Identifying training needs for the implementation of Continuous Cover Forestry in Sweden

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Abstract

In recent decades, continuous cover forestry (CCF) has been (re-)discovered as an important toolbox for promoting biodiversity, helping to deliver a range of ecosystem goods and services as well as to satisfy the needs of various stakeholders. CCF is based on ecological principles and one of its most important tenets is the abandonment of large-scale clearfelling. Despite the demand of various stakeholders to increase the share of productive forest land managed according to CCF in Sweden, CCF has been rarely used in the country to date and knowledge about its methods is lacking. Frame-tree based thinnings are one important part of CCF, since they are useful for promoting complex stand structures and for regenerating stands without clearfelling. So-called frame trees, that correspond to the silvicultural objective(s) of a forest stand are selected and permanently marked. These trees exclusively profit from all silvicultural operations and are to remain in the forest until final harvest or natural death. Immediate competitors in the vicinity of these frame trees are then selected for eventual removal. Marteloscopes are forest research plots where all trees are measured and numbered. Over the last twenty years marteloscopes have become an important component of CCF training and are widely used in many countries. I established a marteloscope in the Svartberget experimental park, close to Umeå in northern Sweden and carried out an experiment involving 13 test persons with and without forestry background. The objective of this experiment was to investigate, whether the participants would be able to select trees for a frame-tree based thinning without prior practical training. I measured the participants' agreement in tree selection and studied to what degree their tree selection corresponded to the theory of frame-tree based thinnings. Since the silvicultural and the experimental situation in Sweden today is similar to that in Great Britain twenty years ago, I contrasted the results of the Swedish experiment with the results of 26 marteloscope experiments carried out in Great Britain. Constructing such a statistical contrast is a useful step for identifying specific training needs when introducing CCF to Sweden. The overall agreement was rather low in all experiments. The participants' tree selection in the Swedish experiment was closer to the theory of frame-tree based thinnings than it was for the British experiments, especially in case of competitor trees. Still, training is needed especially with regard to frame tree resilience and appropriate thinning intensity in the future. Additional experiments with larger and more diverse groups of participants could lead to further, more differentiated results and would allow comparisons between different groups of persons involved in forest management.

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Abbreviations

CCF	Continuous Cover Forestry
G	Basal area
DBH	Diameter at Breast Height (1.3m)
RFM	Rotation Forest Management
RMSE	Root Mean Square Error
QMD	Quadratic Mean Diameter

1. Introduction

The dominant forest management paradigm in Sweden is rotation forest management (RFM), which is based on growing even-aged more or less monocultural stands and clearfelling them as soon as the planned rotation age is reached. In Northern and Central Sweden, RFM is predominantly based on two tree species, Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H. Karst.) (Nilsson et al. 2021).
Over the past decades, this management paradigm led to great financial revenues, as its main goal was wood production for industrial supply. In 1993, this production focus changed as part of a new forest policy introducing an environmental goal with a weight equal to the production goal. As a consequence of this policy change, environmental consideration measures such as certain numbers of retention trees on clearfelled areas have been introduced (Lindahl et al. 2017). Despite these laudible advances, recent research points to some weaknesses of current forest management practice which include progressing biodiversity loss, working against natural disturbance regimes and disadvantaging Sami reindeer herders (Kuuluvainen et al. 2012; Naumov et al. 2018; Svensson et al. 2019).
Several studies mention continuous cover forestry (CCF) as a promising alternative to RFM, since it has been proven to be a useful tool for increasing habitat availability, following natural disturbance regimes more closely and enhancing multifunctionality in production forests (Koivula et al. 2014; Peura et al. 2018; Eyvindson et al. 2021). In addition to that, forests managed with CCF inhibit a more complex structure, which makes them more resilient against storm damage (Hanewinkel et al. 2014). CCF is not a new idea, but it has been present in different parts of Central Europe and North America since the late 19th century. Depending on the region and time, there are many different definitions and (semi) synomyms for CCF, which emphasize different aspects. The dominant feature of CCF clearly is the continuity of woodland conditions, i.e. the need to relinquish large-scale clearcuts. Next to that, mixed species forests with different tree sizes, individual-tree silviculture, consideration of site limitations and the protection of (rare) habitats and endangered species form some of the core components of CCF (Pommerening & Murphy 2004).

At present, several stakeholders in Sweden encourage or even demand an increase of the share of productive forest land managed by CCF. Among those stakeholders is the FSC, who revised its standard for Sweden in 2019 to include additional 5% of the forest land to be managed to enhance conservation and/or social values as primary goals (Sweden, F.S.C. 2020). Another stakeholder is the

EU, who promotes the use of CCF to “help ensure long-term environmental and socio-economic viability of forests” in their forest strategy for 2030 (European Commission 2021). Recently, the Swedish Forestry Agency (Skogsstyrelsen) has committed to facilitating the transformation of 20% of Sweden’s forests to CCF (Appelqvist et al. 2021). Despite that, forestry graduates and professionals are not well prepared to implement CCF, since RFM has so far dominated the forest industry and forestry education (Hertog et al. 2022). This has resulted in a need for CCF training.

Marteloscopes are a useful tool to train foresters in applying different thinnings and other silvicultural methods. They could be used to train forestry staff in applying thinnings for RFM as well, but in practice they are mostly used for CCF trainings (Pommerening & Grabarnik 2019). Marteloscopes are similar to plots used in forest research and can have a size of up to one or two hectares, where all trees or a subset of trees are measured and mapped (Schuck et. al. 2015). In addition to standard individual-tree variables like stem diameter, total tree height, height to crown base, tree identification number and tree species, it is also possible to record estimated tree quality, microhabitats or other additional information for each tree. Within a marteloscope, the tree ID is usually painted well-visibly on two sides of each tree to facilitate the activites carried out in the plot. Marteloscopes can be used for many different purposes (Pommerening and Grabarnik, 2019), like exchanging knowledge and experience on forest management and related issues with a wider audience, for dissemination of research with management implications and for informing policy-makers etc. (Schuck et al. 2015). However, the main purposes of marteloscopes are silvicultural training and human tree-selection research, as it is already indicated by the name “marteloscope”. The name originates from the French term “martelage”, which translates to “marking” (Pommerening & Grabarnik 2019). In the latter approach, researchers study the behaviour of humans selecting trees and their interaction with trees. They do so by inviting different groups of people to experiments in one or several marteloscopes, where the participants receive instructions on how to select trees for e.g. a specific thinning relevant for CCF. The participants’ note down their tree selection and the researchers later analyse these tree-selection data using specialized statistics. The participants’ choice reveals their current state of silvicultural knowledge. (Vítková et al. 2016; Pommerening et al. 2018).

1.1 Literature review

There are currently many training and research activities associated with marteloscopes around the globe (Pommerening et al., 2018), including studies with regard to differences in the behaviour of people when it comes to tree selection for varying purposes, e.g. for thinnings or for conservation. I selected some exemplary studies to illustrate how research on human tree selection behaviour is done and in which countries it has been applied so far.

Almost thirty years ago, researchers for the first time found in scientific experiments, that persons involved in forest management do not select trees exactly according to instructions given in textbooks or management plans. In addition to that, there is a high amount of variation in the participants' tree selection behaviour (Zucchini & Gadow 1995; Füldner et al. 1996; Daume et al. 1998).

Both the deviation of individuals from norms and the lack of agreement among forestry staff vary from country to country and much depends on the direction forestry has taken in different regions and on the quality of forestry education. Consequently, the research done in the studies presented below has been taking place in very different silvicultural contexts, i.e. both in stands managed with RFM and with different variants of CCF.

In Germany, Cosyns et al. (2018) conducted an experiment focussing on the selection of habitat trees, involving trainers for silviculture, forestry students and district foresters. All participants selected habitat trees and the habitat value varied considerably. Silviculture trainers, i.e. forestry staff employed to transfer new silvicultural knowledge from research to practice by training forestry personnel in the field, showed more consistent results than the forestry students or the district foresters. Optimal habitat tree selection therefore seems to require a certain amount of training. Another experiment by Cosyns et al. (2020) looked at different strategies in habitat-tree selection between foresters and conservationists and found that conservationists select habitat trees with a larger diameter and at higher opportunity cost, i.e. they considered commercially valuable trees more frequently as habitat trees than foresters.

Eberhard & Hasenauer (2021) compared four different methods of tree selection: tree selection by forest managers, tree selection by harvester drivers, a random tree selection by a forest simulator and a control simulation where no trees were selected. The experiments took place in Norway spruce stands located in Lower Austria. The authors aimed to find out, if the task of tree selection for thinnings could be delegated to harvester drivers to reduce costs. They found that for 70% of the trees, forest managers and forest machine operators made identical choices, which is an unexpectedly high agreement. They concluded that having trained harvester drivers implement the tree selection would be a cost-efficient method in Austria.

A study conducted in Italy involved three different groups, foresters, agronomists, who sometimes act as substitutes for foresters, and harvester drivers. The 64 test persons could select between five different, but predefined, reasons for their decision to remove a tree: salvage logging, soil protection, regeneration, stand improvement or profit. The authors did not find any differences in the selection behaviour between these groups, but rather among the individuals within the groups, which might be due to differences in experience in tree marking or due to personal preferences. They concluded that delegating tree marking tasks to properly trained harvester drivers might be possible (Spinelli et al. 2016).

Bravo-Oviedo et al. (2020) conducted an experiment involving two experts and eight groups of three participants each with a combination of these pairs of characteristics: male or female, forester or non-forester, above 40 years of age or below 40 years of age. Within a group of participants, these characteristics were homogenuous, i.e. there was a group of female foresters above the age of 40, etc. The participants should select trees for two different silvicultural prescriptions, a “business-as-usual” approach which is the traditional method in the area, and a “systemic” approach, i.e. an Italian variant of CCF. The authors found that foresters rather marked trees according to a method they know well, while non-foresters did not distinguish between the methods. Gender had a more important effect than age when it came to the average thinning intensity and the level of agreement for the “business-as-usual” approach.

As in most countries, also in the UK and Ireland, experiments in marteloscopes have been used to support the transformation from RFM to CCF during the past twenty years. Pommerening et al. (2018, 2021) investigated the behaviour of test persons marking trees for two important thinning types, i.e. low and crown thinnings. In low thinnings, smaller trees are removed, while in crown thinnings, the forest manager focusses on larger, dominant and subdominant, trees. Both thinning types can be implemented either as *global* thinnings, where the whole stand is taken into account, or as *local* thinnings, which focus on the thinning for the benefit of a small number of special trees within the stand.

The main focus of the authors was the *local* variant of crown thinning, which is especially relevant to CCF and frequently referred to as “local crown thinning” or “frame-tree based thinning”. Such a thinning is usually implemented in two steps: first, the forest manager defines small groups of trees within the stand, which typically consist out of 1-5 trees, depending on the structure and basal area of the stand. Within these groups, one frame tree is selected that corresponds to the silvicultural objectives of the stand, e.g. high quality timber, high aesthetic value or high conservation value. This tree is maintained until final harvest or for the tree’s entire life span, depending on the silvicultural objectives. These frame trees exclusively benefit from silvicultural operations and thinnings only take place in the neighbourhood of these trees. Frame trees do not necessarily need to occur throughout the stand. In contrast to a *global* crown thinning, there is no management if in a specific part of the stand there is no frame tree.

As a second step, for each frame tree, one to three competitors in the immediate neighbourhood of the frame tree are selected for removal. These competitors usually are dominant or sub-dominant trees that are likely to compete with the chosen frame tree within the next five to ten years. Frame trees are typically selected at a dominant tree height of around 12 meters and marked permanently. For every subsequent thinning, zero to three competitors are removed around each frame tree to promote the growth and development of those trees. When the stand is young or the frame trees have a comparatively small stem diameter, more competitor basal area per frame tree is removed, i.e. the thinning intensity is heavier in early development.

Using local crown thinnings, it is possible to combine several silvicultural goals in one stand. One could, for example, select a certain number of frame trees with the aim to promote biodiversity, while another set is selected to promote high-quality timber. In addition to that, a stand managed with local crown thinnings usually develops several timber assortments, which can be flexibly harvested over a longer period of time and sold according to market demands, as soon as the anticipated target diameters are reached (Pommerening & Grabarnik 2019; Bartsch et al. 2020).

Recent research from Ireland revealed that laypersons, i.e. people without prior formal forestry education, performed better in selecting trees for a local crown thinning than trained foresters, after receiving respective training. This is most likely due to the experience the trained foresters made in the past, which focussed on RFM and strongly influenced their behaviour (Vítková et al. 2016). Another study carried out in Great Britain looked at training participants with a forestry background that did not have prior experience in local crown thinnings. They achieved a significantly higher agreement in the selection of frame trees than in the selection of frame-tree competitors. The latter appears to be more challenging and therefore requires more attention in the training process (Pommerening et al. 2021). Pommerening et al. (2018) investigated how much agreement foresters achieved when performing low thinnings and crown thinnings in 36 experiments across Great Britain. They found the agreement in thinnings from below to be much higher than in thinnings from above. None of the three studies mentioned above found any significant effect of gender on the tree selection in British and Irish experiments.

Twenty years ago, Great Britain and Ireland faced a situation that is comparable to today's situation in Sweden. Policy makers decided to promote the transformation of the country's plantation forests towards CCF, which met the forestry staff involved rather unprepared. Experience from those countries shows, that the transformation to CCF requires goal-oriented trainings (Vítková et al. 2016; Pommerening et al. 2018). Due to the dominance of RFM in both countries and the resemblance of the challenge to transform forests managed with RFM to CCF, it may be a good idea to study the British experience and research results to learn potential lessons for future activities concerning CCF in Sweden. This can help to avoid costly mistakes and can potentially accelerate the transformation and training process (Soucy et al. 2016). The British experiments and the Swedish one are comparable in a sense that the objectives and the method were the same. (Kruse et al. 2023).

1.2 Objectives of the master thesis

Based on the results of the studies in Great Britain and Ireland and in order to address the potential outlined above, the three goals of this master thesis are:

1) Establishing a 2500m^2 marteloscope in the Svartberget Experimental Park, north-west of Umeå
2) Conducting a pilot experiment introducing the local crown thinning method and to measure, if the participants are able to select trees for a local crown thinning without previous practical training.
    a. Hypothesis 1: Not all participants will manage to select trees for a local crown thinning.
    b. Hypothesis 2: The agreement in tree selection among the test persons is low.
    c. Hypothesis 3: Non-foresters are performing better than foresters.
    d. Hypothesis 4: There is no difference between male and female participants.
3) Benchmark the results of the Svartberget marteloscope experiment against results of experiments for local crown thinnings conducted in Great Britain

2. Materials and Methods

2.1 Marteloscope establishment

For this study I established a marteloscope of 50 m x 50 m during early autumn of 2022 in the Svarberget experimental park, (64°, 24’ N, 19° 78’ E, see Fig. 1), close to Vindeln, which is approximately an hour’s drive north-west from Umeå. We set the marteloscope up according to the protocol described in Pommerening & Grabarnik (2019). The establishment of the marteloscope was the result of a cooperation between the SLU field staff at Svartberget and myself. For each tree, we recorded the species, stem diameter at breast height (DBH), i.e. the tree stem diameter at 1.3 m above ground level, total tree height and height to base of crown. The latter measure is defined as the first whorl of branches from the ground with green needles in case of conifers and the first main branch alive from the forest floor for deciduous trees (Bartsch et al. 2020). We labelled the trees in a preliminary fashion, using weather-proof paper and small ribbons with plastic digits indicating the tree identification number. The data has been processed with MS Excel and R, version 4.2.1 (R Core Team 2022).

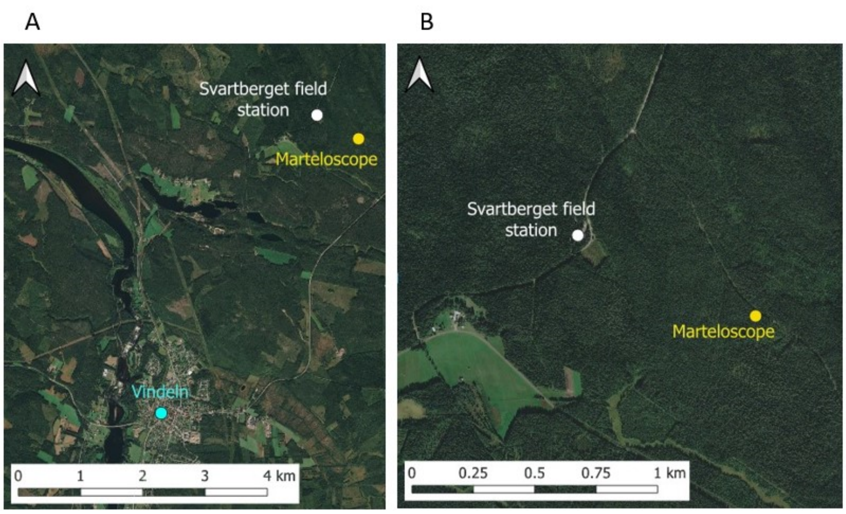

Fig. 1. Location of the Svartberget martelocope. The Svartberget field station and the marteloscope around 5 km North-East of Vindeln (A) and the marteloscope ca. 700 m away from the field station (B).

2.2 Description of the mateloscope stand at Svartberget

The site of the marteloscope has a mean temperature of 1.8°C (-9.5°C in January and +14.7°C in July) and a mean annual precipitation of 614 mm. The elevation is around 120°m a.s.l. The marteloscope in the Svartberget experimental park has a size of 2500°m^2 and is located at a distance of approximately 30 meters from the nearest forest road. We recorded 308 trees above a diameter threshold of 4 cm of three species, *Pinus sylvestris* L.*, Picea abies* (L.) H. Karst. and *Betula pendula* Roth. The dominant tree species is Scots pine with a basal-area share of 81%, followed by Norway spruce with 14% and birch with 5% (Fig. 3). The basal area of the stand counts 26.2 m^2/ha, which is rather low for the 77-year-old stand. Most Scots pine trees fall into the size class of small wood (20-35 cm). The quadratic mean diameter (d_g) for Scots pine is 22.2 cm, while the smallest Scots pine has a DBH of 7.0 cm and the largest one of 33.4 cm, which indicates a high variability in DBH. The trees have been planted in a clearcut area with 3417 1-year-old seedlings per hectare in 1947, while some single Scots pines and birches simultaneously acted as seed trees. The seed trees were harvested in 1953. A precommerical thinning reduced the number of trees to approximately 1800 trees per hectare in 1970 (Larsson 2023). At present, most of the Scots pine stems in the marteloscope show only few lower branches.The crown length of the Scots-pine trees is medium with a mean crown ratio of 0.47. Most crowns of the Scots-pine trees are well-developed, however, some are one-sided or squeezed due to lateral competition by other trees. Some damage, e.g. cracks and scars, is visible on the surface of some of the stems. The Norway-spruce trees are admixed in a single-tree fashion and appear to show a faster growth than Scots pine. For Norway spruce, the tree size varies from young growth to small wood. The d_g of Norway spruce is 15.4 cm, the smallest Norway-spruce tree has a DBH of 4.3 cm, the largest one of 28.8 cm, showing a high variation in stem diameter as well. All Norway spruces have long crowns with a mean crown ratio of 0.79, partly the crowns extend almost to the ground. The Norway-spruce crowns are large and equally well developed towards all sides. Large damage to the crowns is not visible. In the marteloscope, canopy closure varies between loose and light and many trees, including Norway spruce, are potentially of good quality. Apart from one tree, birch does not occur in the main canopy layer. There is scattered birch regeneration in some of the more open areas of the stand. Birch has most likely originated from natural regeneration and has a d_g of 6.0 cm with one exceptionally big stem that has a stem diameter of 25.1 cm. The topography of the forest stand is flat and the soil is stony and wet towards the Eastern side. The shrubs *Vaccinium myrtillus* L. and *Vaccinium vitis-idaea* L. can be found on the forest floor throughout the marteloscope.

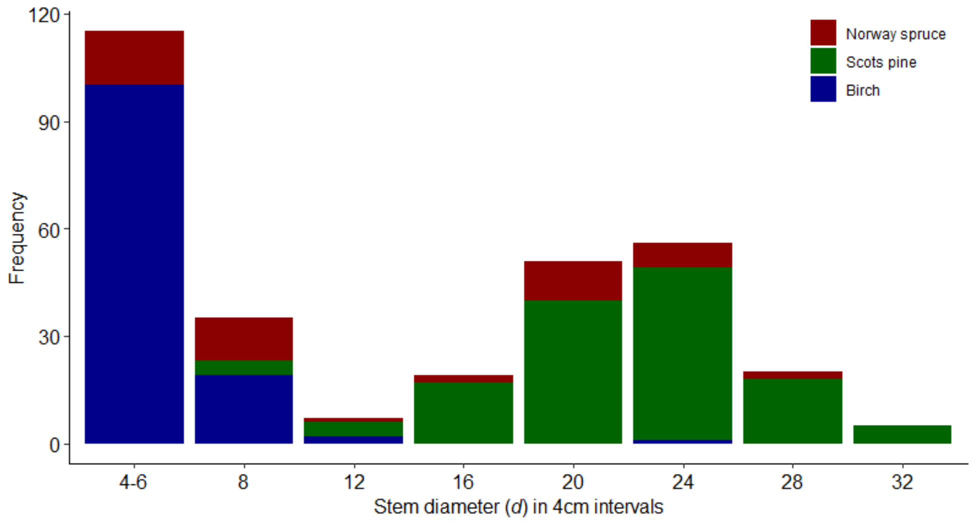

Fig. 2. Stacked diameter distribution of the Svartberget marteloscope stand. The diameter classes have a width of 4 cm, except from the smallest class, where trees with a stem diameter between 4 cm and 6 cm are included.

The empirical diameter distributions of the three tree species follow different patterns (see Fig. 2). Scots pine shows the typical bell-shaped distribution of an even-aged pure stand with a slight left skew due to some smaller trees. For birch, the stem-diameter distribution resembles a (negative) exponential shape, which is typical of forests in the regeneration or colonisation phase. Norway spruce makes up a rather small fraction of the trees and shows a tendency towards a flat uniform distribution. Comparing the conspecific diameter distributions with that of the stand with all species pulled together, it seems evident that the stand started off as an even-aged stand with a mixture of Scots pine and Norway spruce, but has subsequently been colonised by birch, but also by natural Norway spruce and Scots pine regeneration.

Table 1. Basic forestry statistics relating to the marteloscope stand. N – number of trees, d_{min} and d_{max} – minimum and maximum diameters in breast height, d_g – quadratic mean diameter, G [m^2] – basal area on the marteloscope site, G [m^2/ha] – basal area per hectare, G [%] – proportion of basal area in the marteloscope, v_d – coefficient of variation of stem diameter

Species	Birch	Scots pine	Norway spruce	All
N	122	136	50	308
d_{min} [cm]	4.0	7.0	4.3	4.0
d_{max} [cm]	25.1	33.4	28.8	33.4
d_g	6.0	22.2	15.4	16.4
G [m^2]	0.34	5.28	0.93	6.55
G [m^2/ha]	1.36	21.10	3.72	26.18

G [%]	5.2	80.6	14.2	100.0
v_d	0.38	0.21	0.62	0.63

The stand is easily accessible and has one abandoned extraction rack running through the North-Eastern corner. We have chosen this stand, since it appears to be in a suitable condition to initiate the transformation from RFM to CCF. More precisely, the stand has a sufficient amount of stable trees, i.e. trees with a *h/d* (tree height in meters devided by tree diameter in centimeters) below 80. These trees are able to remain in the stand for a time far longer the usual rotation, what is necessary to achieve an irregular forest structure (Schütz 2001). In addition to that, scattered natural regeneration of different heights is already present in the stand, what is a good starting position for a transformation to CCF.

Fig. 3. Impressions of the stand. Mixture of Scots pine and Norway spruce (A). Natural birch regeneration on the forest floor (B).

2.3 British marteloscope sites and experiments

The results of the experiment conducted in the Svartberget martelocope are compared to the results of 26 local crown thinning experiments carried out in 14 different marteloscopes in Great Britain. Most of those stands are dominated by *Picea sitchensis* (Bong.) Carr., *Larix × marschlinsii* Coaz, *Larix kaempferi* (Lamb.) Carr. and *Pinus sylvestris*. All marteloscopes are located in stands which were originally planted as even-aged monocultures. Sometimes, other species have established themselves as well in the meantime, but they were not part of the experiment instructions and make up only a small share of the basal area. There are two marteloscopes with other main tree species, one of them is dominated by *Fagus sylvatica* L. and the other one is situated in a *Picea abies* stand. Except from one marteloscope with a size of 0.133 ha, all British marteloscopes have a size of 0.1 ha. The average basal area across all marteloscopes is higher in the British marteloscopes compared to the one at Svartberget. The only British marteloscope showing a basal area similar to Svartberget is Black Isle (Pommerening et al., 2021). The experiments conducted in Great Britain involved 285 test persons, 95% of them have been employed by the state forest service. They were working in different roles, such as machine operators, work supervisors, forest managers and woodland officers. The remainder of the test persons were forest contractors. In each experiment, between 6 and 20 test persons were asked to mark trees for a local crown thinning, i.e. to select frame trees and in a second step mark competitors around this frame tree (Pommerening et al. 2021).

2.4 Conducting and analysing the experiment

The experiment in the Svartberget experimental park involved 13 test persons, who participanted in three subgroups on three different days within two weeks. All participants were working at the Svartberget experimental park in different functions. Five of them had a forestry background, eight of them did not. Five of them were female, eight participants were male. Each time, the experiment took around two and a half hours to complete. As part of the experiment, I provided a short, twenty-minute introductory indoor and outdoor training seminar. Throughout the indoor part of the seminar, I introduced the participants to the concept of local crown thinnings. Afterwards I exposed the test persons to a nearby stand with characteristics similar to those in the marteloscope. I explained the concept of frame-tree based thinnings by showing examples of how to select frame trees and their competitors. At the same location, the tree-marking sheets were handed out and the participants had the chance to ask questions. The task was to

a) Select approximately 25 frame trees with a distance of ± 10 meters between them,
b) Favour a mixture of Scots pine and Norway spruce trees and to consider the chosen species composition in the selection of frame trees,
c) Select between 0-3 competitors per frame tree.

The marking sheet included the task and some additional instructions of how to record the selected trees. Otherwise the paper was deliberately left blank (see

Appendix. 1) so that the marking sheet would influence the test persons' tree selection behaviour as little as possible. The only stand information given to the participants was the absolute number of trees above a diameter threshhold of 4 cm in the marteloscope, i. e. 308. The participants were free to take as much time as they wanted to complete the experiment, but they were asked not to communicate with each other during the experiment. This was a precaution to limit any possibility of mutual influencing. As another precaution, the test persons started out from different corners of the marteloscope plot (Vítková et al. 2016). Additional metadata such as gender and forestry background of the participants were recorded. We had a brief feedback session directly after the experiment in the forest. Each test person's personal results of the tree marking were sent to them individually by e-mail after completing the analyses.

The participants' tree selections were transferred to MS Excel and converted to a binary format, where 1 denotes that a tree has been selected and 0 that the corresponding tree has not been selected. These data were then pooled across all participants, converted to an ASCII file and processed in R (R Core Team 2022). Using the metadata, the data were post-stratified and separately analysed by groups such as male and female participants as well as foresters and non-foresters to detect differences between groups. Given the comparatively low number of participants the statistical analysis is limited.

2.4.1 Conformity numbers

Within a group of test persons in a marteloscope experiment, I want to test how strong a single test person's tree selection complies with the general selection tendency of the group. Stoyan et al. (2018) proposed a "conformity number" c_i to measure this compliance (Eq. 1).

$$c_i = \frac{1}{n_i} \sum_{j=1}^{n} \mathbf{1}_{X_i}(j) \cdot s_j \text{ for } i = 1,2, \dots, r \tag{1}$$

In Eq. (1), c_i is the absolute conformity number, *r* denotes the number of test persons in the experiment, n_i – is the number of trees selected by the test person *i*, n refers to the number of trees in the marteloscope, s_j denotes the number of times tree *j* has been selected by the test persons of the experiment. $\mathbf{1}_{x_i}(j)$ is 1 if a test person selects this tree, if s/he does not select this tree, it is 0.

The conformity number c_i represents the mean of the numbers of test persons who selected the same trees that have been chosen by test person *i*. For better comparison, Stoyan et al. (2018) recommend the use of the relative conformity number c_i', Eq (2).

$$c'_i = \frac{c_i}{C_i} \tag{2}$$

C_i simulates an opportunist that selects the same number of trees as test person *i*, but selects the "most popular" trees, i.e. the ones with the largest s_j Eq. (3).

$$C_i = \frac{1}{n_i}\sum_{j=1}^{n} s_j \text{ for } i = 1,2,\dots,r \tag{3}$$

In Eq. (3), C_i is the conformity number of the opportunist, *r* represents the number of test persons in the experiment, n_i is the number of trees selected by the test person *i*, s_j denotes the number of times tree *j* has been selected and n refers to the number of trees in the marteloscope.

The relative conformity number c_i' can take values between 0 and 1. The closer the number is to one, the higher the compliance with the selection tendency of the group. An arithmetic mean value and a coefficient of variation of all relative conformity numbers of a group of test persons can give information about the homogeneity of selection behaviour within the group.

2.4.2 Fleiss' Kappa

The degree of agreement among several participants can be measured using Fleiss' Kappa, κ. This measure is based on pairwise comparisons of the marks that individual trees get from different test persons. Fleiss' Kappa usually takes values between 0 and 1. The closer the value is to 1, the higher is the agreement among the test persons (Pommerening et al. 2018). Stoyan et al. (2018) suggested the values given in Table 2 for the interpretation of kappa.

Table 2. Interpretation of the Fleiss kappa characteristic.

κ	**Interpretation**
< 0.10	Poor agreement
0.10 – 0.33	Slight agreement
0.33 – 0.50	Fair agreement
0.50 – 0.67	Moderate agreement
0.67 – 0.90	Substantial agreement
≥ 90	Almost perfect agreement

In contrast to the conformity numbers, κ is an agreement summary characteristic, allowing direct comparison of the agreement between different groups of participants in a single experiment or between several experiments.

2.4.3 Rating and marking bar charts

Rating and marking bar charts provide information about the active and passive tree selection behaviour of test persons participating in an experiment. The rating bar chart relates to *active selection behaviour*, since it depicts the result of the test persons' action. It shows how many trees a test person has selected. The test persons are ranked according to the proportion of trees (P_N), they selected, which features on the *x*-axis of the bar chart. There are as many bars in the rating bar chart as there are participants in the experiment (Pommerening & Grabarnik 2019).
A marking bar chart provides information about *the passive selection behaviour* of the participants. It shows how many times a tree has been selected. Either all test persons select a certain tree, i.e. they "mark" it, or some of the participants select that tree or none of them selects this particular tree. That means a tree can receive between 0 and as many marks as there are participants. As a consequence $r + 1$ bars are required on the x-axis. Assuming there are 10 participants, a tree can receive between 0 and 10 marks and the marking bar chart then has 11 bars. Example information retrieved from a marking bar chart could include that 5% of the trees have received three marks, while 7% of the trees have received five marks and 20% of the trees have received zero marks. The latter proportion, P_0, can be seen as a "negative agreement on unselectable trees". On the other hand, the proportion of trees marked in the 20% highest classes, P_m, that means the proportion of trees that have received 9 or 10 marks out of 10 possible marks, indicates an agreement among the participants that the trees involved are an appropriate choice (Pommerening & Grabarnik 2019).
A high coefficient of variation of the marking bar chart proportions r_m, i.e. of the different bars in the chart, indicates a potentially high agreement of the test persons when it comes to the question of how many trees have been selected several times by the test persons.

2.4.4 Thinning types and intensities

Ratio B_i indicates the type of natural disturbance or tree selection behavior. As shown in Eq. (4), the ratio is calculated by dividing the proportion of the number of selected trees ($P_i^{(N)}$) by the corresponding basal area proportion ($P_i^{(G)}$).

$$B_i = \frac{P_i^{(N)}}{P_i^{(G)}} \tag{4}$$

B values larger than 1 indicate that the proportion of selected stems is larger than the proportion of basal area. That translates to smaller trees being affected. In terms of thinnings, this represents a thinning from below. If the proportion of stems is smaller than the basal-area proportion, the value of B_i is smaller than 1. Larger trees have been targeted in this case, which, indicates a crown thinning (Kassier 1993). Values around 1 indicate a systematic thinning and are often observed in natural disturbances as well (Pommerening & Grabarnik 2019).

2.4.5 Height-Diameter ratios and stem diameters

Height-Diameter (h/d) ratios allow to characterize individual-tree stability and resilience. Ratios <80 indicate high resilience against storm and snow (Bartsch et al. 2020). In local crown thinnings, frame trees with high resilience should be selected, since these are the trees that benefit from local crown thinnings and continue to be exposed to snow and storm after a thinning and throughout their lifetime until final harvest or natural death. Within a forest stand, there is a natural trend of decreasing h/d with increasing stem diameter (Bartsch et al. 2020).

2.4.6 Tree selection probabilities

Logistic regression is a tool to relate the probability of tree selection to one or more predictors. For a local crown thinning, it is important to select among dominant and co-dominant trees and therefore a suitable predictor could be tree size, e.g. stem diameter (d) or total tree height (Pommerening & Grabarnik 2019). For all participants, logistic regressions have been carried out using stem diameter, total tree height and c/h (ratio of crown length to total tree height) separately as predictor variables for both frame trees and competitors. The slope parameter β_1 of the graphs indicates, whether the person has focussed their tree selection on rather dominant or small trees and how strongly their choices have been guided by the respective predictor, i.e. the size variable.

$$P_i^{(s)} = \frac{e^{\beta_0 + \beta_1 \cdot x}}{1 + e^{\beta_0 + \beta_1 \cdot x}} \tag{5}$$

In Eq (5), $P_i^{(s)}$ reflects the probability of tree selection of test person *i*, β_0 and β_1 are model parameters and *x* is the predictor variable. In this experiment stem diameter, total tree height or *c*/*h* were used as predictor variables.
A very high or strongly negative value for the slope parameter (β_1) indicates that this predictor strongly influenced tree selection. Slope parameters around 0 indicate a tree selection behavior that has not been influenced by the predictor variable. Model parameter β_0 gives information about the thinning intensity. In case of equal slope parameter β_1, the person with the higher value β_0 has selected more trees. Negative values for β_0 are associated with *B*-values <1 and a positive slope value, pointing to a crown thinning, while positive values for β_0 are associated with

B-values >1 and negative slope values, pointing to a low thinning (Pommerening & Grabarnik 2019).

2.4.7 Basal area ratios

Local crown thinnings are implemented to foster the growth of frame trees, to reduce the competition from neighbouring trees and to encourage structural diversity. Trees grow faster at younger age and also respond more strongly to thinnings at a younger stage. For these reasons, local crown thinnings automatically implement a higher intensity around younger frame trees or frame trees with a comparably small diameter (Pommerening & Grabarnik 2019; Bartsch et al. 2020). Local crown thinning intensity is implicitly reduced for larger/older trees. To see if the participants' tree selection corresponded to this trend, I calculated the basal area ratio W_i by deviding the basal area sum of the competitors j selected to benefit frame tree i by the basal area of this frame tree using Eq. (6).

$$W_i = \frac{1}{g_i} \sum_{j=1}^{k_i} g_j \qquad (6)$$

In Eq. (6), k_i represents the number of competitors for frame tree *i*, g_j refers to the competitor basal area and g_i denotes the basal area of the frame tree. After calculating W_i, a trendline using a simple power function (Eq. 7) was modelled to facilitate the interpretation of the observed basal area ratios (Pommerening et al. 2021).

$$\widehat{W_i} = a \cdot d^{-b} \qquad (7)$$

For Eq. (7), $\widehat{W_i}$ refers to the predicted value for the basal area ratio, a and b denote model parameters, d is the predictor, i.e. stem diameter in this case.
In order to evaluate the model, characteristics like the efficiency measure (Eq. 8), the relative Bias (Eq. 9) and the relative RSME (root mean square error, Eq. 10) were calculated.

$$E = 1 - \frac{\sum_{i=1}^{n} (\widehat{y_i} - y_i)^2}{\sum_{i=1}^{n} (y_i - \bar{y}_i)^2} \qquad (8)$$

For Eq. (8), *E* represents the efficiency measure, $\widehat{y_i}$ denotes the i^{th} predicted value from the model, y_i refers to the i^{th} observed value, $\bar{y}$ is the mean value of the observed values and *n* stands for the number of frame trees a test person has selected competitors for. The closer the efficiency measure approaches 1, the better the model performance. Values below 0 point to biased estimates (Pommerening et al. 2022).

$$B = \frac{\sum_{i=1}^{n} (\hat{y}_i - y_i)}{n\bar{y}} \tag{9}$$

Eq. (9) gives the relative Bias *B,* where for the notation is the same as for Eq. (8). The closer the value to 0, the better. The root mean square error *RSME* is given in Eq. (10).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{n}} \tag{10}$$

2.4.8 Species mingling and frame tree dominance

When working with mixed species stands, one objective in forest management is to maintain or foster the tree species mixture in this stand. Local crown thinnings are used to steer the stand's development in the desired direction. The mingling index M_i (Eq. 11) provides information about the heterogeneity of tree species between *k* nearest neighbours (Pommerening & Grabarnik 2019). To assess the participants' choice, i.e. whether they tended to remove competitors of the same species as that of a certain frame tree or not, I considered the selected competitors around a certain frame tree as neighbors.

$$M_i = \frac{1}{k} \sum_{j=1}^{k} \mathbf{1}\left(m_i \neq m_j\right); \tag{11}$$

In Eq. 11, *j* denotes a selected competitor, **1**() is an indicator function that returns the value of 1, if the condition given in the round brackets is fulfilled. This translates to the selected competitors being of a different tree species (m_j) than the tree species of the frame tree (m_i). The mingling index can take values between 0 and 1 and the closer the value is to 1, the more competitors have a different species than the frame tree.
To look at the overall behaviour of one participant, the mean value of all M_i, $\bar{M}$, was calculated for each participant, as shown in Eq. 12.

$$\bar{M} = \frac{1}{n_f} \sum_{i=1}^{n_f} M_i \tag{12}$$

n_f denotes the number of frame trees a certain participant has selected competitors for. A high $\bar{M}$ for a mixed stand where two or several tree species are considered in the frame tree selection indicates that test persons rather considered heterospecific neighbours as a threat to the frame tree.

Frame trees play a central role in local crown thinnings. Since all silvicultural efforts focus on those trees, they usually are among the most dominant trees of the stand. A possibility to look at this dominance compared to selected competitors is offered by the dominance index U_i (Eq. 13). It takes values between 0 and 1 and values towards 1 indicate a strong dominance of the frame tree (Pommerening & Grabarnik 2019).

$$U_i = \frac{1}{n_f} \sum_{j=1}^{n_f} \mathbf{1} \left(d_i > d_j\right); \qquad (13)$$

For Eq. 12, **1**() is returned, if the condition is fulfilled, i.e. the frame tree diameter d_i is larger than a competitor diameter d_j, otherwise the value is 0.

3. Results

3.1 Conformity numbers

The conformity numbers for the selection of competitor trees vary between 0.49 (participant no. 4) and 0.86 (person no. 10). The average value for the selection of competitors is 0.72. For the frame-tree marking, the minimum value is 0.55 (person no. 4) and the maximum value is 0.89 (person no. 2). The average conformity number for the frame-tree marking is 0.73 (Fig. 4). There is not much difference in the conformity numbers of frame trees and competitors, although the values for n_i differ, showing less variation for the frame trees. There are no obvious differences between the conformity numbers for male (0.49-0.86) and female participants (0.64-0.89) or between participants with (0.65-0.89) and without a forestry background (0.49-0.85). The wide range of conformity numbers indicates a rather low agreement of the participants.

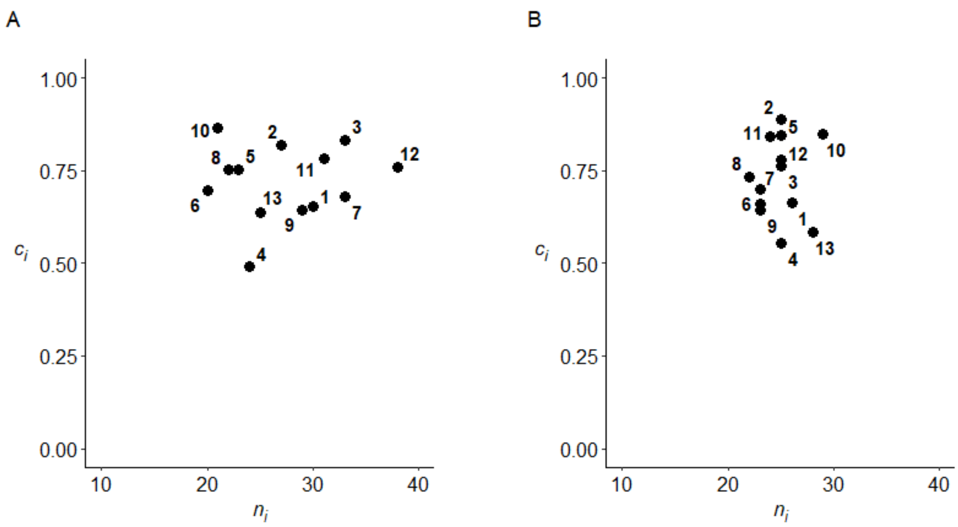

Fig. 4. Conformity numbers (Eq. 1-3) over numbers of selected trees (n_i) for competitors (A) and frame trees (B). Numbers next to the points indicate the test person’s id.

Comparing the relative conformity numbers of this experiment with the conformity numbers of 26 marteloscope experiments conducted in Great Britain (Fig. 5), it is obvious that the Swedish results are well within the British point cloud, both for competitors and frame trees. A conclusion that there is a statistically significant difference does not seem to be justified (Kruse et al. 2023).

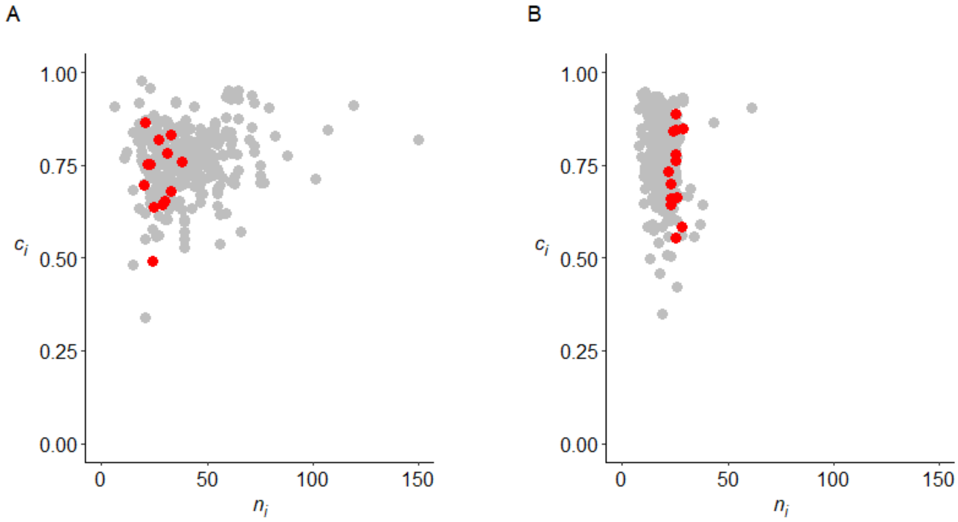

Fig. 5. Conformity numbers for each test person (c_i) over number of selected trees (n_i) for the Swedish experiment (red) and for 26 British experiments (gray). Competitors (A) and frame trees (B).

3.2 Fleiss' Kappa

According to the interpretation of Fleiss' Kappa in Table 2, the participants showed only a slight agreement in both the frame-tree and competitor tree selection. Fleiss' Kappa for the competitor tree selection is 0.221 and it is 0.267 for the frame trees. These results are in line with those of British local crown thinning experiments, as shown in Fig. 6. In most British local crown thinning experiments, the participants had a slight agreement for their competitor tree selection. This holds true in roughly half of the experiments for the frame tree selections as well. Otherwise, the agreement tends to be lower for the competitor trees than for the frame trees. Up to now, there has been no experiment in which the participants achieved moderate, substantial or almost perfect agreement in local crown thinnings.

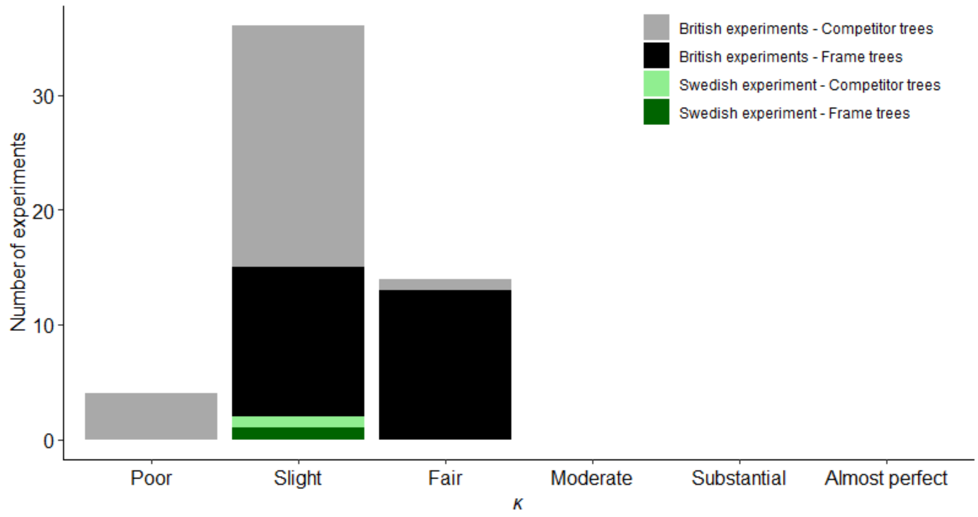

Fig. 6. The empirical distribution of Fleiss' kappa values in 26 British and 1 Swedish local crown thinning experiments.

3.3 Rating and marking bar charts

The rating bar chart for competitors (Fig. 7) shows a strong decrease in the proportion of selected trees from the highest ranked test person to the lowest ranked test person. This decrease is more gradual for the frame trees, which is reflected by the coefficient of variation (r_v) of the proportions of the corresponding rating bar chart. The proportions of selected competitors range from 0.065 to 0.123 with a r_v of 0.2. The lowest proportion for the frame trees is 0.071 and the highest one is 0.094, with a r_v of 0.08.

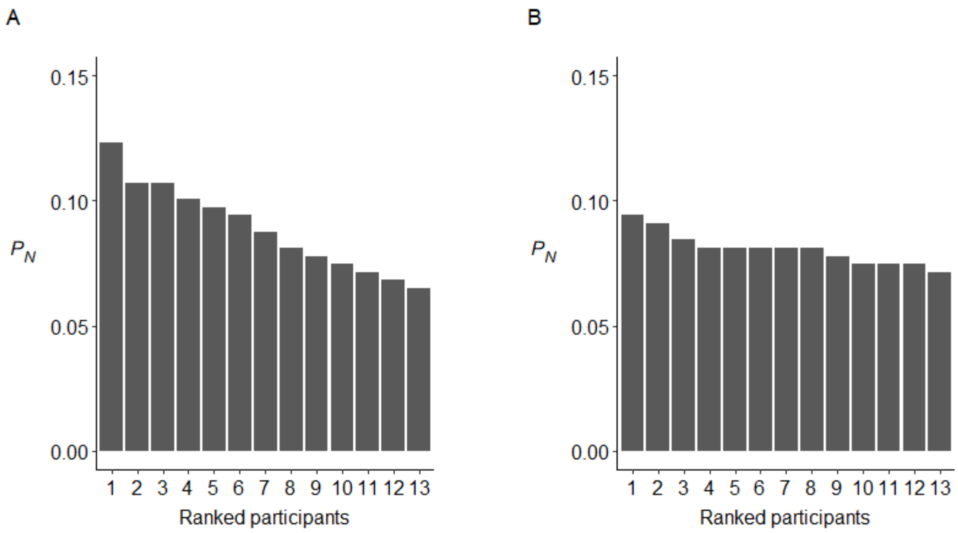

Fig. 7. Rating bar charts with the proportion of selected trees (P_N) over the ranked participants for competitors (A) and frame trees (B). The person who has selected the largest proportion of all trees above 4 cm in stem diameter on the plot has rank 1, the person who selected the least proportion of trees has rank 13.

Similar to the results in Pommerening et al. (2021, Fig. 7), the marking bar charts (Fig. 8) show an almost (negative) exponential distribution with a high proportion of trees in the first class defining P_0, i.e. 0.604 for the competitors and 0.643 for the frame trees. Another interesting point is the low number of trees in the 20% highest classes of the marking bar chart (P_m). For the competitors, P_m is 0 and for the frame trees it is 0.003. The latter result is owed to a single frame tree that has received 11 votes. Particiants did not only select different numbers of trees, but also different trees. For both marking and rating bar charts on a visual inspection there was no apparent difference that could be attributed to gender or forestry background.

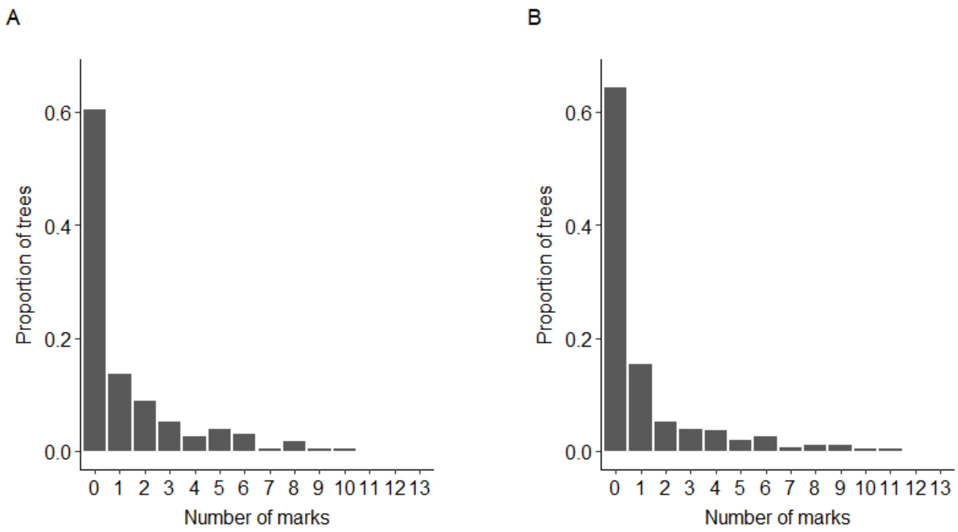

Fig. 8. Marking bar charts with proportion of trees over number of marks for competitors (A) and frame trees (B).

Looking at kappa (κ) and the coefficient of variation of the marking bar chart proportions (r_m) in Fig. 9A, it stands out that the British competitors (gray points) have lower values of r_m and κ than the British frame trees (black points). This is in agreement with the values of *Fleiss' kappa in* Fig. 6. Competitor values of r_m for British experiments vary between 0.86 and 1.72, frame tree values between 1.72 and 3.22. The British competitors also have lower values for P_0 than the British frame trees (Fig. 9B). In Fig. 9B, the two point clouds show a more distinct separation than in Fig. 9A (Kruse et al. 2023). Considering the marking bar chart in Fig. 8B, the large bar for P_0 in combination with the small bars for the other proportions explain the high value of r_m.

Taking a closer look at r_m and the comparison of British and Swedish data (Fig. 9), the Swedish frame-tree data points are situated within the point clouds of the British frame trees, which indicates that the Swedish experiment reproduced the result of the British experiments. The Swedish results for the competitor tree selection on the other hand are outside the British competitor-tree-selection point cloud and instead inside the frame-tree point cloud. This is a hint that for Swedish participants selecting competitors was not more difficult than selecting frame trees, which is in opposition to the results of British experiments (Pommerening et al. 2021).

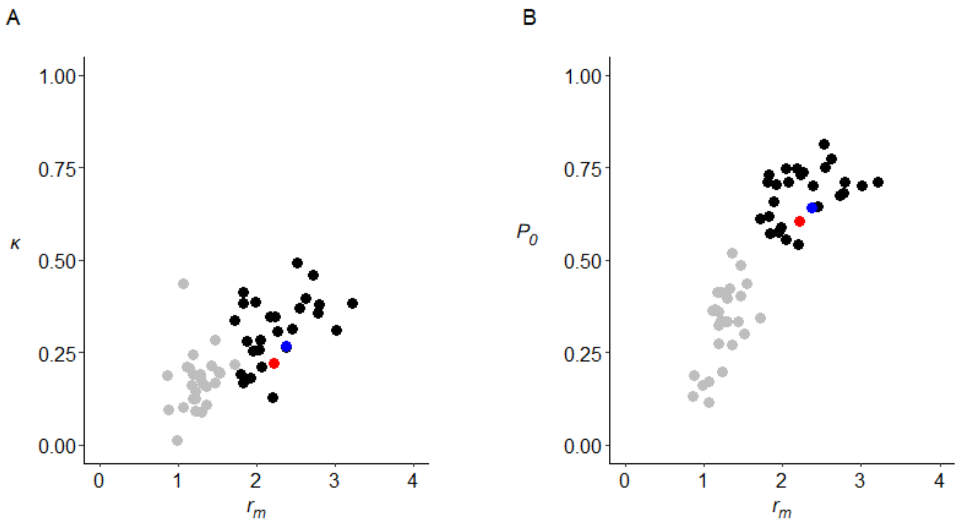

Fig. 9. For 26 British experiments and the Swedish experiment: Kappa (κ) (A) and P_0, i.e. the proportion of trees nobody has selected, (B) over the coefficient of variation of the marking bar chart proportions (r_m); frame trees (British: black, Swedish: blue) and competitors (British: grey, Swedish: red).

3.4 Type and intensity of thinnings

On the *x* axis, the thinning intensity is shown in terms of the proportion P_G of selected basal area (Fig. 10). The thinning intensity for the competitors varies between 9.2% and 21.9% and the selection intensity for the frame trees lies between 15.3% and 23.3%. All observations for the competitor trees and the frame trees lie below the threshold for a low thinning, which is indicated by the dashed line and set at 1. The minimum, maximum and mean *B* values are 0.49, 0.71 and 0.59 respectively for the selection of competitor trees and 0.40, 0.53 and 0.44 respectively for the selected frame trees. This justifies the conclusion, that all participants selected the frame trees and competitors among dominant and co-dominant trees, which is conistent with the rules for local crown thinnings. The selection intensities for the competitors chosen by some participants are low compared to British experiments and on average lower than the selection intensity for the frame trees. This might be due to the overall low basal area of the stand.

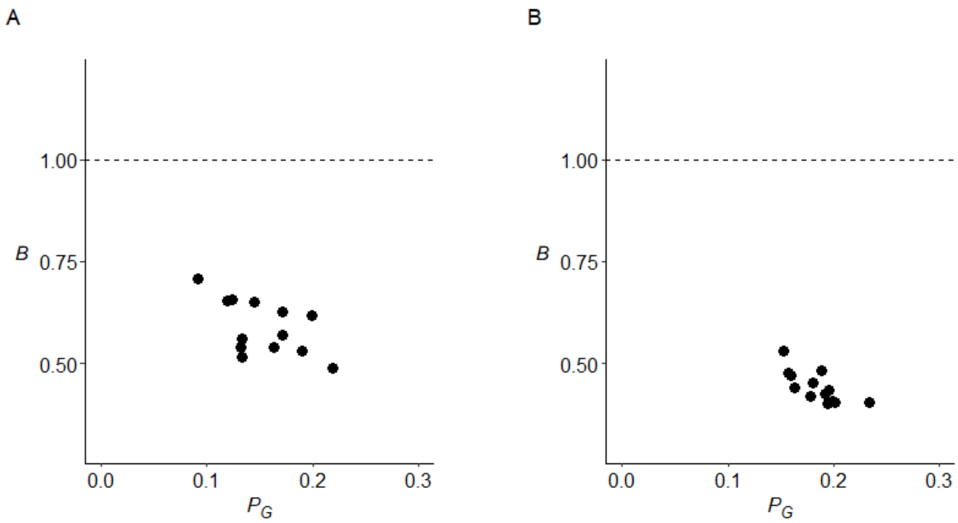

Fig. 10. *B*-ratios (Eq. 4) vs. thinning intensities (P_G) of the Svartberget experiment. Competitors (A) and frame trees (B).

Considering the values of the *B* ratio separately for each tree species (Table 3), a distinct pattern per species emerges (Fig. 11). For the frame trees, all observations apart from one are below the threshold for a low thinning, although the results for Scots pine trees, presented in green, are rather close to the line. The selection intensity is similar for Scots-pine frame trees across all participants. In case of Norway-spruce and birch frame trees, the participants' selection intensity varied more strongly. Still, the participants' frame tree selection largely corresponded to the local crown thinning rules. For competitor trees, almost all values for birch trees, shown in blue, are above the threshold, indicating thinnings from below. The results for Scots pine trees are clustered around the threshold, representing an indifferent thinning, i.e. a thinning which cannot be clearly identified as thinning from below or crown thinning. Only the data points for Norway spruce, in red, are below the threshold, corresponding to crown thinnings.

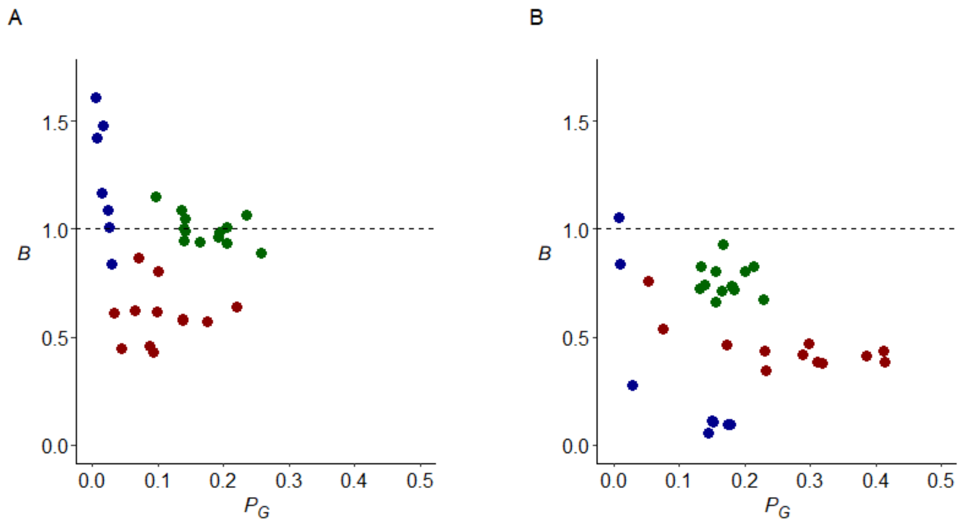

Fig. 11. Species-specific values of the *B* ratio (Eq. 4) over P_G, i.e. the proportion of selected basal area, for the Svartberget marteloscope experiment. Competitors (A) and Frame trees (B). Blue - Birch, red - Norway spruce, green - Scots pine.

The observations for birch appear to be fewer than the observations for Scots pine or Norway spruce (Fig. 11). That is due to the fact that one participant did not include birch in their frame tree selection and only 7 out of 13 participants selected birch as competitors. One participant did not include Norway spruce in their competitor selection either. For the birch frame trees, some participants have made the exact same choice, resulting in some points to overlap.

Table 3. *B*-values of the Svartberget experiment according to tree species.

***B*-values**	**Competitors**			**Frame trees**		
	min.	**max.**	**mean**	**min.**	**max.**	**mean**
Birch	0.84	1.61	1.23	0.06	1.06	0.24
Scots pine	0.89	1.15	1.00	0.66	0.93	0.76
Norway spruce	0.43	0.86	0.60	0.34	0.76	0.45

Some of the competitor trees selected in the British experiments (Fig. 12A), are above the threshold separating the two tree-selection types, but most are below. For the selection of frame trees (Fig. 12B), all results are below the threshold. The *B* ratios (in red) of the frame trees observed in the Swedish experiments are at the lower end of the British observation distribution. This indicates that the Swedish participants selected more dominant trees than the participants in the British experiments. For the selection of competitor trees, the Swedish values are clearly lower than most of the values for the British experiments and are located in the lower region of the British data cloud and beyond. Swedish participants seem to have selected mostly dominant competitor trees, what is unusual compared to the results of other studies (Vítková et al. 2016a; Pommerening et al. 2021). For the British data, the selection intensity is roughly the same for competitors and frame trees, while for the Swedish data, it is lower for the competitors.

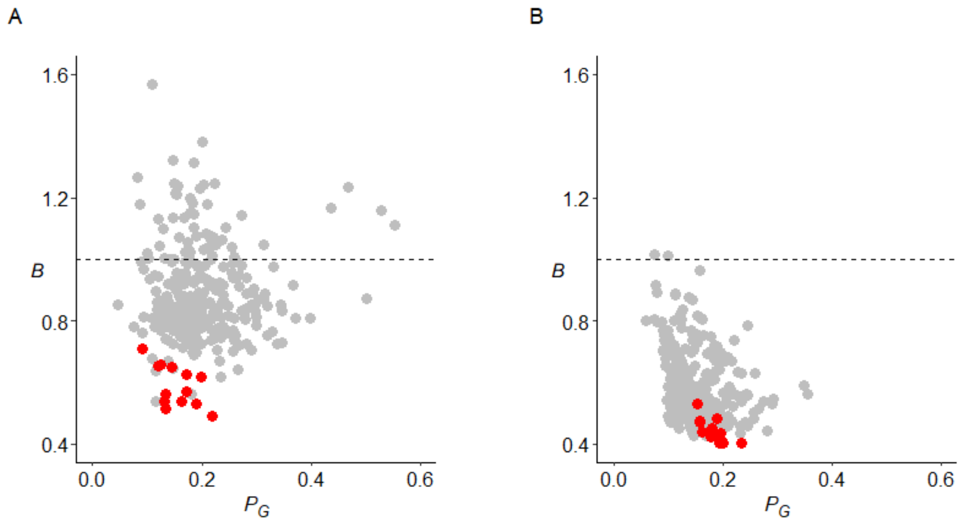

Fig. 12. *B*-values of 26 British experiments (grey points) and the recent Swedish experiment (red points) over P_G, i.e. the proportion of selected basal area. (A) Competitors, (B) frame trees.

3.5 Height-diameter ratio and stem diameters

The observations' h/d ratios show a decreasing trend with increasing stem diameter (Fig. 13). The values for the British frame trees are lower than for the British competitors, which is consistent with the theory of local crown thinnings. When considering trees with a stem diameter larger than 15°cm, the red data points, showing the selected trees in the Swedish experiment, are situated within the upper half of the gray data clouds. The h/d values for trees selected in the Swedish experiment are rather large compared to those of the British experiments. This is different for trees with a stem diameter smaller than 15°cm. For both frame trees and competitors, many trees selected in the Swedish experiment do not align with the selected trees' h/d values in the British experiment. This is due to some participants' attempts to include smaller birch trees with rather low h/d values in their tree selection, particularly as frame trees. The h/d values for Swedish competitors and frame trees are dominantly similar, which is rather unusual, since frame trees require a high individual- tree stability which usually results in lower h/d values.

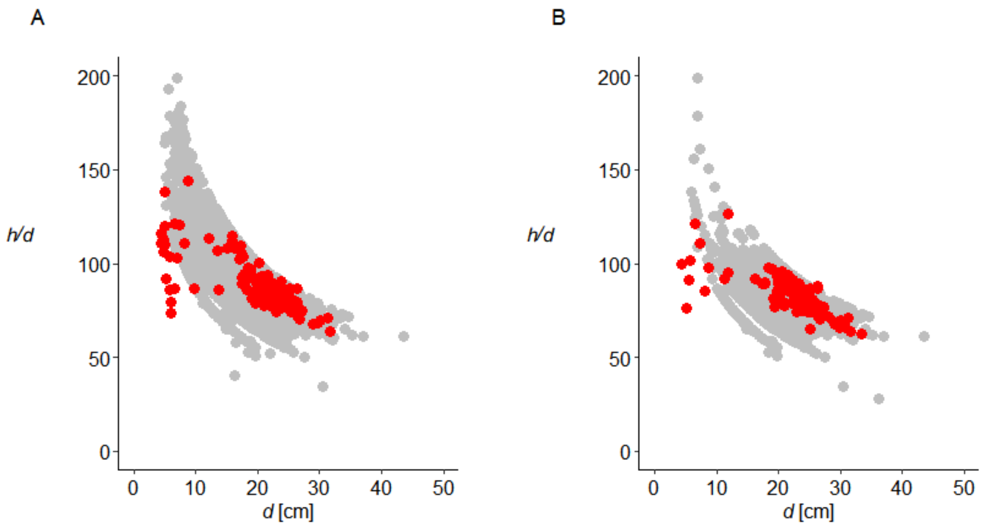

Fig. 13. *h/d* ratios over stem diameter (*d*) for trees selected as competitors (A) and frame trees (B) in 26 British marteloscope experiments (gray points) and in the recent experiment at Svartberget (red points).

3.6 Tree selection probabilities

When plotting the results of the logistic regression using stem diameter as predictor, all slope values β_1 were positive and the *p*-values for stem diameter were significant for all participants (Fig. 14). The higher the slope values, the higher the probability that participants choose large trees. On average, the dependence on stem diameter was stronger for the frame tree selection than it was for recruiting competitors. However, this strongly differed between individual participants. 10 out of 13 participants strongly focused on the stem diameter for both frame trees and competitors. All logistic regressions had negative values for β_0. According to these results, all participants selected more or less dominating trees, which is in line with the theory of local crown thinnings and confirms the overall *B*-ratio results (Fig. 10). Very similar selection probability results were obtained for total tree height (not shown here).

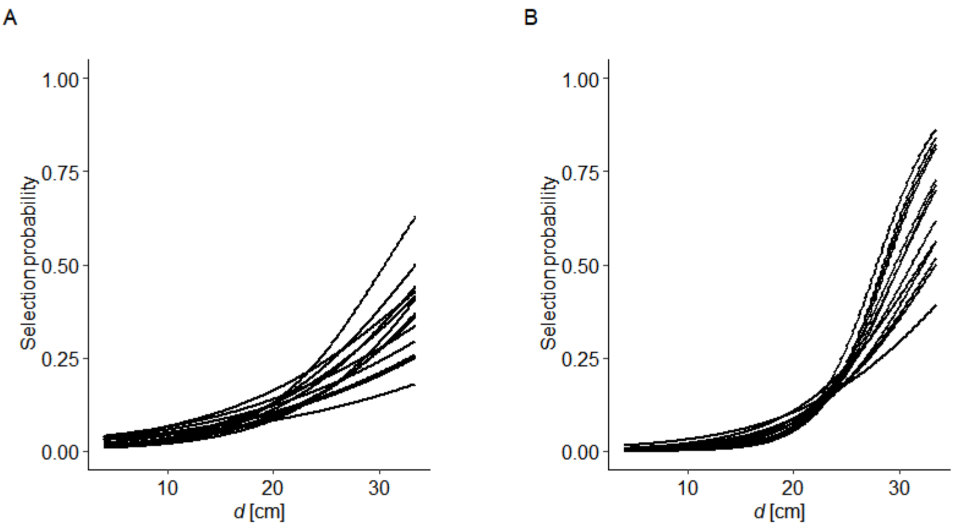

Fig. 14. Selection probability of 13 test persons participating in the Swedish marteloscope experiment at Svartberget. Stem diameter (*d*) served as predictor variable. (A) competitor trees and (B) frame trees.

The ratio of crown length to total tree height, *c*/*h*, was not a major criterion for the test persons. It turned out to be a significant variable for 5 out of 13 participants for the competitor tree selection and in 4 out of 13 cases for the frame-tree selection (Fig. 15). For the competitor-tree selection, the slope value β_1 was in most cases negative or close to zero. For the selection of frame trees, this pattern reversed: most slope values were positive. β_0 has been positive and large for those curves with comparatively strong negative β_1 and vice versa.
A negative slope indicates that participants tend to select trees with shorter crowns, which is a good strategy for selecting competitor trees. This is the opposite for positive slopes - here, trees with long crowns are favoured, which was more prominent in the frame tree selection. Both behaviors are in line with the theory of local crown thinnings, but only one participant combined these two aspects.

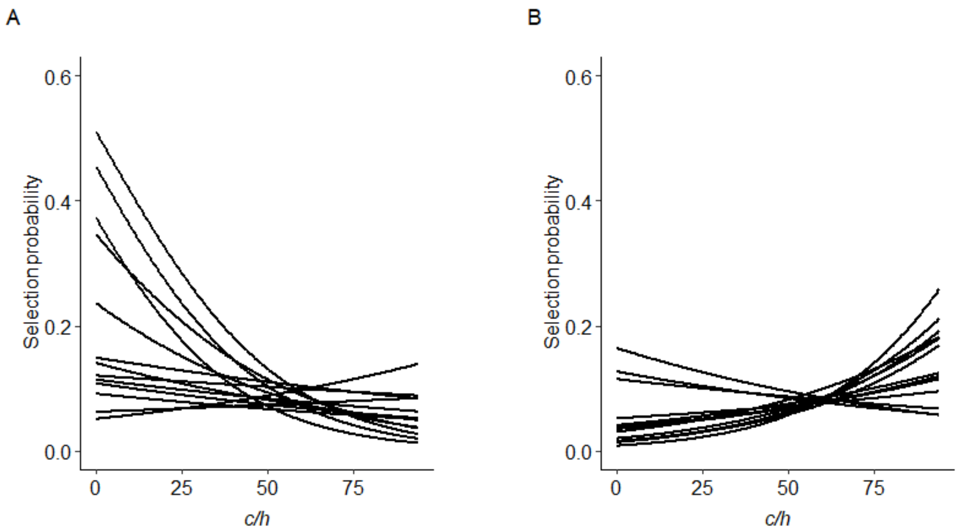

Fig. 15. Selection probability of 13 test persons participating in the Swedish marteloscope experiment at Svartberget. *c/h* ratio served as predictor variable. (A) competitor trees and (B) frame trees.

When comparing β_1 and β_0 for British and Swedish logistic regressions with stem diameter as predictor (Fig. 16), it turns out that for the frame trees (Fig. 16B), all British and Swedish β_1 values are positive and all β_0 values are negative. The British slope values vary between 0.007 and 1.263 and there are three outliers with very large slope values and corresponding negative intercepts. The Swedish observations are located towards the lower bound of the British point cloud. Both British and Swedish participants rather focussed on dominant trees with larger stem diameter in their frame tree selection, although this focus was less dominant for the Swedish test persons. Slope values close to 0 indicate that stem diameter did not play a very strong role in the frame tree selection.

For the selection of British competitor trees (Fig. 16A), there are cases with positive intercepts and negative slope values and negative intercepts and negative slope values, respectively. In the recruitment of British competitor trees, the slope values vary between -0.152 and 0.448. For the competitor-tree selection, participants whose slope values for the logistic regression were negative, rather chose trees with lower stem diameter, i.e. smaller trees, which corresponds to a thinning from below. They make up approximately 15% of all participants, while the remaining 85% rather focussed on larger trees with higher stem diameters, corresponding to a crown thinning. All data points for the Swedish participants are within the British data cloud, but surprisingly none of them simulated a low thinning in their tree selection.

The range of slope values and intercepts is much wider for the British frame trees than it is for the British competitor trees, suggesting small differences in the frame tree selection compared to competitor-tree selection.

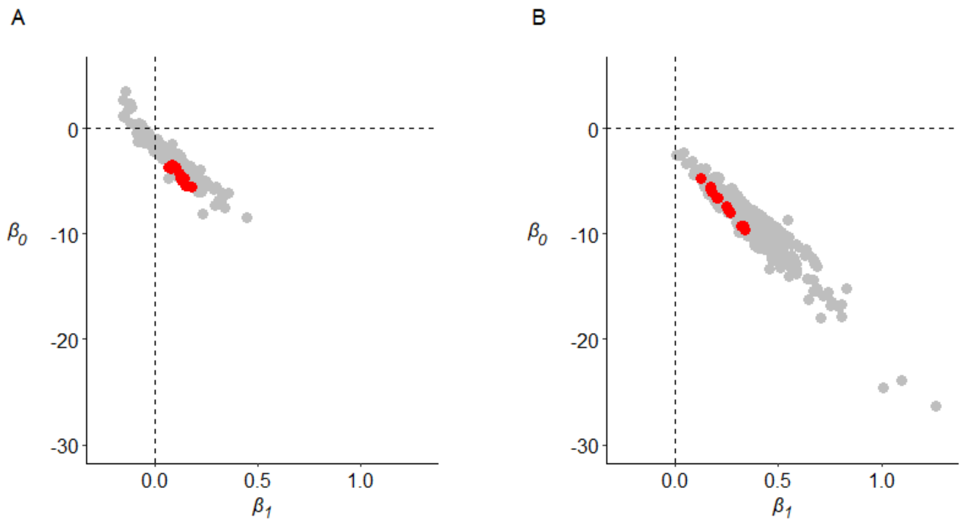

Fig. 16. Scatterplots of the intercepts, β_0 , and slopes, β_1, of the logistic regressions with DBH as predictor in 26 British marteloscope experiments (gray data points) and in the recent Swedish experiment at Svartberget (red data points). (A) competitor trees and (B) frame trees.

3.7 Basal area ratios

Basal area ratios W_i (Eq. 6) and the corresponding trendline model (Eq. 7) provide information about the extent the participants' tree selection corresponded to the theory of frame tree thinnings. The red line in Fig. 17, which represents the trendline of the Swedish basal area ratios, shows a slightly decreasing trend. From a stem diameter of approximately 18 cm to around 33 cm, the slope approaches 0, indicating no trend in this diameter range. In the same data range, the black data points are closely clustered around the red line, showing that test persons rarely selected more competitor basal area for removal than the basal area of the corresponding frame tree. There are not many data points at stem diameters below 18 cm, but for the frame trees represented by these points, the participants selected higher amounts of competitor basal area than for the frame trees above 18 cm.

In contrast, most of the the gray lines of the British experiments show a strongly decreasing trend with increasing stem diameter. The participants of these experiments selected increasingly more competitor basal area the smaller the basal area of the frame tree under study. Especially for the lower stem diameter categories, they removed way more competitor basal area than the Swedish participants. Hence, the Swedish participants did not selected trees according to the expected trend. This seems to somewhat contradict the previous results of the *B*-values or the logistic regressions, but those measures focus on the individual participants and on frame trees and competitors separately. They do not allow any statements on a combination of those aspects.

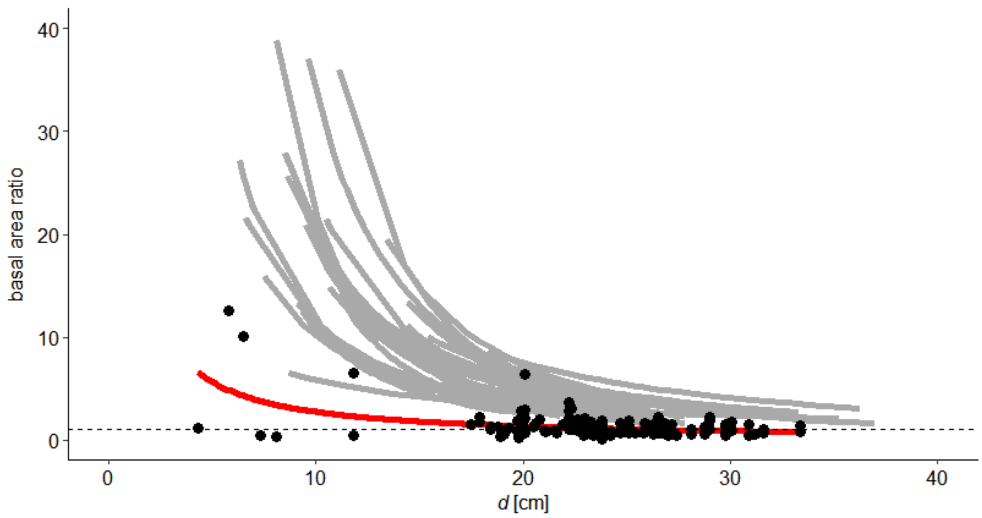

Fig. 17 Basal area ratios (Eq. 6) of the Svartberget experiment (black points) and trendlines (Eq. 7) of the basal area ratios from the 26 British experiments (gray lines) and the Svartberget experiment (red line).

The efficiency measure (Eq. 8) related to the fit of the trendline model for Svartberget is 0.24, which is quite low. The relative Bias (Eq. 9) of 0.01 indicates that there are no systematic errors. The RSME (Eq. 10) of 0.90 is high, suggesting a high variability of the basal area ratios and thus a varied selection behaviour shown by the participants in the Svartberget experiment.

3.8 Species mingling and frame tree dominance

For the mean species mingling, $\bar{M}$, the values of twelve participants of the Svartberget experiment take values between 0.16 and 0.28 (Fig. 18A), which is rather low. Looking at the low proportion of basal area made up by species other than Scots pine in the stand (19%), this is not surprising. It shows that participants also removed other tree species than the frame-tree species.

For the frame tree dominance U_i, the values are quite high and vary between 0.68 and 0.85 (Fig. 18B). The participants mostly selected frame trees with a bigger stem diameter than the competitors, which corresponds to the theory of frame tree thinnings.

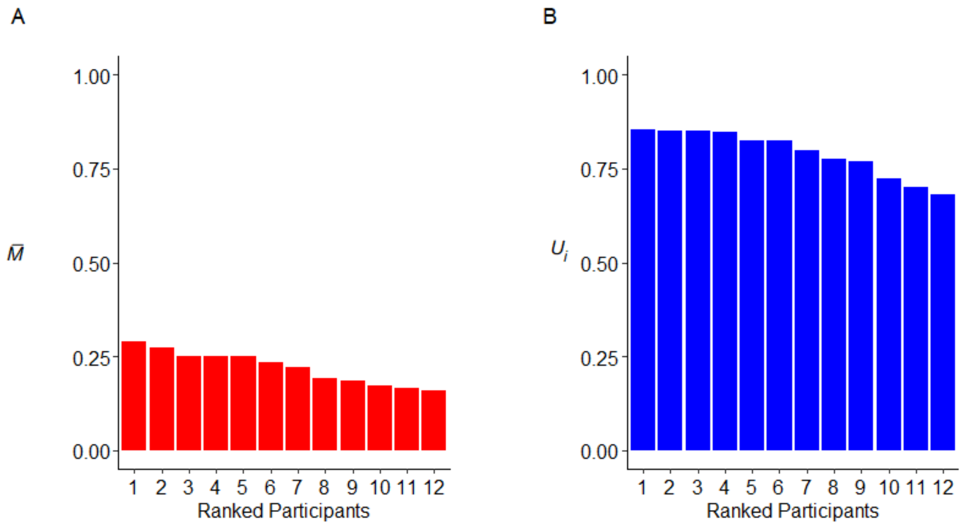

Fig. 18. Species mingling $\bar{M}$ (A) and frame tree dominance U_i (B) for the ranked participants. The ranking does not correspond to the participants' identification number.

One participant is not depicted in the figure, since this test person did not indicate which competitors should benefit which frame tree and therefore an analysis for this person is not possible.

4. Discussion

Several stakeholders, such as certification schemes, the Swedish forestry agency and the EU encourage, if not in the latter case demand, an increase in the share of productive forest land managed according to CCF (Sweden 2020; Appelqvist et al. 2021; European Commission 2021). This often includes a transformation from even-aged monocultural stands to structurally more diverse, mixed stands (Pommerening & Grabarnik 2019). Since this is a complex mission for which the Swedish forestry staff is rather unprepared (Hertog et al. 2022), training in CCF appears to be needed. Marteloscopes are great tools to provide and develop such training and have been widely used in different countries, such as Austria, Germany, Great Britain, Ireland and Italy (e.g. Spinelli et al. 2016; Vítková et al. 2016; Pommerening et al. 2018; Cosyns et al. 2020). Twenty years ago, Great Britain was in a similar situation as Sweden is today. One useful thinning regime in the transformation process to CCF are local crown thinnings, where the forest manager focusses on single groups of trees within the stand. In 14 marteloscopes all over Great Britiain, 26 experiments involving local crown thinnings have been conducted with 285 participants in total (Pommerening et al. 2018). The results of these experiments can prove useful for Sweden and are benchmarked against the outcomes of this study. This was feasible, since the British experiments had the same objectives, followed the same method and represent a variety of site conditions, tree density, tree species mixture as well as tree selection behavior of the participants (Kruse et al. 2023). Results of the Swedish experiment that are unlike those of the British experiments may offer hints to aspects that need to be specifically considered when designing CCF trainings for Swedish forestry staff. One local crown thinning experiment has been conducted in a newly established marteloscope in the Svartberget Experimental Park close to Umeå, involving 13 participants. The two main aspects in the analyses were agreement in tree selection among the participants and success in implementing a local crown thinning without prior practical training.

4.1 Agreement in tree selection

In the Swedish experiment, the conformity numbers for competitors and frame trees showed a high variation (Fig. 4), but there were no observable differences to the British conformity numbers (Fig. 5). The high variation hints at a rather low agreement in tree selection (Pommerening et al. 2018). This was confirmed by the Fleiss' kappa measure, where both competitors and frame trees in the Swedish experiment achieved a slight agreement. This level of agreement was frequently observed in British experiments as well, while no experiment achieved more than a fair agreement (Fig. 6). This similarity was to be expected, since around twenty years ago, despite changes in forest policy, the dominant management paradigm in Great Britain was RFM with patch-clearfelling (Raum & Potter 2015), which is similar in Sweden today. Therefore similar challenges might be present when initiating the (partial) transformation to CCF.

When recruiting competitor trees, the participants' number of selected trees varied quite strongly compared to the variation in the frame trees. This is not surprising, since for the frame trees a guideline on how many trees to select was provided. More surprising is the fact that the marking bar charts for competitors and frame trees looked very similar, i.e. the values for P_0 are quite high in both cases, accompanied by very low P_m values (Fig. 8). Usually, it is easier for participants to select frame trees than it is to select competitors (Pommerening et al. 2021), but this does not seem to apply in the Swedish case. This assumption is strengthened by the similar agreement Swedish participants achieve in their competitor tree and frame tree selection, while for British experiments, participants' agreement is in most cases lower for the competitors than it is for the frame trees.
One possible explanation for these results might be that the requirement to record the frame tree a certain competitor was "evicted" for supported the reflection of the participants on which trees to select. The process of updating their choices while simultaneously taking notes became visible when cross-checking the participants' marking sheets for potential errors during data digitalization.
Another factor might be the ratio of non-foresters to foresters, which is approximately 60%:40%. Vítková et al. (2016) found that non-foresters performed better when learning new thinning approaches than foresters. Contrary to those results, for Svartberget, there was no difference between foresters and non-foresters in their tree selection, neither was there a difference between male and female participants. However, due to the low number of participants, the explanatory power of the group-specific analyses results is limited. A reason for the uniformity in the results of the group might be that all test persons are working at the same institution, i.e. the Svartberget experimental park and that they are rather concerned with scientific experiments than with operational (forest) management. Repeating such an experiment with foresters employed at forest companies, private forest owners, students of different countries etc. might yield different results.

4.2 Thinnings types, intensities and the theory of local crown thinnings

The second major question addressed in this thesis is, whether the test persons actually managed to implement a local crown thinning according to the theory.
One strong evidence that they successfully implemented the thinning method are the results of the logistic regressions with stem diameter as predictor. For the Swedish experiment, stem diameter was significant for all participants, both for frame trees and competitors, indicating that all participants were more likely to choose larger trees. The slope values were even higher for the frame trees than for the competitors (Fig. 14), which indicates a stronger influence of stem diameter in the frame-tree selection. This is in line with previous findings that participants tended to select larger frame trees than competitors (Pommerening et al. 2021). Contrary to the results for the British competitors, there were no negative values of β_1 in the Swedish experiment, indicating that all Swedish participants selected trees for a thinning from above. Given that the test persons most likely did not receive any form of practical training prior to this experiment, this is a positively surprising result and confirms the observation that selecting competitors according to the theory of frame-tree based thinnings did not pose a major challenge to the Swedish participants. The high values of the dominance index U_i provide another proof that the selected frame trees are among the dominant trees in the marteloscope.
Some participants even selected competitors with comparatively short crowns, while others focused on selecting frame trees with large crowns (Fig. 15). Both aspects are in line with the theory of local crown thinnings. Longer crowns are useful for frame trees, since they imply a larger leaf area which enables the tree to intercept more light. If enough water and nutrients are available as well, this usually translates to stronger growth and increased tree stability (Binkley et al. 2013).

Frame trees are constantly exposed to external influences such as storm and snow throughout their lifetime. This is especially true after competitors have been removed in their vicinity. Therefore, they ideally should have h/d ratios below 80 (Bartsch et al., 2020). The h/d values in Fig. 13 suggest that participants mainly selected trees with h/d ratios in excess of 80 and that the h/d ratios did not differ between frame trees and competitors. This is quite unusual, since frame trees require a high individual-tree resilience. The Swedish h/d ratios for stem diameters larger than 15 cm are still situated within the range of British values, but they are close to the upper limit of the British values. This is an indication that frame tree resilience needs to be emphasized in future trainings in Sweden. For a stem diameter smaller than 15 cm, many h/d ratios of selected trees in the Swedish experiment strongly differ from British values, which is due to the fact that some participants attempted to include comparatively resilient, but still small birch and Norway-spruce (frame) trees in their tree selection. This is a good and rather unexpected initiative to promote the (future) tree species mixture in the stand (Pommerening & Grabarnik 2019; Bartsch et al. 2020) which should be encouraged in future trainings.

The *B* ratios confirm the impression of successful local crown thinnings. According to Fig. 10, all Swedish participants selected rather dominant trees as frame trees and competitors, while the frame trees were on average larger than the competitors. This perfectly corresponds to the rules of frame tree management (Pommerening et al. 2021). The overall high coefficient of variation for stem diameter in the Swedish marteloscope (Table 1) might have contributed to the successful implementation of local crown thinnings. This would confirm the findings of Pommerening et al. (2018), that a more complex stand structure facilitates trees selection, i.e. potential frame trees and competitors are easier to distinguish from other trees when there is a strong size differentiation of the trees in a forest stand. As far as possible given the limited choice of tree species other than Scots pine in the marteloscope, the participants also selected tree species as competitors that were different from the frame tree species, as the results for species mingling $\bar{M}$ show. This is a sign that the participants considered the tree species mixture in their tree selection.

All measures analyzed so far suggest that the Swedish participants sucessfully implemented a local crown thinning. Most of those measures examine competitor trees and frame trees separately for each participant, which is valuable for providing individual feedback and analyzing potential group-specific selection behaviors.
Fig. 17 delivers a synthesis using the basal area ratios (Eq. 6) of removed competitor basal area per frame tree basal area and showing respective trendlines (Eq. 7) for each British and the Swedish experiment separately. For a stem diameter larger than 18 cm, the basal-area ratios of the Swedish experiment are consistently lower than for the British experiments. Looking at a stem diameter below 18 cm, the Swedish values are much lower than the British values, indicating that the selection intensity for competitors around smaller frame trees was not sufficiently high. Since frame trees with lower diameters tend to face more lateral competiton, it is important to apply a heavier thinning intensity around those trees to foster their growth (Pommerening & Grabarnik 2019; Bartsch et al. 2020). This has not happened in Svartberget, contrary to all British experiments and points to the need to emphasize the necessity for a stronger competitor removal around smaller frame trees in future trainings.

The participants' behaviour in the Swedish marteloscope experiment at Svartberget is similar to those of British experiments. In some aspects, the results differ, partly in an unexpected way. The Swedish participants not only selected frame trees according to the rules for local crown thinnings, but they did so for competitors as well, which participants in the British experiments did not. This leads me to partially rejecting my first hypothesis that not everyone implements a local crown thinning. On the other hand, this hypothesis is partially true, since the participants managed to mark for a local crown thinning for higher stem diameters, but failed to do to so for stem diameters smaller than 18 cm. However, this was not dependent on the participants' background. Non-foresters performed equally well as test persons with a forestry background. This leads me to reject hypothesis no. 3, which is not consistent with previous research (Vítková et al. 2016). There was no difference between male and female participants, i.e. hypothesis no. 4 cannot be rejected, which supports other findings (Vítková et al. 2016). The overall agreement of the participants was low as expected, what translates to hypothesis no. 2 being true and in line with previous research (Pommerening et al. 2018, 2021).

5. Conclusion

Contrary to initial assumptions, the participants of the marteloscope experiment in the Svartberget experimental park managed to select trees for a local crown thinning without prior practical training. Unexpectedly, the selection of competitor trees did not seem to be more difficult than the frame tree selection. Despite these positive results, there remains a need to emphasize some aspects for future trainings. The first one relates to the selection of frame trees with a higher individual-tree resilience, i.e. with h/d values below 80. The second one is the requirement to mark for heavier thinnings in general and particularly around smaller frame trees for future trainings. Participants should be required to record the identification numbers of the frame tree(s) that benefit from the removal of specific competitors. There is evidence that this measure fosters test persons' reflection on tree selection which might lead to an improved choice. The conscious inclusion of smaller, but resilient frame trees of different tree species should be encouraged in future trainings as well. To validate these findings and to identify further specific requirements for Swedish training in local crown thinnings, more marteloscope experiments with more varied and larger groups of participants are needed. Repeated experiments with the same participants might allow insights into how variable the tree selections of one person are over time, what long-term effects trainings have and what so far unconsidered external influences guide the participants' choice. Eventually, regular trainings for local crown thinnings could form one important component of an overarching training programme in CCF for Swedish forestry students and forestry staff.

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Popular science summary

At present, forests in mid and central Sweden mainly consist of Scots pine and Norway spruce forests which have very uniform appearance. The forest is subdivided into smaller compartments which usually have a size varying between one and twenty hectares. All trees in such a compartment are planted at the same time and therefore have the same age and a similar size. These forest areas are commonly referred to as even-aged, monocultural plantations. They are grown until a certain predefined age and then harvested all at once with heavy machinery, what is called a clearcut. The whole process is termed rotation forest management (RFM) and is mainly focussed in industrial raw material supply. Research has revealed that this form of forest management is decreasing biodiversity, damaging the soils, disadvantaging Sami reindeer herders and does not follow natural processes. In 1993, the Swedish forestry law was changed in an attempt to attenuate those effects, but the efforts implemented in practical forest management have not been sufficient. Currently, the EU, the Swedish forestry agency and the forest certification schemes encourage a more diverse forest management without clearcuts that leads to forests with more than one tree species and differently sized trees. Such forests have proven to provide more living space for other plants and animals, which would foster biodiversity and be advantageous for the Sami reindeer herders. In addition to that, other goals than raw material production can be achieved with this type of forest management, which is named continuous cover forestry (CCF). At the moment, many people working in forest management are unfamiliar with CCF. Since it requires detailed knowledge of natural processes in the forest, trainings for forestry staff are needed. Marteloscopes are forest areas with a fixed size, usually up to one hectare. All trees above a certain diameter are measured, i.e. their diameter at 1.3 meters above ground level, their height from the ground to the top, their tree species and additional parameters are recorded. Many of those forest plots exist internationally and experiments with tests persons are implemented in those martelosopes to develop trainings for CCF. Trees in a forest are competing with each other for light, water and nutrients and require a certain space to grow. The way they grow and which trees can grow stronger can be influenced to a certain extent by repeatedly removing some trees in the forest, what foresters refer to as thinnings. There are different types of thinnings, where e.g. only smaller or only bigger trees are removed. Some thinnings focus on a whole forest area, other thinnings on smaller groups of trees within a certain forest area. The latter thinnings are part of the individual-based forest management and are very useful for CCF, since they prmote mixed forests with differently sized trees. Within each group of trees, the forest manager selects one tree that correspond to the management objective of the forest, e.g. high-quality timber, aesthetic value, old and coarse trees that provide living space etc. Trees that fulfill this role are called frame trees. In a second step, the forest manager selects one to three trees among the immediate neghbours of the frame tree that are already competing with the frame tree or will compete with it within in the next five to ten years. This thinning regime, termed "frame-tree based thinning" allows to have areas without management in the forest and also allows to combine different management objectives. Therefore, it is useful to carry out experiments to see to what extent forest managers are able to implement those frame-tree based thinnings. In the Svartberget Experimental Park, such an experiment took place for the first time in a newly set up marteloscope with 13 participants. 26 similar experiments have been implemented in Great Britain and Ireland over the past fifteen years. Since Great Britain was facing similar challenges regarding their forest management as Sweden is facing today, the results of the Swedish experiments were compared with the British results to extract possible specific needs for training Swedish forest managers. In all experiments, the paticipants received specific instructions on how to select frame trees and competing trees. They were asked to note down their choices on a piece of paper. These papers were collected after the experiment and the data were digitalized and converted to a suitable format for analyses. The participants' tree selection behavior was analyzed using specialized statistics. The analyses focused on how strong the participants agreed on which trees to select and how strong their tree selection corresponded to the theory behind the thinnings. The agreement was similar for British and Swedish participants, but the Swedish test persons' tree selections were closer to the theory, what was somewhat unexpected. Despite this positive result, there remains a need to emphasize the stability of selected frame trees against storm, snow and other external influences and to stress suitable thinning intensities, i.e. the number and size of competing trees to be selected for later removal. More experiments with different groups of participants working in different roles regarding forest management are likely to provide a more in-depth picture of specific training needs.

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Appendix

5.1 Marking sheet for the participants

Local crown thinning experiment Svartberget

Hej! Thanks a lot for your time and interest, it is very much appreciated ☺

Your task is to

- Select ca. 25 frame trees with a distance of ± 10m between them
- Favour a mixture of pine and spruce and consider this in the selection of frame trees
- Include 3 habitat trees in your selection and write down which ones you chose (H)

The sheet is double-sided, so feel free to continue on the back of the page ☺

Please write down all **frame trees** you selected here. One tree, one role: A frame tree **must not** be listed as a competitor at the same time.

Frame tree #

611
651
670
687
693 (H)
...

Please note down the **competitors** you selected here and indicate which frame tree in your opinion they are competing with, as shown in the example:

Competitor Id (frame tree #)

609 (611)
623 (651)
667 (651)
649 (651)
682 (687)
695 (687)
...

Fig. 19 Marking sheet for the participants in the Svartberget marteloscope experiment

5.2 Tables with p-values for the predictors of the logistic regressions

Table 4 P-values of logistic regression predictors. Colorful columns from left to right: dbh, h/d, c/h and total tree height. Color codes: red - p <0.00001, yellow p <0.005, green p<0.02

Item	Intercept	p_dbh	type	Intercept	p_hd	type	Intercept	p_ch	type	Intercept	p_th	type					
1	0.000000	0.000018	Competitors	0.375578	0.077435	Competitors	0.807286	0.007819	Competitors	0.000000	0.000027	Competitors					
2	0.000000	0.000013	Competitors	0.602750	0.036065	Competitors	0.118613	0.120977	Competitors	0.000000	0.000094	Competitors					
3	0.000000	0.000000	Competitors	0.209318	0.000422	Competitors	0.360036	0.035676	Competitors	0.000000	0.000019	Competitors		R_codes		Color code	
4	0.000000	0.002251	Competitors	0.374907	0.077226	Competitors	0.021088	0.394526	Competitors	0.000000	0.001850	Competitors		<0.001	***	0.00001	
5	0.000000	0.000101	Competitors	0.938241	0.013446	Competitors	0.000703	0.801291	Competitors	0.000000	0.000281	Competitors		<0.01	**	0.005	
6	0.000000	0.016902	Competitors	0.127318	0.246538	Competitors	0.007014	0.657169	Competitors	0.000000	0.006113	Competitors		<0.05	*	0.02	
7	0.000000	0.000267	Competitors	0.838935	0.018471	Competitors	0.010308	0.568879	Competitors	0.000000	0.000281	Competitors		<0.1	.	0.08	
8	0.000000	0.000095	Competitors	0.900356	0.008343	Competitors	0.009646	0.570478	Competitors	0.000000	0.000365	Competitors		>0.1		0.2	
9	0.000000	0.000784	Competitors	0.431189	0.063263	Competitors	0.000056	0.338091	Competitors	0.000000	0.000327	Competitors					
10	0.000000	0.000062	Competitors	0.916694	0.014667	Competitors	0.547593	0.018870	Competitors	0.000007	0.000657	Competitors					
11	0.000000	0.000002	Competitors	0.896891	0.008332	Competitors	0.001615	0.974946	Competitors	0.000000	0.000011	Competitors					
12	0.000000	0.000013	Competitors	0.840432	0.019919	Competitors	0.951441	0.004059	Competitors	0.000000	0.000005	Competitors					
13	0.000000	0.001898	Competitors	0.142107	0.216351	Competitors	0.007656	0.617235	Competitors	0.000000	0.000649	Competitors					
14	0.000000	0.000002	Frame_trees	0.172732	0.000323	Frame_trees	0.006821	0.644456	Frame_trees	0.000021	0.000155	Frame_trees					
15	0.000000	0.000002	Frame_trees	0.020874	0.000029	Frame_trees	0.000001	0.046275	Frame_trees	0.000020	0.000358	Frame_trees					
16	0.000000	0.000004	Frame_trees	0.068291	0.000098	Frame_trees	0.000000	0.001889	Frame_trees	0.000000	0.000143	Frame_trees					
17	0.000000	0.000106	Frame_trees	0.997661	0.011104	Frame_trees	0.007156	0.637000	Frame_trees	0.000000	0.000446	Frame_trees					
18	0.000000	0.000002	Frame_trees	0.037206	0.000053	Frame_trees	0.000000	0.009332	Frame_trees	0.000034	0.000458	Frame_trees					
19	0.000000	0.000021	Frame_trees	0.545690	0.002497	Frame_trees	0.000249	0.577070	Frame_trees	0.000006	0.000516	Frame_trees					
20	0.000000	0.000006	Frame_trees	0.075989	0.000117	Frame_trees	0.000290	0.611324	Frame_trees	0.000012	0.000481	Frame_trees					
21	0.000000	0.000014	Frame_trees	0.120204	0.000210	Frame_trees	0.000001	0.043111	Frame_trees	0.000001	0.000365	Frame_trees					
22	0.000000	0.000013	Frame_trees	0.191355	0.000399	Frame_trees	0.000122	0.447712	Frame_trees	0.000003	0.000438	Frame_trees					
23	0.000000	0.000001	Frame_trees	0.009609	0.000013	Frame_trees	0.000003	0.079399	Frame_trees	0.000004	0.000136	Frame_trees					
24	0.000000	0.000003	Frame_trees	0.018768	0.000029	Frame_trees	0.000000	0.016581	Frame_trees	0.000006	0.000410	Frame_trees					
25	0.000000	0.000003	Frame_trees	0.043905	0.000062	Frame_trees	0.000031	0.264907	Frame_trees	0.000029	0.000463	Frame_trees					
26	0.000000	0.000002	Frame_trees	0.187690	0.000359	Frame_trees	0.026352	0.350349	Frame_trees	0.000000	0.000059	Frame_trees					

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2022:07 Författare: Alice Falk
Towards climate optimised riparian buffer zones in boreal forests. Investigation of clearcutting effects on soil temperature, soil moisture and greenhouse gas fluxes in riparian buffer zones with different widths

2022:08 Författare: Pelle Kronborg
Biogeochemistry and Peat Properties of Restored Peatlands

2022:09 Författare: Andreas Souropetsis
Influence of forest mires on wildfire
A landscape analysis of the 2014 Västmanland forest fire

2022:10 Författare: Leon Hauenschild
Alteration of the forest structure in historically impacted Nothofagus spp. forests on the Brunswick peninsula.
Recommendations for their protection and management.

2022:11 Författare: Axel Strömberg
The evaluation of novelty kilns: drying msasa wood at a small scale sawmill in Mozambique

2022:12 Författare: Andreas Karlstrand
Samband mellan föryngringsresultatet år 5 och kvalitetsklassning av markberedning och planteringsåtgärder på SCA:s fasta provytor i norra Sverige.

2023:01 Författare: Tyra Tornberg
Forest regeneration and edge effects – An ecophysiological analysis after gap-cutting

2023:02 Författare: Erik Wickberg
Effekten av växtnäring på överlevnad, tillväxt och vitalitet på planterade tall- och granplantor - En studie gjord på ett kontrollerat försök på en lokal i Västerbotten

2023:03 Författare: Carl Åhlund
Kvävegödslingens effekter på bladyta och trädkronor i tallbestånd

2023:04 Författare: Johan Engström
Increased carbon sequestration of actively restored tropical forests in Sabah, Malaysia
A comparison of natural regeneration and active restoration

2023:05 Författare: Magdalena Fassl
Tree-growth and climate-growth relationships of Scots pine and downy birch in a natural forest in northern Sweden

2023:06 Författare: Ruben Baan Hofman
Riparian vegetation ecology
An observational study into the effects of forest management on understory vegetation communities along boreal headwaters

2023:07 Författare: Nils Helge Havertz
GIS and remote sensing based mapping of microtopography and vegetation composition in a boreal mire complex

2023:08 Författare: Lydia Kruse
Identifying training needs for the implementation of Continuous Cover Forestry in Sweden