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Analysis

Conservation of forest biodiversity using temporal conservation contracts

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ABSTRACT

Temporal conservation contracts are used to protect biodiversity in privately owned lands worldwide. We examine how stand characteristics and habitat requirements of target species affect the contract length in a boreal forest context. We develop an integrated optimization model and apply the model with data on endangered species occurring in spruce forests in Finland. The results suggest that a cost-effective conservation policy for protecting privately owned forest land involves both short- and long-term contracts between landowners and environmental agencies. The higher the conservation objective, the more intensively long-term contracts should be assigned. Managed stands should be assigned short-term contracts. Regarding unmanaged stands both short- and long-term contracts should be used. However, species habitat requirements affect the results and thus the conservation policy.

1. Introduction

Conservation contracting programs are used worldwide as a means to protect biodiversity in privately owned lands. In this policy, landowners receive payments in exchange for land use practices that contribute to the supply of biodiversity. In particular, conservation contracting has been used in many agri-environmental schemes.[1] In Finland, the government initiated conservation contracting to protect private forests in Southern Finland (Government Resolution, 2008). Contract lengths in these programs vary from a few years to an indefinite length of time. However, it is not well known which contract length provides the highest benefits for the cost of the contract.

In practice, conservation contracting requires delaying forest harvests beyond the commercially optimal rotation length (Juutinen and Ollikainen, 2010). Many ecologically important characteristics require long periods of time to emerge and, therefore, delaying harvests beyond commercial stand age increases biodiversity benefits. In some cases, a forest may be left permanently unharvested if its biodiversity values are high enough. These forest stand qualities are well known in forest economics literature (Hartman, 1976; Juutinen, 2008; Koskela and Ollikainen, 2001; Strang, 1983).

However, there is no empirical research on how alternative conservation objectives affect the optimal contract length and how the optimal length differs among forest types. Additionally, setting a management policy target for biodiversity conservation requires landscape-level decisions and it is not well known how broader-scale management planning affects the optimal contracts. Thus, we need to identify the key factors determining the optimal contract length for joint provision of timber and biodiversity across a broader spatial scale in order to allocate limited conservation funds efficiently in practical management planning.

We considered how an environmental planner should target conservation contracts assuming that forest landowners will accept the contracts if they receive a payment equivalent to the harvest revenues foregone under the contract. In particular, we studied how stand characteristics and habitat requirements of endangered species affect the contract length in preserving boreal forest biodiversity by using temporal simulations. We modelled a forest landscape with privately owned forest stands. Our focus was on spruce-dominated forests that cover most of the forest land in our study area and, additionally, host a large proportion of rare and red-listed species. We utilized a habitat suitability index to assess the biodiversity value of a forest stand. Timber production was measured using the net present values of harvest revenues of forest stands. Next, we determined the optimal rotations for the stands by developing an integrated model that adapted to the conservation manager's decision making. That is to say, we maximized the harvest revenues over the 61-year planning horizon subject to a given biodiversity constraint. The decision variables were the rotation lengths of each stand. The model included also a no-harvest option. The examined conservation

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[1] Examples from Europe include the German MEKA program (Wilson, 1995) and the English Environmental Stewardship Scheme (http://www.naturalengland.org.uk/ourwork/farming/funding/es/default.aspx). In the United States examples of the agri-environmental schemes include the Conservation Reserve Program, the Environmental Quality Incentives Program, and the Private Stewardship Program (Johansson, 2006).

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objectives were determined by varying the biodiversity constraint. In our approach, a harvest delay from commercial harvest age was interpreted as a temporal conservation contract in which a landowner implicitly receives a conservation payment equal to the foregone harvest revenues when refraining from any timber harvests for the agreed time period.

The literature on contracting for biodiversity preservation has so far focused little attention on the contract length. Gulati and Vercammen (2005) examined optimal contracts for carbon sequestration on agricultural land. They showed that the farmer's marginal benefit of remaining in the contract is declining over time, whereas the marginal opportunity cost is rising and, therefore, the optimal length of the carbon contract is finite. The optimal carbon contract length varied between 13 and 23 years depending on the parameter values used in the simulations.[2] Similarly, Ando and Chen (2011) studied the optimal contract length for voluntary ecosystem service provision. They examined ecosystem services in grassland and forest environments by varying parameter values of their environmental benefit function. The optimal contracts were longer for forest (environmental benefits mature slowly) than for grassland. Both studies used simulations merely as illustrative examples by assuming various parameter values. In contrast, we elaborate on the contract length by using stand level information on forest growth and structure. However, we do not take into account the information asymmetry between the conservation manager and landowners related, among other things, to the contracting environment, and therefore, our results do not represent exact optimal contract lengths. In addition, we do not place a monetary value on the total biodiversity benefits, but assess the ecological quality of the stands for two species groups. Similarly Nalle et al. (2004) analysed joint production of wildlife and timber, but they did not consider optimal rotations in their exploratory work. In a recent study, Mönkkönen et al. (2011) used the same case study area that is used in this study and assessed implications of alternative conservation strategies utilizing spatio-temporal simulations. However, they did not examine alternative contract lengths. Using this setting, our objective is to derive guidelines for environmental agencies on how to set contract lengths cost-effectively for stands of differing quality and alternative conservation objectives.

2. Methods and data

2.1. Model

Following Nalle et al. (2004), the optimal rotations were estimated by maximizing the present value of harvest revenues of a group of forest stands (land management units) over the simulation horizon subject to a biodiversity constraint. In contrast to Nalle et al. (2004), we formulated the model as a linear integer problem for which it is possible to find exact optimal solutions. In particular, we used a habitat suitability index (HSI) to measure biodiversity without considering spatial interdependence of forest stands in providing biodiversity as will be described later. At a stand level, the HSI describes the ecological suitability of each stand for the species in question, i.e. does the stand include such ecological resources and breeding sites that a given species requires. Intuitively, the higher the value of HSI, the more likely a species will survive and reproduce in a stand. Nalle et al. (2004) focused directly on species viability by taking into account stand interdependence in a nonlinear model. Finding exact optimal solutions is important in our study, because we use solutions of different scenarios to calculate contract lengths, and therefore, we want to ensure that the differences between solutions are not caused by an inefficient heuristic algorithm used to solve a nonlinear model.

[2] The parameters regarding technology imposed in the contract were price for accumulated carbon and discount rate (Gulati and Vercammen, 2005).

To present the model formally, we index stands by i and time by t. Furthermore, we denote the number of stands by N and the end of simulation horizon by T. The per hectare harvest volume of timber assortment b for each stand i and time period t is defined as h_{bit}. The area of a stand i is a_i. The number of timber assortments is denoted by B. The stumpage price of timber assortment b is denoted by p_b and the real interest rate by r. We assume that each stand i can either be clear-cut or no action (no harvest) taken in each t.[3] Accordingly, the choice variable x_{it} gets a value of one if the stand i is clear-cut at period t and zero otherwise. V^* denotes harvest revenues from future rotations, i.e. a soil expectation value due to a steady-state management in maximizing harvest revenues (Faustmann, 1849). We denote by $HSIx_{it}$ the value of HSI in a stand i at time period t under a treatment schedule x_{ti}. HSI_{Ai} is the HSI value of the stand i at the initial time A before any harvesting. In addition, a policy variable k is used to set the biodiversity target at the desired level. We start the simulation from the present time ($t=0$), i.e. the first clear-cut is possible immediately at the beginning of the simulation. The model is as follows:

$$\max_{x_{it}} W = \sum_{t=0}^{T}\sum_{i=1}^{N}\frac{a_i\left(\sum_{b=1}^{B}p_b h_{bit}+V_i^*\right)x_{it}}{(1+r)^t}+\sum_{i=1}^{N}\frac{a_i\left(\sum_{b=1}^{B}p_b h_{bit+1}+V_i^*\right)\left(1-\sum_{t=0}^{T}x_{it}\right)}{(1+r)^{T+1}} \quad (1)$$

s.t.

$$\sum_{t=0}^{T}x_{it}\leq 1 \; i=1,\dots,N, \quad (2)$$

$$\frac{\sum_{t=0}^{T}\sum_{i=1}^{N}a_i HSIx_{ti}}{T}\geq k\sum_{i=1}^{N}a_i HSI_{Ai} \quad (3)$$

$$x_{it}=(0,1) \quad i=1,\dots,N \text{ and } t=0,\dots,T. \quad (4)$$

The first term in Eq. (1) accounts for the revenues from clear-cuts conducted during the simulation period. The second term calculates the "end value" for stands that remain unharvested for the entire simulation (Nalle et al., 2004). Without this auxiliary term there is an undesirable tendency to clear-cut the stands during the simulation horizon because a "no action" management decision would result in a high loss in harvest revenues. Constraint (2) ensures that each stand is harvested only once or not at all during the time periods. We have, however, implicitly allowed multiple clear-cuts as we assume the stands are harvested according to the Faustmann rotations beyond the first clear-cut point of time (Koskela and Ollikainen, 2001). Thus, we consider only a single round of contracts and stands return to their pre-contract use after the contract expires (Gulati and Vercammen, 2005). Constraint (4) restricts all decision variables to binary values.

The biodiversity constraint (3) is defined using the HSI values. By determining the HSI values for the whole simulation horizon under a particular treatment schedule we assume that the Faustmann management is applied beyond the first clear-cut point of time similarly as in calculating the harvest revenues in the target function (1). Thus, the HSI value of a stand in the beginning of the simulation typically increases as the simulation proceeds until the stand is clear-cut. At this point of time, the HSI collapses to zero and starts to increase

[3] Boreal forests in Fennoscandia are typically managed by clear-cutting and they consist of a mosaic of stands of different ages (Esseen et al., 1997). Stands are harvested when they are commercially mature, and a stand is regenerated after harvesting. In this practice, each successional stage (i.e., clear-cut area, seedling and sapling stand, young stand, and mature stand) persists for only a limited period of time. Our approach, however, is slightly simplified and not all environmental management options—such as green tree retention practice—are included in the analyses.