Continuous cover forestry and harvest event analysis

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Continuous cover forest management system is gaining popularity to clear-felling and the rotation management system associated. Very few researches have been done to assess this management system. A harvest event was analysed in a Reinhausen forest compartment of 2ha, belonging to the state forest of Göttingen; Göttingen is situated in the state of Lower Saxony in Germany. The harvest has modified the stem number per hectare mostly in bigger class of diameter. The diameter class the most affected was between 14 and 23 cm. The harvest affected 11% of the stem in the stand and was constituted only by *Fagus silvatica* (7.5%) and *Fraxinus excelsior* (3.5%) which are the main species of this forest. The thinning removed 15% of the basal area and 16% of the volume of the forest stand. The type of thinning was thinning from above (high thinning). Apart from *Fagus silvatica* that the average height of trees reduces of 45cm after harvest, there was no difference on average height after harvest for other species. The harvest event has induced changes on the spatial distribution of the forest stand. The impact of this modification on environment has not been analyzed by this study.

Keywords: Thinning, harvest event analysis, continuous cover forestry, clear-cutting, rotation forest management.

INTRODUCTION

Continuous cover forestry (CCF) is a silvicultural system in which forest stands always maintain trees alive throughout the entire life span (Mason et al., 1999). The system is mainly characterized with a selection system and a shelterwood system. Thinning operations are therefore operated in the forest for improved management or for timber supply. This may cause changes to soil physical, chemical, and biological properties that reduce site productivity (Osman, 2013). A harvest modifies stand structure, species composition, forest density which results to a change on micro-climate, ground vegetation and nutrient cycle (Gadow, 2004). The soil compaction through this operation has effects on the cation exchange capacity, soil respiration, buffer capacity of the soil. The modifications caused by a harvest are abrupt and often drastic and it has been observed that foresters, when given the same set of silvicultural instructions, are not always unanimous in their judgments when marking trees for survival (Zucchini and Gadow, 1995). Harvest event analysis helps to evaluate the changes, to assess the thinning weight, to monitor management activities. The concept requires that before effective thinning operation or harvest, unwanted trees which are competing with target trees and commercial trees are marked. Target trees will remain on site as seed bearers or to ensure continuous cover vegetation in the stand. Prior or post-harvest analysis is done to evaluate the effect of thinning on the remaining stand.

The concept of CCF is usually opposed to the rotation forest management (RFM) which is usually used in industrial timber plantations and consists of establishing young stands by planting, thinning operations and final harvest at a specified rotation age (Gadow et al., 2012;
Despite the fact that most of the world’s forests are dominated by mixed species stands, the management practices in many countries around the world are still dominated by monocultures industrial timber plantations because the popular belief is that this type of management is simple and fibbers production can be maximized (Gerlach et al., 2002). RFM presents several ecological disadvantages. For example, when trees are clear cut in a forest stand (Figure 1), they remove nutrients from the soil and this contributes in the land degradation; therefore, soil may rely in the near or long future on fertilizers to replenish nutrients loss from this system. Adding further fertilizer may improve short term growth of young trees but will further decrease soil productivity as shown in a study in South-eastern Ontario (Jaggard, 2012). Also, the outgoing trees from the forest reduce or eliminate the capacity of the original forest to sequester carbon from the atmosphere. It is often argued that the newly planted forest with fast growing tree species will grow with a higher sequestration capacity (Carrow, 1993). Some environmental groups such as (ARB, 2010) reconsider support for clear-cutting in forestry and argue for GHG-offset of this silvicultural system. The growing potential with higher carbon uptake on a short term will not compensate the other environmental damages on soil and habitat loss for the biodiversity present in the original forest (Pukkala et al., 2012). For instance, (de Blecourt et al., 2013) show that conversion of forest to rubber plantation resulted in losses of soil carbon stocks by an average of 37.4 Mg C ha⁻¹ in the entire 1.2 m depth over a time period of 46 years, which was equal to 19.3 % of the initial soil carbon stocks in the secondary forests. This decline in soil carbon stocks was much larger than differences between published aboveground carbon stocks of rubber plantations and secondary forests, which range from a loss of 18 Mg C ha⁻¹ to an increase of 8 Mg C ha⁻¹. Despite the negative environmental impact of RFM and the lack of old growth trees in this types of forest stands the practice has been in used since the 19th century. One of the reasons in favour to this silvicultural system is that, in the Nordic countries, many foresters still believe that the RFM follows quite well the natural dynamics of the forest (Carrow, 1993; Keto-Tokoi and Kuuluvainen, 2010) which may not likely be always the case. Clear-cuttings are often replaced by monoculture plantations which are more vulnerable, more sensitive to forest fire, wind damage which create serious damages in temperate and boreal ecosystems where this type of silviculture system dominates (Carrow, 1993). Including Alaska, Russia and Canada, the extend of forest fire in boreal forests in these regions range annually between 5 to 20 million hectares (Martinez et al., 2006). Another reason of preference of RFM was that the traditional uneven-aged management with selective cuttings did not provide enough cheap raw materials for the expanding pulp and paper industry in the middle of the 1900s (Pukkala et al., 2012). This situation lead forest authorities in many countries to make declaration against uneven-aged management and to promote RFM with low thinning, clear felling, and planting (Pukkala et al., 2011).

Continuous cover forestry (CCF) represents a possibility to convert the current RFM into a forest management practise near-natural characterized by uneven stands with different ages which are less vulnerable to environmental hazards. The transformation of RFM to a CCF can be achieved in a stepwise process by following...
these successional activities. First, the young stands constituted by even-aged seedlings are subject to low thinning that enhance the growth without favouring trees. Subsequent thinning will consist of removing mainly mature trees from above that may be used to achieve the industrial requirements. As shown in Figure 2, some other big trees will remain on the stand to serve as seed bearers. The open canopy through harvest of mature trees will help for the recruitment of regeneration that will replenish the gaps in the forest stand. The intensity of thinning also refer to in this paper as thinning weight is the amount or the proportion of trees harvested in the forest. The thinning weight may depend on the type of species been promoted in the gap. Fast growing species may need more gaps to grow and in this case, heavier felling may be needed to promote their growth. For the promotion of shade tolerant species, it is recommended to do less intensive felling that will allow the growth of this type of species under the shade of bigger trees. The continuous management of the forest will be done thereafter through a shelterwood system that will consist of regular intervention in the forest for selection of big trees, maintenance of mother trees (seed bearers) and promotion of natural regeneration (Davies et al., 2008). This continuous intervention in the forest at more or less regular interval results to a stock which is more or less constant between the interventions as shown in Figure 3.

This study was carried out to: 1) analyse the effect of the harvest on the remaining stand; 2) determine the thinning type; 3) predict the growth of the remaining stand after the harvest 4) make recommendations for continuous cover forestry.

MATERIALS AND METHODS

Study Site

The study was carried out in 2005 in a 2 ha forest belonging (Reinhausen) to the state forest of Göttingen which is situated in the state of Lower Saxony in
Germany (Figure 4). Reinhausen is located about 8 km Southeast of Göttingen. The primary tree species is the Beech (*Fagus sylvatica*), accounting for 57% of the trees. Other significant species include Oak (*Quercus robur* and *Q. petraea*), Norwegian spruce (*Picea abies*), and Larch (*Larix decidua*). The soils are shallow with a depth of between 20 and 50 cm, pH (H2O) between 5.5–7.4 (0–20 cm), and are rich in base cations and carbonate content. The soil parent material is calcareous bedrock with a calcite content of about 95%. The biological activity in this soil is very high and has caused the development of a mull type litter layer and a humus-rich surface mineral soil (Meesenburg and Brumme, 2009). For the observation period 1990–2002, the annual mean air temperature was 7.4 ± 0.8 (5.5, 8.3) °C; this value varied from 12.6 ± 0.63 (11.3, 13.4) °C in May–October and 2.2 ± 1.18 (-0.4, 3.7) °C in November–April. The annual precipitation in the same period (1990–2002) was 709 ± 193 (537, 973) mm; this value varied from 410 ± 156 (233, 596) mm in May–October and 299 ± 143 (170, 453) mm in November–April (Panferov et al., 2009). The values in brackets represent the minimum and maximum of the observations. For the observation period 1961–1990, the mean annual sunshine duration varied between 1,400 – 1,450 hours; the sum of the radiation per year in this period varied between 960–980 kWh m⁻² and the corresponding irradiance varied between 109.6–111.9 W m⁻² (Panferov et al., 2009).

The studied area was constituted of uneven-aged mixed species with diameter range between 7 and 38 cm and a mean diameter of 16 cm. 35 plots located at equidistance of 23.9 m were selected within the study area at a sampling intensity of 70%. Plots were of circular form with radius of 11.29 m, and subplots of 1 m² in each where natural regeneration was assessed. All trees with diameter more than 8 cm were measured in the entire plot. A total of 1466 trees were recorded for analysis. The parameters recorded were the species name, the dbh (diameter at breast height), the diameter at 20 cm (d0.2), the geographical coordinates, and total height. For trees which were close to the edge of the plots the Relascopic prism was used to check whether the tree was in or outside the plot. All trees with diameter less than 8 cm were assessed in the subplot of 1 m² located at the centre of the plot. Strict regulation did not allow harvest of trees for the research purpose and all trees selected for harvest were just assumed for this study and were marked accordingly.

Trees designed for harvest were marked with a red colour ribbon and the target trees with yellow colour ribbon. As illustrated in Figure 5, target trees were big trees that remain on stand to provide seeds for natural regeneration and also to ensure there will be enough recruitment during the next intervention for timber supply. During the inventory, trees designed for harvest were recorded with the initial H and target trees with the initial T.

### Analysis of Thinning

The forest structure before and after harvest was analyzed. For this study, it was assumed that all trees marked with H will be effectively harvested; therefore, harvest analysis was done under this assumption. The forest composition before harvest was assessed by analysing species distribution in the studied forest. The...
diameter distribution was then plotted to assess how thinning has affected each diameter class and also each species. We also used the geographical coordinates of trees in the plot to generate the map of the forest before harvest. Then, all trees which were marked for harvest were removed to generate another map representing the feature of the forest after harvest. The diameter distribution of the forest before and after harvest was plotted to assess the impact of the thinning on the forest structure. The thinning weight was analyzed by evaluating the importance of the basal area removed from the forest using the formula:

\[
 r_G = \frac{\text{removed basal area}}{\text{total basal area}} \quad (i)
\]

The future development of a forest is not only influenced by the weight, but also by the type of thinning which is defined by the selective removal of specific members of the population. The thinning type is also reflected by the change of the diameter distribution (Gadow and Hui, 1999). In this study, we evaluated the thinning type using this formula:

\[
 (NG \text{ ratio}) \cdot NG = \left( \frac{N_{\text{removed}}}{N_{\text{total}}} \right) \left( \frac{G_{\text{removed}}}{G_{\text{total}}} \right) = \frac{r_N}{r_G} \quad (ii)
\]

where \( NG \) represents the thinning type, \( r_N \) the proportion of stem number removed by thinning and \( r_G \) the corresponding proportion of basal area removed by thinning. Relative spacing is another way of evaluating thinning (Gadow and Bredenkamp, 1992). It is an index
which helps to understand how the density was affected and to evaluate how the average distance between the trees have changed after the harvest. It was evaluated in this study using the two formulas (iii and iv) below:

$$RS = \frac{\text{average distance between trees}}{\text{dominant stand height}}$$  \hspace{1cm} (iii)

Taking into consideration square spacing, formula iii above can be rewritten

$$RS = \frac{\sqrt{10000/N}}{H_d}$$  \hspace{1cm} (iv)

where $N$ is the number of stems per ha and $H_d$ the dominant stand height (m).

The sensibility of thinning to basal area and volume was analysed by plotting per species for basal area and volume the quantity removed and those remaining in the stand. It was also analysed by estimating for each species the proportion of basal area and volume which was removed by thinning. The sensibility of thinning to the stand height was analysed by assessing the average height of each species before and after thinning and by assessing the change in average height before and after thinning in each diameter class.

Uneven-aged forests present usually a negative exponential diameter distribution following a J-shaped (Djomo, 2006; Djomo et al., 2012; Lamprecht, 1989). Schütz et al. (2012) explained that in continuous cover forestry, ideal target number should be defined for each diameter class to compare the real value before thinning and the ideal value after thinning and a J-shaped should be maintained before and after thinning. For this study, we plotted the diameter distribution before harvest as real values, used the values obtained after thinning as guide curve and checked if the J-shaped was maintained before and after thinning.

**Height and Growth Analysis**

For the height - diameter relation different models were tested for each species and we selected the model that provided for a species the best coefficient of determination. The models tested were (Schmidt, 1968):

$$h = a_0 + a_1 \cdot d + a_2 \cdot d^2$$  \hspace{1cm} (v)

$$h = e^{(a_0 + a_1 \cdot \ln(d) + a_2 \cdot d^2)}$$  \hspace{1cm} (vi)

$$h = a_0 + a_1 \cdot \ln(d)$$  \hspace{1cm} (vii)

$$h = e^{(a_0 + a_1 \cdot \ln(d) + a_2 \cdot d^2)}$$  \hspace{1cm} (viii)

The projection of the height growth after harvest was done using the TREEGROSS Software developed by the department of growth and yield of the Forest Research Station of Lower Saxony in Germany (Nagel, 2003). This software was developed based on the shift in silvicultural policy in Lower Saxony in Germany. The silvicultural system moved from stand RFM system to a CCF management system. Therefore, this software focuses on single tree information based on the experimental plots which is scattered over north-west Germany (Nagel, 2003, Nagel et al., 2003). For the actual tree model a simple approach by linear and non-linear regression technique was used. The regression analysis was performed for each species separately (Nagel, 2003).

**RESULTS**

The studied forest was constituted mostly by *Fagus silvatica* (Beech) (65%), followed by *Fraxinus excelsior* (Ash) (28%), *Piceaomorika* (Spruce) and...
Acer pseudoplatanus (Sycamore Maple) represent respectively only 5% and 2%. Only very few stems of Acer platanoides (Norway Maple) and Ulmus glabra (Elm) were found in the forest (Figure 6).

Change of Stand Density and Forest Structure

The stand density is an evaluation of the number of stem on a given land (Gadow and Bredenkamp, 1992). The harvest event has modified the stem number per hectare mostly in bigger class of diameter (Figure 7). The class the most affected was between 14 and 23 cm.

The harvest affected 11% of the stem in the stand and was constituted by Fagus silvatica (7.5%) and Fraxinus excelsior (3.5%) which are the main species of this forest. The proportion of Fagus silvatica harvested within their population was 11.5% while the one of Fraxinus excelsior represented 12.3% (Figure 8).

The removal of a tree modifies the spatial distribution, the radiation and influences a variety of biogeochemical processes (Gadow and Kleinn, 2004). The harvest event has induced changes on the spatial distribution of the forest stand. This can be viewed on the sketch showing the structure of the forest before and after the harvest (Figure 9).

Change of Basal Area and of Volume

The thinning removed 15% of the basal area in the stand and this was constituted only by Fagus silvatica (12%) and Fraxinus excelsior (3%) (Figure 10). The proportion of Fagus silvatica affected within their population was 16% while the one of Fraxinus excelsior represented 15%. The thinning removed 16% of the volume in the
stand and this was constituted by *Fagus silvatica* (13%) and *Fraxinus excelsior* (3%). The proportion of *Fagus silvatica* affected within their population was 17% while the one of *Fraxinus excelsior* represented 15% (Figure 10).

**Change of Height**

For evaluation of the effect of thinning on height, we analysed the average height before and after the thinning per diameter class and per species (Figure 11). The average height of tree harvested (19.4 m) was bigger than the average height of the trees before the harvest (17.9 m) and after the harvest (17.6 m). The average height of the forest reduces after the harvest of 32 cm moving from 17.9 m to 17.6 m. In the diameter class of 29 cm and 35 cm, the average height of the trees increases respectively of 17 cm and 90 cm after the

**Figure 8.** Species structure before and after harvest. Maple (Bah): *Acer pseudoplatanus* (Sycamore Maple); Maple (Sah): *Acer platanoides* (Norway Maple)

**Figure 9.** Spatial structure of the forest before and after harvest

**Figure 10.** Evaluation of thinning effects on volume (left) and basal area (right)
harvest. Apart from *Fagus silvatica* that the average height of trees reduces of 45 cm after harvest, there was no difference on average height after harvest for the other species (Figure 11, left). This result confirms that the average or dominant height is independent of stand density and thus not much affected by thinning (Gadow and Hui, 1999).

**Thinning Weight and Thinning Type**

Table 1 summarizes for *Fagus silvatica*, *Fraxinus excelsior* and the entire forest the thinning weight (rG) and the thinning type (NG). From this table, the value of NG is for all the cases studied less than one showing that the thinning was from above (high thinning). Figure 12 presents the relation between the thinning weight (rG) and the thinning type (NG) for *Fagus silvatica*, *Fraxinus excelsior* and for the whole forest (All).

**Height Curve and Growth Modeling**

Stand height is one of the key variables in most growth models in commercial plantation today (Gadow and Bredenkamp, 1992). The height regression equation of
the forest stand *Piceaomorika, Acer sp., Fraxinus excelsior, Fagus silvatica* has been evaluated (Figure 13). The regression equations and the related coefficient of determination are the follow:

Forest stand \( h = 3.402 + 7.61 \ln (d), \quad R^2=0.42 \) \((ix)\)

*Piceaomorika* \( h = 6.763 + 0.108d + 0.019d^2, \quad R^2=0.73 \) \((x)\)

*Acer s* \( h = -7.525 + 2.484d^{0.055d^2}, \quad R^2=0.61 \) \((xi)\)

*Fraxinusexcelsior* \( h = 7.632 + 3.772 \ln (d), \quad R^2=0.14 \) \((xii)\)

*Fagus silvatica* \( h =5.563 + 8.376 \ln (d), \quad R^2=0.50 \) \((xiii)\)

**DISCUSSION**

Harvest modified the forest structure, the species composition, the stand density, the basal area, the volume of the forest. The change on forest structure may
also modify the radiation which may influence biogeochemical processes (Bartos and Booth, 1994; Gadow and Kleinn, 2004; Gadow, 2004). The management system studied is continuous cover forestry (CCF). This system was characterised by selective harvesting of mature trees which resulted to low thinning from above and the use of natural regeneration to fill the gap opened in the forest through forest renewal and enough retention of some older trees to ensure a good balance between mature trees and regeneration during the next intervention.

The relative spacing moved from 0.17 before harvesting to 0.19 after the thinning. At similar density range, our values were consistent with the findings of (Zhao et al., 2012) who studied relative spacing relationships in pine plantation in USA. Relative spacing is sometimes used as a quantitative measure for comparing thinning regimes or for constructing thinning guide curves (Gadow and Bredenkamp, 1992). Harvest control is based on some ideal diameter distribution (Guldin, 1991; Schütz, 1994; Virgiliotti and Buongiorno, 1997). Figure 15 shows the thinning guide curves for the forest stand. This guide curve which compares before and after harvest may also help to assess the intensity of the intervention and decide whether or not additional tree removal may be needed to ensure a smooth distribution of the trees in all the diameter classes. Plotting this distribution may also help during the next thinning operations by allowing to assess the incoming regeneration and the growth of the trees in all diameter classes (Gadow and Kleinn, 2004). Selective harvesting also favours site-adapted tree species and some kind of “natural forest management” (Gadow and Kleinn, 2004). The studied forest was dominantly constituted by Fagus sylvatica (65%) and Fraxinus excelsior (28%) and the harvest event analysis reveals that these dominant species were the ones affected by thinning. Gadow et al. (2012) explained that the removal preference is another index to determine a pressure on species trough thinning intervention. The removal preference is the ratio of the proportion of trees removed in a structural class to the proportion of trees before harvest in that particular class. The removal preference of Fraxinus excelsior was 44% while the one of Fagus sylvatica was 18%. This index shows that though the proportion of Fagus sylvatica removed was close to the one of Fraxinus excelsior, there was a higher removal preference on Fraxinus excelsior. The relation between rG and NG (Figure 12) also show that there was harvest preference on Fraxinus excelsior through a lower basal area removed corresponding to a higher proportion of stem number. The remaining species in the forest Picea omorika, Acer pseudoplatanus, Acer platanoides and Ulmus glabra represented only about 7% of all trees in the studied area. These species was not affected by thinning. These species which were present in low number in the forest may increase in the future through natural regeneration favoured by the gaps opened in the forest and the preservation of these species in the actual conditions to serve as seed bank for the future.

The vertical and horizontal distributions of tree sizes may determine the distribution of micro-climatic conditions, the availability of resources and the formation of habitat niches and thus, directly or indirectly, the biological diversity within the forest community. Thus, the new forest structure induces by the thinning will contribute to improve the functions and future development potential of
the forest ecosystem (Franklin et al., 2002; Harmon et al., 1986; Ruggiero et al., 1991; Spies, 1997). Thinning exclusively affects mature wood; the effect of thinning becomes more similar to that of initial spacing since thinning favors the development of longer and larger crowns by reducing the rate of crown recession (Briggs and Smith, 1986; Pape, 1999). The most important effects of thinning are on growth rate in the lower half of the stem within the mature wood. Thinning has been found to shift increment downwards on the stem, which results in increasing stem taper (Larson, 1963; Valinger, 1992). Knoke and Seifert (2008) evaluated the influence of the tree species mixture on forest stand resistance against natural hazards, productivity and timber quality using Monte Carlo simulations in mixed forests of Norway spruce and European beech. They found superior financial returns of mixed stand variants, mainly due to significantly reduced risks.

CONCLUSION

The thinning has modified forest structure, forest density, species composition, basal area and volume of the forest. It also reduces competition on target trees which are left on site for the future interventions, and also for ecological and financial return; this may lead to the fast grow of these target trees and also of incoming regeneration in the gap created. The modification of forest structure has impact on radiation, light, soil and fauna population. The impact of this modification on environment has not been analyzed by this study. Harvest event analysis is a tool for monitoring forest management. It has been used in plantations and in the so called Near-Natural Forest Management as now practiced in Germany. In many countries including Canada, clear-cutting is still part of the forest management system. This study may contribute to the discussion to minimize the harmful potential of clear-cutting in the environment through continuous cover forestry.

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