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Estimating the effect of abandoning coppice management on carbon sequestration by oak forests in Turkey with a modeling approach

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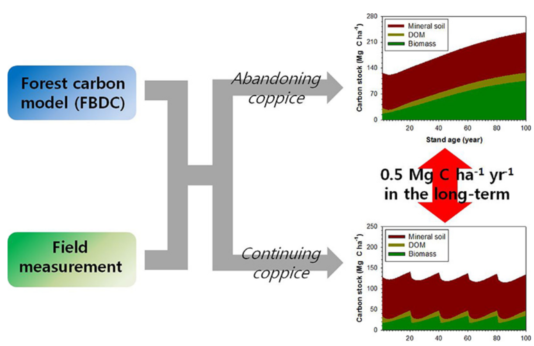
HIGHLIGHTS

- Abandoning coppice in Turkey is expected to affect carbon (C) sequestration.
- C sequestration was estimated under abandoning and continuing coppice scenarios.
- Forest carbon model and field measurement data were combined.
- Abandoning and continuing coppice sequestered 1.1 and 0.6 Mg C ha^{-1} yr^{-1}.
- The abandonment of coppice would enhance the C sequestration in the long-term.

GRAPHICAL ABSTRACT



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ABSTRACT

A significant area of the oak forests in Turkey has been historically managed by short-rotation coppicing for wood production. Coppice management was almost abandoned in Turkey in 2006 and so investigating its impact on forest carbon (C) sequestration has become an important issue. Therefore, we investigated the net effect of this change in management on C sequestration by oak forests in Turkey using field measurement data and a forest C model (Forest Biomass and Dead organic matter Carbon (FBDC) model). The FBDC model estimated the annual forest C dynamics and considered the effect of the substitution of wood for fossil fuels under two management scenarios over a 100-year period: (1) abandoning coppice (no management) and (2) continuing coppice (20-year-interval harvest). The field measurement data were used to parameterize the FBDC model to the study sites and to verify the simulated C stocks. Continuing coppice management constrained an increase in the C stocks (116.0–140.3 Mg C ha^{-1}) and showed a mean annual C sequestration of 0.6 Mg C ha^{-1} yr^{-1} if wood was substituted for fossil fuels. In contrast, abandoning coppicing practices increased the level of forest C stocks (128.1–236.2 Mg C ha^{-1}), enhancing the mean annual C sequestration to 1.1 Mg C ha^{-1} yr^{-1}. Accordingly, the abandonment of coppice management increased the mean annual C sequestration by 0.5 Mg C ha^{-1} yr^{-1} in the long-term. However, sensitivity analysis showed a possibility of a larger difference in C sequestration between the two scenarios due to a decrease in the stand productivity by repeated coppices and a high likelihood of a lower substitution effect. The verification supported the scientific reliability of the simulation results. Our study can provide a scientific basis for enhancing C sequestration in coppice forests.

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1. Introduction

Forest ecosystems have been widely recognized for their role in sequestering atmospheric carbon (C) (IPCC, 2014; Pan et al., 2011). In addition, forest ecosystems provide wood for fuel, which can substitute combusting fossil fuel and reduce associated greenhouse gas (GHG) emissions (Nabuurs et al., 2017; Park et al., 2018; Seo et al., 2017). As many countries have tried to increase the proportion of renewable energy in the electricity sector, wood bio-energy has become an important source of energy (Geng et al., 2017; Welfle et al., 2017). Accordingly, forest management, which can provide wood and enhance forest C sequestration, has gained international interest (IPCC, 2014).

Coppice management, which focuses on continuous wood production, uses a short-rotation harvest and natural sprout regeneration. In particular, this management affects forest vegetation dynamics (e.g., competition and growth patterns), root systems, and decomposition conditions in coppiced forests, whose characteristics are highly different from those of high forests (Adame et al., 2008; Bruckman et al., 2011; Salomón et al., 2016). Although coppice management is particularly prevalent across Europe to meet the demand for wood resources, there has been debate on the functionality of forests subject to repeated coppice management. Coppice management not only produces a continuous supply of wood but it also enhances resistance to water stress by reducing competition among trees (Pietras et al., 2016). In contrast, there are also negative effects, such as a decreased forest stand fertility and a constrained C storage capacity in these coppiced forest ecosystems (Noormets et al., 2015; Vacca et al., 2017). In the context of quantifying C sequestration, coppice management provides a trade-off between the substitution effect of wood as an energy source and forest C storage.

The changes in forest C dynamics due to coppicing practices have been quantitatively investigated. In particular, estimating the growth and C stock of biomass under coppice management has been an area of major research interest (Hoff et al., 2002; Kneifl et al., 2015). Recently, a holistic approach to evaluating coppice management scenarios has been developed that includes all C pools as well as the effect of substituting wood for fossil fuels (Prada et al., 2016; Quinkenstein and Jochheim, 2016). In particular, a modeling approach has been applied in these studies that enable the quantitative assessment of enhanced C sequestration potential by coppice management.

Conversely, assessment of the negative effect of repeated coppicing on C sequestration also needs to be investigated. The forest ecosystems in Turkey have been widely managed by coppicing to produce wood fuel; however, this practice has reduced the fertility of the forests and consequently, >70% of the coppice forests in Turkey are highly degraded (General Directorate of Forestry, 2012). The Turkish government almost abandoned coppice management in 2006 and the portion of the coppiced forests, relative to the total forest area, has decreased from 21% in 1973 to 8% in 2012 (General Directorate of Forestry, 2012). However, there might be a trade-off between the increase in forest functionalities (fertility and C storage) and the loss of bio-energy provision (wood). Investigation of the net effect of coppice management abandonment on the potential for C sequestration is needed. Several studies have conducted field measurements in abandoned coppice oak forests; however, they did not clarify the net effect of abandoning continuous coppicing (Bruckman et al., 2011, 2016; Cotillas et al., 2016; Ohtsuka et al., 2010; Terzaghi et al., 2013; Zenone et al., 2015). The new methodology, using modeling, was not applied to assess the effects and only simulations of coppice management options (e.g., interval and intensity) have been conducted (Hoff et al., 2002; Prada et al., 2016; Quinkenstein and Jochheim, 2016).

Thus, we aimed to quantify the net effect of coppice management abandonment on C sequestration by assessing the forest C dynamics and the effect of substituting wood for fossil fuel. We hypothesized that abandoning repeated coppicing would enhance the mean annual C sequestration. Quantification of the effect was conducted using a combination of field measurement data and a forest C (Forest Biomass and Dead organic matter Carbon (FBDC)) model (Lee et al., 2014, 2016, 2017; Makineci et al., 2015). Furthermore, a sensitivity analysis was conducted on the C sequestration with respect to stand productivity and the substitution effect, which quantified related uncertainties identified in the quantitative analysis. The net effect of the abandonment of coppice management was determined and its implications were considered.

2. Materials and methods

2.1. Study site

The study was conducted using 122 plots of oak stands (20 m × 20 m) in seven regions of Turkey (Makineci et al., 2015), which have been subject to coppice management. The mean annual temperature and precipitation were 10.1–14.5 °C and 550–1053 mm, respectively (Makineci et al., 2015). The major tree species were three deciduous oaks: sessile oak (*Quercus petraea* (Mattuschka) Liebl.), Turkey oak (*Quercus cerris* L.), and Hungarian oak (*Quercus frainetto* Ten.). The C stocks in aboveground biomass, litter, and mineral soil were investigated through destructive tree harvesting, collecting samples, and analyzing C content (Makineci et al., 2011). The stand characteristics and observed C stocks are provided in Table 1.

2.2. The FBDC model

2.2.1. Model description

The FBDC model, a generic model, simulates forest C dynamics using tree biomass growth functions and a set of related parameters on dead organic matter and soil (Lee et al., 2014, 2016). The structural flexibility and low input data requirement of the FBDC model contribute to understanding C dynamics in diverse forest ecosystems (Lee et al., 2014, 2016, 2017, 2018; Yi et al., 2013). The FBDC model was selected for the current study due to these features and because the empirical data from the study sites were not sufficient to enable the use of other models (Kim et al., 2015).

The C stocks and their changes in five pools (aboveground biomass, belowground biomass, litter, dead wood, and mineral soil; IPCC, 2003) could be estimated using the FBDC model simulation. The biomass compartment consisted of stems, branches, foliage, and coarse and fine roots, which were simulated using empirical growth functions. Growth was determined by species, productivity, and stand age. Meanwhile, the annual C stocks of the other pools (litter, dead wood, and mineral soil) were determined by evaluating the differences between annual organic matter inputs and outputs. Further descriptions of the FBDC model are provided in Yi et al. (2013) and Lee et al. (2014).

2.2.2. Parameterization of the FBDC model

To parameterize the FBDC model for the study sites, the biomass growth functions and dead organic matter parameters had to be substituted. First, the growth functions of aboveground biomass (stems, branches, and foliage) with stand age were developed using the destructive tree harvesting data from the 122 plots. The best-fit non-linear model for stem, branch, and foliage was estimated using SAS 9.4 software (Table 2; SAS Institute, 2014). These growth models indirectly reflected the vegetation dynamics in the abandoned coppice forests (e.g., competition and growth pattern) on the basis of field measurement data.

The belowground biomass was not measured in this study, while investigation of root biomass dynamics in oak coppice forests was also lacking. In addition, singular root systems, which are still alive after harvest under the coppice system, require a specific root growth function. For this reason, we developed a new belowground biomass growth function, with a combination of estimated aboveground biomass (Table 2) and an empirical root to shoot ratio with stand age (root to