Ecological Modelling 345 (2017) 99–112

Contents lists available at ScienceDirect

Ecological Modelling

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

Habitat network assessment of forest bioenergy options using the landscape simulator LandSim – A case study of Kronoberg, southern Sweden

Xi Pang[a,*], Ulla Mörtberg[a], Ola Sallnäs[b,c], Renats Trubins[b], Eva-Maria Nordström[d,e], Hannes Böttcher[e,f]

[a] KTH Royal Institute of Technology, Dept. of Sustainable Development, Environmental Science and Engineering, Stockholm, Sweden
[b] Swedish University of Agricultural Sciences (SLU), Department of Southern Swedish Forest Research Centre, Alnarp, Sweden
[c] European Commission Joint Research Centre (JRC), Institute for Environment and Sustainability (IES), Forest Resources and Climate Unit, Ispra, Italy
[d] Swedish University of Agricultural Sciences (SLU), Department of Forest Resource Management, Umeå, Sweden
[e] International Institute for Applied Systems Analysis (IIASA), Ecosystems Services and Management Program (ESM), Laxenburg, Austria
[f] Öko-Institut e.V., Institute for Applied Ecology, Berlin, Germany

ARTICLE INFO

Article history:
Received 29 June 2016
Received in revised form
21 November 2016
Accepted 7 December 2016
Available online 26 December 2016

Keywords:
Habitat networks
Forest bioenergy
Forest management
Landscape simulation
Trade-off analysis
Integrated assessment

ABSTRACT

Forest biomass is a renewable resource that is increasingly utilised for bioenergy purposes in Sweden, which along with the extraction of industrial wood may conflict with biodiversity conservation. The aim of this paper is to present a method for integrated sustainability assessment of forest biomass extraction, particularly from bioenergy and biodiversity perspectives. The landscape simulator LandSim was developed and linked with models for the assessment of biomass yields and habitat networks representing prioritised biodiversity components. It was applied in a case study in Kronoberg County in southern Sweden. Forest growth and management were simulated for the period 2010–2110, following two land zoning scenarios, one applying even-aged forest management on all forest land except for protected areas (EAF-tot), and one applying continuous cover forest management on parts of the forest land, combined with protected areas and an intensified even-aged management on the other parts (CCF-int). The EAF-tot scenario implied higher yields of biomass feedstock for bioenergy, the CCF-int scenario only giving 66% of that yield, while the CCF-int scenario performed substantially better when it came to the habitat network indicators, if habitat suitability was ensured. Conclusively, the case study confirmed that the modelling framework of the LEcA tool, linking the landscape simulator LandSim with the biomass yield assessment and the habitat network model can be used for integrating main policy concerns when assessing renewable energy options.

1. Introduction

Forest is a resource that is used for multiple and potentially conflicting purposes, among other biomass extraction and biodiversity conservation. Furthermore, the demand for biomass as a source of renewable energy for climate change mitigation as promoted by the EU Renewable Energy Directive (2009/28/EC) can be expected to increase substantially. This will put increasing pressure on other ecosystem services as well as on biodiversity. Therefore, sustainable forest management needs to integrate multiple sustainability objectives, concerning both climate and biodiversity, among other (EC, 2010).

In Sweden, energy consumption from biomass, including peat and waste, reached 130.4 TWh in 2015, which accounted for 35.2% of the total energy consumption (SEA, 2016). Forest biomass is one of the most important resources for the total biomass supply in Sweden and today about 85% of the bioenergy in the country comes from the forestry sector (IEA, 2014). For the future, the Swedish government has proclaimed the target of 50.2% renewable energy sources of the final energy consumption by year 2020 (the Swedish National Renewable Energy Action Plan, Government Offices, 2010). According to this plan, biomass will contribute with 59.2% of the total renewable energy consumption, corresponding to 30% of the total final energy consumption.

In Sweden, bioenergy from forest biomass mainly consists of residues from timber harvesting, in the form of tops, branches, stumps and small stems. Both positive and negative impacts of biomass extraction for bioenergy can be expected, depending on

* Corresponding author.
E-mail address: xip@kth.se (X. Pang).

http://dx.doi.org/10.1016/j.ecolmodel.2016.12.006

management (Pedroli et al., 2013). The forest is normally managed by final felling and re-plantation, i.e. even-aged forest management (EAF). EAF has been viewed as having the greatest negative impacts on biodiversity and the environment (e.g. McDermott et al., 2010). The habitat degradation that results from this type of forestry is to a high degree related to the simplification of forest structure and composition (Smith et al., 1997), which impact on biodiversity and ecosystem services (e.g. Lindenmayer and Franklin, 2002; Puettmann et al., 2009; Thompson et al., 2011).

The negative impacts of current forest management regimes on biodiversity have been highlighted by the Convention on Biological Diversity (CBD, 2010). Among European forest types, old growth natural and semi-natural forests are seen as the most valuable in terms of supporting biodiversity, while unsustainable forest management and fragmentation are among the major threats to Europe's forest biodiversity (EEA, 2010). Thus, due to a long history of industrial forestry for timber and pulp production in Sweden and large parts of northern Europe, production forests have become more even-aged and much less structurally diverse than natural forests. Amounts of dead wood, old trees and other properties of importance to biodiversity are much lower compared with natural forest landscapes (Fridman and Walheim, 2000; Josefsson and Östlund, 2011; Peterken, 1996). Additional impacts emerge from the extraction of branches, tops and stumps especially from broadleaved tree species, which may increase the threat of extinction of some red-listed wood-living species (e.g. de Jong et al., 2014; Hedin et al., 2008; Jonsell, 2007). As a consequence, the intensive forest management has caused decreased habitat quality, quantity and connectivity and a loss in biodiversity (e.g. Berg et al., 1994; Grove, 2002; Niemelä et al., 2007; Siitonen, 2001). Therefore, from a biodiversity perspective, land zoning strategies in forestry may be an important complement to protected areas.

1.1. Land zoning and forest management regimes

In Sweden, around 25% of the forest land is exempted from forestry; however this figure includes the 14% of the forest land that is considered to be unproductive and therefore unsuitable for forestry (SFA, 2014; estimates for 2011). Of the total area of forest land, 7% was formally protected by 2011, but only 3.6% of the *productive* forest land. Around 4% of the total forest land, and 4.8% of the *productive* forest land, was set aside voluntarily by forest owners in response to the current forest policy, where legislation and forest-management guidelines have been revised to incorporate environmental concerns into forest harvesting operations (Govt. prop. 1992/93:226; SFS 1979:429). In addition, a requirement that about 5–10% of the stand area must be retained at a final age in all production forests in the country was introduced (Gustafsson et al., 2012). One important function of the retention requirement is to enrich structural diversity in the developing stand by e.g. increasing the amount of old living trees and dead wood (Franklin et al., 1997; Kruys et al., 2013).

Other ways of land zoning in forestry have been discussed; partitioning between main forest management categories such as protected areas, different forms of less intensive, multi-purpose management and intensified forest management for biomass production. According to this concept, the negative ecological impacts of intensified management on a certain portion of the land can be compensated by increasing the fraction of protected areas as well as areas with multi-purpose forest management (e.g. Hunter and Calhoun, 1996; Messier et al., 2009). Multi-purpose management can be EAF with retention, as mentioned, or continuous cover forest management (CCF) which involves selective harvesting methods (Forestry Commission, 1998; Pommerening and Murphy, 2004; Yorke, 1998). The sustainability of CCF compared to EAF, from economic, ecological and other perspectives, has been addressed by e.g. Kuuluvainen et al. (2012) and Nordström et al. (2013), with varying results. From an ecological perspective, CCF may better promote ecological objectives because it can support species that depend on forest continuity, but the ecological performance of such forestry methods on wider spatial and temporal scales remains poorly examined (Jonsson et al., 2005; Kuuluvainen et al., 2012).

Intensified forest management for biomass production aims at increasing production by maximising available technology such as using fertilisers, improved genetic material, introduction of exotic fast growing tree species, and optimized management schedules often including shorter rotations (Lidskog et al., 2013). At the same time such types of management can be expected to result in further simplification of managed stands and negative impacts on other ecosystem services and biodiversity (Gustafsson et al., 2012; Ranius and Roberge, 2011; Smith et al., 1997; Thompson et al., 2011).

1.2. Simulating landscape development and assessing its consequences

In order to address questions concerning land zoning and forest management, models that can simulate forest development on landscape scale and its consequences on both bioenergy and biodiversity aspects are necessary. In order to be useful for integrated sustainability assessment, such models should simulate forest growth under different management regimes, as well as quantify biomass yields and ecological consequences on landscape level.

Most of the existing landscape development models can be included in one of the two categories: (1) models for forest management planning support, and (2) models of land use change. Examples of the first category that also address biodiversity issues are reported in Chumachenko et al. (2003); Gustafson et al. (2006) and Wikström et al. (2011), which in general do not have the possibility to address whole landscapes but only forest stands and tend to have large data requirements (except for Gustafson et al., op cit.). Examples of the second category are reported in Deal and Pallathucheril (2009); Eastman (2012); and Hepinstall-Cymerman et al. (2009). These models usually have a coarser representation of forest dynamics and include fewer or no parameters related to forest management.

For assessment of biodiversity impacts, several ecological assessment models and approaches exist, addressing impacts on habitat quality, quantity and connectivity for prioritised biodiversity components (e.g. Gontier et al., 2006). Among those, models that analyse habitat networks based on graph theory have been developed, that can address habitat quantity and connectivity in a pragmatic way (Dale and Fortin, 2010; Saura and Rubio, 2010; Saura et al., 2011; Urban et al., 2009; Zetterberg et al., 2010). These have been used for addressing, among other, forest management planning (Saura et al., 2011). However, renewable energy options and biodiversity are seldom assessed together in an integrated way (Pang et al., 2014). Thus, there is a need to develop methods that can simultaneously assess the provision of biomass and biodiversity of scenarios for land zoning and forest management regimes, for integrated assessment of their sustainability.

1.3. Aim

The general objective of the study was to develop a method for integrated sustainability assessment of forest bioenergy options. In this paper, the landscape simulator LandSim is presented, that can simulate forest growth under alternative management regimes across whole landscapes. This allowed for integration with assessment of impacts on bioenergy yield and on prioritised habitat networks. The specific objective was to assess the impacts of different land zoning scenarios in Kronoberg County, southern Sweden,