The use of marteloscopes in science

A REVIEW OF PAST RESEARCH AND SUGGESTIONS FOR FURTHER APPLICATION

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https://integratenetwork.org/

http://iplus.efi.int/

1. Introduction

Initially used for field-based training for forestry professionals and students, marteloscopes have been increasingly recognised for their potential in forest research. Since the early 2000s, marteloscope sites[1], data, and the related I+ Software have been used to research a wide range of different topics and have found considerable interest in research projects and proposals. Currently, EFI is involved in numerous ongoing projects with several more on the horizon that have already been approved[2]. As the number of researchers, students, research projects, and proposals using marteloscopes continues to grow, EFI's project "Managing Forests for Resilience and Biodiversity – Bridging Policy, Practice, Science and Education" (FoReSite), aimed to compile information jointly with scientists and students on the potential of marteloscope sites and data for use in research, including in social, natural, and educational science. To achieve this objective, FoReSite developed a questionnaire to collect examples of completed and ongoing marteloscope research, feedback on the use of marteloscopes for research, as well as their potential for further application. The questionnaire had a total of ~50 respondents, including scientists that have been involved in research with marteloscopes or have plans to, former and current students who have used marteloscopes for Bachelor's, Master's, or PhD thesis research, and scientists, educators, and practitioners that have not done research with marteloscopes but had ideas for their potential further application in research.

This report first presents a overview of the scientific literature that uses marteloscopes as a research method, followed by a summary of the questionnaire results. The results begin with a summary of current and past marteloscope research conducted by respondents including published and unpublished research, followed by respondents' review of marteloscopes for research. Finally, the report summarises questionnaire respondents'

[1] There are currently around 150 marteloscopes from 20 European countries in the Integrate database with a total of nearly 70.000 individual recorded trees. All marteloscope sites are presented in a two-page information leaflet and can be accessed at: http://iplus.efi.int/marteloscopes-data.html.

[2] NAT/IT/000104 LIFE Nature and Biodiversity project application, start 09/2020, running); "*Integrate Finland*" (EU Regional Development Fund project; start 03/2021, running); MULTIPLIERS – "*Multiplayers Partnerships to ensure meaningful engagement with Science and Society*" (Horizon 2020, start 11/2021, running); HoliSoils – "Hol*istic management practices, modelling & monitoring for European forest Soils*" (Horizon 2020, start 05/2021, running); Martelkom – „*Marteloskope als Forschungs- und Kommunikationsinstrument für integrative Waldwirtschaft – und Etablierung eines demoskopischen ‚Waldbarometers' in Deutschland*" (FNR, start 09/2022); INFORMA – "*Science-based integrated forest mitigation management made operational for Europe*" (Horizon Europe, start 07/2022); OptForest – "*Harnessing forest genetic resources for increasing options in the face of environmental and societal challenges*" (Horizon Europe, start late 2022/early 2023).

feedback on the potential future application of marteloscopes in research. The report aims to help guide and stimulate future scientists and students seeking to use marteloscopes for research, as well as further facilitate and develop the 'European Marteloscope Network'.

2. Summary of scientific literature using marteloscopes

2.1. Introduction

Outcomes of training exercises done with marteloscopes have been published in the scientific literature, although mainly in German, Dutch, and French (i.e., Mordini and Rotach 2010; Van Daele et al., 2011; Petit et al., 2014; Allenspach et al., 2015). More frequently, marteloscopes have been used in social and natural science research, appearing in the scientific literature since at least the early 2000s (Bruciamaccie et al., 2005), although most literature was published in the last decade. In particular, the design of marteloscopes makes them well-suited to investigate tree-selection behaviour and how behaviour changes depending on certain factors such as expertise. In addition, the database of tree related microhabitats (TreMs) collected from marteloscope sites has been used to investigate the potential of TreMs to serve as ecological indicators for a tree habitat-value and to determine co-occurrences between TreMs.

2.2. Research on tree-selection behaviour

The topic of tree-selection behaviour has recently gained importance due to the increasing need to integrate biodiversity conservation into forests managed for timber production and balance trade-offs between economic and ecological objectives. For example, understanding tree-selection is important in continuous cover forest management where an individual must decide which trees to harvest, and which trees to leave in the stand. Therefore, investigating how tree-selection behaviour differs depending on an individual's profession, expertise level, and stakeholder group, in addition to what influences behaviour, is important for successful implementation of integrative forest management.

Research on tree-selection behaviour using marteloscopes has recently emerged, however may have been ongoing since the early 2000s (Bruciamaccie et al., 2005). A study using marteloscopes in the United Kingdom found that consensus on tree-selection among individuals was low, varies considerably when individuals are asked to perform selection on the same trees repeatedly, may be influenced by an individual's place in the forest, and that an individual's perception of the tree-selection method used may differ from the method used in reality (Pommerening et al., 2015).

A similar study using marteloscopes in Italy looked at the results of tree-selection by foresters, loggers, and agronomists both individually and as groups and found that among individuals consensus was low and decisions most likely depended on experience (Spinelli et al., 2016). However, the study also found that there were no statistical differences in consensus among the three professional groups. Lack of consensus was also identified in a study by Pommerening et al. (2018) which found that when foresters were asked to apply two different thinning methods in marteloscopes across the UK, consensus was low on which trees to select and differed depending on the two thinning methods. This finding suggests that more training is needed in order to successfully implement continuous cover forestry.

How an individual's expertise affects tree-selection decision making was further investigated in a study by Vitkova et al. (2016). Using marteloscopes in Ireland, the study looked at how individuals with different levels of expertise approach tree-selection before and after specific training is given. The study found that before training, experts applied the method they were most familiar with. However, after being trained in a new selection method, the experts were unable to apply the method and had a low consensus on which trees to select, whereas individuals relatively new in the profession were able to successfully apply the new method. The authors suggest that in order for selective forest management to be implemented successfully, experts need to be properly trained and the effectiveness of their approach should be monitored, or management should be delegated to those who do not have as much expertise, as they do not yet have an established strategy that is difficult to change or influence.

Photo: Klaus Striepen

Behaviour of habitat-tree selection of forestry trainers, foresters, and forestry students has also been investigated using a marteloscope in Germany (Cosyns et al., 2019). The study found that the three professional groups consistently selected habitat-trees that had a low economic value and that varied greatly in habitat value. Furthermore, their selection was influenced by expertise and selection by the more experienced forestry trainers was more consistent than those of the students and foresters. The authors suggest that the study's findings could have policy and management implications as it shows that selection of habitat-trees should be done by individuals with specific expertise.

The Cosyns et al. (2019) study was followed by another similar study by Cosyns et al. (2020) that used a more qualitative approach to understanding tree-selection behaviour by comparing and qualitatively investigating habitat-tree selection by conservationists and foresters. The study found that selection of habitat-trees differed significantly between the two groups due to differences in the perceptions of TreM opportunity-costs and values. Similar to Cosyns et al. (2019), the study suggests that perceptions of what qualifies as a habitat-tree differs between the two groups.

A recent study by Joa et al. (2020) using a marteloscope site in Germany also investigated the underlying reasons behind tree-selection behaviour among foresters, conservationists, and students of both professions using qualitative methods. The authors found that selection depends on professional routine and intuition, differs across professional groups, and is not limited to cognitive and rational thought processes. Importantly, the study also acknowledges that marteloscopes can serve as useful tools for facilitating dialogue between foresters and conservationists.

2.3. Research using marteloscope tree-related microhabitat data

The data collected on TreMs in marteloscopes plots has often been used in natural science research. A study by Santopuoli et al. (2018) using marteloscopes in Italy evaluated trade-offs between biodiversity conservation and timber production found that the type and number of TreMs can serve as an ecological indicator for habitat value and provide useful information when performing tree-selection and integrating biodiversity conservation into forests managed for timber production.

A recent study by Courbaud et al. (2021) using TreM data from marteloscopes showed that TreM formation varies greatly among TreM groups, tree species, locations, tree diameter and forest management approaches. The study emphasised the high rate of formation of certain TreM groups on small dimension trees, which has implications for both forestry and biodiversity conservation, as trees of all sizes should be considered for conservation. Based on their findings, the authors point to the potential for adding quantitative models of TreM formation to forest stand dynamic simulators to ensure better integration of biodiversity conservation into forest management.


Photos: Andreas Schuck

A spatially explicit database of [TreMs in marteloscopes across Europe] can be found on the Global Biodiversity Information Facility (GBIF) and contains 42,078 occurrences. The data has been used in several publications including a study by Larrieu et al. (2021) which used a TreM typology previously developed by Larrieu et al. (2018) to investigate TreM co-occurrence patterns. The study found that 11 TreM groups had 33 co-occurrences with other groups related to broadleaves species and nine co-occurrences related to conifer species. The work by Larrieu et al. (2021) further simplifies identification of TreMs as it suggests only some TreM groups may need to assessed in the field due to the high co-occurrence with other TreMs.

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Van Daele, S., G. Geudens, W. Sauwens, and B. Van der Aa. 2011. Marteloscoop: Van rozen en Chinese snorren. Bosrevue 36:5–7

Vítková, L., Ní Dhubháin, Á. and Pommerening, A., 2016. Agreement in tree marking: what is the uncertainty of human tree selection in selective forest management?. *Forest Science*, *62*(3), pp.288-296.

3. Questionnaire results

3.1. Current and past marteloscope related research

A total of 67% of questionnaire respondents were currently conducting marteloscope research or had done so in the past. Research was conducted either by visiting a marteloscope site or sites, or using readily available marteloscope related data (i.e., from GBIF). Natural science was the most commonly conducted type of research, followed by educational and social science research (Fig. 1). Researchers conducted research with marteloscopes for a large variety of projects, ranging from Bachelor's theses to EU framework projects such as the EU LIFE programme. Results from the questionnaire show that research with marteloscopes is popular among students, with Master's theses being the most common type of research project (Fig. 2). Over 70% of respondents that were currently conducting marteloscope research or had done so in the past had also participated in setting up a marteloscope site.

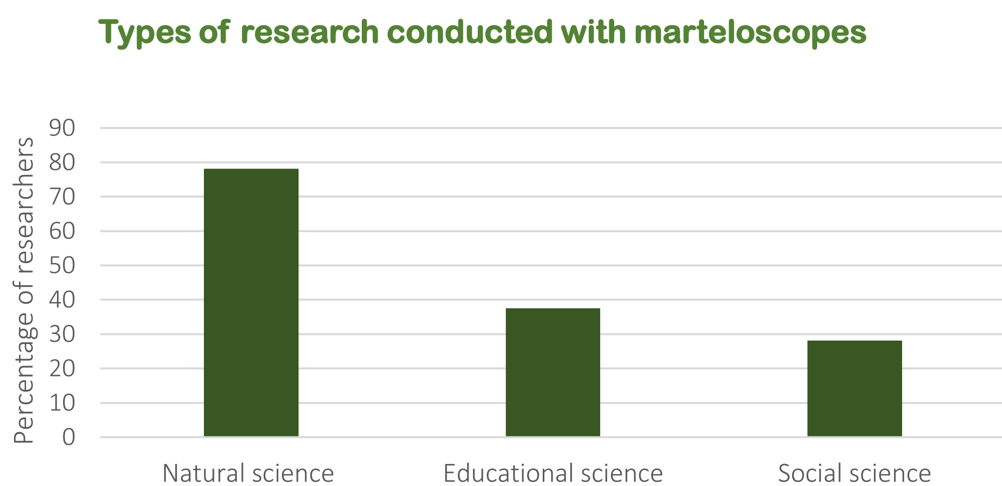

Figure 1: Types of research with marteloscopes conducted by respondents. Total percentage is more than 100% as some respondents were involved in different types of research.

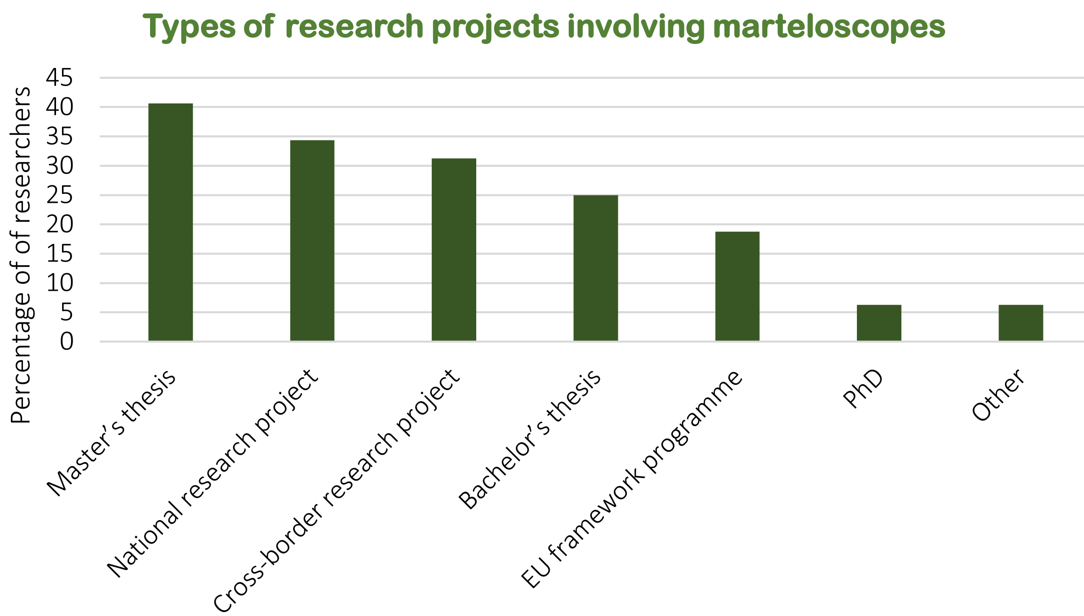

Figure 2: Types of research projects in which respondents' marteloscope research was conducted for. Total percentage is more than 100% as some respondents were involved in multiple different research projects with marteloscopes.

3.2. Research using marteloscope sites

A total of 84% of questionnaire respondents that were currently conducting or had conducted marteloscope research in the past visited marteloscope site(s) to conduct this research, as opposed to using readily available marteloscope related data. Respondents had conducted marteloscope research in 11 countries, most commonly in Germany (Fig. 3). Researchers using marteloscope sites sometimes collected specific variables not recorded in the regular marteloscope procedure (Table 1), which could give some ideas of what variables may be useful to collect regularly in order to foster more research opportunities. Researchers and students using marteloscope sites had diverse research aims. In the social sciences, research aims mainly focused on understanding perceptions and decision making of different forest management professions and related trade-offs. In the natural sciences, many research projects aimed to measure the effects of different silvicultural methods on the forest, study forest dynamics, determine ecological value of different forest structures, or get a better understanding of TreMs, their spatial distribution, and their relationship to certain species.

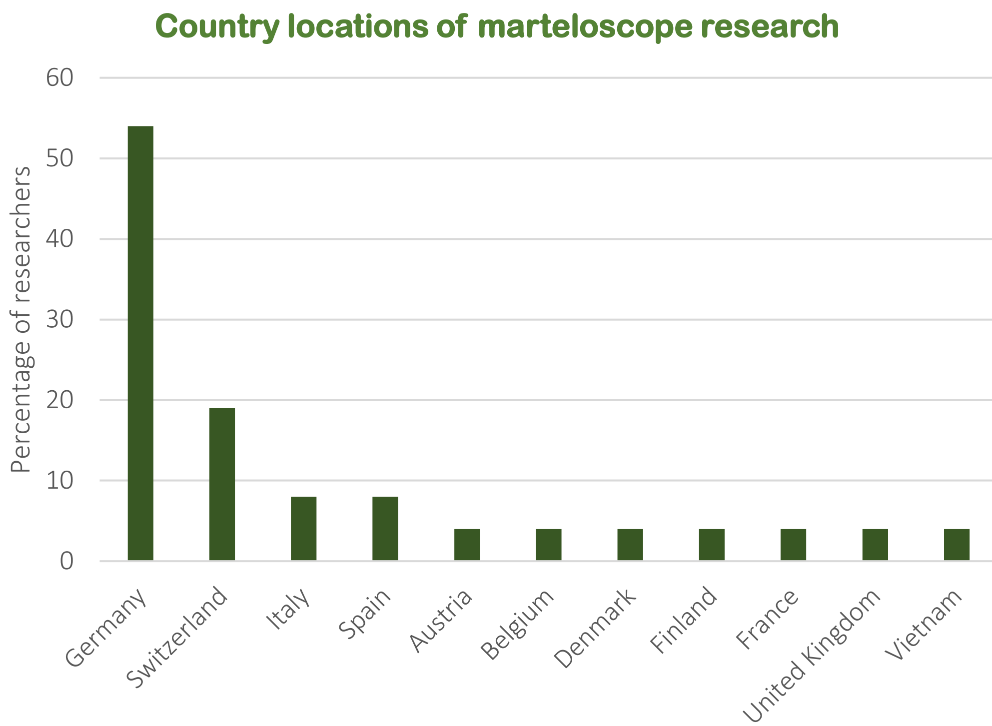

Figure 3: Country locations of marteloscope research conducted by respondents. Total percentage is more than 100% as some respondents conducted research in multiple countries.

Table 1. List of additional variables recorded by researchers. Variables are categorized according to natural, social, or economic sciences.

Natural	Social	Economic
Deadwood	Participants' perceptions and attitudes of marteloscope exercises	Actual local wood prices
Tree regeneration	Participants' professional backgrounds	Future stand revenue
Vegetation cover	Participants' decisions in tree-selection exercises	Wood product end-use
Crown dimensions		Wood product end-use half-life
Measures of light		Detailed local wood quality assortments
Sapling density		
Tree height increments		

DBH increments		
Carbon storage		
Debarking data		
Tree age		
Ecological value of forest stand		
Carbon substitution potential		
Structural indices		
Tree dieback		
Taxonomic sample data		

3.3. Research using readily available marteloscope related data

Research using readily available marteloscope related data was less common than research using marteloscope sites and often used TreM data stored in the GBIF database. Using this TreM data from a wide range of different marteloscopes, researchers aimed to gain a better understanding of TreM spatial distribution and co-occurrence, their relationship to certain species, and what tree attributes influence their occurrence. One researcher also used readily available data from the main Integrate data repository (all Integrate Network marteloscope sites that have been granted permission by data owners to be used in research) hosted by EFI which includes considerably more data for forest development modelling than e.g. the GBIF database.

3.4. Marteloscope related publications and datasets published by respondents

Below is a sample of scientific publications, datasets, Master's and Bachelor's dissertations, and other material related to research with marteloscopes published by respondents.

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4. Review of marteloscopes for use in research

4.1. Researchers' motives for using marteloscope sites/data for their research

4.1.1. Availability of data

The most frequent reason researchers gave for choosing marteloscopes for their research design was the availability of marteloscope plots and related data. One former Master's student explained this factor more in-detail: "Marteloscopes offer a very detailed, and at the same time, diverse picture of a given forest stand. Due to the full inventory [of the marteloscopes], the data is in absolute numbers instead of estimates from random sampling methods. It is great to have such an in-depth inventory of ecological, economic, and forest measures". Specifically, researchers cited the abundance of TreM and dendrometer data as a motive for conducting research with marteloscopes. The spatial explicit nature of the available data (e.g., of trees in the stand) was also an important deciding factor among researchers as it allowed for data modelling.

4.1.2. Stimulation of discussions among forest professionals

The ability of marteloscopes to stimulate discussions among forest professionals about decision-making processes in integrative forest management as well as the outcomes and economical-ecological trade-offs of different forest management scenarios were prominent reasons among researchers for choosing to work with marteloscopes. One former Master's student wrote that these discussions can then help to "flatten the 'conflict' between classical nature conservationists and foresters".

Photo: Andreas Schuck

4.1.3. Social science research on tree-selection behaviour

Researchers who used marteloscopes for social science research, particularly to study the behaviour of tree-selection by foresters and nature conservationists, indicated that marteloscopes provided a useful setting to carry out such research, with the added benefit that training and research questions can be combined. One researcher explained this point more in detail, writing "Potentially, they provide a setting for a (quasi-)experimental study of tree-selection behaviour, although implementing a respective design is demanding for various reasons. They provide conditions close to 'field research' but still give the researcher possibilities to control some aspects".

4.1.4. Education and practical training

The usefulness of marteloscopes for education and practical training has long been reported and several researchers also indicated that this innovative quality makes them ideal for research. One former student wrote that because of the design of marteloscopes, "they are great areas for demonstration - it's easy to explain per hectare measures when seeing a one hectare square out in the forest and people can easily orientate themselves with help from the tree numbering". Another former Master's student explained that he chose to use marteloscopes for his thesis research project because of the potential to gain practical experience in certain exercises, such as tree-marking. In addition to the value to student learning, one researcher also highlighted the usefulness of marteloscopes to foster communication of forest management practices to non-expert forest stakeholders.

4.2. Limitations of marteloscopes for research

Researchers who were currently conducting marteloscope research or have done so in the past were prompted to provide feedback on the limitations of marteloscopes for use in research, either generally or for the specific research they conducted. Common trends in responses are summarised below according to theme.

4.2.1. Lack of data and variables

Researchers' responses indicated that lack of data was a limitation when using marteloscopes for research. Lack of lying deadwood data was most commonly listed, with several other researchers also listing the lack of regeneration and species taxonomic data, as well as seed production data. A researcher who uses TreM data from marteloscopes to develop educational tools for students on the biodiversity value of TreMs responded that if marteloscope sites only have a limited number TreMs and/or diversity of TreM types, it becomes difficult to include sufficient TreM information in educational tools for such sites. In order to provide sufficient data on TreMs, the same researcher then suggested that more marteloscopes could be created in the future. One researcher also thought a potential limitation is that data (e.g. TreM presence and absence data) is not always be regularly updated.

Several researchers thought that the minimal number of variables included in marteloscopes were a limitation of using them for research. One researcher stressed the current focus being restricted to only biodiversity and economic variables, while neglecting other highly relevant forest functions.

Photo: Andreas Schuck

4.2.2. Lack of data standardisation in surveys

Several researchers noted that the data collected in marteloscope surveys cannot always be standardised, and therefore it is very difficult to compare across marteloscopes for research purposes. Several researchers specifically mentioned that the identification and assessment of TreMs cannot be standardised as it is subjective to the professional background of the person conducting the assessment and the identification method used (different typologies exist). Similarly, a former Master's student suggested that a "user manual" for identifying and assessing TreMs could be developed to minimise confusion and allow for standardisation.

4.2.3. Difficulties setting-up and maintaining marteloscope plots

Several researchers cited the time-intensive process of setting-up a marteloscope as a limitation for research, as well as the effort required to maintain them. One previous Master's student noted that the available online guidelines for establishing marteloscopes may not be intuitive enough for all foresters to use. It was also suggested that information could be provided on how to best select the location for a future marteloscope, as certain factors need to be considered (i.e. distance to roads). Maintenance of marteloscopes is necessary given stand development, but can also be difficult in the face of forest dieback and other changes. Due to these changes, one researcher suggested that marteloscopes be re-inventoried at least every five years, acknowledging that this may not be practical or possible for all sites.

4.2.4. Experimental set-up of marteloscopes

One researcher who conducted social science research on decision-making processes in tree-selection provided feedback on potential limitations on the experimental set-up of marteloscopes. He explained that “the experimental setting of a marteloscope can make people behave differently than what they would do in real-life circumstances, including different decision-making”. Therefore, he said it is important to create a scientifically-sound setting for the research, which can be challenging with marteloscopes because exercises are not designed for scientific purposes and it can thus be challenging to keep parameters constant because of changing factors (e.g., instructions, weather, etc.)

4.3. Comments and feedback on I+ Software

A total of 41% of questionnaire respondents that conducted marteloscope related research used the I+ Software to carry out this research. Researchers that had done so were prompted to provide comments and feedback on the use of the I+ Software for research.

4.3.1. Useful additional software modules and features

Several researchers suggested to add new modules to the software including deadwood, carbon, water/watershed management, forest regeneration, and forest recreational and cultural value. One researcher noted that integrating multiple ecosystem services into the I+ Software could help provide information on best practices for multi-functional forest management.

Photo: Jakob Derks

Adding additional features to the I+ Software was also a common recommendation among researchers. Suggestions included calculation of structural indices, future revenue, and the option to carry out other simulations (e.g., removing partial volumes of a selected tree). Some researchers also thought that assessments of ecological value (e.g., deadwood), could be useful for research. In regards to TreM identification, one researcher suggested that the two currently existing TreM typologies should be unified, or at least both available within the I+ Software. Other suggestions were towards simplifying software use, for example one researcher suggested to add the option to select groups of trees as opposed to single tree selection.

Several researchers answered that the inability of the I+ Software to model future scenarios such as stand and microhabitat development is a limitation for research and could provide interesting data if this feature were to be developed. However, one student suggested that marteloscopes may not be fit for statistical modelling over a larger region, as the small spatial-scale of marteloscopes cannot be representative of forests on a larger-scale.

According to respondents, additional graphs that could be generated by the I+ Software may be useful. One researcher suggested that if software could generate graphs that compare the results of the training across different groups, it would be easier to stimulate discussion among participants. A former Bachelor's student also suggested it would be useful if "special maps", for example of ecological value, were placed on the main page.

4.3.2. User-friendly interface for non-forest experts

A user-friendly interface for non-experts would also be welcome according to some researchers, with one even suggesting that a game could be created with the I+ Software with "small movies or animations when you select a tree for cutting (falling trees, use of tree after cutting, etc)" or on TreMs and forest biodiversity, with a point system to compete with other users. One researcher wrote of a research project involving marteloscopes that planned to develop such a tool for citizens.

4.3.3. I+ Software devices

One researcher remarked that that lack of devices during an exercise encouraged participants to share tablet devices, which could be problematic in social science research that aims to determine behaviour of individuals. While a version of the I+ Software has been developed for use on mobile phones, one researcher said that this version is difficult to use due to the small phone screen that can make it difficult to see the full map of trees.

5. Researchers' future plans to conduct marteloscope related research

A total of 58% of questionnaire respondents indicated that they had plans to conduct research with marteloscopes in the future. Out of those who had plans for future research, 68% had conducted marteloscope related in the past, while the remaining 32% had not yet done any related research. The majority of respondents with plans to conduct future research planned to focus on natural science topics. The most common natural science topic was forest and stand dynamics, followed by TreMs research and different modelling topics (e.g. stand dynamics, climate change, silviculture, forest growth, TreMs development). Topics that fell under the "other" category included slope stability, forest resource development, root reinforcement, analysis of photo-spheres, among others (Fig. 4). Future research focused on social science topics were less common among respondents and were mainly limited to tree-selection behaviour, perceptions, values, and beliefs of forests by different stakeholder groups, and pedagogical research. Some topics fell under the category of "other" (e.g., capacity building) (Fig. 5).

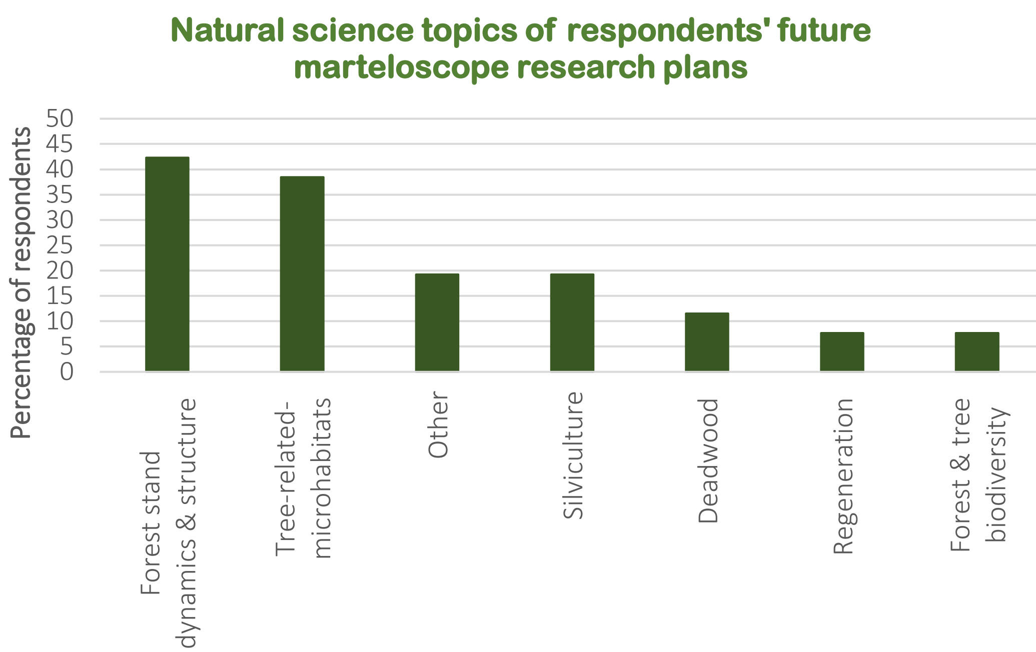

Figure 4. Natural science topics of respondent's future marteloscope research plans. Percentage of respondents refers to the total percentage of questionnaire respondents that had plans to conduct marteloscope research in the future, regardless of the topic. Total percentage is more than 100% as some respondents had plans to research several different topics.

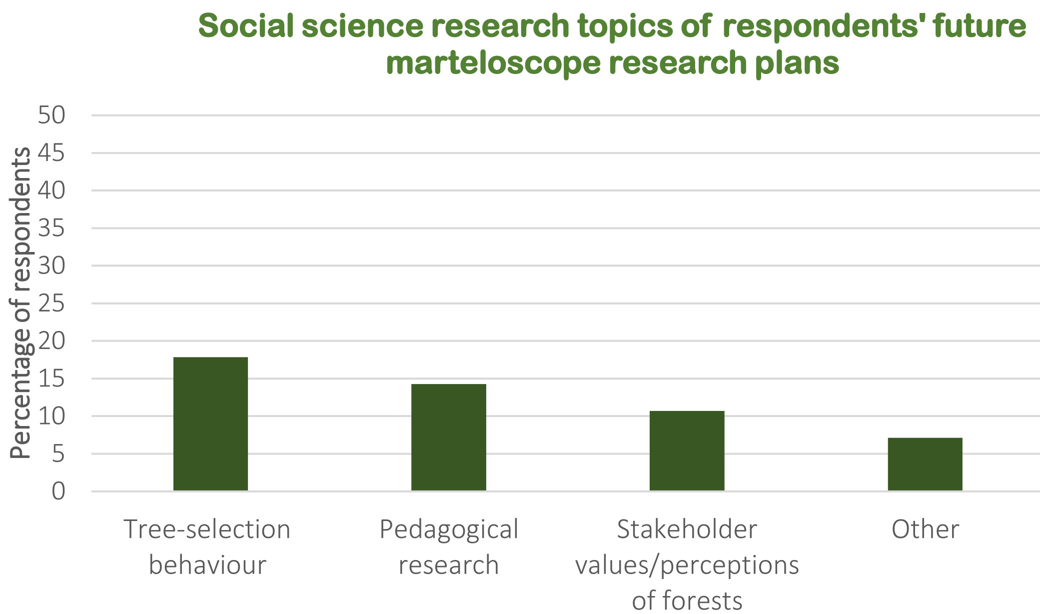

Figure 5. Social science topics of respondents' future marteloscope research plans. Percentage of respondents refers to the total percentage of questionnaire respondents that indicated they have plans to conduct marteloscope research in the future, regardless of the topic. Total percentage is less than 100% as not all researchers who had plans to conduct future marteloscope research had plans to conduct social science related research.

6. Potential further application of marteloscopes in research

Researchers were enthusiastic in their responses regarding the potential further application of marteloscopes in research for a number of topics, which are summarised below and also reflected in some of the researchers' future research plans (see section 5).

6.1. A large and versatile network for science

Questionnaire respondents indicated that the large and versatile network of marteloscopes all over Europe has great potential for future research for a wide range of topics. However, a few researchers pointed out that to fully utilise this potential, marteloscopes should not only be maintained over time but also periodically remeasured. Although the further expansion of the marteloscope network would be beneficial for future research, it also may require a large database to store the data, which could be difficult to develop and should be thoroughly planned, one researcher wrote.

6.2. Exploration of new topics

Modelling of future stand development, forest growth, forest dynamics (including natural disturbances) were some of the most frequently cited topics that respondents thought had a high potential for future marteloscope research. One researcher also mentioned that marteloscopes could be combined with soil and climatic data and modelling in order to increase their potential for future research.

Several researchers also wrote of the potential for future research using the TreM data collected from marteloscopes, for example long-term monitoring of TreMs and also researching different methods to identify and assess TreMs. Other natural science topics for potential future research with marteloscopes included studying the development of forest dieback and climate change impacts in the forest, as well as using artificial intelligence to solve complex integrative forest management questions. According to respondents, social science research on tree-selection behaviour and stakeholders' perceptions of and interactions with forests also have potential for more in-depth research.

Photo: Andreas Schuck

6.3. Combination of research and education

The potential to further combine research with education was another popular response among respondents when asked to share ideas on their future application in science. Several researchers thought marteloscopes provided a great opportunity to teach non-experts about forests. Other respondents thought of potential new training opportunities, for example remote sensing topics within forestry. While the educational value of marteloscopes was shared by many respondents (see section 4.1.4), several researchers also indicated that it would be important to research how effective marteloscopes are for educational purposes.

Photo: Annette Schuck

6.4. Collection of meta-data from training exercises

Researchers also suggested that it may be interesting to record and collect the data that is produced in marteloscope training exercises, which could then be used for different types of research. As this function is already available on the I+ Software but not often used, one researcher mentioned that creating an incentive for participants to upload their meta-data from the training exercise, as well as developing a database to store such data could also be helpful, but would need to be communicated in a transparent way with participants.

7. Conclusion

The results of this questionnaire not only further demonstrate the potential for using marteloscopes for research but also provide valuable feedback and input that will help to further develop marteloscopes and the I+ Software to better serve further scientific applications. Some suggestions for improvement are already being developed in other marteloscope related projects and will become available on the "iplus.ef.int" website, or through respective links, when completed. However, the ideas for further application of marteloscopes in research gathered from the questionnaire far exceed those already being pursued, pointing to potential for further research projects, including for Bachelor's and Master's students interested in conducting research with marteloscopes.

While the potential for research with marteloscopes continues to develop, it is important to note that the main intent of marteloscope sites and the related I+ Software is still for forestry education and training and their availability depends on the forest owner's interest to maintain the site for training or other purposes. Therefore, marteloscope sites are not to be seen as permanent plots. However, the assessed site data will remain available and can be requested from the GBIF website or from the Integrate Network Secretariat. Those interested in conducting marteloscope research should regularly consult on any updates of the marteloscope database for more research opportunities.