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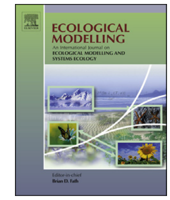

Application of the CBM-CFS3 model to estimate Italy's forest carbon budget, 1995–2020

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ABSTRACT

The estimation of past and future forest carbon (C) dynamics in European countries is a challenging task due to complex and varying silvicultural systems, including uneven-aged forest management, and incomplete inventory data time series. In this study, we tested the use of the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) in Italy, a country exemplifying most of these challenges. Our objective was to develop estimates of forest carbon budgets of the Forest Management area (including all forests existing in 1990) for the period 1995–2009, and to simulate alternative scenarios of natural disturbance (fire) and harvest rates to 2020. A number of methodological challenges required modifications to the default model implementation. Based on National Forest Inventory (NFI) data, we (i) developed a historic library of yield curves derived from standing volume and age data, reflecting the effect of past silvicultural activities and natural disturbances, and a current library of yield curves derived from the current net annual increment; (ii) reconstructed the age structure for a period antecedent to the reference NFI year (2005), to compare the model results with data from other sources; and (iii) developed a novel approach for the simulation of uneven-aged forests. For the period 2000–2009, the model estimated an average annual sink of −23.7 Mt CO_2 yr^{-1} excluding fires in Italy's managed forests. Adding fires to the simulation reduced the sink to −20.5 Mt CO_2 yr−1. The projected sink (excluding all fires) for the year 2020 was −23.4 Mt CO_2 yr^{-1} assuming average (2000–2009) harvest rates. A 36% increase in harvest rates by 2020 reduced the sink to −17.3 Mt CO_2 yr^{-1}. By comparing the model results with NFI data and other independent studies, we demonstrate the utility of the CBM-CFS3 both for estimating the current forest sink in even-aged and more complex uneven-aged silvicultural systems in Italy, and for exploring the impact of different harvest and natural disturbances scenarios in managed forests. This study demonstrates the utility of the CBM-CFS3 to national-scale estimation of past and future greenhouse gas emissions and provides the foundation for the model's future implementation to other European countries.

1. Introduction

Since the early 1990s, growing concerns about global warming as a consequence of increasing concentrations of atmospheric greenhouse gases have added a new demand for forest ecosystem services. Forests are the second largest carbon (C) stock present in the biosphere, after the oceans (Janssens et al., 2003) and they represent an important C sink that is removing from the atmosphere annually about one third of global fossil fuel emissions (Le Quéré et al., 2009; Pan et al., 2011). The climate mitigation role of forests in industrialized countries has been recognized by the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (KP) through the emission and removals from the Land Use, Land-Use Change and Forestry (LULUCF) sector. This role has been further confirmed during the recent international climate negotiations (Grassi et al., 2012). In particular, a number of important decisions on LULUCF accounting for the second commitment period of the KP were taken (UNFCCC, 2011), including: (i) the mandatory accounting of forest management, with future emissions and removals being compared against a predetermined "reference level"; (ii) C stock changes in the harvested wood products pool will be accounted; and (iii) emissions and subsequent removals on forest lands affected by natural disturbances may be excluded from the accounting. In most cases, the implementation of these decisions requires the capacity to model the impact of forest management on the current and future C balance of forests, in a way which is consistent with greenhouse (GHG) inventories of the

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countries; for instance, most countries' reference levels are based on modeled projections of the future C balance under assumed scenarios of business-as-usual harvest (AWG-KP, 2011).

The forest C dynamics can be quantified using (i) empirical models driven by data from national forest inventories (NFI) or (ii) process-based models, driven by the simulation of photosynthesis and other ecological processes. Typically, process-based models have been mainly used to simulate long-term evolution of forest C dynamics (i.e., many decades) including the potential effects of climate change (Pretzsch et al., 2008). While efforts are ongoing to incorporate the impact of forest management into process-based models (e.g., Belassen et al., 2011), empirical models such as EFISCEN (Nabuurs et al., 2000), CO2Fix (Nabuurs et al., 2001) or FORMICA (Böttcher et al., 2008a) still remain the primary tool to simulate the detailed effects of different forest management options in short-term forest C dynamics (i.e., few decades).

Some of the empirical models, such as the CO2Fix V.2, were applied and validated on both even-aged and uneven-aged forests in Europe, Central America and Africa (Masera et al., 2003; Nabuurs et al., 2008) but they cannot directly consider the effects of natural disturbances, such as fires and storms, which may have large impacts on the annual C balance of countries (Lindroth et al., 2009; Stinson et al., 2011). Others, such as EFISCEN (Nabuurs et al., 2000), which have been applied to all the European countries, contain a module to simulate the effect of some natural disturbances (Schelhaas et al., 2002; Seidl et al., 2009) but they generally simplify the silvicultural systems by assuming an even-aged structure for all the forests that is managed by a clear cut system. Although more than 60% of forests are reported as even-aged at the European level, uneven-aged and non-categorized forests cover about 30% and 70% of the total forest area in Central-East and South-West Europe, respectively (UNECE/FAO, 2011a). Moreover, most of empirical forest models can only provide estimates from the reference year of the National Forest Inventory (NFI) onwards. This means that it is not possible to compare empirical model results before the NFI date to the historical data estimated by other sources (e.g., the GHG inventory prepared by the country), and thus a validation opportunity is unavailable.

The current empirical forest models applied to entire European countries have difficulty simulating one or more of the following issues: (i) uneven-aged forests; (ii) natural disturbance events, and (iii) historical estimates of forest C dynamics.

The long-term objective of our work is to quantify past and near future national-scale forest C dynamics of European countries using data from NFIs, including the explicit representation of uneven-aged forest management, the impacts of natural disturbances, and comparing our estimates with historical data from independent sources. Assessing the utility of models to generate reference levels of LULUCF sector emissions and to quantify the outcome of alternative management is of interest to the policy community. We aim to be consistent with the methodological guidance provided by the Intergovernmental Panel on Climate Change (IPCC, 2003, 2006), including the outcome of the recent expert discussion on the use of models (IPCC, 2010). A model needed to meet all these objectives must be sufficiently detailed to accurately represent the flow of C between different pools, and flexible enough to adapt to the complex and varying silvicultural systems, including uneven-aged forests, and ecological conditions typical of most European countries.

Among the available models, the Carbon Budget Model (CBM), developed by the Canadian Forest Service (CFS), appears to meet several of these requirements. The CBM was previously applied at national and regional scales in Canada (Kurz and Apps, 1999; Kurz et al., 2009; Bernier et al., 2010; Stinson et al., 2011) and Russia (Zamolodchikov et al., 2008). It provides the modeling framework and required parameters to simulate natural and human-induced disturbance events (Kull et al., 2006; Kurz et al., 2008; Metsaranta et al., 2010) and the current version of this model (CBM-CFS3, Kurz et al., 2009) meets the IPCC reporting requirements (IPCC, 2003, 2006). However, this model was primarily applied to even-aged forests and has never been applied to an entire European country.

The specific objectives of this study were therefore (i) to test the CBM in different silvicultural systems, proposing a novel approach to include uneven-aged forest structures; (ii) to apply the CBM to a European country, and estimate the forest C balance of the Forest Management area (including all forests existing in 1990, (IPCC, 2003)) from 1995 to 2009 and a projection to 2020, and (iii) to explore the impact on the C balance of different scenario assumptions of future rates of harvest and fire disturbances.

To achieve these objectives, Italy was assumed as a representative case-study of the range of management strategies applied in Europe. This choice was supported by (i) the significant presence of uneven-aged high forests, (ii) a large area of forests affected by fires in the Mediterranean regions, and (iii) the availability of updated data collected through the last NFI in 2005. To be consistent with the definition of forest management under the Kyoto Protocol, in this study we considered only the managed forest area existing in Italy in 1990.

2. Material and methods

This study included methodological developments, and the assessment of different scenarios. Our model assumptions are reported in Sections 2.1, 2.2, 2.3 and 2.5 and the Appendices, and are discussed in the Sections 3.1 and 3.2. Scenarios are defined in Section 2.4 and discussed in Sections 3.3 and 3.4, with detailed comparisons to other studies.

2.1. The Carbon Budget Model (CBM-CFS3)

The Carbon Budget Model is an inventory-based, yield-data driven model that simulates the stand- and landscape-level C dynamics of above- and belowground biomass, and dead organic matter (DOM) including soil (Kurz et al., 2009). The spatial framework conceptually follows Reporting Method 1 (IPCC, 2003) in which, for the purpose of estimation and reporting the spatial units are defined by their geographic boundaries and all forest stands are geographically referenced to a spatial unit. In the present study, the landscape (Italy) was divided into 21 administrative units and 24 climatic units (CLUs, as defined by Pilli, 2012) with mean annual temperatures ranging from −7.5 to +17.5 °C based on climatic data provided by Hijmans et al. (2005). The same approach can be easily extended to all the other European countries. The intersection of the unit boundaries yielded 168 unique spatial units (Fig. 1).

Within a spatial unit, each forest stand is characterized by age, area, and up to 10 classifier types that provide administrative and ecological information, the link to the appropriate yield curves, and parameters defining the silvicultural system (such as forest composition, management strategy and information provided by the Italian National Forest and Carbon Inventory (INFC)).

During the model run, a library of yield tables defines the gross merchantable volume production by age class for each species. These yields represent the volume in the absence of natural disturbances and management practices. The CBM applies the net annual increment (i.e., the periodic increment minus mortality from self thinning) during the model run. Species-specific stand-level equations (Boudewyn et al., 2007) convert merchantable volume production into aboveground biomass, partitioned into merchantable stemwood, other (tops, branches, sub-merchantable size trees) and foliage components. The belowground biomass (coarse and fine roots), its increment and annual turnover are