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ORIGINAL ARTICLE

Effect of the cutting age and thinning intensity on biomass and carbon sequestration – the Gubin Forest District case study

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Abstract

The goal of presented study was to determine possible impact of the cutting age and thinning intensity on biomass and carbon sequestration. Analyses were based on the inventory data from the Gubin Forest District processed for a 10-year period using the Polish empirical stand growth models.

The variants with less intensive thinning treatments and higher cutting age favour biomass accumulation in the short-time horizon. At the same time, an increase in the cutting age leads to a drastic limitation of the possibility of timber utilisation, which may negatively affect financial condition of the district as well as significantly influence long-term forest sustainability. A decade-long analysis proved no influence of the cutting age and thinning intensity on current volume increment i.e. current ability of stands to absorb carbon dioxide. Longer prediction is required in order to recognise directions of changes in the increment.

Keywords

growth model, silvicultural scenario, simulation, carbon sequestration, thinning, cutting age

Introduction

There is a strong conviction among scientists that forest is one of the most effective carbon sequestration sinks (e.g. Righelato and Spracklen 2007). Hence, afforestation of post-agricultural and marginal areas is the simplest method of carbon accumulation increase (Niu and Duiker 2006). Apart from carbon sequestration in tree biomass, the existence of forest guarantees an increase in retention of this element in soil as well as prevention from its release.

In case of no forest management, the carbon budget of large forest areas stays in the state of dynamic balance governed mostly by global climate factors that modify processes occurring in tree stands. In turn, management activities performed in forests, i.e. such silvicultural treatments as PCT (pre-commercial thinning) or thinnings of this type, their frequency and intensity, decisions on the cutting age, a harvesting system, or management of post-cutting remains cause changes in the forest carbon budget. Current carbon accumulation

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in woody biomass is directly related to volume increment. Intensively growing tree stands absorb a significant amount of carbon. On the other hand, the carbon budget should be considered not only from the point of view of woody biomass, but also other elements which assimilate carbon. For example, small post-harvesting remains (little branches, leaves, tree-tops) decay very fast releasing a vast amount of carbon dioxide into the atmosphere. In turn, tree stands where no treatments are performed contain the greatest amount of accumulated carbon. However, they embody little current sequestration ability. That is why forest management should embrace some kind of compromise between the amount of carbon that has already been absorbed and is currently being accumulated (Brzeziecki 2007).

Foresters have at their disposal a wide range of activities that may result in retention of carbon accumulated in forests or its increased absorption. These are often related to resignation from a part of harvested volume (leaving behind clumps or individual old trees). Regeneration activities performed with least intervention into soil during its preparation are also of great importance. Local soil preparation or natural succession allowance are most favourable in this case.

Mathematical growth models can be applied to analyse the influence of treatments performed in forests on carbon sequestration (Czarnowski 1989, Zasada 1999).

Because of the risk of uncertainty related to long-term analyses, in most cases the research becomes a scenario analysis. Hence the main objective of performed simulations is elaboration of the direction and range of changes of a study object as the system response to a particular set of input data (Poznański 2003, Cieszewski *et al*. 2004).

Empirical growth models elaborated in Poland (Bruchwald 1985, 1986) belong to the model type of individual tree which enables, assuming a particular thinning programme, a forecast of volume changes of individual stands in the period of some to several dozen years. In the case of forecast for a group of stands (e.g. forest district, management class), it is possible to optimise the intermediate (Bruchwald 1995) and final cutting (Siekierski 1993a, 1993b, 1995; Bruchwald and Siekierski 1992).

This paper presents an example of application of the growth model in the analysis of changes in biomass and the amount of accumulated carbon in the period of 10 years with regard to various silvicultural decisions. We did not focus on individual stands but on a larger area because the possible number of activity combinations on the stand-scale is too large to obtain useful synthetic results. We decided to analyse the effect of the cutting age, thinning intensity and already accumulated carbon in growing stock of a forest complex. In addition, we analysed the actual ability of carbon sequestration which is the derivative of current volume increment.

There have been many attempts to show long-term projections of forest resources (see eg. Zasada 2007 for the review of large-scale modeling). Some of these projects were extended to assess not only changes of growing stock, but also to simulate changes in carbon sequestration under various management regimes. One of such models was EFISCEN (Sallnäs 1990). It enables the forecast of development of various forest characteristics in changing natural conditions and management scenarios as well as prediction of the amount of carbon sequestrated by forests (Karjalainen *et al*. 2003). Another project of this type was SILVISTRAT, performed by the European Forest Institute (EFI) (Kellomäki *et al*. 2000, Kellomäki and Leinonen 2003). The goal of this study was, among others, to estimate a potential of European forestry for carbon sequestration and to study adaptive management strategies to enhance carbon sequestration in European forests, including impacts of various forest management scenarios on carbon sequestration.

Material and methods

Effect of the cutting age and thinning intensity on biomass and carbon sequestration was illustrated using inventory data from the Gubin Forest District. The District covers 19 968 ha of the forest area and is located in western Poland (Zielona Góra Regional Directorate). According to ecological-forest classification (Trampler *et al*. 1990) the Gubin Forest District is located in the Wielkopolsko-Pomorska province, Pojezierze Lubuskie subprovince, Pradolina Głogowska mezoregion. The district Internet home-page: (http://www.zielonagora.lasy.gov.pl/web/rdlp_zielonagora/informacje_ogolne) informs that forests are dominated by poor conifer forest habitats (55.5%). Mean stand age is 52 years, and mean volume increment is estimated to 3.31 m^3/ha.

Data received from the National Forests Information System databases were processed with the use of the growth model (Bruchwald 1986) with supplemented module for calculation of tree dry biomass. Formulae derived for the Scots pine (Zasada *et al*. 2008) were applied to all species because of pine prevalence in the species structure of the Gubin Forest District forests.

The cutting age and thinning intensity were the parameters that were manipulated in order to analyse various silvicultural scenarios. We decided to perform the simulation for variants in which the cutting age was equal to the currently used in the analysed district, i.e. 100 years, 20 years lower, as well as 20 and 40 years higher. This gave the following cutting ages: 80, 100, 120 and 140 years. In the stands classified to treatments, the thinning module of the growth model simulates the removal of such a number of trees so that the critical level of stocking is achieved (Bruchwald 1988a, Bruchwald *et al*. 1986). The critical level of stocking is defined by the assumed portion of trees that will remain in a stand after the treatment. It depends on the species, age and natural condition of stand (Bruchwald 1988b) and was included into the growth models as a result of empirical measurements. Thus, the percentage of removed volume or number of trees depends on both the critical and actual levels of stocking in stand.

We assumed that thinning would be performed with various intensity variants described by the level of critical stocking. In the standard thinning variant model simulates the removal of such a number of trees so that the critical stocking achieves 0.6. More intensive and the most intensive variants have this feature lowered by 0.1 and 0.2, while less and the least intensive ones – increased by these values respectively.

Performed simulations applied the combination of above-mentioned variants of the cutting age and thinning intensity. As a result we received 13 variants that were later used to assess the effect of a silvicultural manner on biomass production and carbon sequestration.

Results

Table 1 presents the amount of dry woody biomass accumulated in stands of the Gubin Forest District at the end of the forecast 10 years period for the current cutting age and various thinning intensity variants. In each of the analysed cases the woody biomass of the district increased by various percentages up to 110–113 t/ha. Treatments that are more intensive that current ones cause a small and insignificant increase in biomass in comparison to the standard thinning variant. Lower treatment intensity results in the increase of the accumulated biomass by over 3 percentage points.

Table 1. Dry biomass (Bs) of whole trees for the current cutting age and various thinning intensities

Thinning	Beginning		End (+ 10 years)		Biomass change [%]
	Bs [t]	Bs [t/ha]	Bs [t]	Bs [t/ha]	
Weakest	2,088,030	105	2,240,615	113	7.31
Weaker			2,207,363	111	5.72
Standard			2,188,337	110	4.80
Stronger			2,180,118	110	4.41
Strongest			2,178,321	110	4.32

Decrease of the cutting age by 20 years causes a very little up-growth of biomass, which is the smaller the more intensive is the thinning (Tab. 2). In the first 10 years, the increase of the cutting age results in the increase of the amount of accumulated biomass. The higher is the age and the less intensive are the treatments, the more biomass is accumulated (Tab. 3 and 4). Table 5 presents other stand features (intermediate and final cuttings area, volume harvested in intermediate and final cuttings, current volume increment and percentage of harvested increment) in relation to various thinning intensities (current cutting age).

Table 2. Dry biomass (Bs) of whole trees for the cutting age decreased by 20 years and various thinning intensities

Thinning	Beginning		End		Biomass change [%]
	Bs [t]	Bs [t/ha]	Bs [t]	Bs [t/ha]	
Weaker	2,088,030	105	2,117,423	107	1.43
Standard			2,104,329	106	0.78
Stronger			2,100,767	106	0.61

Total production (harvested volume) under the current cutting age and standard thinning regime was defined as 100% (Fig. 1). The increase of the cutting age significantly reduces volume available for harvesting. Difference between the variants of extreme age and thinning intensity reaches 60%. Similarly to the analysis of biomass accumulation, the assessment of changes in production shows that application of thinning intensities gives a smaller range of the results than manipulation with the cutting age. Changes caused by the decrease in the cutting age by 20 years are larger than those occurring when the cutting age is increased by the same number of years.

Table 3. Dry biomass (Bs) of whole trees for the cutting age increased by 20 years and various thinning intensities

Thinning	Beginning		End		Biomass change [%]
	Bs [t]	Bs [t/ha]	Bs [t]	Bs [t/ha]	
Weaker	2,088,030	105	2,194,300	110	5.09
Standard			2,247,315	113	7.63
Stronger			2,274,500	115	8.93

Table 4. Dry biomass (Bs) of whole trees for the cutting age increased by 40 years and various thinning intensities

Thinning	Beginning		End		Biomass change [%]
	Bs [t]	Bs [t/ha]	Bs [t]	Bs [t/ha]	
Weakest	2,088,030	105	2,380,769	120	14.02
Standard			2,301,035	116	10.20

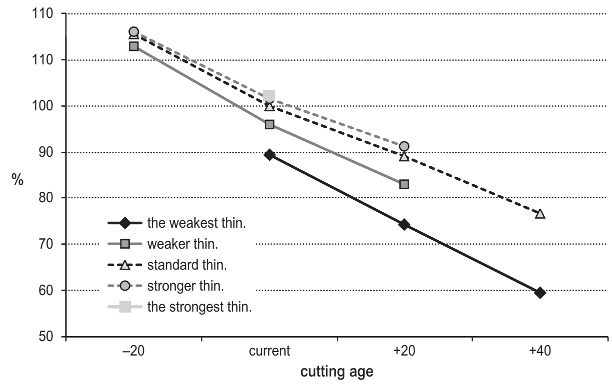

Fig. 1. Total production in various silviculture variants (current cutting age and standard thinning intensity are referred to as 100%)

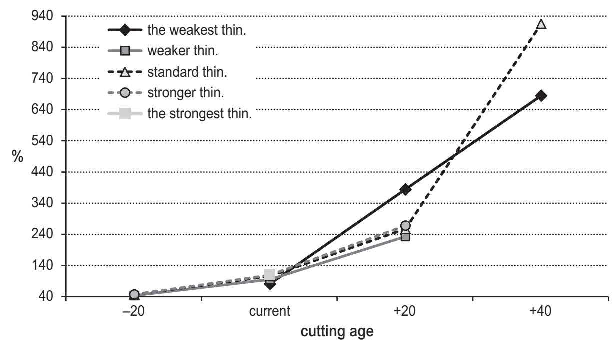

Fig. 2. Ratio of total volume harvested in the intermediate and final cutting in various cutting age and thinning intensity scenarios

Figure 2 presents a ratio between volume harvested in the intermediate and final cuttings. A very remarkable increase of the value appears when taking into consideration the variants of various cutting age. As far as the cutting age of 80 is concerned the intermediate cuttings constitute 40% of the final cuttings. For currently used age (100 years) the volume harvested equals almost the half of intermediate cuttings. Within this variant, the difference between extreme values equals 25%. Situation changes diametrically when we consider the vari-

Table 5. Stand characteristics for the Gubin Forest District determined on the basis of simulation of various thinning intensities (cutting age equals 100 years)

	Thinning				
	Weakest	Weaker	Standard	Stronger	Strongest
Final cutting area (ha)	1,346				
Final cutting volume (m^3)	335,380				
Thinning area (ha)	20,333	21,001	21,449	21,743	21,971
Thinning volume (m^3)	278,459	324,466	352,176	363,502	366,749
CAI (m^3/year)	4.7	4.7	4.6	4.6	4.6
% of harvested CAI	66	71	75	76	76

ants with increased cutting age. In this case, importance of the final cuttings significantly decreases. The higher cutting age causes lower total production (Fig. 1), which is accompanied by the increase of share of intermediate cuttings. In the most extreme simulated scenario (140 years, classical thinning), over 90% of production originated from this kind of treatments.

Figure 3 depicts the area of clear cuts. For comparison we defined that the area of cuts for the age of 100 years equals 100%. Changes in the area covered by the treatment in relation to applied cutting age were very significant. Especially spacious cuts may occur for the cutting age decreased by 20 years. And oppositely – the increase of the cutting age up to 140 years reduces the cut area to about 15% of the current value. One must remember that in this variant the total production falls to 75% of the current one. And because of great importance (and share) of intermediate cuttings, reduction of the area without forest cover is significant.

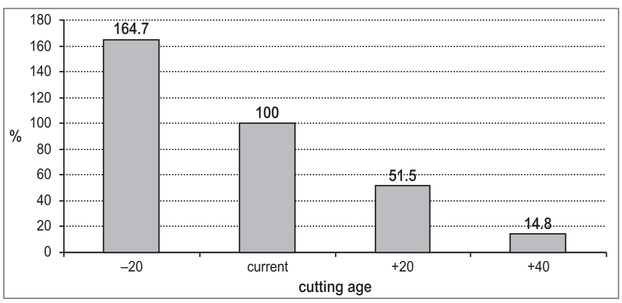

Fig. 3. Felling area in different silviculture variants (100% – cutting age 100 years, standard thinning intensity)

Discussion

The results of the decade simulation showed the relation between biomass accumulation, the cutting age and thinning intensity. However, the difference in amassed biomass is very little with regard to various treatment intensities. As a matter of fact, volume increment also turned to be independent of this feature. More intensive cuts lead to the increase of the total amount of harvested timber in the forest district. This is caused by the larger and larger number of stands subjected to the treatment. The relation between harvested volume and accumulated increment changes as well (Tab. 5). Lower thinning intensity is a favourable factor for biomass and carbon storage. Cutting age manipulation has much more intense effect on woody biomass accumulation in a short period of time. The decrease of the cutting age by 20 years resulted in hardly any accumulation growth in the analysed decade (below 1% for all thinning variants, Tab. 1). However, the length of prediction (10 years) was of great importance. Regarding the forest age structure in the observed district, a forecast for a longer period of time should provide different results (Siekierski 1995, Zasada 2007). The higher cutting age increases biomass accumulation very significantly. In the extreme case (the least intensive thinning, the cutting age increased by 40 years) biomass storage during 10 years raises by 14% in contrast to 4.8% for the current cutting age and classical thinning intensity. However, this type of forest management would be of very little intensity and would be appropriate rather for forests with dominant protection and non-productive functions. Besides, such management can be dangerous due to long-term effects related to increased risk of biotic and abiotic factors (fungi, pests, wind, snow) as well as problems in maintaining sustainability of forests in the future (stands ageing as well as temporal and spatial order of stands and possibility of further sustainable forest utilisation).

Productive functions of forests are very important for the Gubin Forest District whose stands are dominated by the Scots pine growing on poor habitats. That is why it is worth to analyse the total production (intermediate and final cuts) in the above-mentioned silviculture variants. The variant that resembles current forest utilisation the most – i.e. the cutting age 100 years and thinning intensity governed by the value of critical stocking equal to 0.6 – was accepted as the reference for the production of other types.

The variants that assume a decrease of the cutting age have to be pointed out as most unfavourable for biomass accumulation. Scenarios with an increasing cutting age provide high biomass storage, but at the same time, lead to significant limitations in harvest possibility in the stands of analysed district. The increase of the cutting age also causes negative changes in the age structure of forests, which in further perspective results in the decrease in volume increment (that is current ability of carbon dioxide absorption) and hence may threaten forest stability (Zasada 2007). Differences in accumulated biomass are not big as far as the scenarios with the same cutting age but various thinning intensity are concerned. However, less intensive thinning always favours biomass accumulation. It has also be mentioned that an increased cutting age can also lead to the greater than before risk of biotic and abiotic factors (fungi, pests, wind, snow) as well as problems in maintaining sustainability of forests in the future (stands ageing as well as temporal and spatial order of stands and possibility of further sustainable forest utilization).

It was concluded, that growth of forests increases significantly when the rotation period was shortened and thinning was more intense. At the same time, such scenarios have strong effects on the reduction of aboveground biomass. On the other hand, more extensive management (decreased thinning intensity and long rotation period) leads to higher aboveground and belowground biomass. The differences between light and intensive management range from near zero (on Finnish sites) to more than three-fold (on Central European sites).

Conclusions

Paper presents the simulation of changes in dry biomass of the tree stands in the Gubin Forest District in the 10-year period of utilisation with various cutting ages and thinning intensities. The variants with less intensive treatments and higher cutting ages favour biomass accumulation in the short-time horizon. At the same time, the increase of the cutting age leads to drastic limitation of a possibility of timber utilisation, which may negatively affect financial condition of the district as well as significantly influence long-term forest sustainability. The decade-long analysis proved no influence of the cutting age and thinning intensity on current volume increment, i.e. current ability of the stands to absorb carbon dioxide. Longer prediction is required in order to recognise directions of changes in increment.

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