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ARANGE Deliverable D4.5

Improved DSToolBox version 1.0 for multifunctional forest management

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Abstract:

The sustainable provision of ecosystem services is one of the main tasks of our time, a task that is particularly challenging for mountain forest ecosystems, given the complexities of their human and natural systems. The ARAGE ToolBox presented in this document aims at supporting this management process, by transferring information from science to society, and by providing interactive tools that support the management and decision making in this domain. The “Adaptive Forest Management” (AFM) ToolBox contains inter alia web-based interactive tools, and an extensive web knowledge base on adaptive forest management. This document gives a short summary of the AFM ToolBox, and focuses then on the “Landscape Analysis Tool”, covering the concepts, configuration and user interface of the tool.

The AFM ToolBox is available at <http://afm-toolbox.net>.

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1 INTRODUCTION

The management of mountain forest ecosystems is a particularly difficult task due to the diversity of ecosystem services that need to be taken into account, and due to the diversity of stakeholders that are involved. Scientifically sound support of this decision process is the main goal of the Adaptive Forest Management ToolBox. The ToolBox approach combines results of forest ecosystem models with recent advances in decision support science in easy-to-use web-based tools.

This deliverable complements the Deliverable D4.4 (Prototype of the ToolBox) which covers in depth the basic concepts and technologies of the AFM ToolBox. In this document the focus is on the newly developed “Landscape Assessment Tool” (LAT) which itself is a group of tools addressing the analysis of mountain forest landscapes. Unlike the other tools of the ToolBox, the LA Tool is a standalone tool which can be downloaded from the AFM ToolBox website - the analysis algorithms and 3d visualization of LAT are still too heavy for web-technologies.

This document starts with very briefly re-iterating the overall design of the AFM ToolBox (chapter 0). It then focuses on the LA-Tool (chapter 3). Chapters 3.1 to 3.3 describes the installation, start and configuration of the tool, and the following chapters (3.4 – 3.7) discuss the individual analysis tool included in the LAT. Two appendices provide a detailed description of core algorithms and assumption of the analysis tools.

2 ToolBox Overview

The Adaptive Forest Management (AFM) ToolBox combines a number of elements (Figure 1). The main components are the ToolBox DataBase, the interactive tools and the ToolBox website. The input data for the data-driven tools of the ToolBox are created externally by forest ecosystem models, transformed to the common ARANGE data format and then stored in the ToolBox DataBase. The ToolBox website makes the “knowledge base” available to the end-user by means of static and dynamic web pages. The ToolBox Framework is the technical foundation for the tools and ToolBox website, ensuring visual consistency.

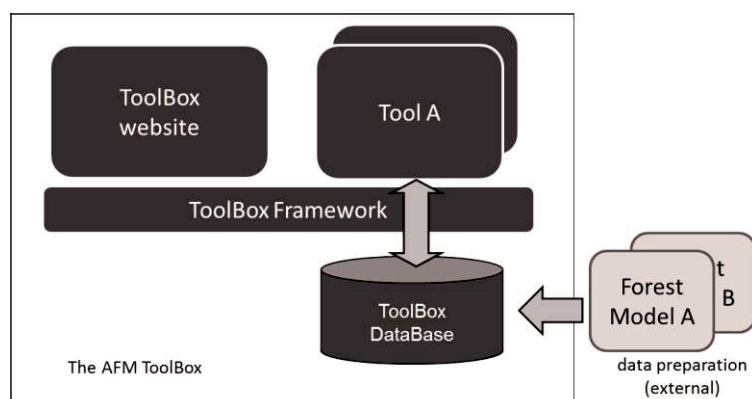


Figure 1. Structural elements of the AFM ToolBox. The ToolBox website and the Tools share a common (technical) ToolBox Framework. The Tools may access data stored in the ToolBox DataBase. Data generated by runs of various forest models can be fed into the database and consequently analyzed with the tools of the ToolBox.

2.1 ToolBox Website

The ToolBox website uses a content management system (CMS) providing various kinds of “soft” information. Most of the material (e.g., examples and background information) is compiled from results of the ARANGE project and previous projects.



Figure 2. Start screen of the AFM ToolBox website.

2.2 Tools in the ToolBox

The tools of the AFM ToolBox aim at providing decision support for selected topics in the context of mountain forest management. The prototype of the ToolBox both new and old tools, i.e., tools that were developed within the frame of the ARANGE context, and tools that were developed in earlier projects and have been adapted to meet the demands of the ARANGE project.

The adapted legacy tools are (1) the “Vulnerability Assessment Tool”, which facilitates multi-criteria techniques to assess climate change impacts of different forest management scenarios on the provisioning of ecosystem services, and (2) the “Optimized Management Plan” tool. The latter tool provides an optimization algorithm to establish an “optimal” management plan for a landscape given a user-defined objective function. Both tools are pure online tools and run in a web-browser.

The newly created tool is LAT, the Landscape scale Assessment Tool. The tool combines a technique for creating realistic single tree initializations based on remote sensing data with functionalities for the assessment of landscape level indicators. The latter can be fed by ARANGE data (i.e., stand level simulations combined to landscapes). Due to the high demands for computation and visualization power, the LAT tool is designed as a client tool which is downloaded and installed on the user computer (the tool is available for Windows, Linux, and Mac platforms). Details on LAT are given in chapter X.

2.3 Database, ToolBox Framework, and data management tools

Less visible, but equally important are the components building the backend of the ToolBox, namely the ToolBox database, the ToolBox framework, and the data management tools. The ToolBox database (described in detail in Deliverable D1.5) includes mainly the results of simulations of a variety of forest stands and/or landscapes under the assumption of various climate and management scenarios. The data is either produced within the ARANGE project (or previous projects), or can be provided by the user of the ToolBox. Either way, the available data is processed analysed by the aforementioned tools.

The second pillar is the ToolBox Framework, which provides the necessary technical foundation for integrating both the tools and the website, and simplifies the process of creating new tools. And third, the tools for data management: this includes the DataViewer tool allowing browsing and downloading the content of the database, and the data import and export tool that provides the interface between the forest models and the ToolBox.

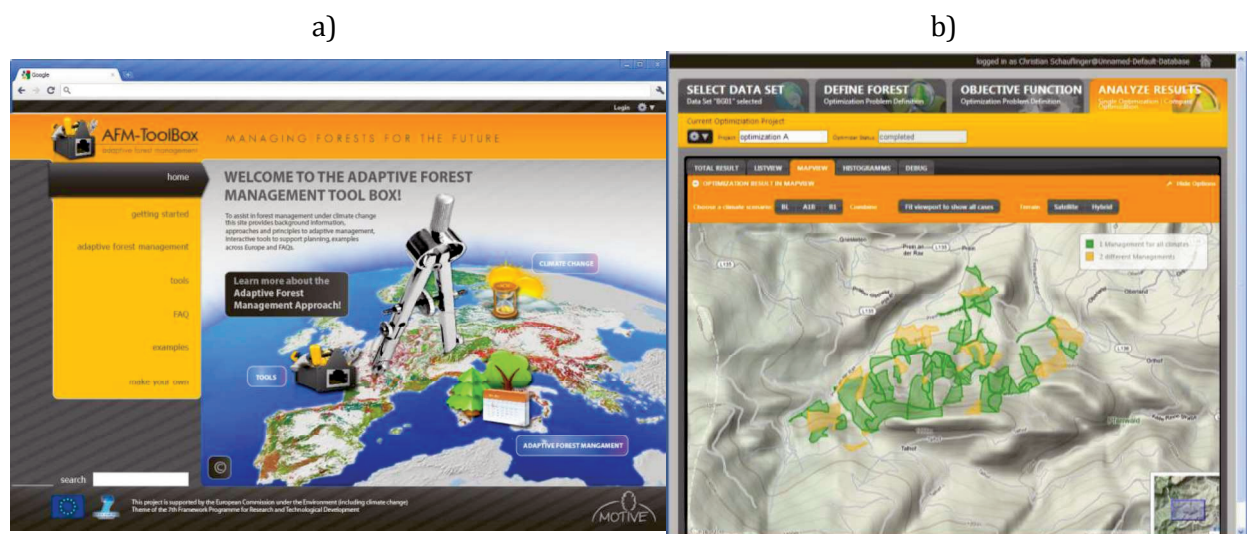


Figure 3. Example screens for the AFM ToolBox. Left panel (a) shows the start page of the AFMToolBox website, and the right panel (b) shows an example for a web based tool (Example: Mixed integer programming tool).

3 Landscape assessment tool

3.1 Getting started

Unlike the other tools of the ToolBox as described in this document, the Landscape Assessment Tool (LAT) software runs directly on a client computer (PC or laptop) and needs to be downloaded and installed from the ARANGE ToolBox. The binary software package is available for Microsoft Windows platforms, but can be executed also for Linux and Mac operating systems. For the latter case, users would need to compile the available source code for their respective target machines.

The LAT tool contains at the moment four separate tools that operate on the same representation of forested (mountain-) landscapes. In addition, the tools share also technical infrastructure (e.g., 3d visualization, processing of GIS files, et cetera). The “Landscape level analysis” tool allows mapping and analysing of simulation data from the ARANGE project. It thus enabled the landscape level assessments referred to from the ARANGE deliverable D2.2. LAT furthermore contains a tool that allows the creation of realistic single-tree based forest structures by jointly processing sample plot or inventory data together with remote sensing based data. A third tool of the LAT “tool box” is dedicated to the assessment of ecosystem services and natural hazards on landscape scale. And, finally, a the bird habitat quality estimates, following the rule set developed within the ARANGE framework, the habitat suitability for bird species on landscape scale.

3.2 Installation and first start

The installation process of LAT is easy: the software package comes as an archive file (ZIP-format) that needs to be extracted to some location on the computer hard disk. The tool package includes all the required binary files and contains also a set of ready-to-run examples in the “examples” subfolder. To start LAT, double-click on the LAT.exe file. The start screen is shown in Figure 4: the left part of the screen provides access to the individual sub tools of LAT, the right part of the screen is divided into the upper main visualization area (empty on start-up) and the lower log-messages areas. Log messages can be very helpful for diagnosing errors (error messages are output in red).

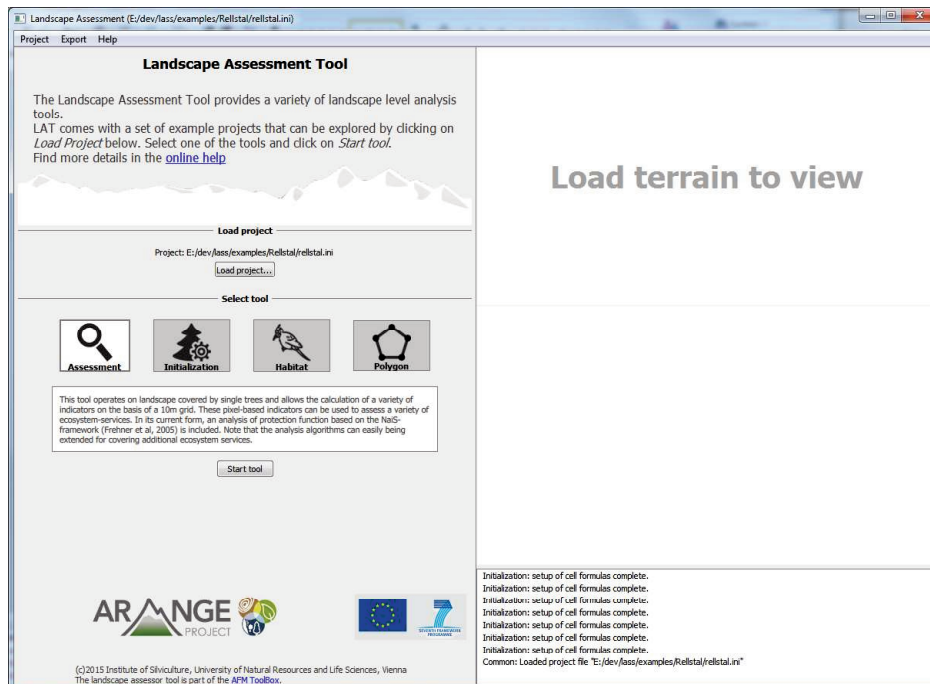


Figure 4. Start screen of LAT.

The first step in using LAT is to load a “project file”. The project is a text file that contains links to further files (digital elevation models, tree data, ...) and parameter values (see below). When working with own data, a user has to prepare such a project file. A project file is loaded by clicking on the “Load project” button in the navigation pane (left) of LAT. After a project is successfully loaded, the individual tools can be accessed by clicking on the respective icon and the “Start tool” button below. A detailed documentation of the structure and syntax of the project file is given below.

3.3 Project files

The project file is a simple text file that follows the widespread INI-standard (https://en.wikipedia.org/wiki/INI_file). The file includes several sections that can be specific to a given tool. Parameter values are given in name-value-pairs. Box 1 gives an example for a section within the project file: Here, the section is **Polygon** and the parameter **AnalysisScript** is set to the value (i.e., a file-name) **Rellstal/analyse.js**. LAT uses GIS-based data, for example a digital elevation model or maps of stand polygons. The **Common** section in the project file describes the location of these files and the size and extent of the project area (Table 1).

Box 1. Overview over required data for the landscape level analysis tool.

```
[Polygon]
AnalysisScript=Rellstal/analyse.js
DataFile=CS3_BAU/CSA3_02.0_B02.0_30_01_xx.xx0_M01_f.csv
LandscapeFile=CS3_BAU/landscape_data.txt
Plan=1
```


Table 1. Common attributes in the project file that describe the study area. These settings are common for all tools within LAT.

Section	Key	Description
Common	DEMFile	Filename of the digital elevation model. The supported file format is the ESRI ASCII grid format. The coordinate system should be metric, but no specific projection is required (see DeltaX/DeltaY). The resolution may vary.
Common	DeltaX	DeltaX and DeltaY define the lower-left corner of the simulated area in the coordinate system used for the DEM. The point given by DeltaX/DeltaY is then the 0/0 point in the local coordinate system of LAT.
Common	DeltaY	See DeltaX.
Common	DeltaZ	In addition to DeltaX/DeltaY the 0-plane ($z=0$) can be changed with DeltaZ (purely visualization related).
Common	SizeX	SizeX and SizeY define the width and length of the rectangle that is actually simulated. Both are in meters.
Common	SizeY	See SizeX
Common	StandGrid	ESRI ASCII Raster file that is a map of stand polygons. The identifiers need to be integer (e.g., the polygon codes of ARANGE landscapes). The projection must be the same as the DEM. The resolution can vary, but internally the stand grid is transformed to a 10m grid.

3.4 Landscape level analysis

The Landscape level analysis tool provides an efficient means to view/ analyse simulation results that are stored in the standard ARANGE file triplets format (see Deliverable D1.5). Table 2 provides an overview over the required data; Table 3 gives the tool-specific settings in the project file.

Table 2. Overview over required data for the landscape level analysis tool.

Data	Required?	Notes
Digital elevation model (DEM)	optional	The DEM is only used for improving visualization
GIS grid with polygon ids	yes	Available from internal.arange-

project.eu

Table linking polygons on the landscape to RSTs	yes	Available from the official RST Excel sheets
File triplets	yes	Available from the ARANGE data base
Analysis scripts	optional	User-defined analysis scripts facilitating the JavaScript bindings of LAT

Table 3. Elements of the Polygon-section in the LAT project file.

Key	Description
AnalysisScript	Optional Javascript file with additional code for analysis. See the respective section below.
DataFile	“Pattern” of the triplet files that LAT should try to load. Note, that the “RST”. The RST part is exchanged by the tool while loading the landscape.
LandscapeFile	Filename of the table that contains the linking information between the polygons and the RST. The CSV-style file requires the following columns: “plan”, “polygon”, “RST”, “STP”
Plan	Standard value for the “plan” that should be loaded. Plans are used to allow different landscape variants (see D1.5)

3.4.1 User interface

Figure 5 shows an impression of the user interface. In a nutshell, the user can:

- Select 3d visualization or a flat terrain
- Select what “scenario” should be loaded – to do this, the user needs to modify the ARANGE triplet-pattern. For example the user can select different climate scenarios, different file types (fhs), et cetera
- A click on “load ARANGE files” loads the data
- The “Display parameters” section is populated with all the data columns that have been found in the data files. For instance, the “s”-Files contain the state information. See Deliverable D1.5 for details.
- The user can either show a specific point in time (when “Aggregate over period” is disabled), or an aggregated value over time (when “Aggregate over period” is true). The sliders allow selecting the point in time and the period begin/end, respectively.

- The landscape level analysis feature allow detailed user-defined analysis that are defined in Javascript

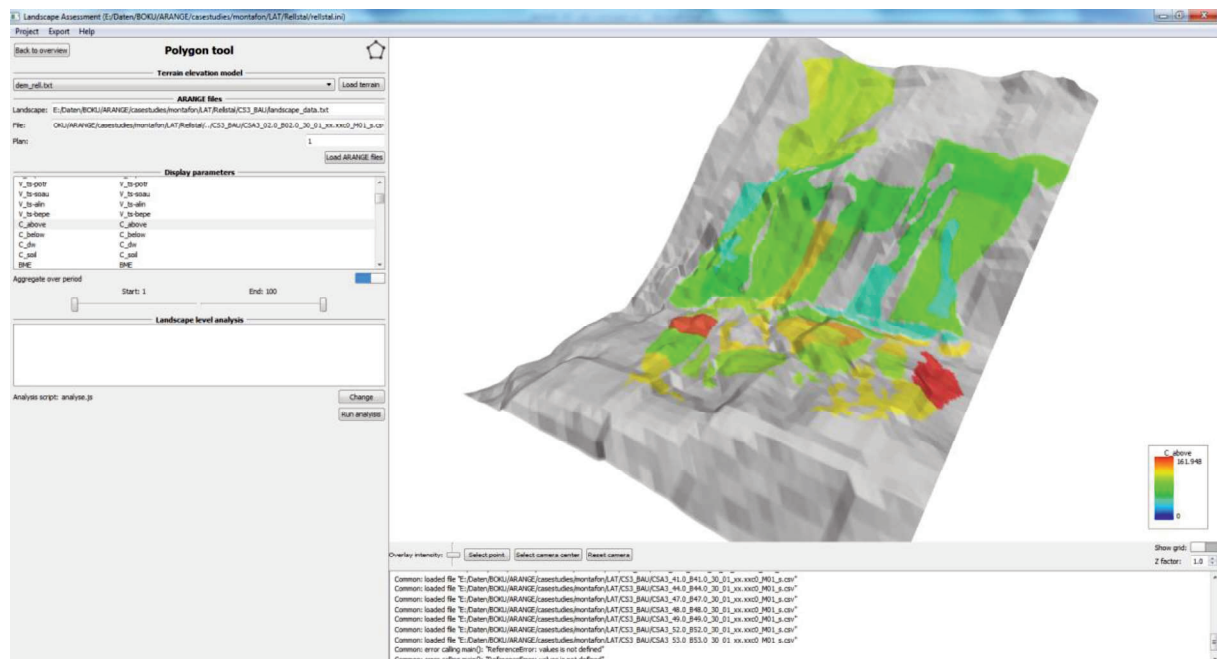


Figure 5. The landscape level analysis. Shown is the mean aboveground carbon (ARANGE variable “C_above”) in the baseline climate over the full simulation length in the “Rellstal” (CSA3).

The standard application of the tool is to visualize ARANGE results on the landscape scale. This allows various analysis: for example, Figure 6 shows the abundance of large standing dead trees for three 20 years periods in the Rellstal (CSA3). Another example is given in Figure 7: here the mean standing volume (over 100 years) are compared between two different climate scenarios (c0=baseline, c5=climate change scenario).

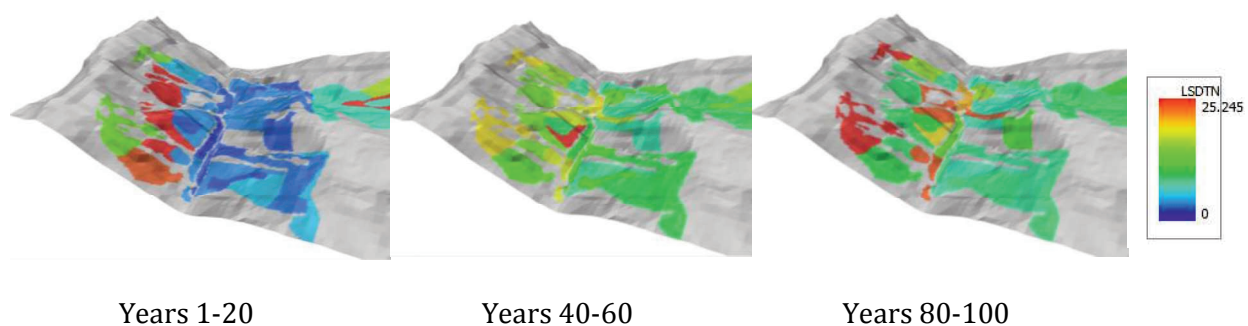
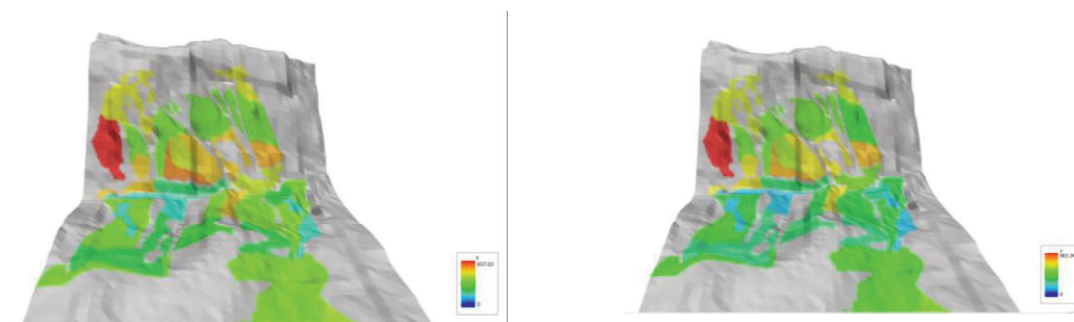


Figure 6. Example of a time series. Shown is the parameter LSDTN (Abundance of large standing dead trees >30cm DBH per hectare). Each image is a mean value over 20 years. Climate=c0, Management = BAU.



Climate c0, BAU

Climate c5, BAU

Figure 7. Mean Standing volume over the whole simulation length (100 years) for two different climate scenarios. Management is BAU.

3.5 Ecosystem service and risk assessment tool

This tool can be used for landscape scale assessments of forested landscapes with regard to ecosystem services in general and the protective function against gravitational hazards in particular. For the assessment of the protective function against gravitational natural hazards a stand scale approach is suboptimal as the gravitational processes do not stop at stand or compartment borders. Therefore an assessment beyond the stand scale is required. In addition, high resolution (i.e. individual trees) is preferable, since gravitational processes are strongly influenced by fine grained spatial differences (i.e, forest texture and structure).

The “Ecosystem service and risk assessment tool” is built for such analysis: it contains a representation of a landscape as a digital elevation model (DEM), which can be populated with single-tree data. Thus, a “snapshot” of a forested landscape within its spatial context can be generated. The tool then provides a number of built-in analysis steps, based on the NaiS-concept of (Frehner et al., 2005). In addition to the NaiS-tools, a powerful Javascript interface allows extending the analysis capacity of the tool.

The single-tree data that is required to populate the landscape can be either static data (if single tree information is available), or be the result of ecosystem simulation models. Thus the analysis of protective functions can be extended from the status quo to whatever scenario can be simulated. The data format is simple and straightforward which makes the process of linking different ecosystem models to the LAT tool very simple. In the moment, data exchange functionality with the PICUS model is readily available.

The built-in assessment algorithm is built upon simple quantifiable indicators following the indicator-based concept of Frehner et al. (2005). The protection effect is reported in three categories at a 10x10 m resolution across the landscape: a) requirements not met, b) minimal requirements met and c) ideal requirements for the protection against the respective hazard met. For each protective function the respective indicators are aggregated by the Boolean operator AND. Either the user interface of tool or a GIS can be used for displaying and

communicating the results. More details on the indicators can be found in Appendix 1 and in Maroschek et al. (2014).

Table 4 provides an overview over required data for running the tool and Table 5 defines the respective entries in the project file.

Table 4. Overview over required data for the landscape level analysis tool.

Data	Required?	Notes
Digital elevation model (DEM)	yes	The DEM is only used for improving visualization
GIS grid with polygon ids	yes	Available from internal.arange-project.eu
Individual tree files	yes	From ecosystem models, or the “initialization” tool of LAT
Analysis scripts	yes	Javascript file that contains the analysis logic of NaiS. Can be extended for user-defined applications.

Table 5. Required keys in the project file for the Protection function tool.

Section	Key	Description
Common	StandMask	Filename “mask” that is resolved for each stand polygon. The string <code>\$stand\$</code> is replaced with polygon-id, and <code>\$year\$</code> is replaced with the year selected in the UI. Example: <code>stands/stand_\$(stand\$.csv</code>
Mapping		The Mapping section allows specifying an exact matching of polygon-ids (see StandGrid) to codes that specify each tree-data-file. See the example file.

The tree data is loaded for each stand from a data file (see Table 5). For each tree a location, species, diameter at breast height and tree height are retrieved from the respective data file (see Table 6 for the definition of the data file). The coordinates of each tree are provided in the local coordinate system of the individual stand (i.e., 0/0 is the lower left corner of the bounding rectangle of the forest stand polygon). LAT transforms coordinates to local project coordinates.

Table 6. Definition of the columns of tree data files. The file is a CSV-style data file; however, delimiters can be tab-characters, semicolons, or commas.

Column	Mandatory	Description
species	Yes	Tree species ID.
x,y	Yes	Coordinates of the tree in x- and y- direction [m].
dbh	Yes	Diameter at breast height (cm)
treeheight		Height of the tree (cm).
age		Age of the tree in years. If omitted, the tree age is estimated.
crown		Start of the living crown in cm (can be omitted).

Figure 8 shows the tool after successfully setting up the landscape including the forest cover based on individual trees from several forest stands.

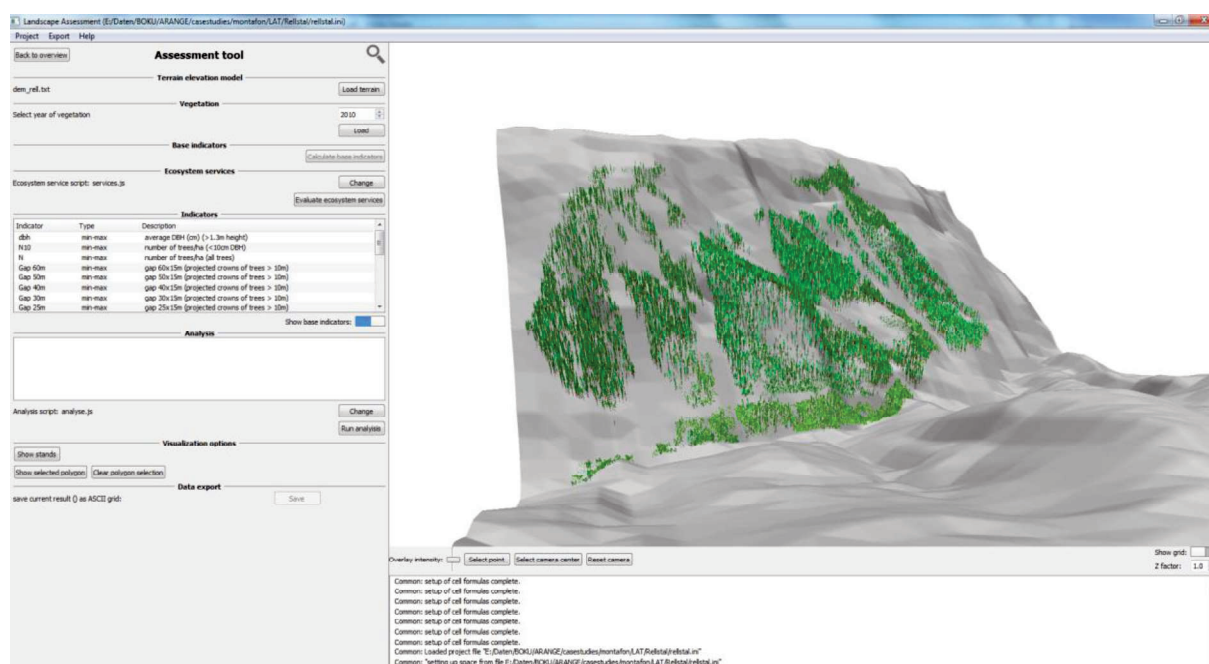


Figure 8. Screenshot of the protection assessment tool with the 3d visualization of the forest landscape with single trees.

Assessing the protective function

The analysis options consist of the following steps:

- **Base indicators:** these are built-in base indicators (such as local mean DBH, gap sizes). The calculation is triggered by clicking on “Evaluate base indicators”. See Appendix 1 for

a detailed overview and description of the base indicators. Base indicators are maps with 10m resolution.

- Evaluate Ecosystem services: This step involves the calculation of risks/ecosystem services. The calculations are based on the base indicators (see above). The calculation logic itself is provided by Javascript code that can be easily extended and modified. This step is run when the “Evaluate Ecosystem Services” is clicked. The result are maps with 10m resolution.
- Additional analysis options are provided by the possibility to invoke user-defined analysis code (written in Javascript). Using this mechanism, complex spatial can be implemented. To demonstrate the potential, calculation of Simpson’s Evenness index, and a Contagion index is included. This step is executed by clicking the “Run analysis” button. The results of this kind of analysis is free text (or index values) that is returned from the Javascript code (see also Appendix 1).
- Finally, result grids (base indicators, ecosystem services) can be exported as GIS files (ESRI ASCII format).

Figure 9 shows the first step, the calculation of base indicators, and Figure 10 an example result for the ecosystem service / risk assessment.

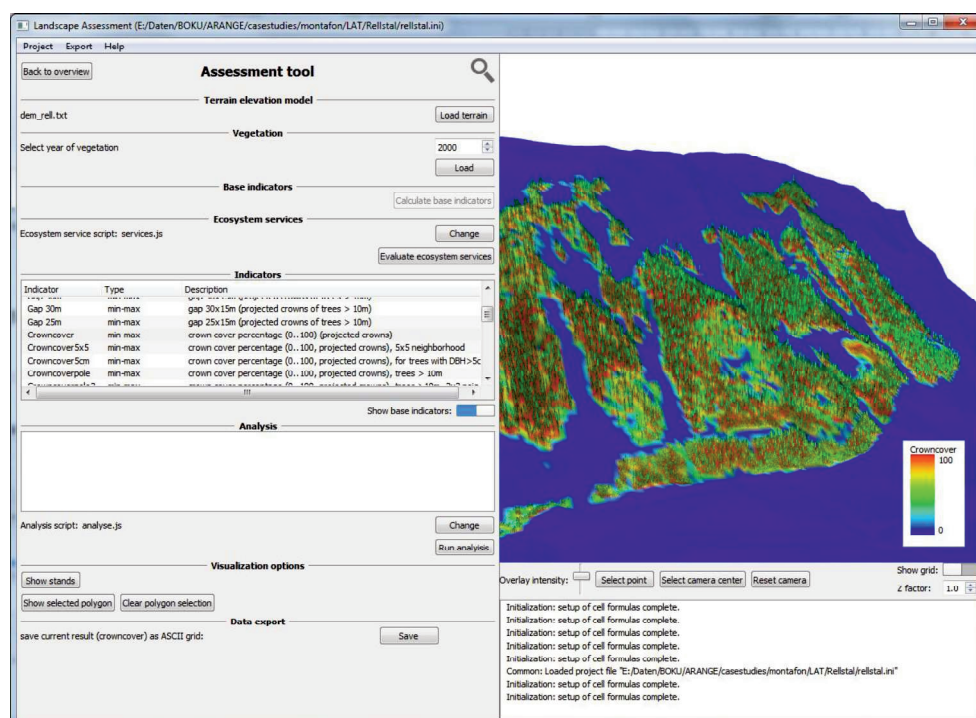


Figure 9. Example for a “base indicator” – here the crown cover (on 10m pixels).

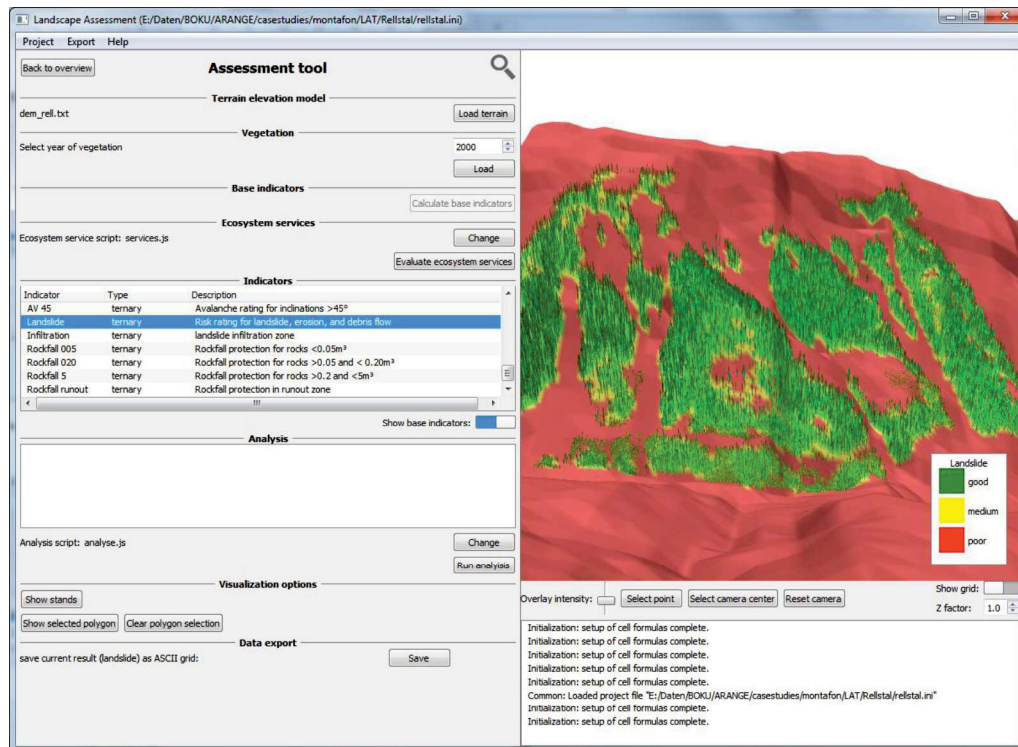


Figure 10. Calculating ecosystem/ risk indicators. Shown here is the ecosystem service “Landslide protection” as defined in the NaiS-framework.

Additional custom spatial analysis can be performed using custom Javascript code. For example, the download package includes code to calculate Simpson’s evenness index and the Contagion index as defined in the FRAGSTATS package (McGarigal et al. 2012). For this particular demonstration landscape, the Simpson’s evenness is 0.458, and the Contagion index is 65.42.

3.6 Creation of realistic forest structures

This tool aims at creating realistic, individual-based forest structures by bridging the gap between traditional inventory based forest data, and increasingly available remote sensing data. It uses inventory or sample plot based data on species, DBH-distribution and stem numbers and combines this with spatial data layers of crown height (NCM, normalized crown model derived from LiDAR), and, when available, includes also derived remote sensing products such as biomass- or volume maps.

The basic approach is as follows: In the tool trees are drawn from a forest stand specific diameter distribution generated from inventory data, starting with the largest DBH class. Each tree is evaluated how well it fits to each 100 m² cell of the stand with regard to (i) total volume, (ii) maximum, mean and minimum tree height, and to (iii) a specified maximum crown projection area employing linear normalized suitability functions which link the three indicators at tree level to the corresponding values at 10m cell level. The resulting suitability values are aggregated and the tree is assigned to the patch with highest suitability. This procedure is performed for all trees of a diameter distribution resulting in a simulation entity populated by trees whose spatial distribution is, except for species distribution (due to a lack of data), comparable to real life forest structure.

The output of the procedure is for each forest stand a file containing diameter, species, and coordinates of individual trees. These data files can either be directly user for other tools of LAT, or also used as input for ecosystem models such as PICUS.

The required data items are given in Table 7, and Table 8 lists the attributes in the Initialization section of the project file. Note, that the individual equations and threshold values can be edited also in the user interface of the tool.

Table 7. Overview over data required for the tool.

Data	Description
Tree-list, stem distribution	For each forest stand a DBH distribution (i.e., species, trees/ha, diameter)
Height grids 10 x 10 m resolution	LiDAR derived grids given for the top-height, mean-height, and min-height.
Volume grid 10 x 10 m resolution [m ³ /ha]	Map of estimated tree volume per 10m cell.

Table 8. Elements of the Initialization section in the LAT project file.

Key	Description
OutputMask	File mask that the tool uses for the output files of the process. The string \$stand\$ is replaced with the current stand id. Example: stands_out/stand_\$stand\$.csv
HMax10	ESRI ASCII grid containing top-heights for 10m pixel.
HMean10	ESRI ASCII grid containing mean-heights for 10m pixel.
HMin10	ESRI ASCII grid containing min-heights for 10m pixel.
topHeightCount	minimum number of trees / hectare that are considered as "top height trees"
heightFormula	The suitability response function for tree heights (see Appendix B).
heightAttractFormula	Formula defining the propensity of trees to accumulate locally with trees of a similar size (see Appendix B)
volumeFormula	Response equation representing the tendency of an even distribution of tree volume (see Appendix B)
crownAreaFormula	Response function representing the competition for crown space (see Appendix B)

The tool can process one stand at a time, or all stands in a sequence (see Figure 11).

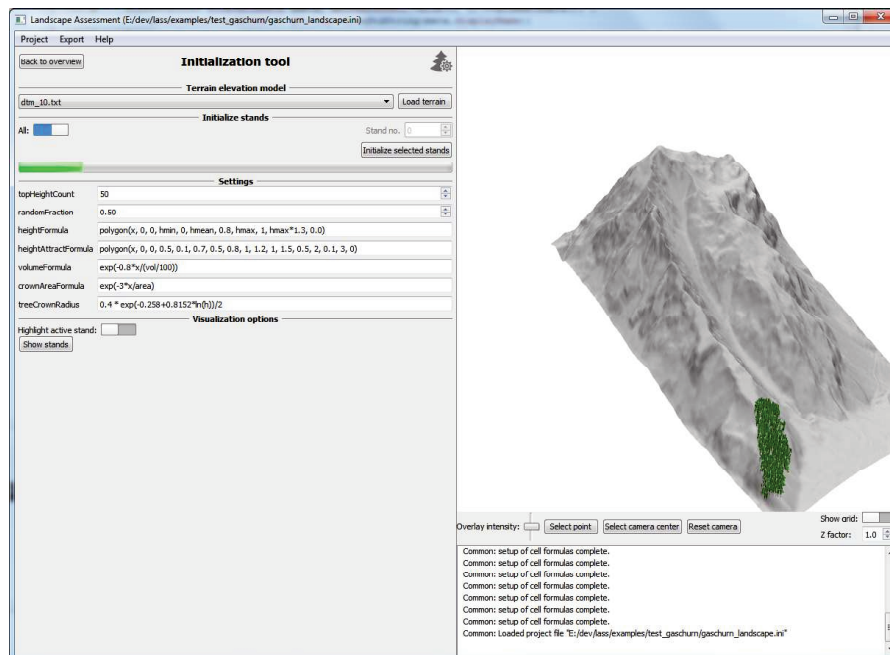


Figure 11. The tool for the creation of realistic forest structures in action. Already one stand of the “Gaschurn”-landscape has been processed by the algorithm.

3.7 Bird habitat assessment

A specific tool for the assessment of bird habitat quality is also part of the LAT tool. The assessment logic follows the ruleset developed within the ARANGE project (see Deliverable 2.2, chapter 4.5 for details).

The indicators used in the assessment are (see Deliverable 2.2):

- Standing dead wood
- Time since the last management intervention
- Veteran trees, here defined as trees above a diameter threshold
- Canopy cover
- Alien tree species

The rule set combining these indicators that is used by the algorithms within the bird habitat tool is given in Deliverable 2.2 (Table 8). The result of the assessment is a ternary indicator, i.e. the result is given in classes of “good”, “medium”, or “poor” habitat quality.

The tool can deal with different types of data and provides several analysis options:

With regard to input data, the landscape can either be filled using ARANGE data triplets (compare the landscape level analysis tool), or by individual trees (see the tools for ecosystem services assessment and forest structure creation).

The habitat quality can either be estimated for the full landscape (i.e., one result for the whole landscape), for each forest stand, or for a superimposed grid of sample plots (with sizes of 1,2, or 5 hectares). Figure 12 shows the bird habitat tool in action.

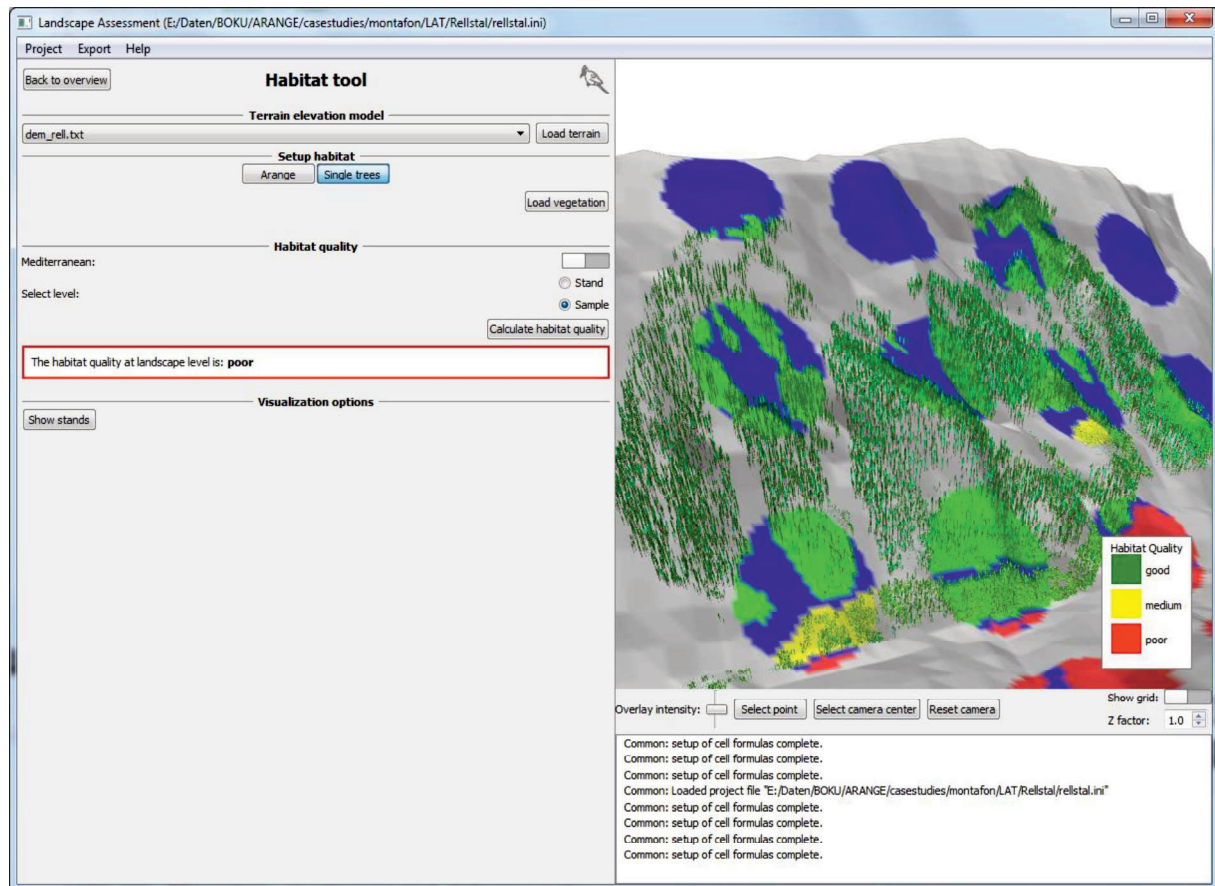


Figure 12. The bird habitat tool is applied on a landscape with individual trees (example Montafon, CSA3) with a grid of sample points. The blue color indicates area that are not covered by forest stands. Green/yellow/red represent the three classes of good, medium, or poor bird habitat quality.

4 Literature

Lexer, M.J., Seidl, R. 2009. Addressing biodiversity in a stakeholder-driven climate change vulnerability assessment of forest management. *Forest Ecology & Management* 258, 158-167.

Luers, A.L. 2005. The surface of vulnerability: an analytical framework for examining environmental change. *Glob Environ Change* 15:214–223

Seidl, R., Rammer, W., Lexer, M.J. 2011. Climate change vulnerability of sustainable forest management in the Eastern Alps. *Climatic Change* 106:225–254

Füssel, H.M., Klein, R.J.T. 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. *Clim Change* 75:301–329

Maroschek, M., Rammer, W., Lexer, M.J., 2014. Using a novel assessment framework to evaluate protective functions and timber production in Austrian mountain forests under climate change. *Reg. Environ. Chang.* in press. doi:10.1007/s10113-014-0691-z

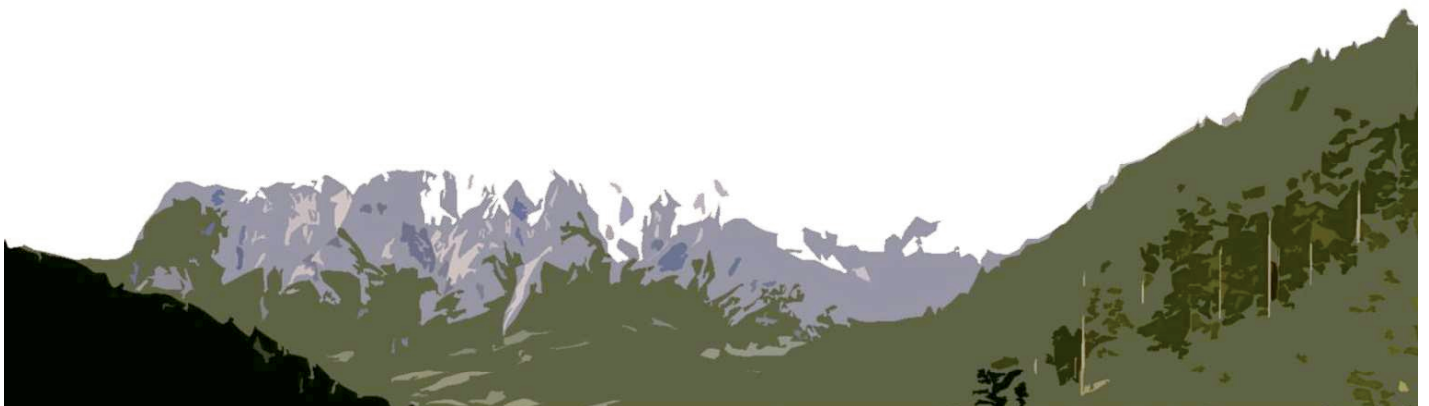
McGarigal, K., SA Cushman, and E Ene. 2012. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: <http://www.umass.edu/landeco/research/fragstats/fragstats.html>



Appendix A

Documentation of the implementation of the NaiS concept within the LAT tool framework

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1. Concept

In NaiS the protective function against following hazards are accounted for:

- a) Snow avalanche release,
- b) Landslide, erosion, debris flow,
- c) Rock fall,
- d) Torrential processes, flooding

For each of the natural hazards the protective function of the forest is assessed by one or more indicators. The indicators are used to describe and evaluate the minimal and ideal structural and compositional requirements for protective forests to fulfill their function. The indicators used by the NaiS concept are judged on an ordinal scale with three classes: (i) requirements not met, (ii) minimal requirements met and (iii) ideal requirements met. The indicators for each protective function are aggregated by AND (Frehner et al., 2005).

In the following the approach for the implementation will be described in detail for each protective function addressed in NaiS. First of all the indicators and thresholds used by NaiS will be presented. Thereafter the technical implementation will be delineated in depth. A more general application of this framework has been done by Maroschek et al. (2014).

1.1. Protection against snow avalanche release

In NaiS the protective function against avalanches is evaluated as the protection against avalanche release. The assessment may be made for two groups of forest types, (i) subalpine and altimontane coniferous forests, and (ii) upper- and low-montane deciduous and mixed forests (Frehner et al., 2005).

1.1.1. Subalpine and altimontane coniferous forests

For larch dominated forests the critical slope inclination for avalanche release is 30° whereas for other coniferous forests it is 35°. If the inclination is greater than or equal to these thresholds assessments according to NaiS are made. The indicators used are a) gap length in slope direction depending on slope inclination and b) crown cover (Table 9). A gap is considered as an opening between the canopy edges of trees from pole to timber stage (Frehner et al., 2005). Pole to timber stage is defined according to Mayer (1992) as trees higher than 10 m. The gap length is only relevant if the gap width is greater or equal than 15 m (Frehner et al., 2005).

Table 9: Indicators for the assessment of the protective function against avalanches in subalpine and altimontane coniferous forests (according to Frehner et al., 2005).

Indicator	Unit	Inclination	Threshold minimal	Threshold ideal	Comment
Gap length	[m]	30 – 35°	< 60 m	< 50 m	Only for larch dominated forests, for trees > 10 m height; if gap width is >15 m
		35 – 40°	< 50 m	< 40 m	for trees > 10 m height; if gap width is >15 m
		40 – 45°	< 40 m	< 30 m	for trees > 10 m height; if gap width is >15 m
		≥ 45°	< 30 m	< 25 m	for trees > 10 m height; if gap width is >15 m
Crown cover	[%]	-	> 50 %	> 50 %	No limitation with regard to tree size

The technical implementation of the evaluation with regard to avalanche release protection in the risk assessor module is described in the following. The slope direction has to be defined in advance. Conceptually, gap detection is based on a rendering of tree positions on a 2 x 2 m grid “tree map”. For this map, in the case of avalanche release protection, the projected crowns of trees higher than 10 m (\geq pole stage) are used. The tree crown radii are estimated with the modified formula provided by Hasenauer (1997; also used for the Montafon tree initialization; but modification factor changed from 0.4 to 0.6). The crowns are converted in a 2 x 2 m grid. As a simplification four crown classes and their shape in the grid are defined (Figure 13). Class 1 is used for trees with a crown radius < 1 m. For trees with a crown radius between 1 and 3 m class 2 is used. Class three is used for trees with a crown radius between 3 and 5 m. For trees with a crown radius larger than 5 m class four is used.

The “target gaps” (gap lengths used in the NaiS concept as thresholds), as defined by NaiS, are rendered with a given angle (slope direction) on a 2 x 2 m grid. A “target gap” is applied on each position of the “tree map”. If all pixels of the target gap corresponded with empty pixels on the “tree map”, the position is considered to be a gap (the center of the pixels is decisive; cf. Figure 14). Thus every 2 x 2 m pixel with its center underneath the “target gap” is considered to be a gap. The “target gap” is moved all over the assessment area. After finishing this assessment step the outcome is aggregated on a 10 x 10 m pixel scale. During the aggregation each 10 x 10 m grid-cell which contains at least one 2 x 2 m grid cell which had been considered to be a gap is considered to be also a gap after the aggregation process (Figure 14).

In the case of avalanche release protection in subalpine and altimontane coniferous forests this procedure is conducted for several gap sizes. For the gap sizes and the indicators used see Table 10.

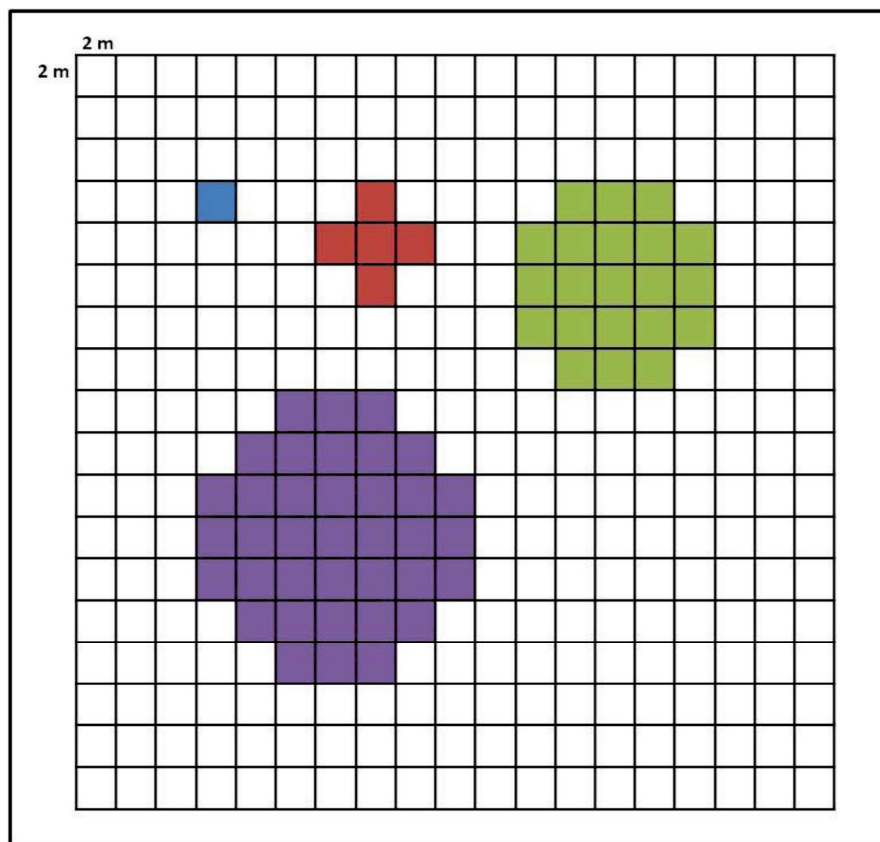


Figure 13: Crown classes used to implement the crown radii in the gap analysis. Class 1= blue, class 2= red, class 3= green, class 4= purple.

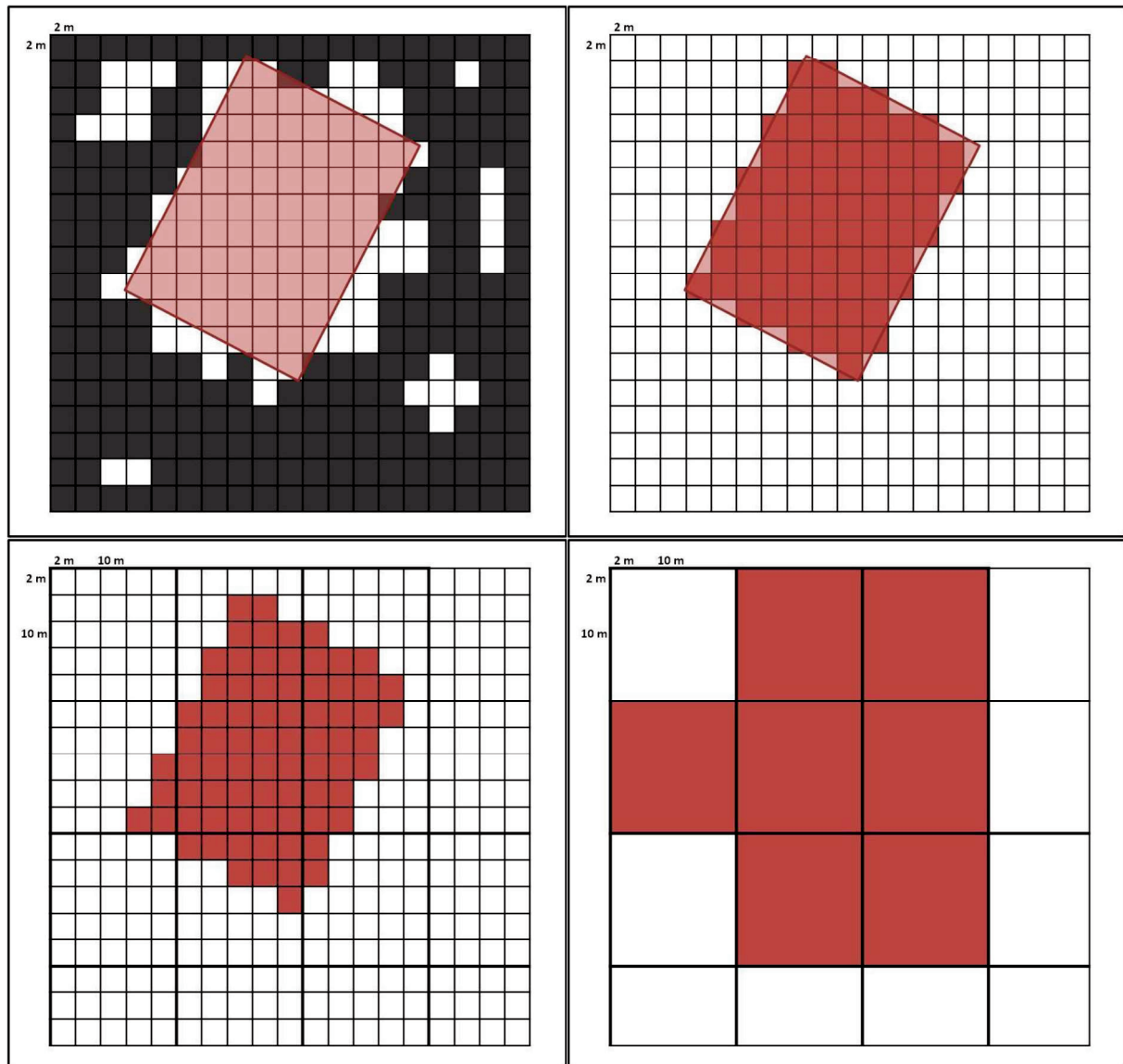


Figure 14: Schematic view of the gap detection procedure using a 15 x 25 m “target gap”. Upper left: black cells indicate crown cover, white no crown cover, red rectangle is the “target gap”; “target gap” fits into the zone with no crown cover, thus a gap is detected. Upper right: all cells underneath the “target gap” (detected gap) are considered as gap pixels (red). Lower left: for the aggregation a 10 x 10 m grid is used. Every 10 x 10 m grid cell which contains at least one 2 x 2 m gap pixel (red) is considered as a gap. Lower right: Result of the aggregation process, the 10 x 10 m grid with gap cells in red.

Table 10: Gap indicators used for the assessment of avalanche release protection in subalpine and altimontane coniferous forests with the risk assessor tool. The target gap width was set to 15 m. Only the projected crowns of trees higher than 10 m were considered.

Indicator abbreviation	Indicator rule
gapa_60	> 0 if gaps \geq 60 m gap length
gapa_50	> 0 if gaps \geq 50 m gap length
gapa_40	> 0 if gaps \geq 40 m gap length
gapa_30	> 0 if gaps \geq 30 m gap length
gapa_25	> 0 if gaps \geq 25 m gap length

Estimates of crown cover are also derived from the “tree maps” based on projected crowns. With regard to avalanche release protection no threshold referring to tree size is used for the crown cover. The crown cover percentage of a 10 x 10 m pixel is the fraction of covered 2 x 2 m pixels. The final indicator for the crown cover is generated with a 50 x 50 m moving window. The arithmetic mean crown cover percentage of the screened 25 10 x 10 m pixels is assigned to the center pixel. For the indicators used see Table 11.

Table 11: Crown cover indicators used for the assessment of avalanche release protection in subalpine and altimontane coniferous forests with the risk assessor tool.

Indicator abbreviation	Indicator rule
crowncover	Area coverage in percent (0-100). Derived from projected crowns of all trees.
crowncover5	average crown cover percentage within a 5 x 5 patch moving window.

The risk assessor module produces results for four different slope classes (Table 12). For each slope class indicators need to be evaluated and aggregated. The results are provided in the three classes according to the NaiS scheme in a 10 x 10 m grid.

Table 12: Description of the result variables of the risk assessment tool for the protection against avalanche release in subalpine and altimontane coniferous forests.

Name	Description
av_30	Avalanche release protection rating for inclinations 30°-35°
av_35	Avalanche release protection rating for inclinations 35°-40°
av_40	Avalanche release protection rating for inclinations 40°-45°
av_45	Avalanche release protection rating for inclinations >45°

The indicators are aggregated by AND. Which technical indicators and thresholds are used is depicted in Table 13 for the different slope class results.

Table 13: Indicators and thresholds used for producing the assessment result for avalanche release protection in subalpine and altimontane coniferous forests.

Name	Ideal	minimal
av_30	If_crowncover5 > 50% AND gapa_60 = 0	If_crowncover5 > 50% AND gapa_50 = 0
av_35	If_crowncover5 > 50% AND gapa_50 = 0	If_crowncover5 > 50% AND gapa_40 = 0
av_40	If_crowncover5 > 50% AND gapa_40 = 0	If_crowncover5 > 50% AND gapa_30 = 0
av_45	If_crowncover5 > 50% AND gapa_30 = 0	If_crowncover5 > 50% AND gapa_25 = 0

1.1.2. Upper- and low-montane deciduous and mixed forests

For these forests the critical slope inclination for avalanche release is 35° according to NaiS. If the inclination is greater than or equal to this threshold an appraisal may be made. The indicators are a) gap length in slope direction depending on slope inclination and b) crown cover (Table 14). A gap is considered as an opening between the canopy edges of trees in pole to timber stage (> 10 m height; according to Mayer, 1992). The gap length is only relevant if the gap width is greater than or equal to 5 m (Frehner et al., 2005).

Table 14: Indicators for the assessment of the protective function against avalanches in upper- and low-montane deciduous and mixed forests (according to Frehner et al., 2005).

Indicator	Unit	Inclination	Threshold minimal	Threshold ideal	Comment
Gap length	[m]	35 – 40°	< 50 m	< 40 m	for trees > 10 m height; if gap width is >5 m
		40 – 45°	< 40 m	< 30 m	for trees > 10 m height; if gap width is >5 m
		≥ 45°	< 30 m	< 20 m	for trees > 10 m height; if gap width is >5 m
Crown cover	[%]	-	> 50 %	> 50 %	No limitation with regard to tree size

The assessment of avalanche release protection in upper- and low-montane deciduous and mixed forests is not yet implemented. An implementation would simply use the same algorithms like the assessment of avalanche release protection in subalpine and altimontane coniferous forests, only the definition of gaps needs to be adjusted.

1.2. Protection against landslide, erosion, and debris flow

With the NaiS concept the protective function against landslide, erosion and debris flow can be assessed for the source- and the infiltration-zone. The protection against debris flow in this context comprises the reduction of the availability of debris by preventing or minimizing erosion and landslides (Frehner et al., 2005).

1.2.1. Source zone

With regard to the source zone landslide and erosion are the addressed processes. In general areas with an inclination greater than 25° are possible source zones for landslide and erosion. The indicators are a) gap-size b) crown cover and c) occurrence of heavy and windthrow-prone trees (Table 15). A gap is defined as an opening between the canopy edges of trees in pole to timber stage (> 10 m height; cf. Mayer, 1992). Also for the crown cover only trees ≥ pole stage are considered (Frehner et al., 2005). The indicator heavy and windthrow-prone trees is not defined in detail. Due to the qualitative nature of this indicator it was not implemented in the risk assessor module.

Table 15: Indicators for the assessment of the protective function against landslide, erosion and debris flow in the source zone (according to Frehner et al., 2005).

Indicator	Unit	Threshold minimal	Threshold ideal	Comment
Gap size	[m ²]	600 m ² 1200 m ²	400 m ² 800 m ²	≥ pole stage ≥ pole stage, with existing regeneration
Crown cover	[%]	≥ 40 %	≥ 60 %	≥ pole stage
Heavy and windthrow-prone trees				Not defined and not implemented

The technical implementation of the evaluation with regard to landslide, erosion and debris flow in the source zone in the risk assessor module is described in the following. The slope direction has to be defined in advance. Conceptually, gap detection is based on a rendering of tree positions on a 2 x 2 m grid “tree map”. Similarly, like for the assessment of avalanche release protection, the projected crowns of trees higher than 10 m are used to map canopy and gaps. The tree crown radii are estimated with the modified formula provided by Hasenauer (1997;

also used for the Montafon tree initialization; but modification factor changed from 0.4 to 0.6). The crowns are converted in a 2 x 2 m grid. Therefore four crown classes have been defined (Figure 13). Class 1 is used for trees with a crown radius < 1 m. For trees with a crown radius between 1 and 3 m class 2 is used. Class three is used for trees with a crown radius between 3 and 5 m. For trees with a crown radius larger than 5 m class four is used.

The “target gap” is rendered with a given angle (slope direction) on a 2 x 2 m grid. As, in contrast to the assessment of avalanche release protection, the slope direction and the orientation of the gap is not decisive according to Frehner et al. (2005) the algorithm is adapted. Instead of one “target gap” in slope direction, three “target gaps” per gap size are rendered (two rectangular and one square; cf. Figure 15; cf. Table 16).

Table 16: Gap sizes used for the assessment of landslide, erosion and debris flow protection in the source zone and their different shapes used for the gap detection algorithm.

Gap size [m ³]	Rectangular in slope direction [m]	Rectangular perpendicular to slope direction [m]	Square [m]
400	40 x 10	10 x 40	20 x 20
600	40 x 15	15 x 40	24 x 24
800	40 x 20	20 x 40	28 x 28
1200	50 x 24	24 x 50	34 x 34

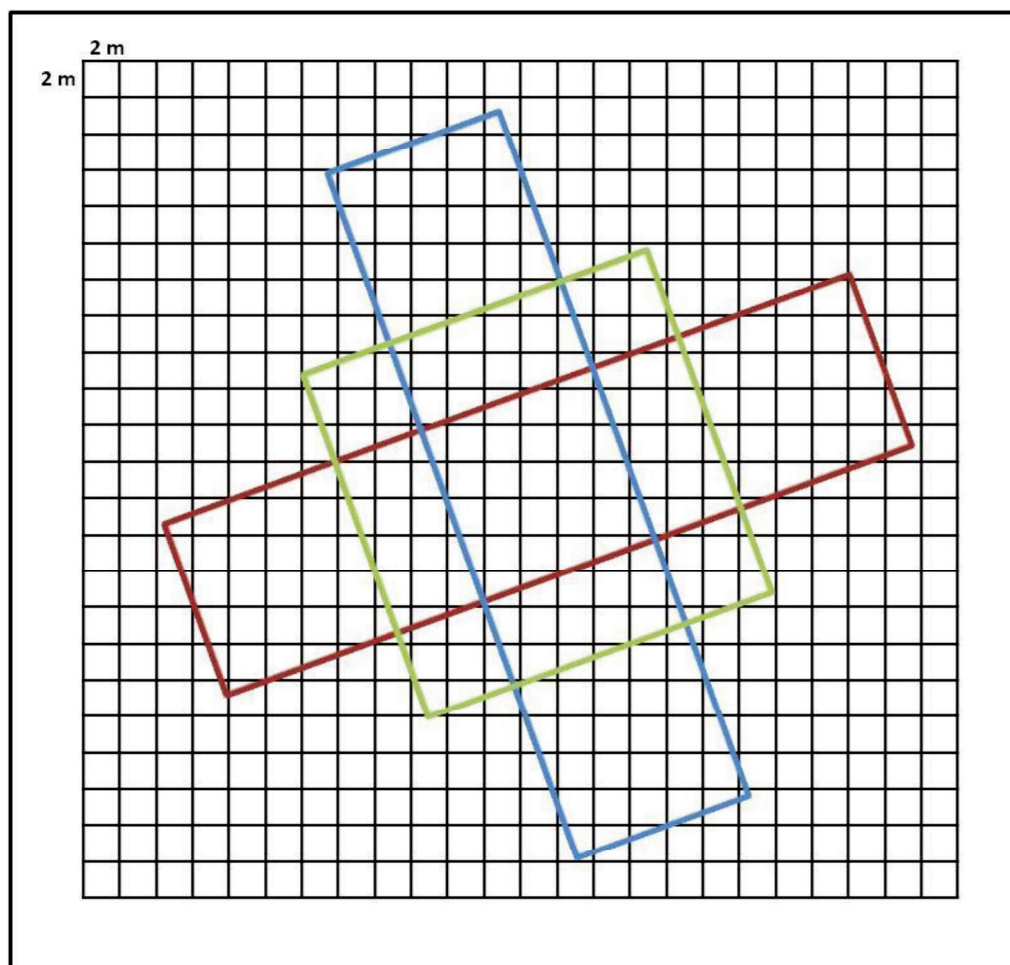


Figure 15: The three “target gaps” rendered for a gap size of 400 m². Blue = 40 x 10 m; red = 10 x 40 m; green = 20 x 20 m.

The “target gaps” are applied on each position of the “tree map”: if all pixels of the target gap correspond with empty pixels on the tree map, the position is considered to be a gap (the center of the pixels is decisive; cf. Figure 14). Thus every 2 x 2 m pixel with its center underneath a “target gap” is considered to be a gap. The “target gaps” are moved all over the assessment area. The logical combination of the three “target gaps” is OR. After finishing this assessment step the outcome is aggregated on a 10 x 10 m pixel scale. During the aggregation each 10 x 10 m grid-cell which contains at least one 2 x 2 m grid cell which had been considered to be a gap is considered to be also a gap after aggregation (Figure 14).

In the case of landslide, erosion and debris flow protection in the source zone this procedure is conducted for several gap sizes. For the gap sizes and the indicators used see Table 17.

Table 17: Gap indicators used for the assessment of landslide, erosion and debris flow protection in the source zone with the risk assessor tool. Only the projected crowns of trees higher than 10 m were considered.

Indicator abbreviation	Indicator rule
gap_400	>0 if gaps with 400 m ² occur
gapa_600	>0 if gaps with 600 m ² occur
gapa_800	>0 if gaps with 800 m ² occur
gapa_1200	>0 if gaps with 1200 m ² occur

Estimates of crown cover are also derived from the “tree maps” based on projected crowns. With regard to landslide, erosion and debris flow protection in the source zone a threshold of 10 m referring to tree height is used for the crown cover. The crown cover percentage of a 10 x 10 m pixel is the fraction of covered 2 x 2 m pixels. The final indicator for the crown cover is generated with a 50 x 50 m moving window. The arithmetic mean crown cover percentage of the screened 25 10 x 10 m pixels is assigned to the center pixel.

To decide whether regeneration exists, the “tree map” is screened for trees below 10 m height. This indicator is generated with a 50 x 50 m moving window producing an arithmetic mean stem number of trees < 10 m which is again assigned to the center pixel. If the indicator value exceeds 1000 n/ha for a 10 x 10 m pixel the pixel is classified as with regeneration. For the indicators used see Table 18.

Table 18: Crown cover and stem number indicators used for the assessment of landslide, erosion and debris flow protection in the source zone with the risk assessor tool.

Indicator abbreviation	Indicator rule
crowncoverpole	Area coverage in percent (0-100). Derived from projected crowns of all trees >10 m height.
crowncoverpole5	Average crown cover percentage of pole stage trees within a 5x5 moving window.
N_10	Number of trees per below 10 m height

The risk assessor module produces results by evaluating and thereafter aggregating indicators. The results are provided in the three classes according to the NaiS scheme in a 10 x 10 m grid. The indicators are aggregated by AND. Which technical indicators and thresholds are used is depicted in Table 19.

Table 19: Indicators and thresholds used for producing the assessment result for landslide, erosion and debris flow protection in the source zone.

Name	Ideal	minimal
landslide	If crowncoverpole5 ≥ 60 AND N_10 ≤ 1000 AND gap_400 = 0 OR if crowncoverpole5 ≥ 60 AND N_10 > 1000 AND gap_800 = 0	If crowncoverpole5 ≥ 40 AND N_10 ≤ 1000 AND gap_600 = 0 OR if crowncoverpole5 ≥ 40 AND N_10 > 1000 AND gap_1200 = 0

1.2.2. Infiltration zone

The infiltration zone is defined as the area where water infiltrates the slide prone soil-body. However, as hydrological processes are complex, therefore the whole catchment area upslope of a potential landslide might be considerate as the infiltration zone. The indicators are a) crown cover and b) sustainably ensured regeneration (Table 20) (Frehner et al., 2005). As the indicator sustainably ensured regeneration is very qualitative it is not implemented in the risk assessor module.

Table 20: Indicators for the assessment of the protective function against landslide, erosion and debris flow in the infiltration zone (according to Frehner et al., 2005).

Indicator	Unit	Threshold minimal	Threshold ideal	Comment
Crown cover	[%]	≥ 30 %	≥ 50 %	\geq pole stage
regeneration				Not defined and not implemented

The technical implementation of the evaluation with regard to landslide, erosion and debris flow protection in the infiltration zone in the risk assessor module is described in the following. The only parameter estimated is the crown cover. For this indicator the same crown cover algorithm as for the landslide, erosion and debris flow protection in the source zone is used. The indicators used are presented in Table 21.

Table 21: Crown cover indicators used for the assessment of landslide, erosion and debris flow protection in the infiltration zone with the risk assessor tool.

Indicator abbreviation	Indicator rule
crowncoverpole	Area coverage in percent (0-100). Derived from projected crowns of all trees >10 m height.
crowncoverpole5	Average crown cover percentage of pole stage trees within a 5 x 5 patch moving window.

The risk assessor module produces results by evaluating and thereafter aggregating indicators. As the only relevant indicator is crowncoverpole5 no aggregation has to be done. The results are provided in the three classes according to the NaiS scheme in a 10 x 10 m grid. Which thresholds are used is depicted in Table 22.

Table 22: Indicator and thresholds used for producing the assessment result for landslide, erosion and debris flow protection in the infiltration zone.

Name	Ideal	minimal
landslide	If crowncoverpole5 ≥ 50	If crowncoverpole5 ≥ 30

1.3. Protection against rockfall

With the NaiS concept the protective function against rockfall can be assessed for the source-, transit-, and runout-zone (Frehner et al., 2005).

1.3.1. Source zone

The indicator is the existence of instable, heavy trees (Frehner et al., 2005), which is not defined more in detail in the NaiS framework (Table 23). Due to its qualitative nature, this indicator and thus, also the assessment of the protection against rock fall in the source zone, could not be implemented in the risk assessor module.

Table 23: Indicator for the assessment of the protective function against rockfall in the source zone (according to Frehner et al., 2005).

Indicator	Unit	Threshold minimal	Threshold ideal	Comment
Instable, heavy trees				Not defined and not implemented

1.3.2. Transit zone

The indicators are a) stem-number greater than a certain DBH-threshold depending on the expected rock size and b) tree free distance in slope direction (pole stage, trees > 10 m height; cf. Mayer, 1992) (Table 24) (Frehner et al., 2005).

Table 24: Indicators for the assessment of the protective function against rockfall in the transit zone (according to Frehner et al., 2005).

Indicator	Rock size	Unit	Threshold minimal	Threshold ideal	Comment
Stem-number	< 0.05 m ³	N > 12 cm DBH	> 400	> 600	
	0.05 – 0.20 m ³	N > 24 cm DBH	> 300	> 400	
	0.20 – 5.00 m ³	N > 36 cm DBH	> 150	> 200	

Tree free distance	-	[m]	< 20 m	< 20 m	≥ pole stage
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The technical implementation of the evaluation with regard to rockfall protection in the transit zone in the risk assessor module is described in the following. Estimates of stem numbers are derived from the “tree maps”. The stem numbers are calculated using a moving window approach with a window size of 5 x 5 patches, i.e. 50 x 50 m = 0.25 ha. Thus, the indicator value for a single patch (10 x 10 m cell) is the average of 0.25 ha. According to the requirements for different rock sizes three minimal thresholds in terms of DBH are used to calculate stem numbers. The thresholds are 12 cm, 24 cm, and 36 cm. The respective indicators are presented in Table 25. Figure 16 shows a graphical interpretation for the indicator n₂₄ in the risk assessor module.

Table 25: Stem number indicators used to assess the protection against rock fall in the transit zone.

Indicator abbreviation	Indicator rule
n₁₂	Number of trees with a DBH > 12 cm
n₂₄	Number of trees with a DBH > 24 cm
n₃₆	Number of trees with a DBH > 36 cm

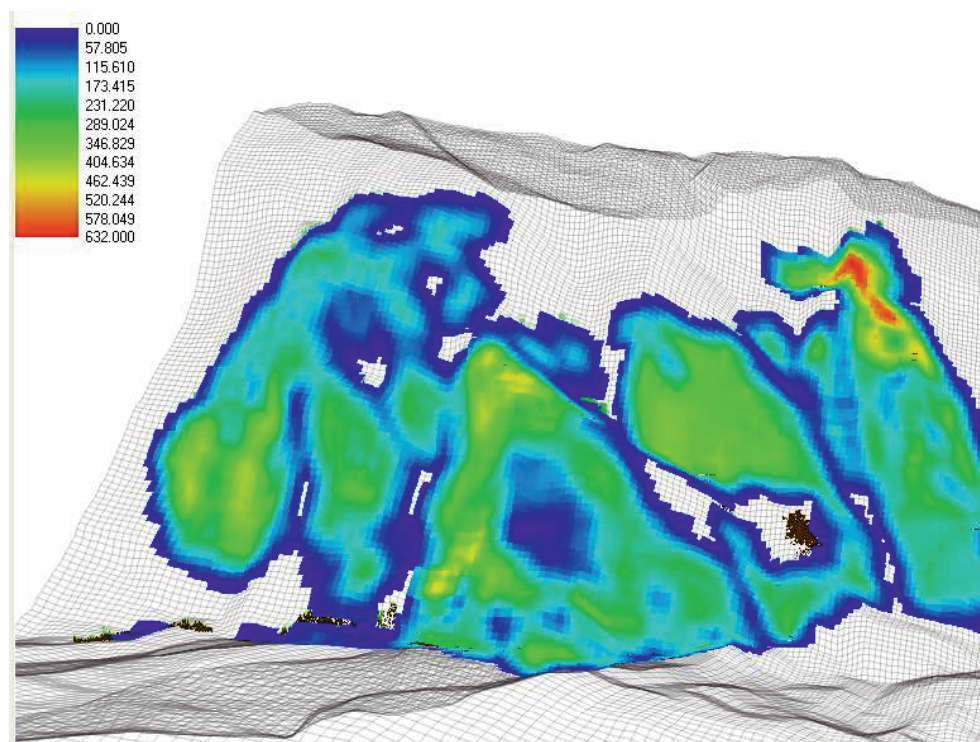


Figure 16: Graphical illustration of the indicator n₂₄ in the risk assessor module. Scale from 0 to 632 n/ha (blue to red).

The tree free distance indicator is treated similar to the gap indicators in the previous sections. First the slope direction needs to be defined. As the tree free distance is an indicator to evaluate the obstacle-free distance in a rockfall trajectory not only the length but also the width is important. As NaiS does not give any information about the width of a rockfall trajectory such a width has to be defined. By testing widths from one to twelve meters a width of six meters produced plausible results (Figure 17).

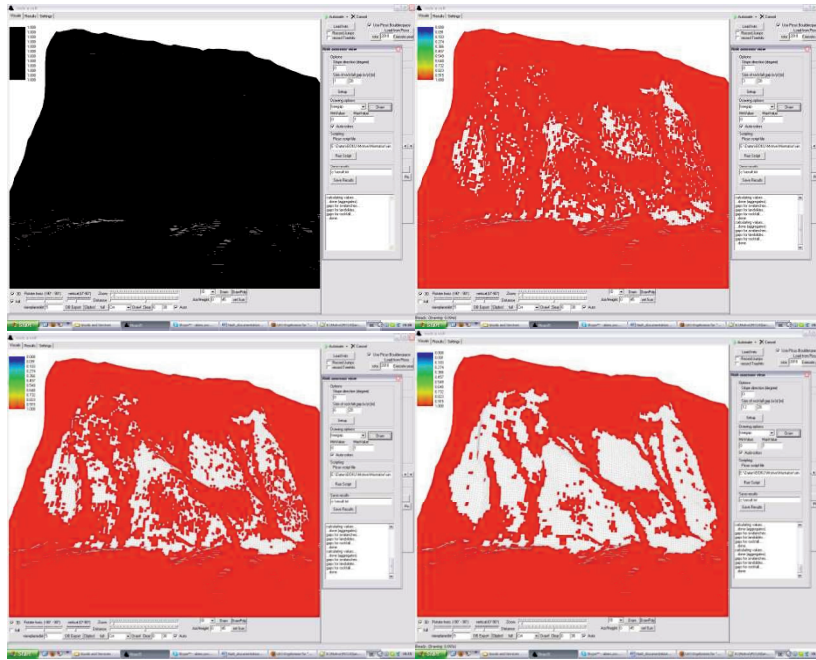


Figure 17: Gap detection (tree free distance) for protection against rockfall as a function of gap width. Gap width from top left 1m, 4m, 8m, 12 m. Gaps are displayed black for 1 m gap width and red for all other widths.

Conceptually, gap detection is based on a rendering of tree positions on a 2 x 2 m grid “tree map”. In contrast to the assessment of avalanche release protection and landslide, erosion, and debris flow protection in the source zone, not the canopy, but the stems are used for gap detection. All trees larger than 10 m in height are used to produce the “tree map”. Every 2 x 2 m grid cell hosting a tree > 10 m is considered to be not part of a gap, every empty grid cell is considered to be a potential part of a gap.

The “target gap” is rendered with a given angle (slope direction) on a 2 x 2 m grid. The “target gap” is defined to be 6 m in width and 20 m in length. The “target gap” is applied on each position of the “tree map”. If all pixels of the target gap corresponded with empty pixels on the tree map (no tree > 10 m on the pixel), the position is considered to be a gap (the center of the pixels is decisive; cf. Figure 14). Thus every empty 2 x 2 m pixel with its center underneath the “target gap” is considered to be a gap pixel. The “target gap” is moved all over the assessment area. After finishing this assessment step the outcome is aggregated on a 10 x 10 m pixel scale. During the aggregation each 10 x 10 m grid-cell which contains at least one 2 x 2 m grid cell

which had been considered to be part of a gap is considered to be a gap also after the aggregation (Figure 14).

For the indicator used see Table 26.

Table 26: Gap indicator used for the assessment of rockfall protection in the transit zone with the risk assessor tool. Only trees higher than 10 m were considered.

Indicator abbreviation	Indicator rule
treegap	>0 if gaps between tree stems exist (trees > 10m height). Recommended "target gap" size 6 x 20 m.

The risk assessor module produces results for three different rock sizes (Table 27). For each size, indicators need to be evaluated and aggregated. The results are provided in the three classes according to the NaiS scheme in a 10 x 10 m grid.

Table 27: Description of the result variables of the risk assessment tool for the protection against rockfall in the transit zone.

Name	Description
rockfall005	Rockfall protection for rocks < 0.05 m ³
rockfall020	Rockfall protection for rocks ≥ 0.05 m ³ and < 0.20 m ³
rockfall5	Rockfall protection for rocks ≥ 0.2 m ³ and < 5 m ³

The indicators are aggregated by AND. Which technical indicators and thresholds are used is depicted in Table 28 for the different rock size class results.

Table 28: Indicators and thresholds used for producing the assessment result for rockfall protection in the transit zone.

Name	Ideal	Minimal
rockfall005	If n ₁₂ > 600 AND treegap = 0	If n ₁₂ > 400 AND treegap = 0
rockfall020	If n ₂₄ > 400 AND treegap = 0	If n ₂₄ > 300 AND treegap = 0
rockfall5	If n ₃₆ > 200 AND treegap = 0	If n ₃₆ > 150 AND treegap = 0

1.3.3. Runout zone

The indicators are a) stem-number greater than a 12 cm DBH and b) tree free distance in slope direction (pole stage trees, trees > 10 m height; cf. Mayer, 1992) (Table 29) (Frehner et al., 2005).

Table 29: Indicators for the assessment of the protective function against rockfall in the runout zone (according to Frehner et al., 2005).

Indicator	Unit	Threshold minimal	Threshold ideal	Comment
Stem-number	N > 12 cm DBH	> 400	> 600	
Tree free distance	[m]	< 20 m	< 20 m	≥ pole stage

The technical implementation of the evaluation with regard to rockfall protection in the run out zone is very similar to the transit zone. The difference is, that only the stem number of trees > 12 cm DBH is relevant (cf. Table 30).

Table 30: Indicators used for the assessment of rockfall protection in the run out zone with the risk assessor tool. Only trees higher than 10 m were considered.

Indicator abbreviation	Indicator rule
n_12	Number of trees with DBH > 12cm
treegap	>0 if gaps between tree stems exist (trees > 10 m height). Recommended "target gap" size 6 x 20 m.

The risk assessor module produces one result for the protection against rockfall in the runout zone (Table 31) which is basically the same like the result for protection against rock fall in the transit zone for rocks < 0.05m³. The indicators need to be evaluated and aggregated. The results are provided in the three classes according to the NaiS scheme in a 10 x 10 m grid.

Table 31: Description of the result variables of the risk assessment tool for the protection against rockfall in the runout zone.

Name	Description
rockfall_runout	Rockfall protection in run-out zone.

The indicators are aggregated by AND. Which technical indicators and thresholds are used is depicted in Table 32 for the different rock size class results.

Table 32: Indicators and thresholds used for producing the assessment result for rockfall protection in the runout zone.

Name	Ideal	minimal
rockfall_runout	If n_12 > 600 AND treegap = 0	If n_12 > 400 AND treegap = 0

1.4. Protection against torrential processes and flooding

With the NaiS concept the protective function against torrential processes and flooding can be assessed for the catchment area and the channel banks (Frehner et al., 2005).

1.4.1. Catchment area

For the catchment area the influence of forests on the maximum discharge is evaluated. The indicators used are a) crown cover and b) sustainably ensured regeneration. The indicators have different thresholds depending on the sitetype of the forest to be assessed (Table 33) (Frehner et al., 2005). The sitetypes are divided into four classes in the NaiS concept. This and the very qualitative definition of the regeneration indicator inhibit an implementation in the risk assessor module in the current design.

Table 33: Indicators for the assessment of the protective function against torrential processes and flooding on the catchment scale (according to Frehner et al., 2005).

Sitetype	Indicator	Unit	Threshold minimal	Threshold ideal	Comment
Class 1	Crown cover	[%]	≥ 60%	≥ 70%	≥ pole stage
Class 2	Crown cover	[%]	≥ 50%	≥ 70%	≥ pole stage
Class 3	Regeneration				Needs to be defined
	Crown cover	[%]		≥ 50%	≥ pole stage
Class 4	Crown cover	[%]		≥ 50%	≥ pole stage

1.4.2. Channel banks

For the channel banks the prevention of negative effects due to woody debris in the channel is evaluated. The indicator is the occurrence of instable and slide-prone trees (Table 34) (Frehner et al., 2005). The spatial resolution of channels in the risk assessor module and the very qualitative definition of the indicator inhibit an implementation in the risk assessor module in the current design.

Table 34: Indicator for the assessment of the protective function of the forest against torrential processes and flooding on the channel banks (according to Frehner et al., 2005).

Indicator	Unit	Threshold minimal	Threshold ideal	Comment
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Instable, slide-prone trees	N	< 1	< 1	Needs to be defined
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5 Example code

5.1 Ecosystem service / risk assessment

The box exemplifies the use of Javascript within the LAT tool. The full source code is part of the download package of the LAT tool.

```
function main() {
    registerValues();

    for(var x = 0; x < values.sizeX(); x++) {
        for(var y = 0; y < values.sizeY(); y++) {
            var value = values.at(x, y);
            var dbh = value.get("dbh");

            if(dbh > 0) {
                snow(value);
                landslide(value);
                rockfall(value);
            }
        }
    }
}

// evaluate the avalanche risk
function snow(value) {
    // value 0 if crowncover below threshold
    if(value.get("crowncover5x5") < 50) {
        return; // default value is "0"
    }
    // 30° inclination
    if(value.get("gap_a60") === 0) {
        value.set("av_30", 1); // minimal
    }
    if(value.get("gap_a50") === 0) {
        value.set("av_30", 2); // ideal
        value.set("av_35", 1); // minimal
    }
    if(value.get("gap_a40") === 0) {
        value.set("av_35", 2); // ideal
        value.set("av_40", 1); // minimal
    }
    if(value.get("gap_a30") === 0) {
        value.set("av_40", 2); // ideal
        value.set("av_45", 1); // minimal
    }
}
```

```

    }
    if(value.get("gap_a25") === 0) {
        value.set("av_45", 2); // ideal
    }
}

```

5.2 Custom spatial analysis

The code below exemplifies the use of Javascript to execute advanced spatial analysis within the framework of the LAT tool. A more complete example is part of the download package of the LAT-Tool.

```

function main() {
    results.add("Simpson's evenness index: " + simpson().toFixed(3));
    results.add("Contagion index: " + contagion().toFixed(3)); // not included
}

function simpson() {
    var size = 0;
    var classCount = [0, 0, 0, 0, 0, 0];

    for(var x = 0; x < values.sizeX(); x++) {
        for(var y = 0; y < values.sizeY(); y++) {
            if(!values.active(x, y)) {
                continue;
            }

            size++;
            classCount[getDBHClass(x, y)]++;
        }
    }

    var quadraticSum = 0;
    for(var i = 0; i <= 5; i++) {
        var count = classCount[i];
        var proportionalCount = count / size;
        quadraticSum += proportionalCount * proportionalCount;
    }

    var index = (1 - quadraticSum) / (1 - (1 / 6));

    return index;
}

/// rest omitted.... See full source code.

```

2. References

Frehner, M., Wasser, B., Schwitter, R., 2005. Nachhaltigkeit und Erfolgskontrolle im Schutzwald. Wegleitung für Pflegemassnahmen in Wäldern mit Schutzfunktion, Vollzug Umwelt. Bundesamt für Umwelt, Wald und Landschaft, Bern, p. 564.

Hasenauer, H., 1997. Dimensional relationships of open-grown trees in Austria. Forest ecology and management 96: 197-206.

Mayer, H., 1992. Waldbau auf soziologisch-ökologischer Grundlage. Gustav Fischer, Stuttgart, Jena, New York, p. 522.

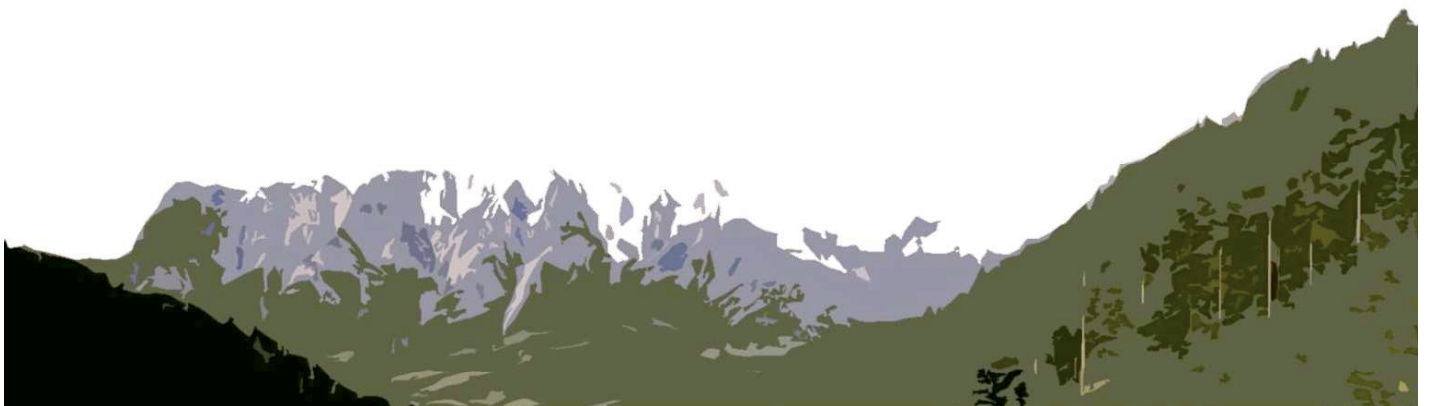
Maroschek, M., Rammer, W., Lexer, M.J., 2014. Using a novel assessment framework to evaluate protective functions and timber production in Austrian mountain forests under climate change. Reg. Environ. Chang. in press. doi:10.1007/s10113-014-0691-z

Rammer, W., Brauner, M., Dorren, L.K.A., Berger, F., Lexer, M.J., 2010. Evaluation of a 3-D rockfall module within a forest patch model. Natural Hazards and Earth System Science 10(4): 699-711.



Appendix B

Creation of realistic tree initializations



Concept

For each tree in the tree-list the procedure described in the following is conducted. First the trees are brought into a descending order with regard to their height. The first trees which are processed are the trees taller than the 90th percentile (tree height) or the largest 50 trees per hectare, whichever is larger. The procedure starts with the tallest individual. Thereafter the trees smaller than the 90th percentile or than the 50 tallest trees per ha are processed beginning with the smallest tree. For each tree the “suitability” of a patch to “host” the tree is assessed based on a) height and b) volume information for the patch as well as c) a height attractor function and d) a crown area estimate for the patch. In each of the four categories a value between 0 and 1 (0=totally unsuitable, 1=totally suitable) is derived by functions described in the subsequent paragraphs. The product (multiplicative combination) of the four categories yields the overall suitability of a patch to “host” the specific tree. The tree is assigned to the patch with the largest overall value.

Height

For each patch (PICUS 10 x 10 m simulation entity) the minimal height (h_{min}), the medium height (h_{mean} ; arithmetic mean) and the maximum height (h_{max}) in meters is known. The information is derived from a normalized crown model (nCM) which is available in a 1 x 1 m resolution. This grid file is converted in ESRI ArcMap 9.2 with the aggregate tool of the spatial analyst toolbox to a 10 x 10 m raster. The respective aggregation techniques are minimum, mean and maximum. Potentially a median height (h_{medi}) would also be available.

For each height aggregate the suitability to host a tree (p_{height}) a value between 0 and 1 is assigned. Additionally to the three height aggregates two further height thresholds are introduced 0 and $h_{max} \cdot 1.3$. This is necessary as otherwise not the whole height range, a tree can possibly span, is covered. The factor of 1.3 has been chosen based on literature. Similarly as for the thresholds derived from the grids, values between 0 and 1 are assigned to these two additional thresholds characterizing the suitability of a patch to host a tree. The values yield a function which is displayed in Figure 18.

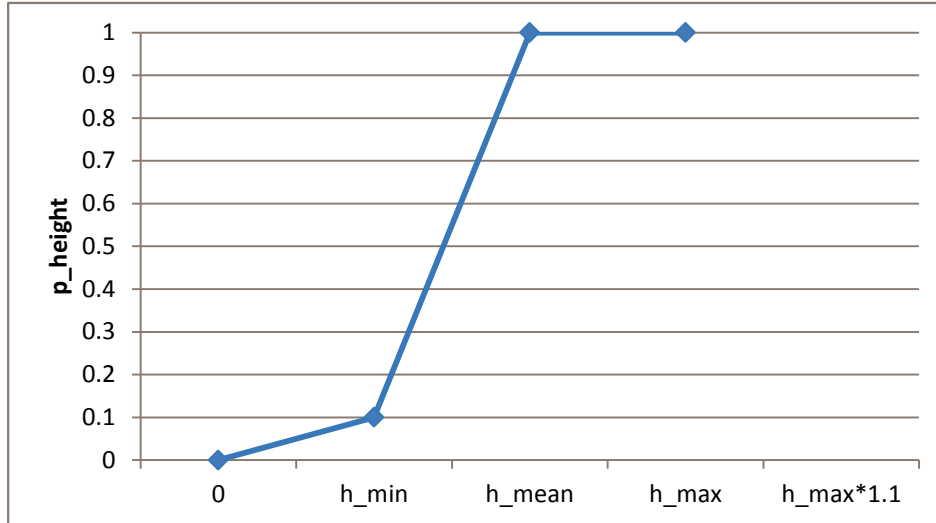


Figure 18: Height dependent suitability function.

Volume

For each patch a volume estimate based on the nCM (1 x1 m resolution) in m³/ha is available (cf. Hollaus et al., 2002). This grid file is converted in ESRI ArcMap 9.2 with the aggregate tool of the spatial analyst toolbox from a 1 x 1 m to a 10 x 10 m raster. The respective aggregation technique is mean.

For each patch the suitability to host a tree (p_volume) based on volume estimates is calculated. The respective equation (Eq. 1) and its graph (Figure 18).are shown in the following

$$p_{volume} = e^{\left(\frac{V_{patch} \times -0.8}{\frac{V_{target}}{100}} \right)} \quad \text{Eq. 1}$$

The suitability for a patch to host a certain tree (p_{volume}) is a function of the volume estimate for the patch (V_{target}) and the volume already standing on the patch (V_{patch}). V_{target} is obtained from the volume grid file. V_{patch} is the sum of the single tree volumes already standing on the patch. These volumes are calculated based on the Pollanschütz formula for Norway spruce (*Picea abies*).

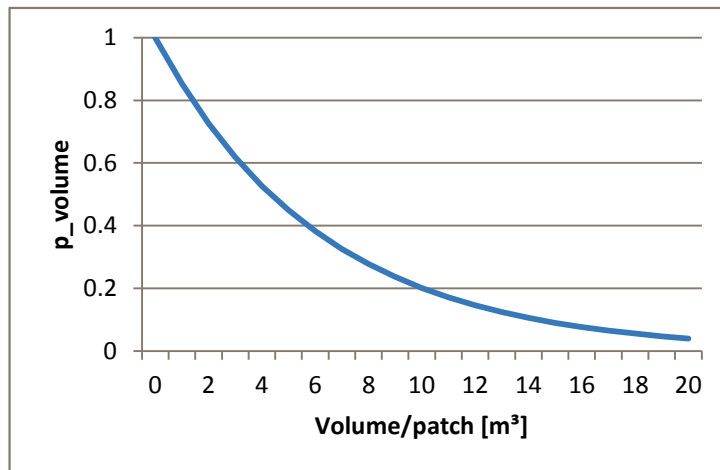


Figure 19: Volume dependent suitability function of the initialization procedure.

Height attractor

For each patch a rule with regard to the actual mean height (arithmetic) of each patch is executed. The purpose of this element is to allocate small trees to small ones and taller trees to taller ones to avoid a too large heterogeneity within a patch. For each patch an actual mean tree height is calculated with the trees already assigned to the patch. If no trees are on the patch yet, the procedure is stopped and the suitability value for the patch to host a tree with regard to the height attractor ($p_{\text{height_attract}}$) is set to 1. If there are already trees on the patch, the height of the tree to be assigned is set in relation to the mean patch tree height. The closer the height of the tree to be assigned matches the mean patch tree height the larger is the suitability of the patch to host the tree. The respective function is displayed in Figure 20.

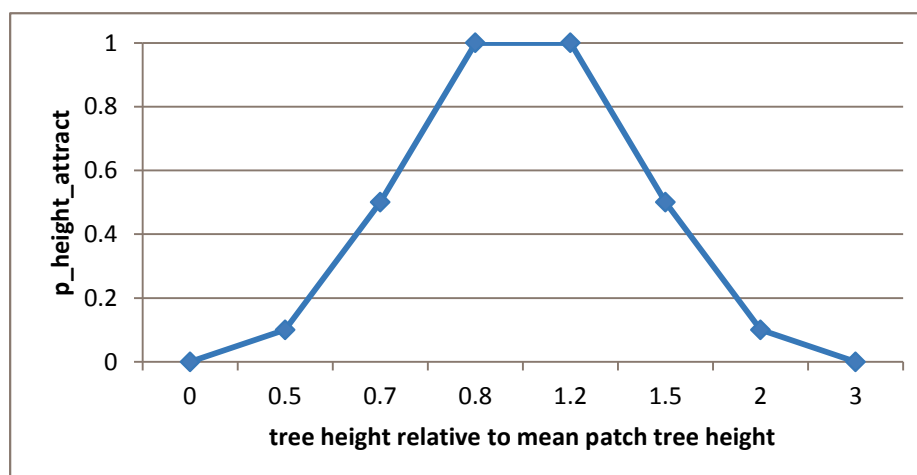


Figure 20: Suitability function to assess the suitability of a patch to host a tree based on tree height and the mean patch tree height.

Crown area

For the suitability with regard to the crown area no LiDAR information is used. The estimates are based on an assumption on crown radius of trees. The basis is the height – crown radius correlation of solitary trees according to Hasenauer (1997). The equation for the crown radius calculation based on tree height is described in the following (Eq. 2). Due to simplicity reasons only the formula for Norway spruce, is used for all tree species. The radius (r) is a function of the tree height (h).

$$r = \frac{e^{-0.258+0.8152 \times \ln h}}{2} \quad \text{Eq. 2}$$

To account for the fact that crowns of trees in competition with other trees are smaller in diameter the values obtained by the Hasenauer formula are reduced by the factor 0.4 (Eq. 3, Figure 21).

$$r = 0.4 \times \frac{e^{-0.258+0.8152 \times \ln h}}{2} \quad \text{Eq. 3}$$

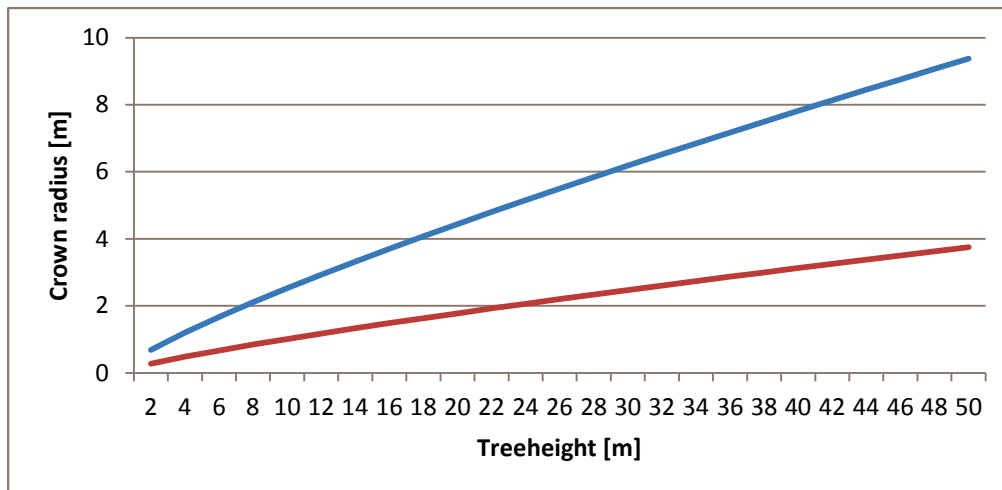


Figure 21: Calculation of the crown radius of solitary trees based on tree height according to (Hasenauer, 1997; blue) and the modification of the formula to allow the assessment of crown radii of trees under competition (red).

For each patch the target crown area is set to 100 m². The actual crown area of a patch is calculated by summing up the crown areas of the trees already standing on the patch. The crown areas of the single trees are estimated based on the radius obtained by Eq. 3.

The function used to assess the suitability of a patch to host a tree with regard to the crown area (p_{area}) is described in the following (Eq. 4). It is a function of the crown area already standing on the patch (C_{patch}) and the target crown area for a patch (C_{target}). The graph of Eq. 4 displayed in Figure 22.

$$p_{area} = e^{-2 \times \frac{C_{patch}}{C_{target}}} \quad \text{Eq. 4}$$

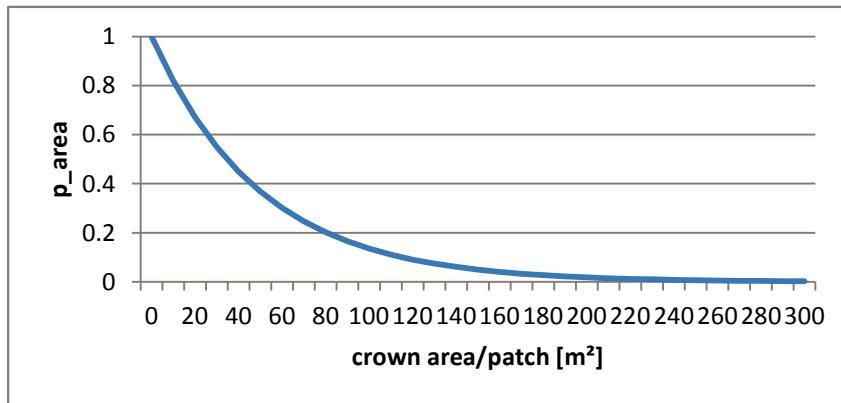


Figure 22: Crown area dependent suitability function.