**BALTIC FORESTRY**

http://www.balticforestry.mi.lt
ISSN 1392-1355
eISSN 2029-9230

Baltic Forestry 2022 28(1): 556
Category: Research article
https://doi.org/10.46490/BF556

# Empirical observations of the yield of logs from trees of the boreal region

**PETRI P. KÄRENLAMPI** *

*Lehtoi Research, 81235 Lehtoi, Finland*

*Correspondence:* *petri.karenlampi@professori.fi*

**Kärenlampi, P.P.** 2022. Empirical observations of the yield of logs from trees of the boreal region. *Baltic Forestry* 28(1): article id 556. https://doi.org/10.46490/BF556.

**Received** 4 February 2021 **Revised** 26 January 2022 **Accepted** 5 February 2022

***Abstract***

The yield of sawlogs and plywood logs from boreal trees is discussed. First, taper curves are used to compute geometric (maximal) sawlog and plywood log contents. Then, a quality reduction is implemented, according to previously published models. Finally, the outcome is verified using empirical observations. Regarding spruce trees, the different estimates of sawlog content agree. In the case of birch and pine trees, the estimates differ. The sawlog and plywood log yield from large trees is greater than prognosticated, probably due to missing over-aged trees in the empirical data. The yield of sawlogs and plywood logs from small trees is smaller than prognosticated, most of the empirical data originating from thinnings with a focus on the quality of the remaining trees. The sawlog content of individual trees from clearcutting displays a skew distribution around the expected value. The distribution in thinning trunks shows a binary component, with a large proportion of trees with zero sawlog content.

**Keywords**: sawlog, plywoodlog, *Picea abies*, *Betula* species, *Pinus sylvestris*

## Introduction

The business of forestry produces a variety of products and services. Essential outcome however are wood logs used in further chemical or mechanical processing. Different assortments of wood logs differ significantly in price, and the yield of the assortments consequently is a major factor in the economics of forest management.

Wood logs used in mechanical processing, like sawmilling or veneer plywood production, typically show greater market value than pulpwood logs, compared on a volumetric basis. Simultaneously the requirements are greater, with respect to log dimensions, as well as in terms of quality. Different sizes of trees naturally yield wood logs of different dimensions, and this applies not only to tree diameter but also to tree height.

There is not very much published information regarding the sawlog content of tree trunks. Some information is found from regional statistics. Inventory data from Queensland, Australia, has indicated that the sawlog content in that area would be 65% of harvestable tree trunk volume (Ngugi et al. 2018). Recent regional statistics from Finland (2010–2019) indicates that sawlogs and plywood logs have constituted 42% of total industrial harvesting, 58% regarding spruce, 40% regarding pine, and 11% in the case of broad-leaved trees (Luke 2021). Regional statistics naturally does not indicate how the assortment distribution within any trunk depends on trunk size and other trunk characteristics.

Recovery of sawlogs depends on dimensional and other requirements, as well as silvicultural practices and harvesting procedures. Observations from short-rotation plantations in Vietnam indicate that sawlog content in final harvesting may vary from 28% to 68% depending on whether the plantation is thinned (Huong et al. 2020). Bucking simulations based on a stand database from Finland has indicated that clear-cuts of spruce and pine might yield 65% and 68% of sawlogs, respectively. Corresponding percentages for thinnings would be 36 and 14 (Malinen et al. 2018). It is worth noting that the difference between clear-cuts and thinnings is not only due to the harvesting pattern since also stand characteristics differ. Value recovery may become compromised due to technical or organisational difficulties (Boston and Murphy 2003, Carey and Murphy 2005, Nordmark 2005, Spinelli et al. 2011).

There is a variety of ways to predict the yield of different kinds of wood logs from trees. The most straightforward way might be to estimate tree trunk tapering and then divide the trunk into sections corresponding to the size requirements of any assortment. Estimation of trunk tapering is relatively straightforward since there is a large body of literature discussing taper curves (Kilkki and Varmola 1981, Ojansuu and Maltamo 1995, Gaffrey et al. 1998, Strub et al. 2005, Saarinen et al. 2019). Such a procedure, however, would neglect quality requirements, apart from the required dimensions. Such negligence has not been uncommon in forest management investigations (Tahvonen et al. 2010, Rämö and Tahvonen 2015, 2016, Tahvonen and Rämö 2016, Kärenlampi 2019, 2020a, 2020b), obviously resulting in biased results and flawed recommendations.

This study intends to clarify the yield of sawlogs and plywood logs from trees. This is aspired by presenting an empirical material and comparing it to the outcomes of previously existing assortment yield models. First, taper curves are applied to clarify the geometric (maximal) yield. Then, a quality correction is implemented, based on a previously published procedure (Mehtätalo 2002), grounded in Finnish National Forest Inventories 1992–2000. Finally, empirical observations collected by five different single-grip harvesters in 2017–2020 are organised, and the computed log yield results are verified using the empirical data.

## Materials and methods

A dataset of 6,123 spruce trees and 4,127 birch trees was collected by four different single-grip harvesters, operated by six individuals at four harvesting sites. Log cutting instructions provided by three different sawmilling companies were applied, reflecting their somewhat different processes and product specifications. The minimum top diameter over bark was 160 mm for spruce sawlogs and 150 mm for pine sawlogs in all cases. The minimum sawlog lengths however varied from 310 cm to 430 cm. The minimum plywood log top diameter varied from 180 mm to 200 mm. One thinning site was located at Vihtari, two thinning sites, and one clearcutting site at Ilomantsi, all in Eastern Finland. The width of the sampling territory was 100 km (West to East), and the length was 30 km (South to North). Elevation varied from 115 to 205 m above sea level. The number of Scots pine sawlog trunks on the four sites was small. The dataset was complemented with two more thinning sites at Ilomantsi, resulting in a dataset of 4,037 harvested pine trees.

The taper curve models of Laasasenaho (1982) were used to compute the geometric (maximal) sawlog or plywood log content within any trunk of known breast-height diameter. Breast-height diameters were discussed in 25 mm classes. The taper curve is given in terms of relative tree heights, which required knowledge of total tree height. For any diameter class, such a height was used which gave the same commercial volume as observed for the empirical observations collected from the harvesters. The maximum geometric sawlog or plywood log yield was determined from the taper curves for any diameter class. This geometric log content was compared to yield tables given by Rämö and Tahvonen (2015, 2016, Tahvonen and Rämö 2016), applied in a variety of forest management studies (Tahvonen et al. 2010, Kärenlampi 2019, 2020a, 2020b).

After the determination of the geometric sawlog or plywood log content, the yield reduction model of Mehtätalo (2002) was used. The model, grounded in observations of a Finnish National Inventory, has been composed based on 9,750 spruce trees, 13,020 pine trees, 969 silver birch trees, and 1,054 white birch trees. The correction factors by Mehtätalo (2002) depend not only on tree size but also on tree age. A typical age for any diameter was introduced as a nonproportional linear model for any tree species, established based on literature data (Vuokila 1956, 1960, Raulo 1977, Vuokila and Väliaho 1980, Oikarinen 1983). The outcome of this model was then compared with sawlog and plywood log yields in the empirical observations.

## Results

Spruce sawlog proportion in the commercial section of trees of different sizes is shown in Figure 1. It is found that the yield table by Rämö and Tahvonen (2015, 2016, Tahvonen and Rämö 2016) follows the theoretical maximum (Laasasenaho 1982) relatively closely, apart from the resolution in tree diameters. The empirical yield results follow the curve corrected by the model of Mehtätalo (2002) relatively closely, with three deviations.

Firstly, at 175 mm diameter, the empirically observed sawlog yield is greater than predicted. The observed yield is even greater than the theoretical maximum. The latter indeed appears strange. However, a logical explanation is that real-life taper curves scatter. There also is a 25 mm span of diameters in the diameter class. Consequently, some trees have yielded a sawlog even if the average taper curve applied to the central diameter would not indicate that.

Secondly, in Figure 1 trees of breast-height diameter from 287 to 387 mm appear to yield sawlog contents smaller than predicted by the Mehtätalo model (2002). Trees of breast-height diameter between 387 mm and 513 mm yield sawlog contents greater than predicted by the Mehtätalo model.

Birch plywood log proportion in trees of different sizes is shown in Figure 2. It is found that the yield table by Rämö and Tahvonen (2015, 2016; Tahvonen and

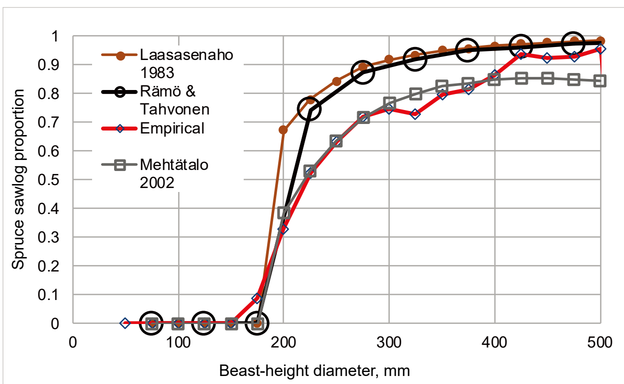


**Figure 1.** Spruce sawlog proportion in the commercial section of tree trunks as a function of trunk diameter

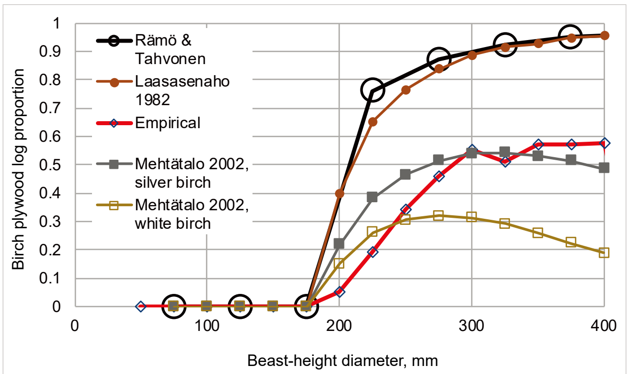


**Figure 2.** Birch plywood log proportion in the commercial section of tree trunks as a function of trunk diameter

Rämö 2016) follows the theoretical maximum (Laasasenaho 1982) relatively closely in the case of small and large trees. About 250 mm breast-height diameter, the plywood log content computed from the taper curve of Laasasenaho (1982) is smaller than that taken from the yield table of Rämö and Tahvonen (2015, 2016; Tahvonen and Rämö 2016).

The yield reduction models of Mehtätalo (2002) have been composed separately for silver birch and white birch, whereas in harvesting operations they usually are not separated. Empirical observations in Figure 2 show that the plywood log content of trees of diameter less than 287 mm has been smaller than predicted for silver birch and greater for trees bigger than that. The relationship with the white birch is qualitatively similar but the transition appears at 237 mm diameter.

A general observation in Figure 2 is that the plywood log yield from birch is much smaller than the sawlog yield from spruce (Figure 1). This naturally agrees with regional and national wood supply statistics. Also, the reduction of the log yield from the taper-curve approximation (Laasasenaho 1982) is much greater in Figure 2, in comparison to Figure 1.

Pine sawlog proportion in trees of different sizes is shown in Figure 3. It is found that the yield table by Rämö and Tahvonen (2015, 2016; Tahvonen and Rämö 2016) departs the theoretical maximum (Laasasenaho 1982) due to the applied diameter resolution. Another slight difference is found in the vicinity of 250 mm breast-height diameter.

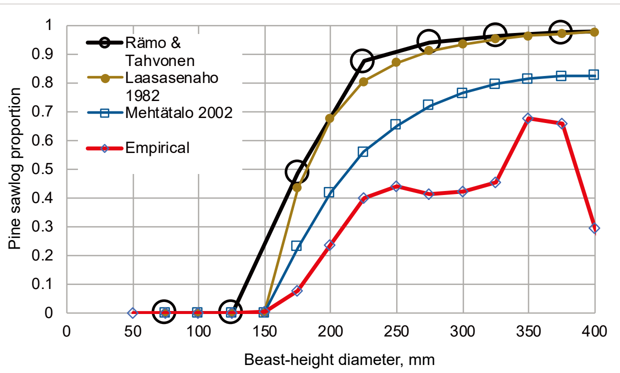


**Figure 3.** Pine sawlog proportion in the commercial section of tree trunks as a function of trunk diameter

The yield reduction models of Mehtätalo (2002), applied to the geometric sawlog yield gained from the taper curve (Laasasenaho 1982), yield sawlog contents greater than empirical data.

## Discussion

The sawlog and plywood log reduction model by Mehtätalo (2002) being grounded in National Forest Inventory, has taken no stance on any harvesting pattern to be applied. On the other hand, the results of harvester measurements do depend on the harvesting procedures. In thinnings, trees of lesser quality are often removed, the best trees being saved for final harvesting (Malinen et al. 2018). Correspondingly, deviations of the empirical observations from the inventory predictions possibly can be explained by the applied harvesting pattern.

In Figure 1, there is a total of 482 trees of breast-height diameter from 287 to 387 mm. Of these, 46% originated from thinnings, and 54% from clearcuttings. The total number of trees of diameter between 387 and 513 mm was 80, and 81% originated from clearcuttings. This possibly explains why the first mentioned diameter range shows sawlog contents smaller than the inventory-based prediction, and the latter diameter range larger sawlog contents. Empirical observations regarding trees of diameter from 197 to 287 mm closely agree with the inventory-based prediction (Mehtätalo 2002). The number of such trees in Figure 1 is 1,748 of which 23% originated from clearcutting.

An empirical power-law model was fitted to the data appearing in Figure 1. Again, the sawlog content of trees between diameter 300 and 400 mm was overestimated, and that of bigger trees was underestimated.

The difference in the sawlog content of spruce trees originating from clearcuttings and from thinnings is elaborated in Figure 4. The Figure confirms that the harvesting pattern in thinnings has aimed to remove trees of lesser quality. It is also found from Figure 4a that the distribution of the sawlog content in trunks from clearcuttings is very much skewed. Most of the trunks show a sawlog content slightly higher than the expected value. On the other hand, there is a wide distribution of sawlog contents less than the expected value, the latter obviously corresponding to trunks of quality deficiencies. In Fig. 4b, the distribution of sawlog content of thinning trunks appears to contain a strong binary component, containing many trees that do not yield any sawlog.

In Figure 2, there is a total of 129 trees of breast-height diameter from 287 to 413 mm. Of these, 71% originated from clearcuttings. The total number of trees of diameter between 187 and 287 mm was 764, and 41% originated from clearcuttings. This possibly explains why the first mentioned diameter range shows plywood log con-

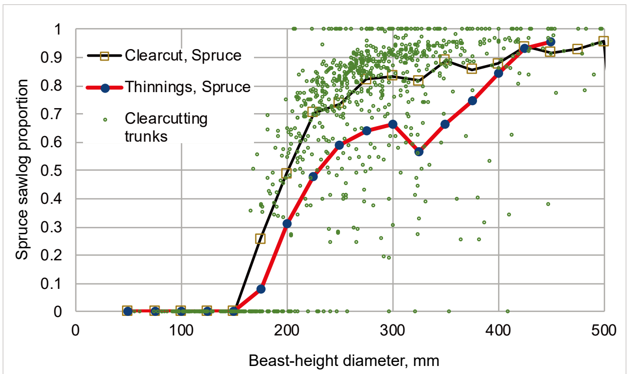


**Figure 4a.** Spruce sawlog proportion in the commercial section of tree trunks as a function of trunk diameter in thinnings and in clearcuttings, along with sawlog content of individual trunks from the clearcutting

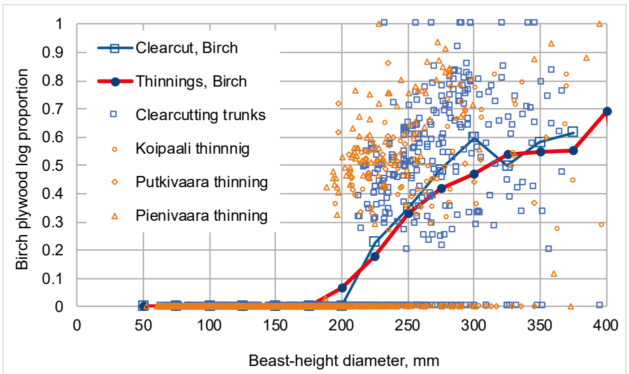


**Figure 5.** Birch plywood log proportion in the commercial section of tree trunks as a function of trunk diameter in thinnings and in clearcuttings, along with plywood log content of individual trunks

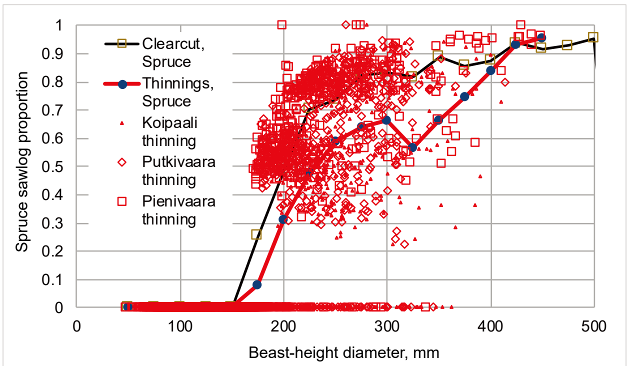


**Figure 4b.** Spruce sawlog proportion in the commercial section of tree trunks as a function of trunk diameter in thinnings and clearcuttings, along with sawlog content of individual trunks from the thinnings

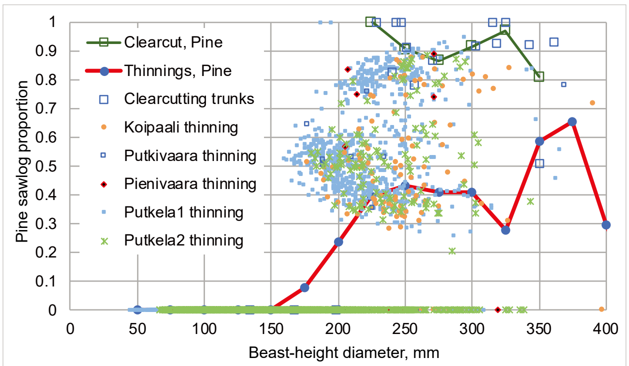


**Figure 6.** Pine sawlog proportion in the commercial section of tree trunks as a function of trunk diameter in thinnings and in clearcuttings, along with sawlog content of individual trunks

tents greater than the inventory-based prediction, and the latter diameter range smaller plywood log contents. It is also worth noting that plywood log content predicted based on inventory data (Mehtätalo 2002) clearly declines as a function of tree size, after the maximum. This is due to the existence of over-aged trees in the inventory data, however nonexistent in the empirical data.

The difference in the plywood log content of birch trees originating from clearcuttings and from thinnings is elaborated in Figure 5. The Figure indicates that there is no dramatic difference between clearcuts and thinnings. One can conclude that greater plywood log content in comparison to inventory data (Mehtätalo 2002) rather results from the absence of over-aged trees in the empirical data. Interestingly, Figure 5 shows that the plywood content distribution of clearcutting trees shows a strong binary component, unlike the spruce trunks in Figure 4. Such a binary component also is found in thinning trunks in Figure 5, the main differences being that the thinning trees have been predominantly smaller, and the binary component in the distribution is stronger.

In Figure 3, there is a total of 2,692 trees of breast-height diameter from 137 to 313 mm. Of these 0.4% originated from clearcuttings. The total number of trees of diameter between 313 and 363 mm was 21, of which 29% originated from clearcuttings. This possibly explains why the first mentioned diameter range shows sawlog contents smaller than the inventory-based prediction, and within the latter diameter range the predicted proportion is approached. It is worth noting that clearcutting compartments in the empirical data are considered too fertile for growing good-quality pine sawlogs. Consequently, a small number of good-quality pine trees have remained through thinnings to clearcutting. Figure 6 confirms that the sawlog content of pine trees in clearcuttings is much greater than in thinnings. Again, the distribution of sawlog content of thinning trunks appears to contain a strong binary component, many trees that do not yield any sawlog. The binary component is apparently stronger than in Figure 5 and much stronger than in Figure 4b.

A few earlier verifications of the sawlog reduction model by Mehtätalo (2002) have been conducted. Malinen et al. (2007) compared the result with those gained by bucking simulators. Interestingly, spruce sawlog content showed features qualitatively resembling those in Figure 1: small tree sawlog content was overestimated by the reduction model; large tree sawlog content was underestimated. Sawlog content of pine trees was always underestimated, but more the case of large trees. The latter trend, however, was the opposite with birch trees, in direct contradiction with Figure 2 of this paper. Further considering that the study of Malinen et al. (2007) discussed only stands ready for clearcutting, the bucking simulator study does not appear to be in concert with the empirical results of this paper.

It is of interest to which degree the deviation of the empirical results from the inventory-based predictions (Mehtätalo 2002) are due to stand characteristics and to which degree to harvesting patterns. Obviously, to some degree, the deviation has resulted from quality thinning, even thinning from below. Results might change if bad-quality trees would be removed in the first thinning and thinning from above would be applied later on. Sawlog and plywood log content from small trees probably would be closer to the inventory-based prediction. On the other hand, the value-reducing effect of over-aging, most pronounced in Figure 2, does not depend on selective harvesting, but rather on the timing of final harvesting.

## Conclusions

The yield of sawlogs and plywood logs from trees depends on product quality requirements and harvesting patterns, as well as local physical circumstances. Such factors vary in time, as well as by case. A case-specific trunk value model would be a favourable base for forest management. In the absence of such a value model, an inventory-based regional value model appears useful.

Any case-specific harvesting yield dataset is partially incomplete and may soon become outdated. Even if a local dataset would be available, it is beneficial to compare its outcome with a regional, inventory-based value model. A functional value model may be based on a combination of a private dataset and public inventory data.

## Acknowledgement

*The author is obliged to many individuals who contributed to technical arrangements. In particular, the contribution of Prof. Jori Uusitalo was invaluable in the analysis of harvester data. Risto-Matti Räsänen, Ari Haapalainen, Keijo Jormanainen, Tero Luukkainen and Tuure Korhonen kindly assisted in the collection of the yield data. This research was partially funded by Niemi Foundation.*

## References

**Boston, K. and Murphy, G.** 2003. Value Recovery from Two Mechanized Bucking Operations. *Southern Journal of Applied Forestry* 27(4): 259–263.

**Carey, P.B. and Murphy, G.E.** 2005. Mechanised versus manual log-making in two Chilean Pinus radiata stands. *New Zealand Journal of Forestry Science* 35(1): 25–34. https://doi.org/10.1108/AFR-02-2020-0028.

**Gaffrey, D., Sloboda, B. and Matsumura, N.** 1998. Representation of tree stem taper curves and their dynamic, using a linear model and the centroaffine transformation. *Journal of Forest Research* 3: 67–74. https://doi.org/10.1007/BF02760304.

**Huong, V.D., Mendham, D.S., Beadle, C., Hai, N.X. and Close, D.C.** 2020. Growth, physiological responses and wood production of an *Acacia auriculiformis* plantation in southern Vietnam following mid-rotation thinning, application of phosphorus fertiliser and organic matter retention. *Forest Ecology and Management* 472: 118211.

**Kilkki, P. and Varmola, M.** 1981. Taper curve models for Scots pine and their application. *Acta Forestalia Fennica* 174: 7621. https://doi.org/10.14214/aff.7621.

**Kärenlampi, P.P.** 2019. Harvesting design by capital return. *Forests* 10(3): 283. https://doi.org/10.3390/f10030283.

**Kärenlampi, P.P.** 2020a. Net present value of multiannual growth in the absence of periodic boundary conditions. *Agricultural Finance Review* 81(1): 39–50.

**Kärenlampi, P.P.** 2020b. Estate-Level Economics of Carbon Storage and Sequestration. *Forests* 11(6): 643. https://doi.org/10.3390/f11060643.

**Laasasenaho, J.** 1982. Taper curve and volume functions for pine, spruce and birch. *Communicationes Instituti Forestalis Fenniae* 108, 74 pp.

Luke. 2021. Tilastopalvelu [Statistical service]. Available online at: https://www.luke.fi/avoin-tieto/tilastopalvelu/.

**Malinen, J., Kilpeläinen, H., Piira, T., Redsven, V., Wall, T. and Nuutinen, T.** 2007. Comparing model-based approaches with bucking simulation-based approach in the prediction of timber assortment recovery. *Forestry: An International Journal of Forest Research* 80(3): 309–321. https://doi.org/10.1093/forestry/cpm012.

**Malinen, J., Kilpeläinen, H. and Verkasalo, E.** 2018. Validating the predicted saw log and pulpwood proportions and gross value of Scots pine and Norway spruce harvest at stand level by Most Similar Neighbour analyses and a stem quality database. *Silva Fennica* 52(4): 9972. https://doi.org/10.14214/sf.9972.

**Mehtätalo, L.** 2002. Valtakunnalliset puukohtaiset tukkivähenysmallit männylle, kuuselle, koivuille ja haavalle. [National sawlog reduction models for pine, spruce, birch and aspen]. *Metsätieteen aikakauskirja* 4/2002: 575–591 (in Finnish).

**Ngugi, M.R., Neldner, V.J., Ryan, S., Lewia, T., Li, J., Norman, P. and Mogilski, M.** 2018. Estimating potential harvestable biomass for bioenergy from sustainably managed private native forests in Southeast Queensland, Australia. *Forest Ecosystems* 5: 6.

**Nordmark, U.** 2005. Value recovery and production control in bucking, log sorting, and log breakdown. *Forest Products Journal* 55(6): 73–79.

**Oikarinen, M.** 1983. Etelä-Suomen viljeltyjen raudus-koivikoiden kasvatusmallit [Suumary: Growth and yield models for silver birch (*Betula pendula*) plantations in southern Finland. *Communicationes Instituti Forestalis Fenniae* 113, 75 pp. (in Finnish with English summary). Available online at: http://urn.fi/URN:ISBN:951-40-0619-4.

**Ojansuu, R. and Maltamo, M.** 1995. Sapwood and heartwood taper in Scots pine stems. *Canadian Journal of Forest Research* 25(12): 1928–1943.

**Raulo, J.** 1977. Development of dominant trees in *Betula pendula* Roth and *Betula pubescens* Ehrh. plantations. Seloste: Viljeltyjen raudus- ja hieskoivikoidenvaltapuiden kehitys. *Metsaentutkimuslaitoksen-Julkaisuja (Finland). Communicationes Instituti Forestalis Fenniae* 90.4: 1–15.

**Rämö, J., and Tahvonen, O.** 2015. Economics of harvesting boreal uneven-aged mixed-species forests. *Canadian Journal of Forest Research* 45(8): 1102–1112. https://doi.org/10.1139/cjfr-2014-0552.

**Rämö, J., and Tahvonen, O.** 2016. Optimizing the Harvest Timing in Continuous Cover Forestry. *Environmental and Resource Economics* 67(4): 853–868. https://doi.org/10.1007/s10640-016-0008-4.

**Saarinen, N., Kankare, V., Pyörälä, J., Yrttimaa, T., Liang, X., Wulder, M.A., Holopainen, M., Hyyppä, J. and Vastaranta, M.** 2019. Assessing the Effects of Sample Size on Parametrizing a Taper Curve Equation and the Resultant Stem-Volume Estimates. *Forests* 10(10): 848. https://doi.org/10.3390/f10100848.

**Spinelli, R., Magagnotti, N. and Nati, C.** 2011. Work quality and veneer value recovery of mechanized and manual log-making in Italian poplar plantations. *European Journal of Forest Research* 130: 737–744. https://doi.org/10.1007/s10342-010-0464-2.

**Strub, M., Cieszewski, C. and Hyink, D.** 2005. Self-referencing Taper Curves for Loblolly Pine. In: McRoberts, R.E., Reams, G.A., Van Deusen, P.C., McWilliams, W.H. and Cieszewski, Ch.J. (Eds.) Proceedings of the Fourth Annual Forest Inventory and Analysis Symposium; Gen. Tech. Rep. NC-252. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station, p. 59–64. Available online at: https://www.fs.usda.gov/treesearch/pubs/14388.

**Tahvonen, O. and Rämö, J.** 2016. Optimality of continuous cover vs. clearcut regimes in managing forest resources. *Canadian Journal of Forest Research* 46(7): 891–901. https://doi.org/10.1139/cjfr-2015-0474.

**Tahvonen, O., Pukkala, T., Laiho, O., Lähde, E. and Niinimäki, S.** 2010. Optimal management of uneven-aged Norway spruce stands. *Forest Ecology and Management* 260(1): 106–115. https://doi.org/10.1016/j.foreco.2010.04.006.

**Vuokila, Y.** 1956. Etelä-Suomen hoidettujen kuusikoiden kehityksestä. Viljeltyjen havumetsiköiden kasvatusmallit [On the development of managed spruce stands in Southern Finland]. *Communicationes Instituti Forestalis Fenniae* 48: 1 (in Finnish).

**Vuokila, Y.** 1960. Männyn kasvusta ja sen vaihteluista harventaen käsitellyissä ja luonnontilaisissa metsiköissä, 38 pp., kuv. [On growth and its variations in thinned and unthinned Scots pine stands]. *Communicationes Instituti forestalis Fenniae* 52: 7 (in Finnish).

**Vuokila, Y. and Väliaho, H.** 1980. Viljeltyjen havumetsiköiden kasvatusmallit [Growth and yield models for conifer cultures in Finland]. *Communicationes Instituti forestalis Fenniae* 99: 2 (in Finnish).