Estimating the Need for Early Cleaning in Norway Spruce Plantations in Finland

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Effective management of Norway spruce (*Picea abies* (L.) Karst.) plantations requires detailed information on stand development, which is costly to measure. However, estimating the need for early stand management from site attributes that persists stabile after ones measured, may provide an inexpensive alternative. This study compared hardwood competition in spruce plantations of varying ages and tested the usability of this information in estimating the need for early cleaning.

The data included 197 spruce plantations (4–7 years old) inventoried in southern Finland in 2007. The level (Low, Substantial, High) of need for early cleaning was subjectively determined by contrasting location and size of competing hardwoods to a conifer crop tree. Then the stage of the need for early cleaning was modelled according to site and stand attributes.

Nearly 60% of the conifer crop trees in the plantations were subjectively judged to require early cleaning (Substantial 37.2%, High 21.2%), but only 10 per cent of the evaluated area was cleaned. Need for cleaning was intense on peatlands or damp soils, whereas it was mild on unprepared soils or cleaned sites. Traditional site characteristics used in forest management planning can be useful for recognising the peripheral cases, where need for cleaning is probably high or low. However, on a typical mineral soil plantation (uncleaned, soil prepared) the model indicates the differences in the need for early cleaning weakly.

The need for early cleaning was already high in 4-year-old plantations, why stand age did not have significant effect on development of the need. Thus, the timing of an operation can not be predicted with the model. Nonetheless, early cleaning very likely opens growth space of crop trees in a 4–7-year-old spruce plantation. Therefore, from an aspect of crop growth, an uncleaned Norway spruce plantation in this age group is quite consistently worth cleaning.

Keywords cleaning, conifer release, cost-effectiveness, forest vegetation management, early cleaning
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1 Introduction

Young stands are managed in order to enhance the growth of commercially valuable trees (Huuskonen and Hynynen 2006). In Norway spruce (*Picea abies* L.) plantations, the main idea of young stand management is to optimise the density of the stand, to produce timber effectively. Influencing the quality of the wood in young stand management is not as important in spruce stands as it is in Scots pine (*Pinus sylvestris* L.) stands (Nilsson and Gemmel 1993, Huuskonen et al. 2008).

Forest vegetation control substantially increases the growth and survival rate of the released seedlings. Weeds (Nilsson and Örlander 1999, Siipilehto 2001, Hytönen and Jylhä 2008) and hardwoods (Walfridsson 1976, Boateng et al. 2009) are serious problem. In the first few years after planting, weeds seem to reduce the availability of water and nutrients in particular for trees (Nilsson and Örlander 1999). After weed competition, hardwoods start to compete for resources with conifer crop trees and cause physical damage to them.

In the early stage, competition affects diameter more than height growth of a conifer (Comeau et al. 2000, Jobidon 2000). The first few hardwood competitors inflict the greatest reduction of growth on conifer seedlings, and sustained serious competition may lead to regressive growth of young conifers (Jobidon 2000). Jobidon (2000) reported huge differences in above-ground biomass of white spruce (*Picea glauca*) when he compared the growth of totally released conifers to that of unreleased ones. From the standpoint of wood production, it seems reasonable to release a conifer tree when even a few competitive hardwoods grow near it.

In the first place, mechanical soil preparation can be helpful in controlling competition with weeds (Nilsson and Örlander 1999) and hardwoods (Boateng 2009, Uotila et al. 2010). Despite the proper regeneration and soil preparation, plantation still often needs a release treatment. Forest vegetation control with herbicides is a cost-effective option (Nilsson and Örlander 1999, Lautenschlager et al. 1998, Jobidon 2000, Hytönen and Jylhä 2008, Boateng 2009). However, the use of herbicides in forestry has strong public opposition (Lautenschlager et al. 1998), and for example in Finland, forest certification restricts the use of chemicals, especially in hardwood control (PEFC FI 1003:2009), why alternative methods are rather used.

In mechanical forest vegetation control, the timing of the operation is critical. The size of the hardwoods removed (basal area at cutpoint) has a strong correlation with young stand management costs (Hämäläinen and Kaila 1983, Kaila et al. 1999), so the work time needed for cleaning increases as a function of a plantation age (Kaila et al. 2006). To sustain good growth of the crop trees and to prevent increased work time, early cleaning should be carried out as soon as necessary but with an attempt to avoid the re-establishment of the removed vegetation (Kiljunen 2006).

In this article, the term early cleaning means an operation, after which another young stand management operation is expected. Re-establishment of the removed vegetation is often intense after mechanical release treatment (Comeau et al. 2000). Hardwoods grow vigorously from the stumps or roots of cut trees (Björkdahl 1983). Development of sprouts is an argument for delaying young stand management. However, on plantations where growth-reducing competition develops quickly, early cleaning is considered as a necessary operation, even if precommercial thinning would be expected after early cleaning.

Silvicultural instructions for early-stage stand management (Hyvän metsänhoidon… 2006) indicate that successful establishment of a Norway spruce plantation requires intensive management during the first few years after planting. The first silvicultural operations aim at releasing conifers from competing weeds. In the second place, conifers need to be released from competition from hardwoods at the age of 5–10 years (early cleaning), depending on earlier management operations and growing conditions. These are the rules of thumb for early-stage stand management.

In Finnish silviculture, the need for early cleaning (= hardwoods are hindering the free growth of conifer crop trees) is usually evaluated by a managerial employee of a forest service provider. The evaluation is relatively costly operation and does not produce merchantable goods to end-user, i.e. forest owner. Therefore, it must be carried out as cost-efficiently as possible. In addition, the need for the operation, and, especially, further operations, can be difficult to evaluate. If the need for a cleaning operation can be predicted from some site characteristics with a known level of risk, this costly evaluation can be avoided.

The need for cleaning is unquestioned for young spruce plantations. According to Saksa and Kankaanhuhta (2007), 27% of three-year-old spruce plantations in southern Finland needed releasing of conifers within 0–2 years and 44% were considered to need it after 2 years. According to Korhonen et al. (2010), four per cent of spruce plantations with a height less than 1.3 metres were cleaned and 66% of these needed cleaning. The corresponding figures for taller spruce plantations were 33% and 58%. However, the exact dependence of young stand management on site type, stand age, or site preparation method is not so well known.

Kiljunen (2004) used machine learning algorithms to predict need for early tending on Norway spruce plantations. The prediction was based on inventory data for three-year-old plantations. According to Kiljunen (2004), many site attributes affected the need for early tending, but prediction of the need for an individual stand was poor. However, in that data set, the plantations surveyed were rather young from the standpoint of early cleaning.

In this study, competition between planted spruce saplings and the trees with low commercial value is analysed. An attention is to add comprehension of the conditions where a plantation is most likely to need intensive early-stage stand management or vice versa. The main intention is to develop a model to predict need for early cleaning on 4–7-year-old Norway spruce plantations in central Finland based on major site characteristics, which are determined in forest management planning.

Table 1. The shares of the analysed categorical variables as frequencies of plots.

Variable	n	%
Excess soil moisture		
Yes (Dampness)	124	4.0
No	2957	96.0
Early cleaning (EC)		
Yes	308	10.0
No	2773	90.0
Site type		
OMT	1367	44.4
MT	1714	55.6
Soil texture		
Medium	1946	63.2
Fine	976	31.7
Peat	159	5.2
Soil preparation		
Unprepared (UN)	116	3.8
Patching (PA)	1482	48.1
Disc trenching (DT)	834	27.1
Mounding (MO)	649	21.1
Total	3081	100.0

2 Material and Methods

2.1 Study Material

In total, 197 spruce plantations established in 2000–2003 were inventoried in 2007, at the age of 4–7 years (see Table 1). The sampling of the plantations based on the obligatory declarations of the establishment of a seedling stand (Forest Act 1224/1998), sent to the Pohjois-Savo Forestry Centre. The sample was stratified according to plantation age and the six Forest Management Associations in the territory covered by the Forestry Centre. The plantations within a stratum were a random sample from the above mentioned declarations. The area of the plantations ranged from 0.5 to 8.8 hectares. The plantations were located between 62–64°N and 26–29°E in WGS84 coordinates. Time interval between a clearcut and an establishment of a stand (regeneration delay) was approximated according to the time interval between the Forest use declaration and the declaration of the establishment of a seedling stand (Forest Act 1224/1998) as growth seasons.

The inventory method was a systematic line survey with circular sample plots (Kankaanhuhta et al. 2009). Depending on the area of a plantation, 8–23 systematically located circular plots of 20 m^2 were established as a grid over the plantation according to the cardinal directions. The total number of the plots was 3081 (see Table 1).

Site fertility was classified for each plot as *Oxalis-Maianthemum type* (OMaT), *Oxalis-Myrtillus type* (OMT), *Myrtillus type* (MT), or

Table 2. The average values of the analysed continuous variables according to the level that the variable was determined on.

	Mean	SD	Min.	Max.	N
Stand level					
Area of a plantation, ha	1.6	1.1	0.5	8.8	197
Stand age, years	5.6	1.1	4	7.0	197
Regeneration delay, growth seasons	1.4	1.1	0	5.0	197
Plot level					
Conifer crop trees, ha^{-1}	1569	839	0	3000	3081

Vaccinium type (VT) according to Cajander's (1926) site type classification. Soil texture was determined in the field in accordance with the work of Luoranen et al. (2007) and separated into four categories: coarse, medium, and fine mineral soils and peat. In addition excessive soil moisture (dampness) were subjectively determined, in terms of whether it was considered to impair crop plants' development considerably (0 = No, 1 = Yes). The soil preparation method – no preparation (UN – unprepared), disc trenching (DT), patching (PA), or mounding (MO) – was also determined in the field. Luoranen et al. (2007) describes the characteristics of the soil preparation methods in more detail.

The total numbers of planted and natural conifer crop trees were counted on each plot (see Table 2). The crop trees were classified into three need for early cleaning (NC) categories on the basis of their competitive position according to the following instruction: 1 = Low (No taller hardwoods than the crop tree within one metre radius of the crop tree), 2 = Substantial (hardwoods near a crop tree are as tall as the crop tree or the crop tree is slightly overtopped), 3 = High (a crop tree has already suffered from overtopping or hardwoods near the crop tree are substantially taller than the crop tree). The instruction was given to all of the measurers to attain a converge result. The instruction bases on the diminishing effect of competition according to the distance to, and the size or amount of competing vegetation (Andersson 1993, Jobidon 2000). The total number of recorded crop trees on a plot was restricted to six at maximum (3000 ha^{-1}). The height of the nearest crop spruce from the centre of each plot was measured.

2.2 Statistical Analysis of the Need for Early Cleaning

A multinomial logistic regression model was used in the analysis of NC. The statistics software used was MLwiN 2.25 (Rasbash et al. 2009). The estimation procedure was the first order marginal quasi-likelihood (MQL) procedure.

A multinomial logistic regression model consists of J-1 logistic regression models, where $j = j$, …, J is the number of categories for a dependent variable (Agrestis 1990). One category is a reference class (J, for identifiability $\beta_j = 0$), and the logarithm of the odds of the reference class and class $j = 1, \ldots, J$-1 is expressed as a linear combination of parameters (see Eq. 1). In addition to the fixed effects part, random stand (v_l) and plot (u_{lk}) level factors were included in the multilevel multinomial logistic regression model used. Predicted probabilities of a tree belonging to different NC categories were calculated via Eqs. 2 and 3, with only the fixed part of the model.

$$\log \frac{\pi_j(x_i)}{\pi_J(x_i)} = \beta_j x_i + v_l + u_{lk} \quad (1)$$

$$\pi_j(x_i) = \frac{\exp(\beta_j X_i)}{1 + \sum_{j=1}^{J-1} exp(\beta_j X_i)} \quad (2)$$

$$\pi_J(x_i) = \frac{1}{1 + \sum_{j=1}^{J-1} exp(\beta_j X_i)} \quad (3)$$

where $\pi_j(x_i)$ is the observed outcome of response j at the ith setting of values of t explanatory variables $x_i = (1, x_{i1}, \ldots, x_{it})$. The observed outcome of the ith individual in the reference class is $\pi_J(x_i)$. The parameters are represented in β_j. The random factors are represented by υ_l for stand level and u_{lk} for plot level effects.

The dependent variable was tree-level NC separated into three categories: Low (n=3855), Substantial (n=3446), High (n=1966). The group needing least cleaning (Low) was the reference category of the dependent variable. Continuous stand level variables were stand age, regeneration delay, and area of a plantation, whereas conifer crop tree density was a continuous plot-level independent variable. Site type, soil texture, soil preparation method, and dampness were analysed as plot level categorical independent variables (Table 1). The coarse (n=73) and medium (n=1873) soil texture groups, as well as site types OMaT (n=39) and OMT (n=1328) and types MT (n=1587) and VT (n=127) were combined to avoid small sample categories. Standard errors of parameter estimates and results of likelihood ratio test were examined when selecting the variables to the model; if likelihood ratio test indicated significant difference, then the variable included had to have significant effect or at least nearly significant and logical effect in the model.

3 Results

3.1 Description of the Studied Stands

The average number of Norway spruce saplings in the study stands was about 1460 ha^{-1} and the standard deviation 580 ha^{-1}. Only small part, 10%, of the area evaluated in the study was already cleaned. In the contrast, already a massive part, 58.4% of the conifer crop trees were considered to have high (21.2%) or substantial (37.2%) need for cleaning. Trees in these categories are considered to suffer considerable growth loss because of competition.

Between different soil textures, the share of the trees needing early cleaning (substantial and high need) is the highest (72%) on peatlands and the lowest (55%) on medium textured mineral soils (Tables 3 and 4). The difference between mineral soils is small, but it is consistent trough different site types (Table 3). In the total figures, need for early cleaning is a bit higher in MT site type than in OMT. However, within the soil texture categories, share of the trees needing early cleaning is consistently higher on OMT site type than on MT. This occurs because of the uneven distribution of the observations between site type and soil texture categories.

Table 3. Relationships of soil texture and site type to trees needing early cleaning. Number of the occurences of need for early cleaning (EC, including categories substantial and high) is marked with ‘n’ and above it, is the share of the ‘n’ occurences compared to the total number of the cases in the category.

Soil texture	Site type		
	MT	OMT	Total
Fine			
Trees needing EC, %	54	58	55
n	1161	622	1783
Medium			
Trees needing EC, %	57	63	59
n	1860	1492	3352
Peat			
Trees needing EC, %	70	74	72
n	138	139	277
Total			
Trees needing EC, %	63	62	58
n	3159	2253	5412

Share of the trees needing early cleaning is low (47%) on plantations that has not been treated with soil preparation (Table 4). Between soil preparation methods the differences are small. However, soil texture groups can effect on differences between soil preparation methods, for example, the share of the trees needing early cleaning is 91% in combination of disc-trenching and peatland soil texture. Nonetheless, strong multicollinearity between soil texture and site type, or soil texture and soil preparation method is unilkely, according to Tables 3 and 4.

3.2 Prediction of the Need for Early Cleaning

The model for predicting the need for early cleaning consisted of six explanatory variables (Table 5). Only one of the variables was continuous, stand density, and the rest of the variables were categorical. Highly relevant variables were soil dampness and early cleaning. Also in the vari-

Table 4. Relationships of soil texture and soil preparation method to trees needing early cleaning. Number of the occurences of need for early cleaning (EC, including categories substantial and high) is marked with 'n' and above it, is the share of the 'n' occurences compared to the total number of the cases in the category.

Soil texture	Soil preparation				
	Unprepared	Mounding	Disc-trenching	Patching	Total
Fine					
Trees needing EC, %	50	48	60	58	55
n	6	511	527	739	1783
Medium					
Trees needing EC, %	46	67	58	59	59
n	147	488	932	1785	3352
Peat					
Trees needing EC, %	67	69	91	73	72
n	14	129	21	113	277
Total					
Trees needing EC, %	47	57	59	59	58
n	167	1128	1480	2637	5412

able soil texture, category peatland increased the share of both high and substantial need for cleaning gategories of the dependent variable rather much compared to mineral soils (fine, medium). In addition, site type was very significant predictor in the sub-model 2, when predicting category "High". However, other variables were rather weak predictors of the need for early cleaning. Especially stand age and regeneration delay were very poor predictors, why they were not included in the model. The variation of the need for early cleaning was much higher between stands than between plots within a stand.

One of the most important results was that neither age of a stand nor regeneration delay, the time difference between clearcut and planting, were significant predictor of early cleaning. Distribution of saplings in to the different need for cleaning categories was almost stabile in 4–7 years old Norway spruce plantations. This indicates that need for early cleaning was already formed in in four years old plantations, and the plantations that have low need for cleaning in that age, have low need for cleaning also further on. Regeneration delay, on the other hand, may not affect much to the need for early cleaning, when the stands are soil prepared between clearcut and planting. However, we did not get enough data from the timings of soil preparations to analyse it.

If soil preparation was not carried out on a stand, the need for cleaning was low (Fig. 1). Nonetheless, it should be borne in mind that on unprepared soils competition from weeds can be immense. Also implemented early cleaning kept the level of need for cleaning very low, which is also the desired effect from cleaning. On the other hand, on peatlands or on damp mineral soils need for cleaning was rather high. Then, on typical mineral soil stands (soil prepared, not damp) the need for cleaning and the proportions of the need for cleaning categories were nearly constant.

The total classification efficiency of the model was not strong. About 43% of the trees were classified correctly (Table 6). Best classification efficiency was in the category "Low", in which about 61% of the observed trees were predicted correct. In "High" category, only 10% of the trees were classified into the correct category.

4 Discussion

The study explored the possibilities of using site and stand variables, which are stabile after ones measured, to predict competition and need for early cleaning in 4–7 years old Norway spruce plantations. The main finding was that need for early cleaning was considered rather high already in 4–7 years old spruce plantations, but they have

Table 5. The multinomial multilevel logistic regression model for predicting the probability of a crop tree belonging into a need for cleaning category: Low (reference category), Substantial or High. The parameter of stand density has been centred around the mean density of the estimated trees per plot. Therefore, by dismissing the variable, the model can be easily used when the density of the stand is unknown. If stand density is known, for example 1600 trees per hectare, then the parameter value will be 1.6 – 1.9927 = –0.3927.

Parameter	Estimate	SE	Odds ratio
Sub-model 1: Substantial need for cleaning			
Intercept	–0.047	0.070	0.954
Site type (ref. OMT)			
MT	0.059	0.070	1.061
Soil texture (ref. Medium)			
Fine	–0.094	0.072	0.910
Peat	0.265	0.152	1.303
Soil preparation (ref. DT)			
Unprepared	–0.507	0.224	0.602
Patching	0.011	0.106	1.011
Mounding	0.159	0.125	1.172
Early cleaning	–1.190	0.172	0.304
Stand density, th. conifers/ha (ref. 1.9927)	0.211	0.036	
Dampness	0.578	0.124	1.782
Early cleaning * Site type (ref. Uncleaned, OMT)			
Early cleaning * MT	0.496	0.211	1.642
Sub-model 2: High need for cleaning			
Intercept	–0.191	0.144	0.826
Site type (ref. OMT)			
MT	–0.463	0.084	0.629
Soil texture (ref. Medium)			
Fine	–0.161	0.088	0.851
Peat	0.521	0.173	1.684
Soil preparation (ref. DT)			
Unprepared	–0.745	0.321	0.475
Patching	–0.074	0.158	0.929
Mounding	0.031	0.183	1.031
Early cleaning	–1.484	0.218	0.227
Stand density, th. conifers/ha (ref. 1.9927)	–0.015	0.042	
Dampness	0.486	0.148	1.626
Early cleaning * Site type (ref. Uncleaned, OMT)			
Early cleaning * MT	–0.137	0.302	0.872

Random part of the models: The variances (var) and the covariances (Cov) of the random stand (υ_l), and within stand, random plot (u_{lk}) effects for the sub models 1 and 2

	Estimate	SE
Stand		
var(υ_l1)	0.284	0.040
var(υ_l2)	0.808	0.097
cov(υ_l1, υ_l2)	–0.186	0.047
Plot		
var(u_{lk}1)	0.140	0.039
var(u_{lk}2)	0.099	0.051
cov(u_{lk}1, u_{lk}2)	0.065	0.033

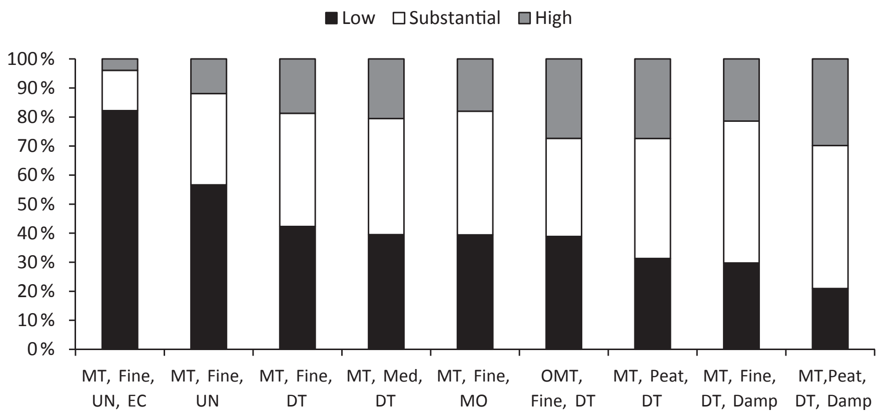

Fig. 1. Examples of distributions of trees into the different need for cleaning categories according to site type (MT, OMT), soil texture (Fine, Med, Peat), soil preparation method (UN, DT, MO), and dampness, and early cleaning (EC).

Table 6. The observed and predicted numbers (n = 9267) of crop trees in the various need for cleaning categories.

Observed	Predicted				
	Low	Substantial	High	Correct, %	Total, %
Low	2369	1246	240	61.5	41.6
Substantial	1886	1374	186	39.9	37.2
High	1169	597	200	10.2	21.2
Correct, %	43.7	38.7	38.3	42.5	
Total, %	58.5	34.7	6.8		100.0

seldom been cleaned in practice. In addition, few variables did fairly well as predictors of the need for early cleaning.

The multilevel multinomial logistic regression model constructed, described the tendency of a Norway spruce plantation to be exposed to competition relatively weakly. The model's overall classification efficiency to predict three different need for cleaning categories was about 43%. In the most common site conditions need for cleaning was rather constant. However, the model can be used to recognise the peripheral cases, where the need for cleaning is predicted to be extremely low or high. Early stand management operations can be directed on the plantations where they are most likely to be needed.

In comparison to the study of Kiljunen (2004), application of a different approach and use of slightly older plantations did offer some aid in determination of the need for young stand tending from site attributes. Kiljunen (2004) predicted only two need for early tending categories (No, Yes), and the most accurate method for predicting no need for tending, had precision of 45.9% correct. In this study, 61.5% of the trees in the category of low need for early cleaning were predicted correct. Best overall classification efficiency was much higher (59.4%) in the model of Kiljunen (2004) than our model (42.5%), but the models are not directly comparable by their classification efficiencies because we predicted three categories and Kiljunen (2004) only two categories.

A noticeable fact was that age of the stand was very poor predictor of the need for early cleaning. A plantations need for cleaning seemed to achieve constant state already at the age of four, which means that the need for cleaning can be recognised already then. However, this study was not a follow-up study, why, for example, yearly climatic variation can be a reason why an upward climbing pattern of need for early cleaning as a function of age was not recognised.

Time delay between clearcut and planting was also a variable that was assumed to work as a predictor for early cleaning, but it did not. The time difference between clearcut and planting included a possible error, because the declarations used to determine the timings allowed relatively high variation in the implementation dates of the operations. It is very likely, that regeneration delay increases amount of hardwoods on a plantation. On the other hand, rather than the time difference between clearcut and planting, need for early cleaning likely depends more on the time delay between soil preparation and planting, but we failed to achieve enough data to get proper analyse of it.

Soil preparation generally increased the need for cleaning. However, there were no significant differences between different soil preparation methods. Typically, a soil preparation method that exposes a large area of mineral soil, like disc trenching, produces a great amount of hardwoods to compete with conifer crop trees (Uotila et al. 2010). In this case, it should be borne in mind that the choice of work sites in practice might have affected the results. Mounding with ditching is the recommended method if drainage of the site is needed (Hyvän metsänhoidon… 2006). In that kind of conditions, also establishment of hardwoods can be intense. Nonetheless, the model describes the outcome of the different soil preparation methods in practice, why the result of the model are valid for the purpose of practice.

It should also be considered that soil preparation can affect development of hardwoods different ways on different site conditions. In the analysis of the need for cleaning, interactions between soil preparation methods and soil textures were tested, and some logical differences found. However, complex interactions in multinomial model are troublesome to comprehend and variation of the estimates of interaction terms were so high, that they were not included in the final model.

Estimating the need for young stand management operations seems to be difficult when one employs a simple determination of site attributes. According to the observations in field, one of the most important development stages in estimating hardwood competition could be quantitative and more precise method for determining soil moisture. In addition, acquiring precise timing of the previous management operations is also essential.

In this study, the need for cleaning was subjectively determined at tree level. The need for cleaning was determined according to the competition and growth reduction that hardwoods cause to conifer crop trees (Andersson 1993, Jobidon 2000). The higher the need, the more a released tree is likely to benefit from the release. The economic profitability of early cleaning was not evaluated in this study.

Quantifying the need is a difficult problem, why subjective determination was considered rational. In subjective evaluation, many aspects of the competition can be quickly evaluated. In contrast, any quantifying method would be very time consuming to measure in this kind of an extensive inventory study, and only a certain aspect of competition could be quantified at a time. With the subjective determination method used, almost 60% of the conifer crop trees were judged to need early cleaning treatment substantially or more. Considering the figures, management of Norway spruce plantations were approximated to be at rather low level. In addition, it seems reasonable to evaluate economic profitability of early cleaning already in 4-year-old plantations.

The effects of mechanical conifer release treatment in different situations are unclear. However, they are important to understand because of the noticed lack of early management of the plantations. Competition affects the growth of a conifer and changes the structure of the tree, in such a way that it becomes more susceptible to damages (Jobidon 2000). The main issues are 1) how different timing of early stand management affects the growth of crop trees and sprouting of hardwoods and 2) whether the structural changes of crop trees have long-lasting growth-reducing effects in unmanaged stands.

From practical standpoint of estimating the need for early cleaning, share of the trees in different need for cleaning categories is insufficient in determining the worksite level need for cleaning. First, in cost effective young stand management, the size of the area needed to clean should be large enough. Depending on a stand, total area to be cleaned per worksite should be about one hectare in order a worker could work there one day. Second, profitable forestry needs only a limited amount of free growing crop trees.

With fixed regeneration costs, optimal stand density for Norway spruce plantations is somewhere around 2 000 crop trees per hectare (Hyytiäinen et al. 2010). However, about 1000 spatially evenly distributed well growing crop trees per hectare should make fairly good economic result, because it is the necessary number of the trees after the first commercial thinning. In practice, the trees are not growing as spatially evenly distributed, why the level of probability of a tree to need cleaning has different importance in different parts of a plantation. In dense spots, the surrounding trees are probable to grow freely without early cleaning even if one tree would need it. However, in sparse spots, there might be only one crop tree to grow on relatively large area. When growth of the only crop tree is threatened, then the value of that certain spot starts decreasing heavily.

Because of the way the model was constructed here, it can be widely used in estimating cost efficiency of a worksite. The tree-level probabilities can be generalized to consider plantation or worksite level need for cleaning, when one employs data that includes the attributes included in the model.

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