species are *Alnus viridis chaix* D.C. and *Castanea sativa* Mill. (11% and 8%, respectively). Production forests cover about 60% of the total forest area, followed by protection and recreational forests (38% and 2%, respectively).

For the study, data related to 2019 forest stands (total forest area $A_T = 3.7 \times 10^4$ ha, approximately) were extracted from 45 FMPs collected in the Cadastral FMPs database (CPA v2) made available by the Mountain Community. The dataset covered the period from 1984 (starting year of the oldest FMP) to 2016 (no more recent data were made available from the CPA v2).

To calculate the gross annual increment, specific growth parameters were used for each of the j-stand, according to species and type of management (Vitullo 2018); these parameters were made available by the Italian Institute for Environmental Protection and Research (ISPRA) and represent the ones used for the official UNFCCC National Inventory Report (NIR) for Land Use, Land Use Change and Forestry (LULUCF) sector for the Lombardy Region. The $GS_{RMn(j)}$ (t $year^{-1}$ DM) were assumed equal to 9.25% of the $GAI_{n(j)}$ (Tabacchi et al. 2010; Magnani and Raddi 2014). As a preliminary assessment, no differences among stands were introduced. The $GS_{IMn(j)}$ (t $year^{-1}$ DM) were not considered because no data were made available from the CPA v2. To calculate the $HR_{n(j)}$ (t $year^{-1}$ DM), as well as the $AWB_{n(j)}$ and the $BWB_{n(j)}$ (t $year^{-1}$ DM), the coefficients suggested by Federici et al. (2008) for the Italian forests were used. To simulate the $DOM_{n(j)}$ decomposition, not having specific data related to the Italian forests, the values of decay rates suggested by Harmon et al. (2001) for temperate forests were applied. Specific values of $k_{C\_AWB(j)}$ were considered, by taking into account the stem of the leading species (Thomas and Martin 2012). Moreover, it was assumed that $k_{C\_AWB(j)} = k_{C\_BWB(j)} = k_{C\_DOM(j)}$.

3 Results and Discussion

The main results about the last 2 years of the analysis (2015 and 2016)—for which the data of all the stands were made available from the CPA v2—are shown in Table 1.

Table 1 WB and forest C stocks related to the 2019 stands considered in the case study

		Unit	Year	
			2015	2016
Growing stock harvested	H_n	t $year^{-1}$ DM	1.5×10^4	4.1×10^3
Gross annual increment	GAI_n	t $year^{-1}$ DM	8.6×10^4	8.6×10^4
Net annual increment	NAI_n	t $year^{-1}$ DM	7.8×10^4	7.8×10^4
Growing stock	GS_n	t $year^{-1}$ DM	3.1×10^6	3.2×10^6
Aboveground woody biomass	AWB_n	t $year^{-1}$ DM	4.1×10^6	4.2×10^6
Carbon stock in the aboveground woody biomass	C_{AWBn}	t $year^{-1}$ C	2.0×10^6	2.1×10^6
Belowground woody biomass	BWB_n	t $year^{-1}$ DM	9.0×10^5	9.2×10^5
Carbon stock in the belowground woody biomass	C_{BWBn}	t $year^{-1}$ C	4.4×10^5	4.5×10^5

For both the year 2015 and 2016, the growing stock harvested (H_{2015} and H_{2016}, respectively) is lower than the net annual increment (NAI_{2015} and NAI_{2016}, respectively) ($H_{2015} = 19.4\% \ NAI_{2015}$; $H_{2016} = 5.3\% \ NAI_{2016}$). The ratio between H_n and NAI_n represents the effective extraction rate ($EER \geq 0$) and is one of the most important indicators for the sustainable forest management. In fact, if in the short term H_n can exceed NAI_n ($EER > 1$), i.e. for years characterized by a high demand of woody biomass (for energy and/or building purposes), in the medium-long term this condition should never occur ($EER \leq 1$), to avoid the depletion of the growing stock over time and of the stand's productivity (UNECE/FAO 2011; Magnani and Raddi 2014). The EER values can be calculated with a higher accuracy by taking into account also the irregular mortality (disturbances), that strongly affects the NAI_n of the stands. Therefore, it is recommended to improve the data collection in the CPA v2 by including information about the natural disturbances for all the stands affected. H_n, if performed in compliance with the sustainable forest management indicators, should be considered as a positive event because, besides allowing the rational use of an economically exploitable local resource, can promote a further increase of the annual increment and—as consequence—of the carbon sequestration. As a result, the homeostatic capacity of the forests can be enhanced, promoting a higher resistance to natural disturbances. The results provided by this study also show that the belowground woody biomass, generally not taken into account by the FMPs, is an important carbon pool, because it can stock about 22% of the total carbon of the aboveground biomass. These results can be obtained for each stand under analysis, single municipality, species, forest structure or function, making it possible to carry out a great deal of analysis and comparisons.

By integrating the model WOCAS with a Geographic Information System (ArcGIS®) a stand classification worksheet (SCS) was produced for each of the j-stand.

Each SCS provides two kinds of information (K_1 and K_2). K_1 contains general input information extracted from the CPA v2 (e.g. location, stands' owner); K_2 contains specific input (e.g. growing stock at the starting year of the FMP, growing stock harvested over time, forest typology, type of management) and output (calculated by the model) data, as well as information related to the mechanization (type of cutting performed and forestry machines that can be used according to the site-specific working conditions).

4 Conclusions

The use of management models able to calculate WB and forest C stocks is essential to analyze the contribution of these lands to climate change mitigation. In the alpine regions, the use of stand-level models based on data collected in the FMPs could be an interesting solution if the use of single-tree level models clashes with the technical-economic impossibility of the Local Authorities to provide the data required. In this study, the empirical stand-level model WOCAS was briefly presented and the main results about its application to a dataset of 2019 forest stands of Valle Camonica District were discussed. The main advantage of this model is that—besides being based on the international 2006 IPCC Guidelines—it uses the growing stock (generally available in any FMP) as the main driver for the calculation; as a result, it can be applied in any other forest area where the same input data are collected. Two aspects are currently under development: the first one concerns the definition of different management scenarios to quantify the mass of the woody assortments (and their corresponding carbon stock) that can be extracted from each stand and used for building and/or energy purposes. This aspect is very important, also considering that the commitments of the recent post-2012 agreements of the Kyoto Protocol include not only the need to report carbon emissions and removals related to forest management, but also the carbon stock in the harvested woody products. The second aspect consists in the definition of future scenarios based on both current and improved forest management practices (i.e. conversion of coppices to high forests) to test the model on different temporal and spatial scales and under different management conditions. In this way, it will be possible to make predictions and formulate prescriptions, promoting an efficient use of the local forestry resources.

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