Aboveground growth dynamics of *Picea mariana* in a boreal forest in Canada: Examination of internal and external factors

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Recent global climate change could cause boreal forests to become carbon sources instead of large carbon sinks. A robust prediction of the carbon uptake capacity of such forests is therefore necessary. However, even though leaf production is a determinant of forest carbon sink capacity, reconstructing annual leaf production in evergreen conifers is still challenging. Moreover, the estimation of biomass increment still also requires numerous assumptions, even though the biomass increment through tree growth represents the amount of carbon stored by forests.

The present thesis promotes understanding of the fundamental characteristics of annual aboveground productions and tree's response to the environmental conditions of a boreal conifer species, *Picea mariana*. Annual aboveground productions were examined separately for photosynthetic organ-leaf (Chapter 2) and non-photosynthetic organs-branch and stem (Chapters 3-5). The growths of non-photosynthetic organs were further divided into apical and cambial growths.

In chapter 2, a new method was proposed to reconstruct the past yearly variation in leaf production of evergreen conifers and was applied to an open stand of *Picea mariana* in Canada. A significant linear relationship was obtained between annual shoot length and leaf dry mass. Yearly variations in annual shoot elongation of primary branches were synchronized within trees, which suggests that the measured variation could be scaled up from the branch to the tree level. They were also synchronized among most of the sample trees, except two trees showing different variations. These differences must be considered in scaling up from the tree to the stand level. Neither tree-ring width nor radial area increment of the stem at breast height predicted leaf production. Temperature and rainfall during the growing season were the dominant climatic drivers of leaf production reconstructed from annual shoot lengths. The results of chapter 2 mean that it becomes possible to estimate past yearly variations in leaf production for an evergreen conifer stand from a single-year sampling even in stands without long-term tree census data. This novel approach can potentially be used in stands of other Pinaceae species that are widely distributed with open canopies in the boreal and subalpine forest biomes.

In chapter 3, the similarity of interannual dynamics of apical and cambial growths on stem and branch were examined, which suggested if they are controlled by the same factors. Two of the ten sample tree stems had a similar interannual variation between apical and cambial

growths, while most trees did not. Effective drivers may not be the same between apical and cambial growths on stems. Branch apical and cambial growths were not completely independent from each other, which means they can be affected by the same factors. In addition, apical growths on stem and branch had a similar interannual variation, thus they would be affected by the same drivers. On the other hand, cambial growths did not have the similarity between branch and stem. It suggests that the factors that influence cambium growths may vary depending on the organs. Stem diameter increments corresponded to stem volume increments more than tree height increments. The coefficients of determination were low for the model which did not consider the individual tree difference. This is because the tree height is different among trees even if the diameter of the stem is the same.

In chapter 4, size effects on apical and cambial growths were analyzed using mature black spruce trees from the same stand. Apical growth was not influenced by branch or stem length. The main driver in shoot elongation would be other than the length of stem or branch. In contrast, cambial growth was influenced by branch or stem diameter and cross-sectional area, however, its impact differed between stems and branches. The diameter was affected as a positive factor in stem cambial growth, while as a negative factor in branch cambial growth. Overall, the size effect differed between apical and cambial growths.

In chapter 5, the combination of key factors for apical and cambial growths was analyzed using both stem and branch. The drivers were different between apical and cambial growths in both stem and branch. The drivers were more complex for branch than stem for apical growth, while both of their shoot length become long if the temperature during the growing season increase with global warming. The stem shoots are longer than the branch shoots because of the longer growing season in stem shoots. Stem cambial growth can be explained by only its diameter before current year growth and may not be controlled by environmental conditions. Branch cambial growth might be affected by microenvironment of individual tree and snow. Thus, the effective factors were not the same between branch and stem for cambial growth.

According to the present results, each aboveground production behaved responds differently to the internal and external factors, as a result of which each growth had their own interannual variation. Overall, it leads to misunderstandings about the climate response of tree growth when only one part of the growth is used as an indicator of whole tree growth. The results from the climate response analysis for a tree growth do not fit for the other part.