The European Integrate Network

Integrate Network
facilitated by EFI

Integrate+ software for virtual training exercises in forest stands

Andreas Schuck[a], Daniel Kraus[b,c], Frank Krumm[d], Simo Varis[e],
Sergey Zudin[e], Tommi Suominen[f]

This paper is available for download: integratenetwork.org and iplus.efi.int

Photos: Ted Wilson (cover); Andreas Schuck (page 15 and 22)

Contents

Abstract

Forests are asked to provide a multitude of ecosystem services and forest managers need to ensure in their daily work these are well balanced. This is a demanding task and requires best available knowledge and continuous training. To serve such needs the software package 'I+' was developed jointly by research and software developers and tested by practitioners. It runs on handheld devices and is used for training exercises in designated forest sites, so called marteloscopes. I+ allows to perform virtual tree selections and directly displays the outcomes of silvicultural interventions on site. Having intervention results readily available stimulates fact-based interaction and discussion among exercise participants. The software is currently tailored to address impacts and trade-offs of biodiversity conservation in commercially managed forests. Due to its modular design, it can easily be expanded to cover other highly relevant forest management topics such as carbon balancing. Through data export functions, exercise results can be utilized in more sophisticated tools such as forest growth simulators. The paper presents the key parameters used for training and the corresponding software solution. The I+ software components are then illustrated along examples. The software is freely available for download at the **'Iplus'** website.

Keywords

Mobile device software, virtual interventions, silviculture training, marteloscopes, tree microhabitats

1. Introduction

Forest management in Europe is traditionally focused on timber production. Due to dwindling natural resources and expected effects resulting from climate change, policy and society countries in Europe and beyond strive towards bio-based economies (Staffas et al. 2013; European Commission 2013; European Environment Agency 2014; Hetemäki 2014; Roberts & Nikolakis 2014). Forest ecosystems, however, are increasingly asked to provide other services besides that of timber production. Such include soil protection, clean water, climate regulation, carbon storage, recreation and protective functions (World Resources Institute 2005; Bastrup-Birk et al. 2016; Directorate-General for Environment 2016). Forests are home to a vast part of our biodiversity (European Environment Agency 2015; Forest Europe 2020; Bastrup-Birk et al. 2016). This diversity of demands is being addressed by multifunctional forest management, especially where forest area is limited and may lead to conflicts of interests. One example is the debate at national, European and international level on the percentage of

forest area to be set aside for protection. Large set aside areas like national parks and forest reserves are undoubtedly a mainstay of nature conservation. The majority of forests in Europe, some 85 % and more, however, continue to be managed in order to guarantee the supply of one of our main renewable resources (Parviainen et al. 2000; Frank et al. 2007; Bastrup-Birk et al. 201; Schuck & Lier et al. 2020).

On this majority of forest area management should pursue the goal of permanently preserving forest ecosystems as a whole while ensuring the provision of the different forest functions equally (Bollmann 2011; Bollmann & Braunisch 2013; Kraus & Krumm 2013; Krumm et al., 2020). However, which path is the right one for a particular forest area or stand is not always clear. Managing future forests commercially while addressing an ever increasing emphasis on ecological and other aspects, needs skill and training (Krumm et al. 2013; Krumm et al., 2020). Forest professionals can gain a sense for viable silvicultural options based on observation, assessment, and on-site decision-making. There is also a wide range of theoretical strategies and silvicultural concepts available for forest management, but also those will allow foresters room for interpretation and may then lead to different results in practical implementation on the same forest area (Kraus, Mergner, et al. 2016; Mergner and Kraus, 2020). Pommerening et al. (2015) further elaborate that even a high level of detail in given instructions is likely to result in variation when it comes to decision making amongst different individuals. Consequences resulting from forest management decisions, however, can be measured, both in economic and ecological terms (Niedermann-Meier et al. 2010). Therefore, tree marking exercises and field training are crucial for promoting education, life-long learning and continuous professional development (Pommerening et al. 2015; Spinelli et al. 2016; Vítková et al. 2016; Pyttel et al. 2018; Cosyns et al. 2018, Cosyny et al., 2020, Joa et al., 2020). Especially conducting virtual management interventions in actual forest stands can provide such insights. This is exactly what can be done with the help of so called 'marteloscopes'. Those are training sites or so called 'outdoor forest classrooms" (Bruciamacchie 2005).

The above leads to the question this paper aims to address. What kind of a solution would allow to train learners in situ at different levels of expertise given the fact that forests are often asked to deliver a multitude of ecosystem services and support understanding the effect different management decisions have on these services? Additionally, solution should work for groups allowing for in situ comparison of results and facilitate on site discussion between stakeholders representing different viewpoints. The answer to this question focusses on presenting the I+ software (referred to in this paper as 'I+'). It was developed for implementing virtual tree selection exercises directly in forest training sites and thus runs on mobile, handheld devices. The software allows to make directly available the results of exercises in tables and graphical formats to support fact-based interaction among training participants in the field. This IT solution is thus unique as so far exercises have been mainly conducted using a pen and paper approach with an analysis of the intervention results back in classrooms or as virtual forest visits (Rosset et al. 2019).

2. Materials and Methods

2.1 Marteloscopes and tree data

The concept of marteloscopes was originally developed in France (Bruciamacchie 2005). The name derives from the French term tree marking ('martelage') and the Greek "skopein" (look). It thus intends to illustrate that a particular tree selection is thoroughly investigated or "looked at under the magnifying glass". The use of marteloscopes as a tool for training and education was recognized and such sites soon found application not only in France but also Switzerland, Great Britain and Ireland (Poore

2011). During recent years, marteloscopes have been established also in many other countries. Projects implemented between 2013 and 2022 have contributed to that growth (see acknowledgements). To date more than 200 such marteloscope sites have been established in 24 European countries because of these projects (*Figure 1*). They are mostly located on public forest but also community and private forest land. The sites cover a broad range of forest types (e.g., beech-oak, beech-fir-spruce), oak-hornbeam, pine-spruce, etc.), altitudinal gradients (from 25 m – 1850 m) and site conditions and natural forest communities (e.g., Luzulo-Fagetum or Larici-Piceetum).

Figure 1. Distribution of established marteloscopes in the frame of the European Integrate Network (http://iplus.efi.int/marteloscopes-data.html, accessed August 2023*).*

A marteloscope is usually 1 ha in size, where each tree above a diameter of 7.5 cm at breast height (dbh) is inventoried and its spatial position assessed. All trees are permanently marked. Further, each tree is assigned a habitat and an economic value. Those two parameters are introduced in

more detail as they are crucial when conducting training exercises (*Chapter 2.2* and *2.3*). All data listed in *Table 1*, including calculated values (basal area, volumes, economic and habitat value), are applied in the I+ software package.

Table 1. Parameters recorded in the marteloscope plots (Schuck et al. 2015; Kraus et al. 2018).

Type	Unit
Tree species	Fagus sylvatica (Fasy), Abies alba (Abal) etc.
Tree location*	polar coordinates
Tree status	dead (0), alive (1)
Diameter at breast height	dbh [m] (>7.5 cm)
Tree height	h [m]
Crown base height	h_{cb} [m]
Tree related microhabitats	abundance
Timber quality	class (A, B, C, D/IT, F for fuelwood) and section length [m]
Calculated values	
Basal area	m^2 sum of stem cross-sections at dbh on the plot
Volume	m^3 standard calculation methods differentiated by tree species (form indices or specific tapering values)
Habitat value	in points
Economic value	in Euro (€) or national currency (e.g. CHF, Kč)

*methods may vary between sites based on preferred/available instruments.

2.2 Tree related microhabitat structures

Large quantities of deadwood and a high density of old microhabitat-bearing trees are characteristic elements of natural forests, especially of old-growth phases (Lassauce et al. 2011; Larrieu, Cabanettes, Gonin, et al. 2014). Tree harvesting has shown to reduce both tree microhabitat density and their diversity at stand level (Winter & Möller 2008; Larrieu et al. 2012; Larrieu, Cabanettes, Brin, et al. 2014; Winter et al. 2015; Larrieu et al. 2017). Yet, an important share of forest biodiversity is strictly or primarily dependent on such structures and substrates (Jonsson et al. 2005; Müller et al. 2005; Vandekerkhove et al. 2005; Müller et al. 2007; Paillet et al. 2010; Müller & Bütler 2010; Juutilainen et al. 2011; Larrieu et al. 2012; Lachat et al. 2013; Regnery et al. 2013; Bouget et al. 2013; Bouget et al. 2014; Larrieu et al. 2017; Wende et al. 2017). Conservation of biodiversity in commercial forest stands is thus linked to retaining such tree related microhabitat structures (further referred to as 'TreMs'). TreMs are unequivocally identifiable, and identification can be trained in field exercises (***Figure 2***). They are complementary with forest surveys and applicable during tree marking operations. To ensure a standardized recording of such microhabitats a hierarchical structured catalogue was developed which is used for recording TreMs in marteloscope sites (Kraus et al. 2016).
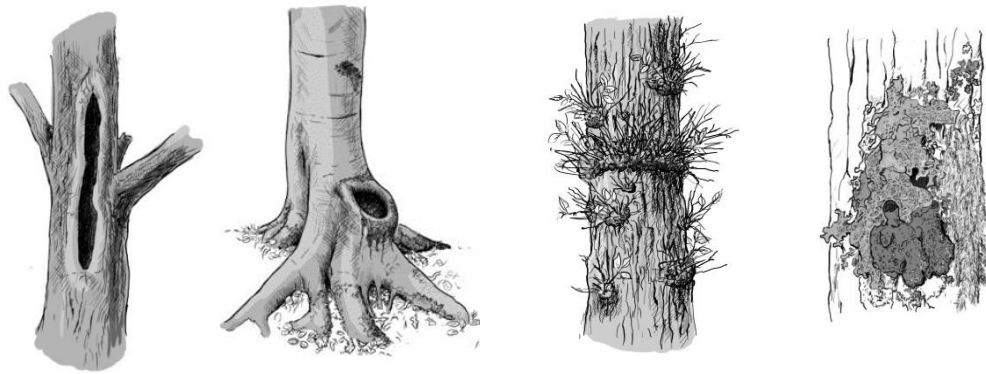
Figure 2. Selected tree related microhabitat structures. From left to right: mould cavity, dendrotelmata, witches broom and epiphytic foliose and fruticose lichens (images taken from Kraus et al. 2016).

The habitat value is calculated for each tree based on the number of recorded TreMs. The calculation considers the relative rarity of a habitat in near-natural forests and the time span needed for it to develop. The result is then expressed as a habitat value and indicated by 'points'.

$$H_i = \sum_{j=1}^{n} N_j \times s_j \times (R_j + D_j)$$
(eq.1)

where H_i is the habitat value of tree i, N_j the number of microhabitat type j, R_j is a value for the rarity of a TreM, D is a value for the time a TreM takes to develop or is available, and s_j is a size score (physical size of a TreM) within a TreMs group (Kraus et al. 2018).

2.3 Economic value

Up to five distinct timber quality classes are distinguished, each corresponding to a tree section (minimum length 0.5m). Timber quality classes are A- quality ('veneer'), B- and C- qualities (e.g., 'sawnwood'), 'IT/D'- quality ('industrial timber') and F- quality ('fuelwood' / 'energy wood'). The length of each section is visually assessed considering the overall tree height. Volumes are calculated for each section based on the length, diameter at the middle of each section and locally adapted and species-specific tapering factors. Timber market prices for each quality class are provided by local forest managers at the time of data collection.

3. Results

3.1 Components of the solution for a field training software

The starting point for building a mobile-device-based training solution for field use is the improved time and cost efficiency to conduct an exercise in the forest with immediate feedback on the exercise results while still at the training site. The manual alternative of recording tree selections with pen and paper and compiling and evaluating the results back at the classroom or office, may then necessitate a follow up visit to the forest to jointly evaluate exercise outcomes. In addition to the immediate availability of exercise results, the ability to directly revisit your choices in-situ also stimulates increased learning (Cosyns et al. 2018, Cosyns et al., 2020).

The task of carrying out training exercises in the forest implies a set-up made of multiple technological components. Exercises will need to be conducted in winter, in rainy

weather and with bright background lighting. The physical devices used for training must function in such conditions. An Internet connection cannot be relied on when conducting exercises in remote forests. Should the database of marteloscope information be contained in the software app itself, it would be necessary to download a new app version every time there is a change in the data. This is not feasible due to the expected frequency of changes in data. The number of marteloscopes will continue to increase over time and be subject to change due to e.g., disturbance events (tree loss through storm, fire) or in-growth (trees reaching dbh threshold > 7.5 cm). Further, exercise results will need to be saved and stored.

Such requirements imply the need for a repository that can manage updates to training site data and allow to administer exercises and their results. To simplify and secure the exchange of data between the mobile-device software and the database, an Application Programming Interface (API) was designed to handle this communication. A management application was designed to load data for new training sites, maintain data for existing sites and define exercises. The resulting architecture for the software package is thus comprised of four components (*Figure 3*): the Integrate+ Trainer (*'I+ Trainer'*), the API (*'I+ API'*), the central Integrate+ Database (*'I+ Repository'*) and the Integrate+ Manager (*'I+ Manager'*). Considering the use of the software in training events in different countries or by international groups, the I+ Trainer and I+ Manager are designed to be multilingual.
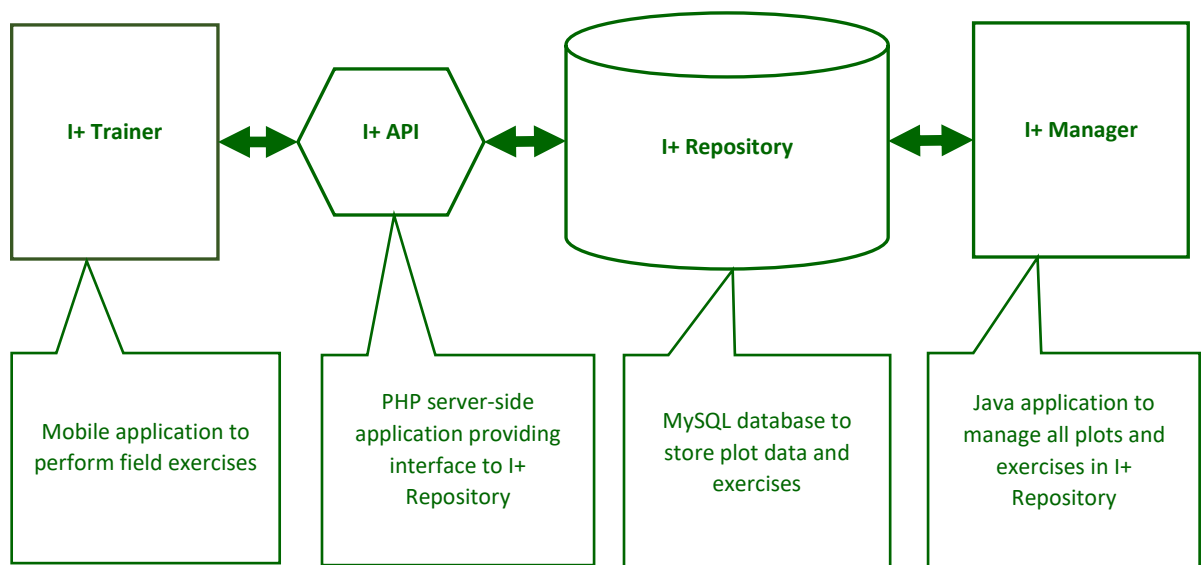
Figure 3. Integrate+ software components.

3.1.1 I+ Repository

A focal point of the Integrate+ software is the I+ Repository. There are two separate versions of the same database design: the central database and local databases on each training device, which are light versions of the I+ Repository in terms of content and structure. The *I+ (server) Repository* holds the complete information of all marteloscope training sites. The marteloscope attributes are standardised, with both compulsory attributes and optional attributes. The I+ Repository holds each marteloscope plot's metadata, a full

tree inventory, a complete record of tree microhabitats and the economic values of all trees. The definitions and results of training exercises are also stored. To support intellectual property right management of marteloscope data, it has user access management as not all datasets can be assumed public. These preconditions restrict copying the full data set to the local I+ Trainer database, as then a user cannot be prevented from viewing all content of a local database (with external tools). All operations for updating and editing the inventory content and defining exercises into the I+ Repository are handled using the I+ Manager.

The *I+ Trainer's local database* keeps subsets of the I+ Repository. The local database contains only the necessary information for performing a training at a specific marteloscope site: the data defining a marteloscope site and the exercises have previously been given in the I+ Manager and relayed via the I+ repository. The I+ Trainer communicates with the I+ Repository via the I+ API for updating the local database and sending back exercises results.

The I+ Repository (on a server) is technically implemented as a MySQL database. The distributed local instances of the central database, which only contain the information downloaded from the I+ Repository, are implemented in SQLite. The main difference between SQLite and MySQL, is that SQLite is not a database server, but a "file system engine using SQL syntax". This makes SQLite easily embeddable and well-suited for small devices with limited CPU power and memory. Although small mobile devices have limits on data size, all modern tablets and smart phones have at least one gigabyte RAM and several gigabytes disk

space. Therefore, they are in general well suited to run the Integrate+ software package. The performance of an SQLite database would not have been significantly hindered by the full server dataset when properly indexed.

Benchmarking results show[1] that the role of how many entries are made diminishes, as the time for finding an entry in a database of 19k vs 1.6M entries increases only by 19 percent. One main limitation of SQLite is it does not support as many data types as genuine SQL databases. SQLite omits some standard SQL features like *'right outer join'*. For the Integrate+ local Database, the choice was made for using SQLite on the mobile devices, in consideration of the limitations and the advantages in terms of device performance.

3.1.2 Integrate+ API (I+ API)
An application programming interface (API) is a set of clearly defined methods for communication between software components. An API eliminates the need and the possibility to know the implementation or data structure of the published methods of the API. For the programmer, an API simply offers clearly defined services. The I+ API provides the mechanism for safely exchanging data through Internet between the I+ Trainer and the I+ Repository. The I+ API is used to download exercise data from the I+ Repository to local databases in the I+ Trainer installations. It is also used to upload data of conducted exercises into the I+ Repository, which in turn can then be accessed using the I+ Manager. The I+ API also provides access control for authenticating these transactions. Eliminating direct communication between

---

[1] ttps://stackoverflow.com/questions/33456278/sqlite-performance-on-large-tables (accessed 28.03.2018)

these two databases, makes it possible to change the I+ Repository data structure without affecting the existing I+ Trainer installations. This happens e.g., when adding new features to the I+ Manager and I+ Repository. The API also makes the system more secure, as the I+ Trainer communicates directly with the API, which blocks unauthorised attempts to access or manipulate I+ Repository content.

The API is written in PHP language[2], built on top of the Lumen micro-framework[3] and runs on a Linux server. The Linux server runs Ubuntu Server 14.04, Apache 2.4, MySQL 5.6 and PHP 5.6. The Lumen framework version used is 5.2. The I+ Trainer uses standard HTTP to send requests in the JavaScript Object Notation (JSON) format and the API returns the data in JSON format. The design of the I+ API is illustrated in *Figure 4*.
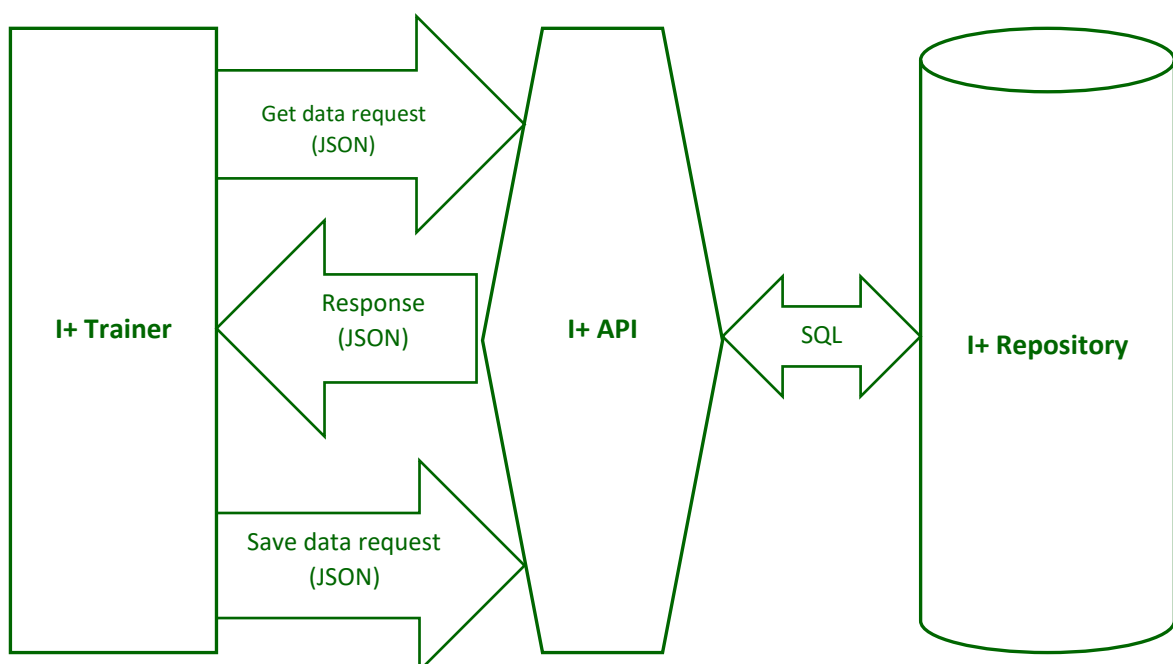

Figure 4. Outline of the I+ API design.

3.1.3 I+ Manager and I+ Trainer

The I+ Manager is a cross-platform desktop application developed in Java 8 programming language. The graphical user interface was implemented using JavaFX. Database operations are performed using the Hibernate Framework[4]. The I+ Manager is used for managing all marteloscope and exercise data. It requires a stable internet connection. Android was chosen as the primary platform, for implementing the I+ Trainer. However, the possibility to support other platforms was regarded as important by field trainers and software developers (e.g., iOS, Windows). However, each of the main mobile platforms has a different native programming language, resulting in the need to develop and maintain native versions of the application for multiple platforms. For this reason, the I+ Trainer was implemented as a hybrid mobile application. Such applications are built using web

---

[2] https://php.net/ (accessed 28.03.2018)

[3] https://lumen.laravel.com/ (accessed 28.03.2018)

[4] http://hibernate.org/ (accessed 28.03.2018)

technologies like HTML and JavaScript, and then "wrapped" inside a native container for the target platform. When such an application is run, the device's WebView[5] is used to display the HTML content instead of a web browser. This gives the app the appearance of a regular app, while in fact it is being run as an interactive webpage. The Apache Cordova mobile application development framework[6] was used for the I+ Trainer as it is an open-source project and one of the most used frameworks supporting all main mobile platforms. It can provide hardware functions to HTML applications that are unavailable for a web browser, for example access to a GPS. Apache Cordova itself is a cross-platform software, which made it possible to carry out the I+ software development in parallel on both Windows and Linux computers. The I+ Trainer was first created with Cordova 4 and currently uses Cordova 6.5. Cordova has proven to be a very good tool for developing a hybrid application. Even though GPS was eventually not used, due to the inadequate accuracy inside the small sized marteloscope plots (1 ha or smaller), it was highly beneficial to utilise the available hardware functions. For example, in future the I+ Trainer might use cameras that allow taking photos of identified tree microhabitats. The I+ Trainer was programmed with JavaScript, CSS and HTML. In addition, some open-source libraries were used, including the tree map drawing by Konva canvas framework[7]. As mentioned, the I+ Trainer runs a SQLite database and is currently available for Android with plans for publishing a Windows application. The I+ Trainer software is primarily developed for tablet computers but can be used also on smart phones. Due to screen size, usability is possible but limited on such devices.

3.2 The I+ Software functionality
3.2.1 The I+ Manager

The Tab '*plot management*' allows entering new marteloscopes (***Figure 5***). Tree information, uploaded in Excel format is then sent to the I+ Repository. In the process of uploading, data is checked for completeness and possible errors. The field course teacher can directly analyse and correct any faulty data in the I+ Manager. Data can also be updated for existing marteloscopes. This may be the deletion of fallen trees or updating single tree information in the course of re-measuring in the field (e.g., dbh and tree height increase; adding trees exceeding the measurement threshold of 7.5 cm; add or delete tree microhabitats; update wood prices). Site information can be entered in the I+ Manager (including e.g. site location, general information on the plot and terrain details).

---

[5] https://developer.android.com/reference/android/webkit/WebView (accessed 28.03.2018)

[6] https://cordova.apache.org/ (accessed 28.03.2018)

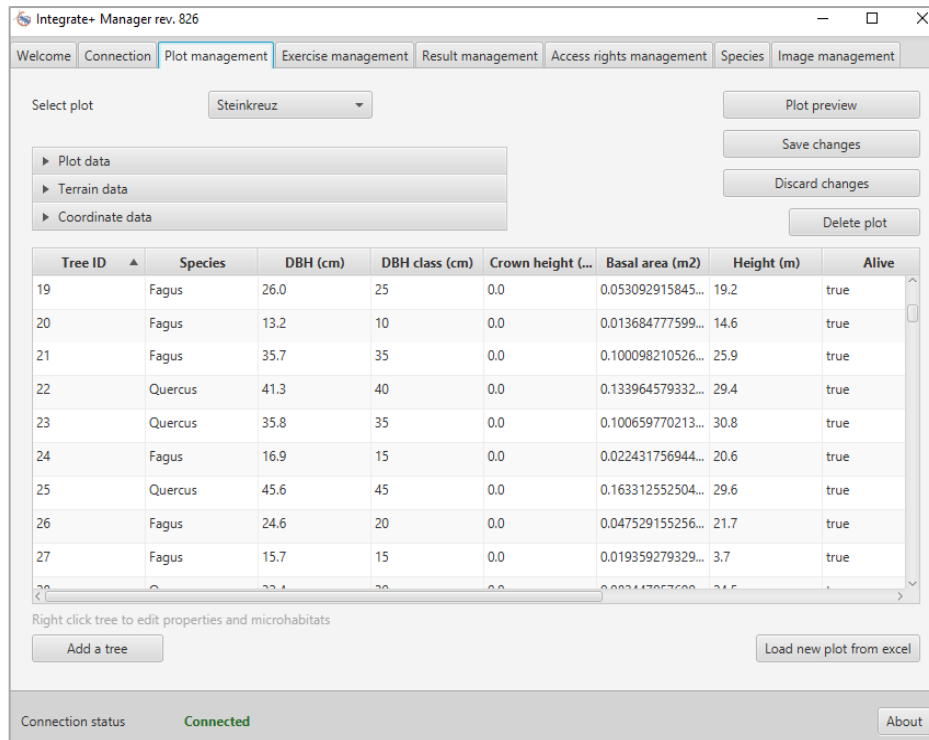[7] https://konvajs.org/ (accessed 28.03.2018)

Figure 5. I+ Manager plot management window.

The user of the I+ Manager can access the marteloscope plot map and a set of graphs by tree species or consult summarised stand data. The plot preview functionality can be helpful for checking the validity of the site information and when designing field exercises *(Figure 6)*.
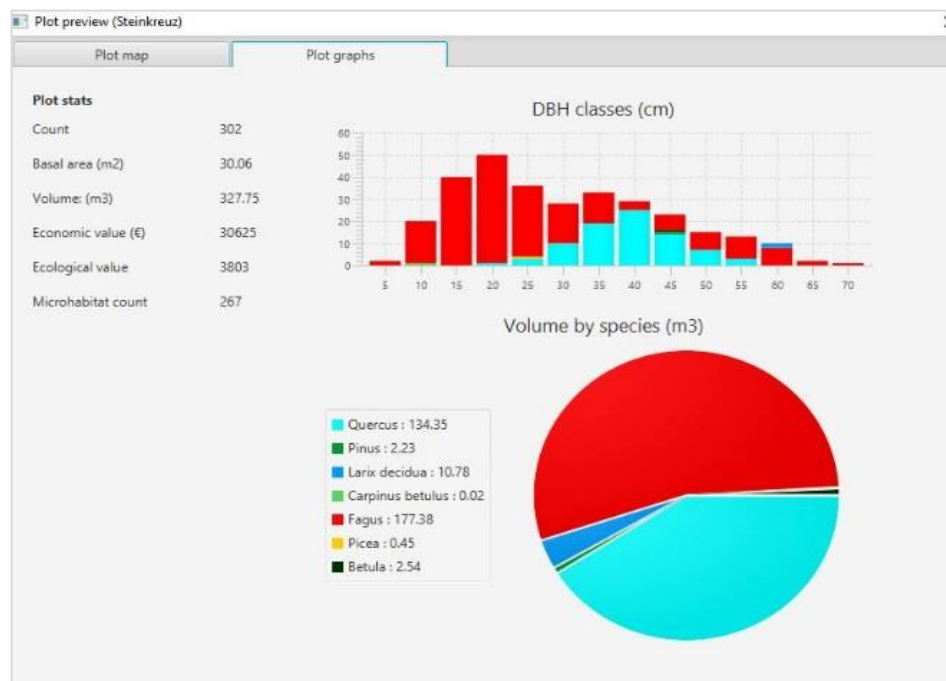

Figure 6. I+ Manager plot preview (numerical data and graphical displays).

The I+ Manager allows to tailor exercises to serve a particular training target. This is done under the Tab 'exercise management' (*Figure 7*). Exercise definition contains a detailed description of training objectives. The field course teacher can also decide which information will be visible to training participants. This is important as experience levels can vary widely from one user group to another (e.g., forest and nature conservation managers, university students, private forest owners, school pupils, public).
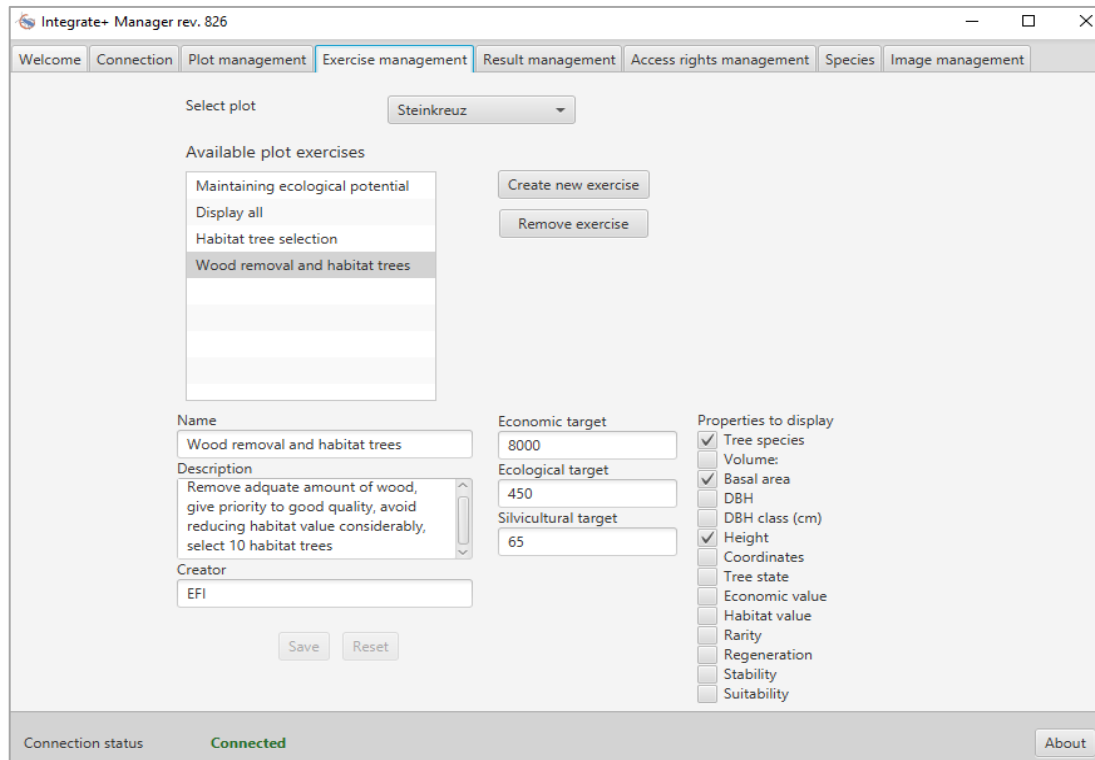

Figure 7. Exercise management window displaying an exercise for a selected marteloscope site.

If the aim of an exercise is e.g., to identify the most valuable habitat trees in a stand or to remove a defined volume of growing stock, the teacher can disable showing information on tree microhabitat points, tree volumes or tree-based quality assortments on the mobile devices. Further specifications can be made by the field course teacher for economic, ecological, or silvicultural targets. Such can be how much income to generate from harvesting, estimating wood volume removals, not encompassing a set threshold for removing habitat points or identifying a pre-defined number of future trees. Exercise results can then be compared to these set values.

Once a field exercise has been conducted using the I+ Trainer, all results can not only be stored on the mobile device or uploaded to the I+ Repository once Internet access is available but also exported as CSV files to other software programmes for further processing. The field course teacher can then use the Tab 'result management' in the I+ Manager to load, view and analyse the results from all available exercises of the selected Marteloscope plot. The 'result management' functionality can further be used for analysing the performance and distribution of individual participants' or groups' results as compared to a master solution. The exercise outcomes thus serve the field course teacher as reference for planning additional field training.

The Tab *'access rights'* is a feature for managing access rights for individual marteloscope sites. This allows marteloscope owners and field course teachers to securely access and store their exercises and corresponding training results. The Tab *'species'* allows adding new tree species not yet in the database while the Tab '*image management*' provides a location for uploading photos as illustrative material together with the marteloscope metadata.

3.2.2 The I+ Trainer

The user interface of the I+ Trainer was developed over time because of extensive field testing. New features were added while others removed. This iterative process between software developers, field course teachers and exercise participants were extensive and resulted in the current mobile trainer application.

Figure 8. Implementation of a field exercise using the I+ Trainer software.

Before visiting a marteloscope, participants install the I+ Trainer software on their mobile devices and upload the dataset of the site they will visit. For this a reliable Internet connection is required. Afterwards, the marteloscope data on the mobile device can be used offline.

Tree selection

Once the field course teacher has introduced the objective of the exercise, participants walk through the marteloscope site either as individuals or in small groups and select trees for retention and/or removal according to the given task (*Figure 8*). In our example participants received only partial information as they are experienced forest managers.

All trees are visible on a map displayed on the handheld device. They appear numbered, are geo-referenced and correspond with those tree numbers in the marteloscope. The circle size indicates the tree dbh dimensions while colours refer to different tree species. Training participants can then retain or remove trees via the touchscreen - tree map. Once they have selected a tree number the tree selection menu appears (*Figure 9*).
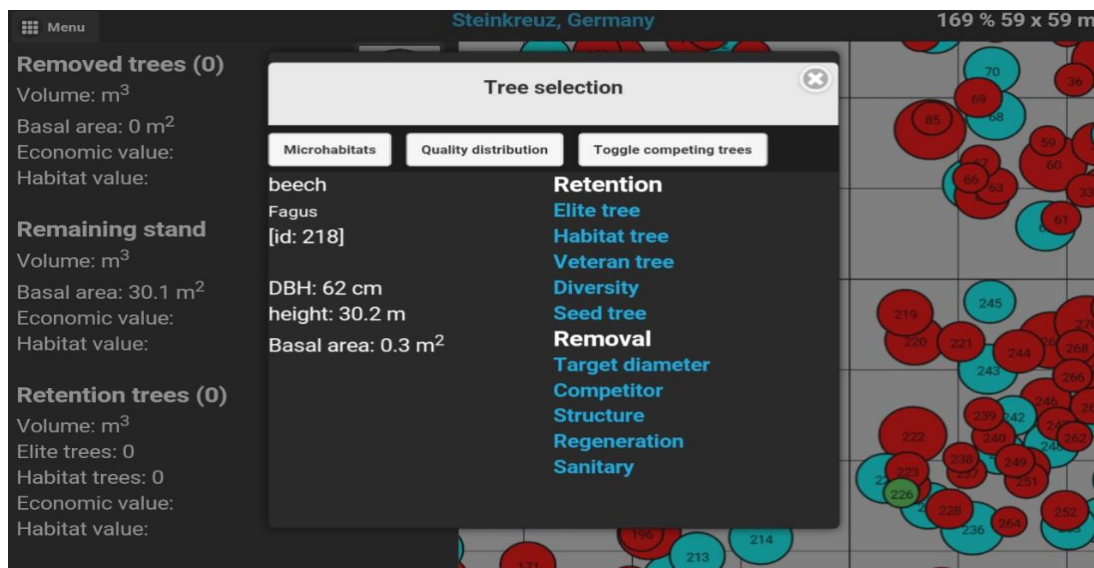
Figure 9. Tree selection and specifying the reason for intervention.

Removal options such as target diameter, competitor, regeneration are given while retention provides the selection of e.g. elite tree, habitat tree or seed tree. Depending on the level of detail visible to the participants, information on '*quality distribution*' and '*tree microhabitats*' can be consulted (***Figure 10***). Once a tree is selected it is marked with a circle on the map (removal yellow; retention green) and the numerical figures in the menu on the left are automatically updated. For ease of use a set of features allow to zoom into the map, change circle width for better visibility (e.g., if trees in close proximity overlap). Tree selection is then repeated until the exercise task is finalised.
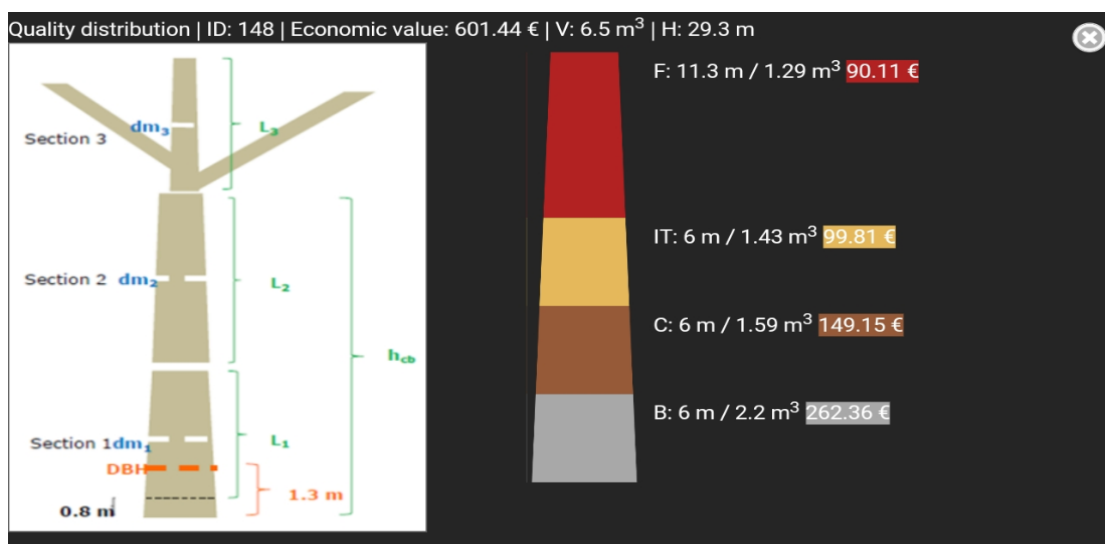

Figure 10. Information on quality distribution of a selected tree.

Exercise results

In a next step training participants can retrieve the results of their virtual tree selections by opening the Tab '*exercise results*' from the Menu. The first window displays the numerical values of removed and retained trees and those of the remaining stand. The numbers are

supported by thematic tree maps (*Figure 11*). Circle sizes of trees indicate their value e.g., in terms of volume, economic return or importance as habitat tree. Red circles in our example are removed trees. Using a forward arrow, additional analysis results are available. The next window displays an interactive data table and bar chart (dbh distribution). They show the original stand data 'before' the intervention and the effects of an intervention i.e., stand data 'after' intervention; 'removed' during exercise (*Figure 12*).

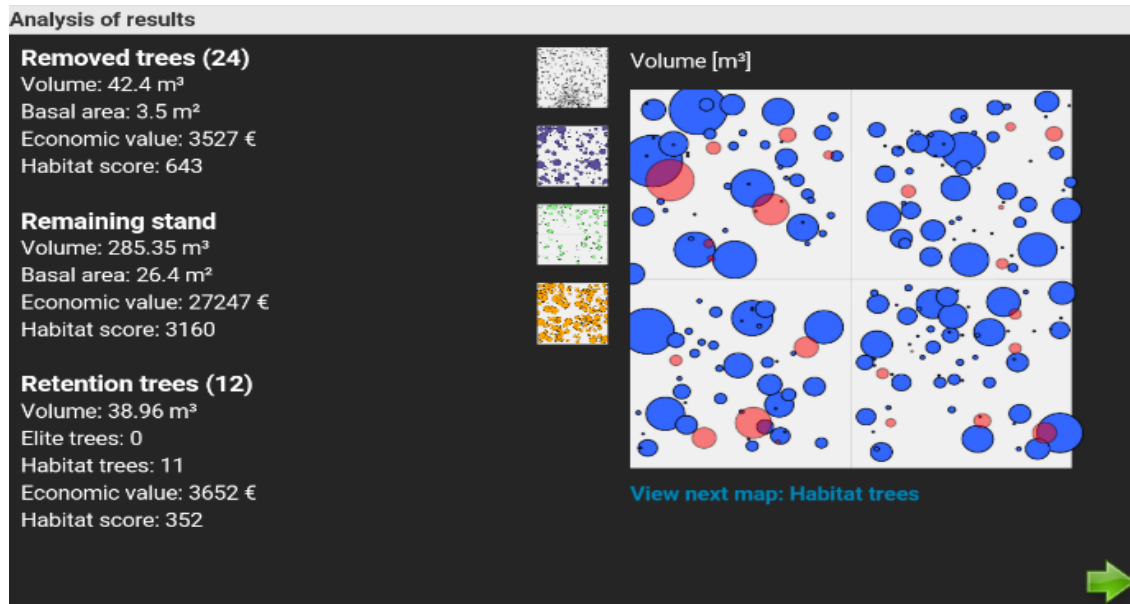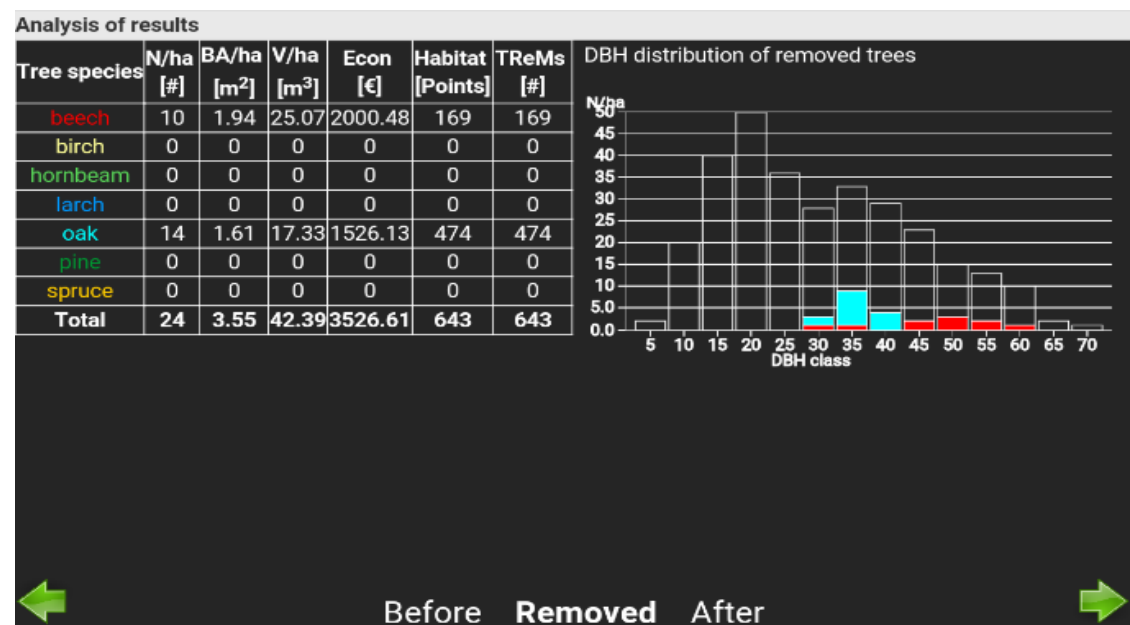**Figure 11**. Numerical results of an exercise and a map displaying removed volume.

Figure 12. Intervention results (removals).

The bar chart in the next window shows as default all available tree microhabitats in the stand (*Figure 13*). Participants can visualise how many and what type of tree microhabitats they have removed as result of their intervention ('*after*' and '*removed*').

Figure 13. Tree microhabitat distribution after intervention.

Having gone through all analysis windows participants can exit the exercise. The window '*finish exercise*' asks to save exercise results to the I+ Repository and simultaneously creates a pdf and CSV file including all exercise information. It is also possible to return to the initial tree map to either redo the exercise or revise it. Saving exercises to the I+ Repository allows the field course teacher to access them via the I+ Manager software for further analysis.

4. Discussion

The paper presents the I+ software input parameters and their calculation, its components and functionality. The main rationale for developing I+ was to allow performing virtual tree selection exercises in a real forest setting using specifically designated marteloscope sites. Therefore, the technical solution was to ensure the software runs on mobile, handheld devices. The I+ software package consists as described of a centralised database, a manager software, and a trainer module.

While the manager allows to design field exercises prior to training events, the trainer is used to record tree selections which can then be directly displayed following an exercise.

The I+ software is thus a contribution to objectifying discussions in the forest between different actors managing forests for different ecosystem services, as well as for other stakeholder groups dealing with or with an interest in forests. Focus in software development was put to providing tools for training and education on opportunities, challenges and consequences of integrating nature conservation aspects to forest management. Thus I+ contributes operational tools to the political debate on forest protection, biodiversity conservation and the need for wood as a renewable resource. However, I+ has the potential to be applied also to other topics such as carbon sequestration or related to silvicultural measures (climate resilient tree species, regeneration) either by utilising already available information or by collecting additional field data (**Chapter 4.2**).

4.1. Performance validation

An extensive number of marteloscope exercises have been conducted with the I+ Software. The feedback from exercise participants has been essential for evaluating the I+ Trainer software and its performance. Experiences were collected by field course teachers either orally or by using evaluation sheets. Exercise participants and teachers provided numerous suggestions for new software features and functionalities both during field exercises and at a tailored workshop[8]. Those most requested are briefly described in Chapter 6.

4.1.1 Improvements to the I+ Trainer software based on user feedback

Having exercise results available on mobile devices has been shown essential for stimulating learning, understanding and lively discussions. This was confirmed by many participants of various professional backgrounds (Cosyns et al. 2020; Joa et al. 2020; Cosyns et al. 2018; Pyttel et al. 2018). The exercise participants noted that exchanging on rationales for tree selections using actual figures becomes more objective and target oriented.

To support such effective exchange, summary sheets of each exercise result are created dynamically in pdf format and are immediately available to course participants. There were requests for improving the pdf summary sheets, including the wish of having all details on selected trees available or providing a detailed map that displays selected trees with their tree numbers for easy on-site revisits. Another proposal was related to a more tailored display of exercise results for different user communities. Such could be done by following main training aspects such as silviculture, economy or biodiversity while tailoring the result outputs to the knowledge of users (e.g., forest managers, students, school pupils, general public) for better understanding.

Further suggestions were to improve the general user-friendliness of the I+ Trainer software or to provide additional display features in the results section. One recurring request was to have available an application of selecting trees from the map by typing the tree number. Such a feature is relevant if two or more tree circles strongly overlap. The touchscreen does have a function to reduce circle size of the trees but in sites with high tree numbers this does not suffice. One display option proposed was a stand profile view before and after a virtual intervention. This would then allow visualising e.g., if a thinning was performed from below or as a crown thinning but also whether an intervention supports natural regeneration.

4.1.2 Improvements to the I+ software architecture

The use of the Hibernate ORM for the Database – I+ Manager communication, the saving of large amounts of data from the I+ Manager to the database is quite slow. Saving a new marteloscope plot can take up to one hour depending on the number of trees in the plot or internet connection. An improvement has been designed to resolve this issue of slow performance. An I+ Server Component reduces the number of connections through a firewall from the I+ Manager(client) to the I+ Repository(server). Data is then uploaded in bulk using JSON from the I+ Manager to the new I+ Server

---

Component. It translates the JSON to Hibernate ORM operations. Moving these large number of connections performed by Hibernate ORM take place on the same server (within the firewall) shortens the saving time from the I+ Manager considerably.

4.2 Development prospects of the I+ software

While the developers of the Integrate+ field training concept and software did expect interest for the approach, the positive feedback surpassed initial expectations. This was considered a validation for the need of such training tools and gave encouragement to chart improvement prospects to further increase the usefulness of the software (Schuck et al. 2016; Schuck 2020). There are two main lines of expanding software functionality.

4.2.1 Forest management and silviculture

I+ is highly valued for its ease of use and clear focus on selected parameters. Exactly these qualities should be preserved. It was argued by many training participants and trainers that software extensions could be designed modularly. New modules may be manually activated or disabled depending on the training objective or target group. A first test was implemented using a set of silviculture parameters (tree stability, stand regeneration, tree species suitability). Other options for such modular approaches are e.g., deadwood accumulation, regeneration, group selection harvesting or carbon sequestration.

The integration of stand development models was emphasized (Pretzsch et al. 2002; Komarov et al. 2003; Courbaud et al. 2015; Pretzsch et al. 2015; Courbaud et al. 2017). This would allow for modelling growth of individual trees and stands or TreMs utilising exercise results. However, some models (Komarov et al. 2003) may require additional information e.g. on forest soil. A current project[9] is developing a simple approach based on available information in marteloscopes including dbh and distances between individual trees and linked with growth functions for tree species (where available) for 20 years prediction.

4.2.2 Applications for other training purposes and research

When linking to any external software component a data exchange mechanism is needed. When converting I+ Trainer exercise results to a standardised file format, e.g., xml or CSV (CSV file type has been implemented), they can be exported to or linked with other external tools such as growth models or statistical computing tools such as 'R' or 'SPPS'.

Building interfaces to mobile phone based forest inventory tools is another application option for the I+ software (Molinier et al. 2014; Rosset et al. 2016; Molinier et al. 2016). As all tree properties are known, this would enable training possibilities in the field of forest inventory, with a validation of performed inventory accuracy (Molinier et al. 2016).

The platform martelage.sylvotheque.ch (MSC) allows for tree selection exercises in marteloscopes based on 360° photographs, so-called photospheres (Rosset et al. 2019). A user can take virtual tours mainly related

---

[9] https://efi.int/projects/integrate-metsanomistajien-paatoksenteon-tuki-muuttuvassa-toimintaymparistossa

to stand thinning and regeneration in close to nature forests. Tree selections performed during a virtual visit are immediately displayed allowing to compare results before and after an intervention. The tool is used in teaching, further education, and public relations. The I+ software and MSC both base on full inventoried marteloscopes. They are thus highly complementary in terms of training with I+ being applied in marteloscopes in the field while MSC runs in a virtual environment.

Besides performing education and training, the I+ software components generate large amounts of data that can be utilised for studies addressing the analysis of tree selection behaviour (Pommerening et al., 2015, Spinelli et al., 2016, Vitkova et al., 2016, Cosyns et al., 2020, Joa et al., 2020). That can include e.g., patterns of the most/least often selected trees, the frequency of meeting set exercise objectives, the comparison of users' movements on the marteloscope or comparing the results of different user groups having performed the same exercise task.

Tree-specific information currently collected in marteloscopes contains tree species, volumes, and wood quality classes. Adding a carbon module to the I+ software could not only visualise the amount of carbon stored in a marteloscope stand or how much is removed during a virtual intervention but could be linked further to the life span of wood products. Combining information layers such wood quality classes which correspond to particular wood products (Masera et al. 2003; Jasinevičius et al. 2017; Aleinikovas et al. 2018) the I+ software could educate exercise participants not only on their economic return but also how much carbon has been bound in wood products and for how long.

The development of tree microhabitats and future habitat potential is a central question for forest managers: how to ensure a continuous supply of tree microhabitat formation in managed forest stands and which are the trees displaying promising future habitat potentials are pressing issues when embedding nature conservation aspects to managed forests. Courbaud et al. (2017) are developing modelling approaches for predicting the probability of tree microhabitat formation. Once a robust methodology to project the development tree microhabitats is available the I+ Trainer could aim at embedding a simple tree microhabitat projection module on its mobile device or allow to export results to external modelling tools.

Single tree data from all marteloscopes has been made publicly available via the Global Biodiversity Information Facility – GBIF (Zudin et al.,2022; Kraus et al. 2017). GBIF is an international network and research infrastructure funded by the world's governments and aimed at providing anyone, anywhere, open access to data about all types of life on earth. The current data set includes nearly 37 000 trees single tree entries and is regularly updated. It can be utilised for research but also for further advancing I+ as a field training software (Courbaud et al, 2021, Larrieu et al., 2021; Santopuoli et al. 2019).

5. Conclusions

The innovation presented in this paper is the development and application of a suite of software tools that enable to efficiently carry out silvicultural training exercises in the forest. The software runs on handheld devices and thus considerably supports more time efficient training and improved learning results. One main aspect the software was asked to address is the

identification of tree microhabitat structures and their role for forest dwelling species while displaying potential trade-offs between economic return and conserving biological diversity. The immediate

availability of exercise results strongly supports factual discussions amongst participants and a better understanding for deviating views (Krumm et al. 2019).

Figure 14. Groups comparing and discussing their virtual tree selection results.

Highly appreciated by both teachers and exercise participants was that the software tool focussed on main aspects, thus being self-explanatory and easy to use. By providing only essential figures enough room is given for constructive discussions and sharing own knowledge and practical experiences (*Figure 14*).

Extending functionalities, analysis tools or adding new data types should be well thought in how far such will serve training purposes. Allowing the export of exercise results to other existing software and modelling tools (e.g., growth simulators, statistical analysis programmes) or providing modules for conducting tailored training (e.g., forest protection, carbon sequestration) that can be selected on

demand are seen as viable options for the further advancing the I+ software and it use. One of the European Commission's six main priorities (2019-2024) is a Europe fit for the digital age[10]. Its digital strategy aims at empowering people with a new generation of technologies. I+ contributes at an operational level to getting familiar with applying digital tools which will in future become increasingly part of daily work routines.

---

[10] https://ec.europa.eu/info/strategy/priorities-2019-2024_en

6. Software availability

Having been developed in a project context, an association is envisaged to ensure the long-term availability of the developed tools, on a non-commercial basis. A main concern is that continued funding is required for maintaining the server-based software components. This especially concerns the I+ Central Database. It is currently (2021) hosted by the European Forest Institute. The I+ API is shared as open source on Github[11]. The ambition is to share the code of the I+ Trainer and the I+ Manager as open source, but to date this is not yet the case. The I+ Trainer and I+ Manager are available free of charge. The I+ Trainer can be downloaded at a designated website '**iplus**'. The I+ Manager is available on request for site owners/managers at adminbonn@efi.int.

Loading martelscopes to the I+ Software

Proper training use requires access to an existing marteloscope and the corresponding data. Working with marteloscope sites and their data on mobile devices requires contacting the site / data owner(s). Permission to use marteloscope data for research was given by many of site / data owners. See Kraus et al. (2021) or contact adminbonn@efi.int for more information. Reference must be given to used data sources.

I+ software user manuals

The *I+ Trainer Software User Manual* is available for download (English, German, Spanish and Finnish).
The *I+ Manager Software User Manual* is available for download (English only).

7. Acknowledgements

---

[11]

https://github.com/EuropeanForestInstitute/integrate (accessed 27.7.2020)

8. Author details

[a]European Forest Institute, Platz der Vereinten Nationen 7, 53113 Bonn, Germany, andreas.schuck@efi.int

[b] Bayerische Staatsforsten (BaySF), Kronacher Straße 8, 96365 Nordhalben, Germany, daniel.kraus@baysf.de

[c]Secondary affiliation: University of Freiburg, Chair of Silviculture, Tennenbacherstr. 4, 79085 Freiburg im Breisgau, Germany

[d]Swiss Federal Institute for Forest, Snow and Landscape, Zürcherstrasse 111, 8903 Birmensdorf, Switzerland, frank.krumm@wsl.ch

[e]European Forest Institute, Yliopistokatu 6B, 80100 Joensuu, Finland, simo.varis@efi.int / sergey.zudin@efi.int

[f]CSC – IT Center for Science Ltd, P.O. Box 405, FI-02101 Espoo, Finland, tommi.suominen@csc.fi

9. References

Aleinikovas M., Jasinevičius G., Škema M., Beniušiene L., Šilinskas B., Varnagiryte-Kabašinskiene I., 2018. Assessing the effects of accounting methods for carbon storage in harvested wood products on the national carbon budget of Lithuania. Forests. 9(12).

Bastrup-Birk A., Reker J., Zal N., 2016. European forest ecosystems: State and trends. Luxembourg: Publications Office of the European Union.

Bollmann K., 2011. Naturnaher Waldbau und Förderung der biologischen Vielfalt im Wald [Internet]. [accessed 2020 Jul 27]:27–36. https://www.mendeley.com/catalogue/fd253e50-39b4-3c55-8cf5-8ffdcd94b2d8/

Bollmann K., Braunisch V., 2013. To integrate or to segregate: balancing commodity production and biodiversity conservation in European forests. In: Kraus D, Krumm F, editors. Integrative approaches as an oppurtunity for the conservation of forest biodiversity p. 18–31.

Bouget C., Larrieu L., Brin A., 2014. Key features for saproxylic beetle diversity derived from rapid habitat assessment in temperate forests. Ecol Indic. 36:656–664.

Bouget C., Larrieu L., Nusillard B., Parmain G., 2013. In search of the best local habitat drivers for saproxylic beetle diversity in temperate deciduous forests. Biodivers Conserv. 22(9):2111–2130.

Bruciamacchie M., 2005. Le marteloscope, un outil pour apprendre la gestion durable - Exemple d'évaluation de différents scénarios au marteloscope de Zittersheim (Vosges du Nord). In: Vallauri D, André J, Dodelin B, Eynard-Machet R, Rambaud D, editors. Bois mort à cavités – une clé pour des forêts vivantes Éd. Tec & Doc-Lavoisier; [Internet] [accessed 2020 Jul 27]; p. 237–252. https://infodoc.agroparistech.fr/index.php?lvl=notice_display&id=100856

Cosyns, H., Joa, B., Mikoleit, R., Krumm, F.,Schuck, A., Winkel, G., Schulz, T., 2020. Resolving the trade-off between production and biodiversity conservation in integrated forest management: comparing tree selection practices of foresters and conservationists. Biodiversity and Conservation. https://doi.org/10.1007/s10531-020-02046-x

Cosyns H., Kraus D., Krumm F., Schulz T., Pyttel P., 2018. Reconciling the Tradeoff between Economic and Ecological Objectives in Habitat-Tree Selection: A Comparison between Students, Foresters, and Forestry Trainers. For Sci 65(2):223–234. https://academic.oup.com/forestscience/article-abstract/65/2/223/5114434

Courbaud B., Larrieu, L., Kozak, D., Kraus, D., Lachat, T., Ladet, S., Müller, J., Paillet, Y., Sageb-Talebi, K., Schuck, A., Stillhard, J., Svoboda, M., Zudin, S., 2021. Factors influencing the formation rate of tree related microhabitats and implications for biodiversity conservation and forest management. Journal of Applied Ecology. DOI: 10.1111/1365-2664.14068

Courbaud B., Pupin C., Letort A., Cabanettes A., Larrieu L., 2017. Modelling the probability of microhabitat formation on trees using cross-sectional data. Methods Ecol Evol. 8(10):1347–1359.

Courbaud B., Lafond V., Lagarrigues G., Vieilledent G., Cordonnier T., Jabot F., de Coligny F., 2015. Applying ecological model evaludation: Lessons learned with the forest dynamics model Samsara2. Ecol Modell. 314:1–14.

Directorate-General for Environment., 2016. Mapping and Assessment of Ecosystems and their Services Mapping and assessing the condition of Europe's ecosystems: Progress and challenges. Publications Office of the European Union; [Internet] [accessed 2020 Jul 27]. https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/3rdMAESReport_Condition.pdf

European Commission., 2013. A new EU Forest Strategy: for forests and the forest-based sector. Brussels: EUROPEAN COMMISSION; [Internet] [accessed 2020 Jul 27]. http://eur-lex.europa.eu/resource.html?uri=cellar:21b27c38-21fb-11e3-8d1c-01aa75ed71a1.0022.01/DOC_1&format=PDF

European Environment Agency. 2014. Resource-efficient green economy and EU policies [Internet]. Publications Office of the European Union; [Internet] [accessed 2020 Jul 27]. http://www.eea.europa.eu/publications/resourceefficient-green-economy-and-eu.

European Environment Agency., 2015. State and Outlook 2015 the European Environment. Copenhagen: Publications Office of the European Union.

Forest Europe., 2020. State of Europe's Forests 2020. 394p.

Frank G., Parviainen J., Vandekerhove K., Latham J., Schuck A., Little D., 2007. COST Action E27 Protected Forest Areas in Europe - Analysis and Harmonisation (PROFOR): Results, Conclusions and Recommendations. Frank Georg, Parviainen Jari, Vandekerkhove K, Latham James, Schuck Anderas, Little Declan, editors. Vienna: Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW). http://bfw.ac.at/020/profor/pdf/COST_Aktion_E27_2007.pdf

Hetemäki L, editor. 2014. Future of the European forest-based sector: Structural changes towards bioeconomy. European Forest Institute; [Internet] [accessed 2020 Jul 27]. https://www.efi.int/publications-bank/future-european-forest-based-sector-structural-changes-towards-bioeconomy.

Jasinevičius G., Lindner M., Verkerk P.J., Aleinikovas M., 2017. Assessing impacts of wood utilisation scenarios for a Lithuanian bioeconomy: Impacts on carbon in forests and harvested wood products and on the socio-economic performance of the forest-based sector. Forests. 8(4).

Joa, B., Paulus, A., Mikoleit, R. and Winkel, G., 2020. Decision Making in Tree Selection – Contemplating Conflicting Goals via Marteloscope Exercises. Rural Landscapes: Society, Environment, History, 7(1), p.3. DOI: http://doi.org/10.16993/rl.60

Jonsson B.G., Kruys N., Ranius T., 2005. Ecology of species living on dead wood – lessons for dead wood management. Silva Fen. 39(2):289–309.

Juutilainen K, Halme P, Kotiranta H, Mönkkönen M. 2011. Size matters in studies of dead wood and wood-inhabiting fungi. Fungal Ecol. 4(5):342–349.

Komarov A., Chertov O., Zudin S., Nadporozhskaya M., Mikhailov A., Bykhovets S., Zudina E., Zoubkova E., 2003. EFIMOD 2—a model of growth and cycling of elements in boreal forest ecosystems. Ecol Modell [Internet] [accessed 2020 Jul 27] 170(2–3):373–392. https://www.sciencedirect.com/science/article/pii/S0304380003002400

Kraus D, Bütler R, Krumm F, Lachat T, Larrieu L, Mergner U, Paillet Y, Rydkvist T, Schuck A, Winter S. 2016. Catalogue of tree microhabitats – Reference field list http://iplus.efi.int/uploads/Tree%20Microhabitat%20Catalogues/Catalogue_TreeMicrohabitats_EN.pdf

Kraus D., Krumm F. (eds), 2013. Integrative approaches as an opportunity for the conservation of forest biodiversity. European Forest Institute. 284 pp.

Kraus D, Mergner U, Schuck A, Krumm F, Haußmann T. 2016. Integrate+: Wieviel Narurschutz kann der bewirtschaftete Wald leisten? Der Dauerwald – Zeitschrift für naturgemäße Waldwirtschaft (54):33–38.

Kraus, D., Schuck, A., Bebi, P., Blaschke, M., Bütler, R., Flade, M., Heintz, W., Krumm, F., Lachat, T., Larrieu, L., Lehnerova, L., Levin, M., Mergner, U., Pach, M., Paillet, Y., Pyttel, P., Rydkvist, T., Santopuoli, G., Sever, K., Sturm, K., Vandekerkhove, K., Winter, S., Witz, M., Winnock, M., Marcandella, M., Roth, I., Jakob, A., Dickele, R., Hofmann, G., Ruis-Eckhardt, D., Boschen, S., Schölmerich, U., Leder, B., Guericke, M., Merkel, H., Löffler, D., Schusser, S., Runkel, M., Steinmetz, A., Marx, K. H., Mongelluzzi, A., Wilshusen, F., Boutteaux, J., Duchamp, L., Dericbourg, N., Rouyer, E., Csikos, V., Sweeny, K., Steichen, D., Leytem, M., Konczal, S., Stereńczak, K., Kazimirovic, M., Šebeň, V., Baiges Zapater, T., van der Maaten-Theunissen, M., Pommer, A., Nord-Larsen, T., Fuhr, M., Delebeque, L., Navarro, L. M., Lasala, D., Zudin S., 2021. Spatially explicit database of tree related microhabitats (TreMs). Version 1.9. Institut national de recherche pour l'agriculture, l'alimentation et l'environnement (INRAE). Occurrence dataset https://doi.org/10.15468/ocof3v

Kraus D, Schuck A, Krumm F, Bütler R, Cosyns H, Courbaud B, Larrieu L, Mergner U, Pyttel P, Varis S, et al. 2018. Seeing is building better understanding - the Integrate+ Marteloscopes [Internet]. [accessed 2020 Jul 27]. https://www.dora.lib4ri.ch/wsl/islandora/object/wsl%3A19349/

Krumm F., Lachat T., Schuck A., Bütler R., Kraus D., 2019. Marteloscopes as training tools for the retention and conservation of habitat trees in forests. Schweizerische Zeitschrift fur Forstwes. 170(2):86–93.

Krumm, F., Schuck, A., Rigling, A. (eds), 2020. How to balance forestry and biodiversity conservation – A view across Europe. European Forest Institute (EFI); Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmendorf. 644 p.

Krumm, F., Rigling, A., Bollman, K., Brang, P., Dürr, C., Gessler, A., Schuck, A., Schulz-Marty T., Winkel, G., 2020. Synthesis: Improving biodiversity conservation in European managed forests needs pragmatic, courageous, and regionally-rooted management approaches. In Krumm, F., Schuck, A., Rigling, A. (eds): How to balance forestry and biodiversity conservation – A view across Europe. European Forest Institute (EFI); Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmendorf. 608-633

Krumm F, Schuck A, Kraus D. 2013. Integrative management approaches: a synthesis. In: Kraus D., Krumm F., editors. Integrative approaches as an opportunity for the conservation of for biodiversity. European Forest Institute; p. 256–262.

Lachat T., Bouget C., Bütler R., Müller J., 2013. Deadwood: quantitative and qualitative requirements for the conservation of saproxylic biodiversity. In: Kraus D, Krumm F, editors. Integr approaches as an Oppor Conserv For biodiversity Focus – Manag For Eur. Freiburg: European Forest Institute; p. 92–102.

Larrieu, L., Cabanettes, A., Courbaud, B., Goulard, M., Heintz, W., Kozák, D., Kraus, D., Lachat, T., Ladet, S., Müller, J., Paillet, Y., Schuck, A., Stillhard, J., Svoboda, M., 2021. Co-occurrence patterns of tree-related microhabitats: A method to simplify routine monitoring. Ecological Indicators 127 (2021) 107757. 1-10. https://doi.org/10.1016/j.ecolind.2021.107757

Larrieu L., Cabanettes A., Brin A., Bouget C., Deconchat M., 2014. Tree microhabitats at the stand scale in montane beech-fir forests: Practical information for taxa conservation in forestry. Eur J For Res. 133(2):355–367.

Larrieu L., Cabanettes A., Delarue A., 2012. Impact of silviculture on dead wood and on the distribution and frequency of tree microhabitats in montane beech-fir forests of the Pyrenees. Eur J For Res. 131(3):773–786.

Larrieu L., Cabanettes A., Gonin P., Lachat T., Paillet Y., Winter S., Bouget C., Deconchat M., 2014. Deadwood and tree microhabitat dynamics in unharvested temperate mountain mixed forests: A life-cycle approach to biodiversity monitoring. For Ecol Manage. 334:163–173.

Larrieu L., Cabanettes A., Gouix N., Burnel L., Bouget C., Deconchat M., 2017. Development over time of the tree-related microhabitat profile: the case of lowland beech–oak coppice-with-standards set-aside stands in France. Eur J For Res. 136(1):37–49.

Lassauce A., Paillet Y., Jactel H., Bouget C., 2011. Deadwood as a surrogate for forest biodiversity: Meta-analysis of correlations between deadwood volume and species richness of saproxylic organisms. Ecol Indic. 11(5):1027–1039.

Masera O.R., Garza-Caligaris J.F., Kanninen M., Karjalainen T., Liski J., Nabuurs G.J., Pussinen A., de Jong B.H.J, Mohren G.M.J., 2003. Modeling carbon sequestration in afforestation, agroforestry and forest management projects: the CO2FIX V.2 approach. Ecol Modell. 164:177–199. http://www.sciencedirect.com/science/article/B6VBS-48GNNFT-3/2/e5af33c811c4c0c205704d178a394710

Mergner, U. and Kraus, D., 2020. Ebrach – Learning from nature: Integrative forest management. In Krumm, F., Schuck, A., Rigling, A. (eds): How to balance forestry and biodiversity conservation – A view across Europe. European Forest Institute (EFI); Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmendorf. 204-217.

Molinier M., Hame T., Toivanen T., Andersson K., Mutanen T., 2014. Relasphone - Mobile phone and interactive applications to collect ground reference biomass data for satellite image analysis. In: Int Geosci Remote Sens Symp. Institute of Electrical and Electronics Engineers Inc.; p. 836–839.

Molinier M., López-Sánchez C., Toivanen T., Korpela I., Corral-Rivas J., Tergujeff R., Häme T., 2016. Relasphone—Mobile and Participative In Situ Forest Biomass Measurements Supporting Satellite Image Mapping. Remote Sens [Internet]. [accessed 2020 Jul 10] 8(10):869. http://www.mdpi.com/2072-4292/8/10/869

Müller J., Bußler H., Bense U., Brustel H., Flechtner G., 2005. Urwald relict species – Saproxylic beetles indicating structural qualities and habitat tradition. Waldökologie online AFSV-Berichte der Arbeitsgemeinschaft Forstl Standorts- und Veg [Internet]. [accessed 2020 Jul 27] (2):106–113. http://publikationen.ub.uni-frankfurt.de/frontdoor/index/index/docId/19732

Müller J., Bütler R,. 2010. A review of habitat thresholds for dead wood: a baseline for management recommendations in European forests. Eur J For Res 129(6):981–992. http://link.springer.com/10.1007/s10342-010-0400-5

Müller J., Hothorn T., Pretzsch H., 2007. Long-term effects of logging intensity on structures, birds, saproxylic beetles and wood-inhabiting fungi in stands of European beech Fagus sylvatica L. For Ecol Manage. 242(2–3):297–305. http://www.sciencedirect.com/science/article/B6T6X-4N4409K-8/2/e15f85780a16f26fd1d1b618f116c9f2

Niedermann-Meier S., Mordini M., Bütler R., Rotach P., 2010. Habitatbäume im Wirtschaftswald: ökologisches Potenzial und finanzielle Folgen für den Betrieb. Schweizerische Zeitschrift fur Forstwes. 161(10):391–400.

Paillet Y., Bergès L., Hjältén J., Ódor P., Avon C., Bernhardt-Römermann M., Bijlsma R-J., De Bruyn L., Fuhr M., Grandin U., et al., 2010. Biodiversity Differences between Managed and Unmanaged Forests: Meta-Analysis of Species Richness in Europe. Conserv Biol. 24(1):101–112. http://doi.wiley.com/10.1111/j.1523-1739.2009.01399.x

Parviainen J., Bücking W., Vandekerkhove K., Schuck A., Päivinen R., 2000. Introduction Strict forest reserves in Europe: efforts to enhance biodiversity and research on forests left for free development in Europe (EU-COST-Action E4). Forestry. 73(2):107–118.

Pommerening A., Vítková L., Zhao X., Ramos C.P., 2015. Towards Understanding Human Tree Selection Behaviour. For FACTS – Results from Swedish Univ Agric Sci [Internet]. [accessed 2020 Jul 27] (9):1–6. https://www.slu.se/globalassets/ew/ew-centrala/forskn/popvet-dok/faktaskog/faktaskog15/faktaskog_09_2015_eng.pdf

Poore A., 2011. The Marteloscope A Training Aid for Continuous Cover Forest Management. Woodl Herit.

Pretzsch H., Biber P., Ďurský J., 2002. The single tree-based stand simulator SILVA: construction, application and evaluation. For Ecol Manage 162(1):3–21. https://linkinghub.elsevier.com/retrieve/pii/S0378112702000476

Pretzsch H., Forrester D.I., Rötzer T., 2015. Representation of species mixing in forest growth models. A review and perspective. Ecol Modell, 313:276–292. https://www.sciencedirect.com/science/article/pii/S0304380015003002

Pyttel P., Kraus, D., Schuck, A., Krumm, F., Bauhus, J., 2018. Mit „Marteloskopen" lehren und lernen. AFZ-DerWald 4/2018. 26 – 29.

Regnery B., Couvet D., Kubarek .L, Julien J.F., Kerbiriou C., 2013. Tree microhabitats as indicators of bird and bat communities in Mediterranean forests. Ecol Indic. 34:221–230.

Roberts D., Nikolakis W., 2014. Thoughts on transforming the forest sector: The potential (and reality) of the bio-economy. In: Nikolakis W, Innes J, editors. For Glob Challenges Oppor Sustain Dev. Taylor and Francis; p. 25–35.

Rosset, C., Sciacca, S., Fiedler, U., 2019. Exercices de martelage et suivi sylvicole sur martelage.sylvotheque.ch (MSC) Schweizerische Zeitschrift fur Forstwesen(170), S. 98-101. https://doi.org/10.3188/szf.2019.0094

Rosset C., Brand R., Caillard I., Fiedler U., Gollut C., Schmocker A., Weber D., Wuillemin E., Dumollard G., 2016. MOTI – L'inventaire forestier par le smartphone. Remagen: Verlag Kessel.

Santopuoli G., Di Cristofaro M., Kraus D., Schuck A., Lasserre B., Marchetti M., 2019. Biodiversity conservation and wood production in a Natura 2000 mediterranean forest. A trade-off evaluation focused on the occurrence of microhabitats. IForest 12(1):76–84. https://iforest.sisef.org/

Schuck, A. (lead author), Lier, M., (lead author), Jo Van Brusselen, Jakob Derks, Parviainen, J., Bastrup-Birk, A., Gasparini, P., Bozzano, M., Oggioni, S., Raši, R., Vogt, P., Biala, K., Köhl, M., Konczal, A., de Koning, J., Alberdi, I., Voříšek, P., Schwarz, M-, Linser, S., 2020. Criterion 4: Maintenance, Conservation and

Appropriate Enhancement of Biological Diversity in Forest Ecosystems. In FOREST EUROPE, 2020: State of Europe's Forests 2020. 109-150.

Schuck A., 2020. Excursions, exchanges and training events (2017-2020) [Internet]; [accessed 2020 Jul 27]. www.iplus.efi.int

Schuck A., Held A., Kraus D., Krumm F., Quadt V., Schmitt H., 2016. Integrate+ training, excursions and exchanges. Summary sheets. European Forest Institute. [Internet]; www.iplus.efi.int

Schuck A., Krumm F., Kraus D., 2015. Marteloscopes - Description of parameters and assessment procedures European Forest Institute. [Internet]. http://iplus.efi.int/uploads/2019_Marteloscope_Methodology_Final.pdf

Spinelli R., Magagnotti N., Pari L., Soucy M., 2016. Comparing tree selection as performed by different professional figures. For Sci. 62(2):213–219.

Staffas L., Gustavsson M., McCormick K., 2013. Strategies and policies for the bioeconomy and bio-based economy: An analysis of official national approaches. Sustain. 5(6):2751–2769.

Vandekerkhove K., De Keersmaeker L., Baeté H., Walleyn R., 2005. Spontaneous re-establishment of natural structure and related biodiversity in a previously managed beech forest in Belgium after 20 years of non intervention. In: For Snow Landsc Res. Vol. 79. p. 145–156.

Vítková L., Dhubháin Á.N., Pommerening A., 2016. Agreement in tree marking: What is the uncertainty of human tree selection in selective forest management? For Sci. 62(3):288–296.

Wende B., Gossner M.M., Grass I., Arnstadt T., Hofrichter M., Floren A., Linsenmair K.E., Weisser W.W., Steffan-Dewenter I., 2017. Trophic level, successional age and trait matching determine specialization of deadwood-based interaction networks of saproxylic beetles. Proc R Soc B Biol Sci. 284(1854).

Winter S., Höfler J., Michel A.K., Böck A., Ankerst D.P., 2015. Association of tree and plot characteristics with microhabitat formation in European beech and Douglas-fir forests. Eur J For Res. 134(2):335–347.

Winter S., Möller G.C., 2008. Microhabitats in lowland beech forests as monitoring tool for nature conservation. For Ecol Manage. 255(3–4):1251–1261.

World Resources Institute., 2005. Ecosystem and Human Well-Being - Synthesis. Washington, DC.: Island Press; [accessed 2020 Jul 27]. http://wedocs.unep.org/handle/20.500.11822/8701

Zudin S., Heintz W., Kraus D., Krumm F., Larrieu L., Schuck A. (2022) A spatially-explicit database of tree-related microhabitats in Europe and beyond. Biodiversity Data Journal 10: e91385. https://doi.org/10.3897/BDJ.10.e91385

EFI

Integrate Network
facilitated by EFI