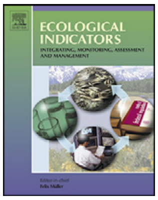
Ecological Indicators 11 (2011) 27–35

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



Assessing impacts of intensified biomass removal on deadwood in European forests

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ARTICLE INFO

Article history:
Received 1 September 2008
Received in revised form 16 March 2009
Accepted 3 April 2009

Keywords:
Biodiversity
Bio-energy
Deadwood
EFISCEN
Impact assessment

ABSTRACT

Deadwood is a key indicator for assessing policy and management impacts on forest biodiversity. We developed an approach to include deadwood in the large-scale European Forest Information Scenario (EFISCEN) model and analysed impacts of intensifying forest biomass removal on the amount and type of deadwood in forests of 24 European Union member states. In EFISCEN, deadwood consists of standing and downed deadwood, resulting from mortality, and stem residues from felling activities. To include deadwood in EFISCEN we developed mortality functions and re-estimated the model's increment functions. Further, we modelled the development of standing deadwood. Decomposition of downed deadwood and stem residues was modelled through the soil model YASSO. We used the extended model to analyse the impacts of a baseline scenario (no policy changes, a moderate increase in wood removals and no extraction of residues) and a bio-energy scenario (an increase of wood and residue removals to the maximum potential) on deadwood in 2030. In our baseline scenario the average amount of deadwood was 12.3 ton ha^{-1} in 2005 and increased by 6.4% in 2030. Intensified biomass removal could fully counteract this development and lead to a reduction of 5.5% in 2030 below the levels in 2005. The type of deadwood changed as well; residue removal led to a general decrease in the amount of smaller deadwood fractions (i.e. stem residues). Further, if felling levels are increased as in our bio-energy scenario, a decrease can be expected in the amount of standing deadwood and of large-diameter deadwood. We conclude that without additional management measures to protect deadwood, intensification of biomass removal could negatively affect deadwood-dependent species, which constitute an important part of biodiversity in European forests.

1. Introduction

Biodiversity is an important component of sustainable forest management, but assessing how 'life in all its forms' (Hunter, 1990) may change due to policy or management decisions is complicated. Indicators offer a practical solution (Hagan and Whitman, 2006) and the amount of deadwood has become a key indicator for forest biodiversity. Deadwood is particularly suitable, because it refers to resource availability and is positively correlated with species richness (Lonsdale et al., 2008) and as indicator it is applicable at a larger spatial level (Jonsell, 2007).

Deadwood is an important food source and serves as habitat for many fungal, lichen and bryophyte, arthropod, mammal and bird species (Berg et al., 1994; Grove, 2002; Harmon et al., 1986; Heilmann-Clausen and Christensen, 2004; Jonsell et al., 1998; Jonsell et al., 2007; Lonsdale et al., 2008; Siitonen, 2001). In addition, variable types of deadwood offer a range of conditions for different saproxylic (i.e. deadwood-dependent) species with variable requirements. The type of deadwood is therefore also important and refers to properties such as whether deadwood is standing or lying, size-dimensions and tree species of deadwood. All these aspects determine the suitability of deadwood for different species or species assemblages (Berg et al., 1994; Grove, 2002; Harmon et al., 1986; Heilmann-Clausen and Christensen, 2004; Jonsell et al., 1998; Jonsell et al., 2007; Siitonen, 2001). In general, downed deadwood is more species rich than is standing deadwood (Berg et al., 1994; Franc, 2007; Heilmann-Clausen and Christensen, 2004), but some species or species assemblages are confined to standing or downed deadwood only (Franc, 2007; Harmon et al., 1986; Jonsell et al., 1998), indicating that both types are important deadwood types. Felling residues form yet another type important to many species (Jonsell et al., 2007). The size-dimension (diameter) of deadwood is also an important deadwood property, because different saproxylic species are confined to different size-dimensions (Grove, 2002; Heilmann-Clausen and Christensen, 2004).

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doi:10.1016/j.ecolind.2009.04.004

Nowadays, the amount of deadwood is measured in many national forest inventories in Europe and around the world (Woodall et al., in revision). Inventoried amounts of deadwood are low compared to deadwood found in natural forests. For example, in Finnish forests the amount of deadwood is reduced by 90–98% compared to natural levels (Siitonen, 2001). Strong reductions of deadwood are common in other parts of Europe as well (see e.g. Debeljak, 2006; Green and Peterken, 1997; Lombardi et al., 2008) and are due to past or current intensive forest management practices (Siitonen, 2001; Kirby et al., 1998; Lombardi et al., 2008).

Several studies have suggested options to increase the amount of deadwood, but these suggestions generally reduce the amount of biomass that can be extracted. At the same time, forest biomass is important for renewable energy production (Bosch et al., 2007) and if current energy targets are to be met, a significant increase in demand for forest biomass can be expected (Hetsch et al., 2008). The amount of deadwood in forests and bio-energy production both depend on the biomass that is removed from the forest. Consequently, extracting forest biomass for bio-energy production may conflict with efforts to increase the amount of deadwood to prevent further loss of biodiversity. Simulation models are helpful tools to analyse such conflicts and to assess impacts of policies on biodiversity and deadwood in particular. The large-scale European Forest Information Scenario model (EFISCEN; Sallnäs, 1990; Schelhaas et al., 2007) is a model that simulates forest resource development at the spatial levels relevant to policy making.

The aim of this study was (1) to develop an approach to include deadwood as an indicator for biodiversity in EFISCEN and (2) to analyse impacts of intensifying forest biomass removal on the amount and type of deadwood in forests of 24 European countries (European Union (EU) excluding Cyprus, Greece and Malta). We aimed to answer the question how intensification of forest biomass removal affects the amount of deadwood and how it affects the type (standing and downed deadwood and stem residues) and size-dimensions of deadwood.

2. Methods

2.1. The EFISCEN model

2.1.1. General description

EFISCEN is a large-scale forest scenario model that projects forest resource development on regional to European scale (Eggers et al., 2008; Nabuurs et al., 2007). A detailed model description is given by Schelhaas et al. (2007). In EFISCEN, the state of the forest is described as an area distribution over age- and volume-classes in matrices, based on forest inventory data. Transitions of area between matrix cells during simulation represent different natural processes and are influenced by management regimes and changes in forest area. Growth dynamics are simulated by shifting area proportions between matrix cells. In each 5-year time step, the area in each matrix cell moves up one age-class to simulate ageing. Part of the area of a cell also moves to a higher volume-class, thereby simulating volume increment. Growth dynamics are estimated by the model's growth functions whose coefficients are based on inventory data or yield tables.

Management scenarios are specified at two levels in the model. First, a basic management regime defines the period during which thinnings can take place and a minimum age for final fellings. These regimes can be regarded as constraints on the total harvest level. Thinnings are implemented by moving area to a lower volume class and final fellings by moving area outside the matrix to a bare-forest-land class, from where it can re-enter the matrix. Second, the demand for wood is specified for thinnings and for final felling separately and EFISCEN may fell the demanded wood volume if available. The proportion of volume from thinning and final fellings that is removed from the forest is specified; stem parts that are left in the forest become stem residues (e.g. stem tops). Another parameter defines the fraction of stem residues that is removed from the forest. Model outputs consist of forest area and volumes of growing stock and increment for 5-year time-steps.

2.1.2. Mortality

We extended EFISCEN to include mortality and deadwood in the forest resource projections. Mortality was defined as death of trees through ageing, suppression and/or disturbances. In the model the level of mortality is dependent on the management intensity, firstly because in managed forests thinnings and final fellings counteract mortality (Cooper, 1983) and secondly, upon (large-scale) disturbances fresh deadwood is often recovered and included in wood removal statistics (Schelhaas et al., 2002). To capture both effects, mortality occurs in the model on areas that have not been recently thinned or have not been clear-felled in the same time-step. Mortality is implemented in the model by transferring area one volume-class down as determined by the specified mortality rate and management intensity.

2.1.3. Standing deadwood

Due to the importance of different deadwood types for different species or species assemblages (see Section 1) we included standing deadwood, downed deadwood and stem residues in our modelling approach. Upon tree death standing deadwood is formed, which eventually falls down and forms downed deadwood. We did not explicitly consider standing deadwood removal to avoid double counting, because during forest management usually some standing deadwood is removed from the forest and may therefore be partly included in wood removal statistics, which are used to parameterise the management scenarios.

We applied a negative exponential curve to describe the rate at which standing deadwood falls down (Storaunet and Rolstad, 2004). The amount of standing deadwood is calculated from the initial volume, the input from mortality and the volume falling down:

$$\mathrm{SDW}_t = \mathrm{SDW}_{t-1} + m_t - k \times \mathrm{SDW}_{t-1} \qquad (1)$$

where SDW_t is the volume (m^3) of standing deadwood at time t, m_t the projected mortality at time t, and k the volume fall rate constant. SDW_t can also be expressed in mass (g) by conversion using basic wood densities from IPCC (2003). The standing deadwood pool is initialised as equilibrium between the input from mortality of the first time-step and the fall rate. No loss in mass due to decomposition is assumed while standing. This assumption is supported by previous studies that reported either no (Krankina and Harmon, 1995), or minor (Mäkinen et al., 2006) losses of standing deadwood through decomposition.

2.1.4. Downed deadwood

After falling down, standing deadwood becomes downed deadwood. We applied the soil model YASSO (Liski et al., 2005) to describe the physical fractionation and decomposition of downed deadwood on mass basis. Downed deadwood enters YASSO in its coarse woody litter compartment and is transferred to different compartments based on chemical quality of the deadwood. The total decomposition time of downed deadwood