SUPERB
Upscaling Forest Restoration

Protocol for regular forest inventory (Essential-only)

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Project Acronym: SUPERB

Systemic solutions for upscaling of urgent ecosystem restoration for forest related biodiversity and ecosystem services

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DISCLAIMER

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Objectives

The purpose of the forest inventories is to describe the change in forest structure and composition along the restoration gradient, and to determine its effects on ecosystem biodiversity and functions. This information will be employed to complete the Monitoring, Reporting and Verification of Biodiversity and Ecosystem Services (MRV-BES) reports for your demo area, and thus the quality of the data provided by the demos will be key to developing quality MRV reports for your restoration actions. The observations will be conducted and recorded at the plot scale, involving several aspects of the stand structure. Some essential aspects are required for all demos (regular or extended) and include measurement of the adult trees, saplings and seedlings as well as ground vegetation inventory of non-tree species. These aspects are described in these guidelines. Once the acquisition of the essential inventory data needed for the MRV reports has been secured, depending on the resources that each demo partner may have available, additional measurements can be added. These additional non-compulsory data are described in a separate guideline document including both essential and additional measurements. The Excel spreadsheets provided combine both Essential (Essential-only guidelines) and Additional data (Essential-plus-additional guidelines) that are marked in different colours, to clarify the difference in each case. When your inventory data is ready, **liaise directly with the MRV-BES Task 6.3 Leader** (ruben.valbuena@slu.se) **to provide the data** and speak about how your data will be used, if you have not done so already during the experimental design stages.

Sampling design

The measurements will be conducted at the sampling point (plot) scale. A minimum of 3 sampling points per stand (~1 ha) will be established (= 54 in total for regular demos, and = 108 for extended demos) following the cross design from Figure 1. This design suggests a central potential sampling point (C), surrounded by four additional potential sampling points, each of them in a specific cardinal direction (N, E, S, W) and at a fixed distance (d) from 'C' (Figure 1). In order to avoid biasing the location of the sampling points (for example, by establishing them in the middle of a clearing, or seeking equidistance to trees nearby), the location of 'C' (from which the location of the rest of the potential sampling points are calculated) will be randomly determined within the stand. Fig. 1 is only a guideline for plot distribution that need to of course be adapted to the special circumstances and shape of each given stand. Out of the five potential sampling points (C, N, E, S, W), a minimum of 3 will be randomly selected for sampling. The specific number of potential sampling points to select should be determined based on the heterogeneity of the forest stand, by making sure that the observed within-stand spatial variation in structure and composition is captured. Once the sampling crew is located a given forest stand, we advise to secure the random selection of plot positions by walking a fixed number of steps in a fixed direction from the stand

border. This is a way to eliminate perception biases and tendencies to position plot centres at a clearing or at equidistance from nearby trees, which could yield biased estimations of the total stand density.

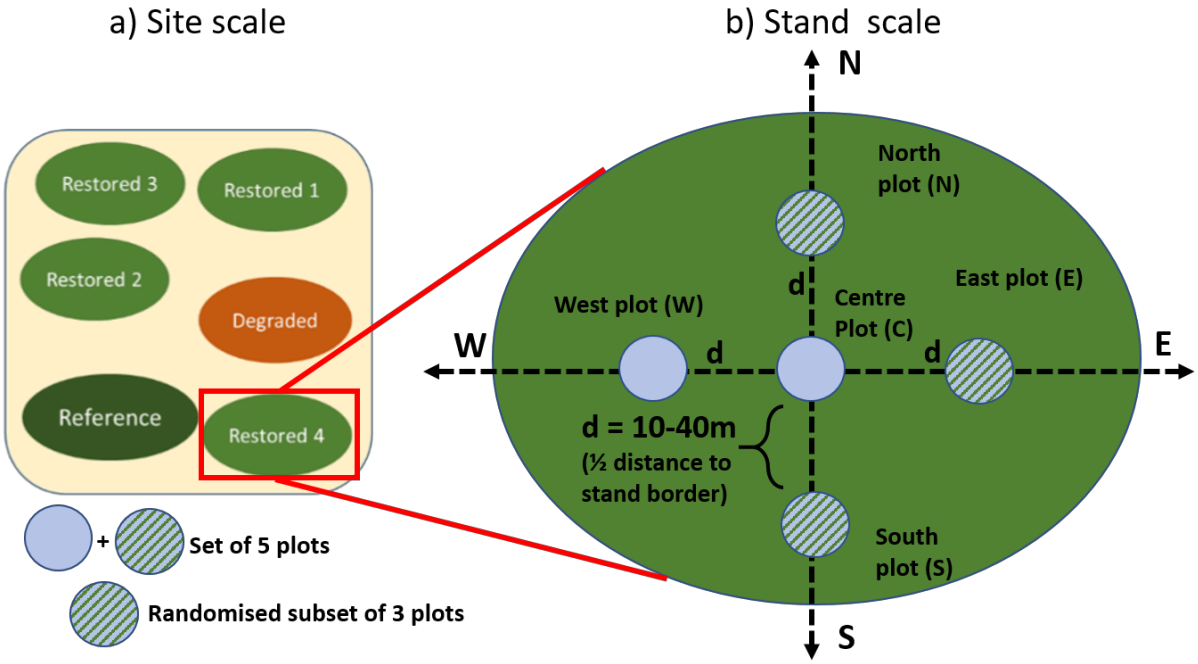

Figure 1. Design for the distribution of the sampling points, where "d" is equivalent to ½ of the estimated distance to the stand border from the central sampling point, with approximate distances and distribution to be adapted to each real case.

Staking out and marking the plot centre. Once the selection has been made, the plot centre should be staked out by leaving the GPS receiver occupying its positioning at the plot centre during the time required for plot mensuration[1]. In addition, the position of each selected sampling point will be marked or highlighted in the field, to allow revisiting later in time. One option is to mark with two horizontal lines the closest healthy living tree, and record the bearing and distance from that tree to the sampling point. If there is no tree within 3 m around the plot, a wooden stake may be nailed in the ground. Another possibility would be to bury a metallic nail that can be later searched with a metal detector.

Concentric subplot design. Around each selected sampling point, concentric plots of different sizes will be used to measure the different components of forest structure, to ensure efficiency in the inventory effort (Figure 2). Accordingly, characteristics that require higher effort are measured over smaller plots, whereas larger plots are employed to record rarer events only. To quickly decide in the field which trees belong to each subplot type[1], you may simultaneously measure diameter at breast height (dbh) and distance to plot centre. The different plot sizes (Fig. 2) are designed to be integer divisions of a hectare, to facilitate rapid in situ assessment of within-stand variability (i.e. whether more than 3 plots are needed to capture the range of stand heterogeneity). The different subplots involved are:

[1] Some of these aspects are here explained only concisely. Please, ask Prof. Rubén Valbuena for details if needed, via email (ruben.valbuena@slu.se).

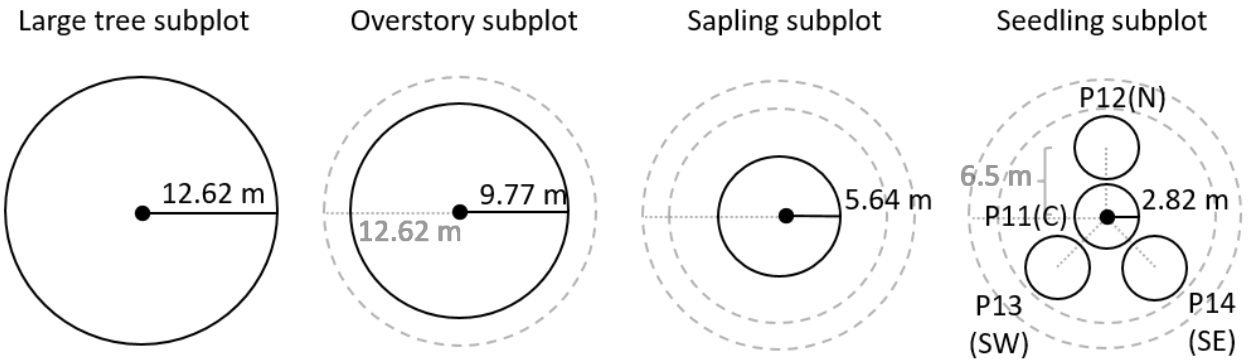

Figure 2. Field plot design for multilayered forest following a circular subplot design.

1. One large tree subplot (12.62 m radius) where only large adult trees (>27 cm dbh) will be measured;
2. One overstory subplot (9.77 m radius) where all adult trees (> 7cm dbh) will be measured;
3. One sapling subplot (5.64 m radius) where the smaller trees (saplings) will be measured and deadwood biomass will be assessed;
4. Four seedling subplots (2.82 m radius) where seedlings will be counted.
5. In addition, aground vegetation inventory of non-tree species will be done over 1-m quadrats within seedling subplots.

Timing and duration

As temporal replicates are not needed for regular forest inventory work, the data can be acquired during a short campaign taking place anytime between the 1st and 3rd year of the project (i.e., until the end of summer 2024). However, we highly encourage all demos to have all the inventory data ready by summer 2023, or earlier to the extent possible. Depending on the characteristics and goals of each demo, some may be surveyed at the beginning of the project, and others later. For the extended demos it might be most convenient to carry out the forest inventory at the same time as other field measurements. Assuming one stand is taken care of every day, the 18 stands of the regular demo regions could be sampled in maximum 3-4 weeks, whereas the 36 stands of the extended demos could be sampled in 6-8 weeks. To identify tree regeneration and assess ground vegetation diversity, we suggest the inventories should be conducted during the growing season, and thus each area will need to identify the most suitable 3-4 weeks to carry out the campaign.

In the case of non-tree species surveys, it would be good to have temporal replicates, if possible. This is because shrub and herbaceous species composition usually change quickly. Extended demos could therefore link the collection of temporal replicates of herbaceous surveys to their temporal replicates for the other field measurements (DNA metabarcoding and bioacoustics).

Equipment required

- Crews of at least two people working simultaneously on a single plot
- Printed version of the inventory protocol
- Excel workbook provided to fill in the data, open in suitable electronic device. Alternatively, data collection may be carried out over printed sheets, but the inventory crew should be responsible for filling in the data in the final Excel workbook. We do recommend to always have hardcopies of printed sheets available, to cover eventualities such as battery shortages.
- Spray painting, to mark the trees relative to the sampling points, and/or wooden stakes. Metallic nails may be used, and a metal detector employed in revisiting campaigns.
- Diameter tape or calliper.
- Vertex, or similar device that can measure distances remotely. This would be employed to measure distances of trees to plot centre simultaneously to dbh measurement, which allows quick determination on whether each tree belong to each corresponding subplot (Fig. 2). Alternatively, a measuring tape may be used, but it is cumbersome and in such case it is recommended to increase the crew to three people.
- A smartphone with iNaturalist app.
- Quadrats of 1-m side, or markers.
- A survey-grade GPS device. Or the best available alternative[1].

Measurements

- **General information**

Record the data collected in the Excel spreadsheet provided. General information should be recorded under the label 'Plot'. Table 1 explains the data to include at each field. Include the GPS coordinates, specifying in the comments which is the geographical system employed for them (please, use ESPG codes for national systems). Optionally, you may record approximate terrain slope and aspect in the site, or rather extract that information from LIDAR-derived digital terrain models if available for the area. Relevant observations on the plot environment and location can also be recorded (e.g., proximity to roads or infrastructure, recent management interventions, previous land use) in the field 'Comments'. You may also optionally add approximate percentages of coverage for each of the tree, shrub and the herbaceous layers, assessed visually and expressed separately and not relatively to each other (their sum may therefore higher than 100%).

Table 1: Plot variables (Label 'Plot'). .Opt. denotes fields that are optional and thus non-compulsory.

Variable	Description	Format Ex.
Country	Two-character code of the country	"FR"
Stand	The unique stand number	"01"
Plot	The unique plot number	"03"
Plotcode[2]	Unique generated plotcode	"ES_01_01"
Coordinates (Opt.)	The latitude/longitude coordinates of the plot centre	12.65 / 49.06
Slope (Opt.)	Terrain slope in percentage of change in altitude	10
Aspect (Opt.)	Direction of the slope, in centesimal degrees from North bearing	200
Herb. cover (Opt.)	% of herbaceous cover	70
Shrub cover (Opt.)	% of shrub cover	60
Tree cover (Opt.)	% of tree cover	50
Comments	Free hand	"char.string"

In the label 'Species' (Table 2) you will find the species codes that we will use across all demo areas. Please provide suitable allometric models for the species in your demo area which you feel would make the best biomass predictions according to your local knowledge. There are additional fields where you can add any relevant information concerning allometry: height or below ground biomass, relevant references, etc.

Table 2: Species (Label 'Species'). Opt. denotes fields that are additional and thus non-compulsory.

Variable	Description	Format Ex.
Species code	List of all code for the most common European tree species/genus	"ABIALB"
Binomial name	Corresponding Latin name of the species	"*Abies alba*"
Rank	Taxonomic level	"Species"
Best Biomass model (Opt.)	Best local model for each species	
Any relevant allometry (Opt.)	Other relevant models	
Reference (Opt.)	Free hand	"char. string"

[2] A function 'CONCATENATE()' has been added to calculate this automatically. If the spreadsheet is opened with a MS Excelversion other than English, this syntax would have to be manually adapted to the local language.

- **Adult tree inventory (Large tree and overstory subplot)**

The tree inventory will involve all the standing, living or dead adult trees (dbh > 7 cm). Intermediate-sized trees (dbh between 7 and 27 cm) will be measured on a 9.77-m radius plot, whereas large trees (dbh > 27 cm) will be measured on a 12.62 m-radius plot (Fig. 2). In each case, the species, dbh, and condition (living or dead) of all the corresponding trees will be recorded (Table 3). Where the species of dead trees cannot be determined, it should be recorded whether these are hardwood or softwood species. It is important that each height measurement is linked to a dbh measurement, and thus, that it is recorded at the row corresponding to the same tree (can leave the rest of rows empty of height measurement). If dead top-broken trees are found within the plot their decay class will be recorded according to Table 3.

Table 3: Overstory & Sapling variables (Labels '1_Overstory-Individual' and '2_Saplings'). Opt. denotes fields that may be filled only for few applicable trees (see instructions for measuring tree heights).

Variable	Description	Format Example
Plotcode	The unique plot code	ES_1_1
Tree number	Number of the tree in the plot	001 (Adult); 101 (Sapling)
Treecode	The unique code of the tree	ES_1_1_T001 (Adult) ES_1_1_T101 (Sapling)
SpeciesID	Unique ID for the species	"QUEROB"
dbh	The diameter at breast height (1.30 m) of the tree (in cm).	54.3
Height (Opt.)	The height of the tree. Measured in m.	2.25
Dead Tree (Opt.)	A digit indicating Dead trees (0 – Living; 1 – Dead)	1
Decay Classs (Opt.)	A code indicating: 1 – Sound (recently dead); 2 – Intermediate (partially rotten); or 3 – rotten	2
Hard/Softwood (Opt.)	If not identifiable species: 0- hardwood; 1 - softwood	1
Date of survey	Date where data was collected YYYYMMDD	20220607
Comments (Opt.)	Free hand	"Character string"

Tree heights need to be determined for few living trees only: 3 measurements for each of the dominant species present, trying to approximately cover the full range of tree heights and giving measurement of one small, median and one tall tree. Height measurements can be conducted either on the intermediate-sized trees from the 9.77 m-radius plots, or on the large trees from the 12.62 m-radius plots. It is however important that each height measurement is linked to a dbh measurement, and thus recorded at the row corresponding to the same tree (can leave the rest of rows empty of height measurement). If dead top-broken trees are found within the plot their decay class will be recorded according to Table 3.

- **Saplings inventory (Saplings subplot)**

Trees with dbh < 7 cm will be also measured individually and recorded, as long as they are higher than 1.30 cm (saplings). These trees will however be measured only when they are at a distance within 5.64 m from the plot centre, to limit the surveying effort needed for these smaller trees. Individual tree codes for saplings will start the count from "101", to aid their distinction from the bigger trees and facilitate the combination of overstory and sapling layers. If the height measurement of the smaller tree was taken from one of these saplings, add its corresponding height here alongside its dbh. Please also record the mortality status and decay class (if relevant) following the adult tree inventory.

- **Lying deadwood (Saplings subplot)**

For all lying deadwood pieces (diameter > 7 cm) found within the 5.64 m-radius saplings subplot (Fig. 2), the diameter at mid-length, total length, and decay class will be recorded. For pieces of deadwood intersecting the borderline, the criterion for inclusion will be whether any part of it within the 5.64 m distance of the plot centre as a diameter > 7 cm. It is recommended to use a tree calliper for measuring lying deadwood diameter. The decay class will be determined according to the categories described in Table 4.

Table 4: Lying deadwood variables (Labels '6_Lying_Deadwood')

Variable	Description	Format Example
Plotcode	The unique plot code	ES_1_1
Piece number	Numbering of the deadwood piece in the plot	D4
Deadwood piece code	The unique code of the deadwood piece	ES_1_1_D4
dbh at mid length	The diameter at mid-length (in cm).	54.3
Total length	The length of the piece of deadwood (in cm).	78
Decay Class	A code indicating: 1 – Sound (recently dead); 2 – Intermediate (partially rotten); or 3 – rotten	2
Comments	Free hand	"Char. string"

- **Seedlings inventory (Seedlings subplots)**

For trees with height below 1.30 m no individual measurements will be recorded, and they will only be counted. The counting will be done over 4 different subplots of 2.82 m radius, which should be distributed according to Figure 2 to avoid biases in their placement (plots P11, P12, P13, and P14; see Fig. 2). Using a telescopic pole, rapid counts of seedlings can be carried out around each subplot centre. Record seedling counts per subplot grouped by species and height class (Table 5). Height classes only need to be determined approximately: below 20 cm (class 1), 20-80 cm (class 2), or above 80 cm (class 3). There are also some fields for optional measurements of canopy cover (see Essential-plus-additional guidelines).

Table 5: Seedlings variables (Label '3_Seedlings'. Opt.. denotes fields that are additional and thus non-compulsory (for Essential-plus-additional only).

Variable	Description	Format Example
Plotcode	Unique generated plotcode	"ES_01_01"
Subplot code	Subplot code	"P11"
Unique subplot code	Plotcode + subplot code	"ES_01_01_P11"
Seedling SpeciesCode	Unique 6 character code of the species	"POPNIG"
Number of seedlings (class 1)	Total number of seedlings in the subplot below 20 cm	10
Number of seedlings (height class 2)	Total number of seedlings in the subplot with a size between 20 and 80 cm	7
Number of seedlings (height class 3)	Total number of seedlings in the subplot above 80 cm	4
Sprouts SpeciesCode	Unique 6 character code of the species	"POPNIG"
Number of sprouts (class 1)	Total number of sprouts in the subplot below 20 cm	10
Number of sprouts (height class 2)	Total number of sprouts in the subplot with a size between 20 and 80 cm	7
Number of sprouts (height class 3)	Total number of sprouts in the subplot above 80 cm	4
Percentage Cover (Opt.)	Percentage cover calculated using a densitometer (in %)	70
Photograph ID (Opt.)	Name of the file from hemispherical photograph	"character string"
Leaf litter layer (Opt.)	Depth of leaf litter layer (cm)	10
Comments (Opt.)	Free hand	"character string"

- **Richness of ground vegetation using iNaturalist[3] (Central quadrats at seedling subplots)**

Each species of non-tree vascular plants (herbs, ferns, shrubs) present in each if the 1-m quadrats within each seedlings subplots will be identified using the iNaturalist application. To be included in this list, plants can originate either within the quadrat, or outside it, as long as some part of them is present either directly on the quadrat floor, or on its vertical projection, up to a height of 5 m.

Before going in the field, you will need to:

- Download the iNaturalist app for iPhone or Android.
- Create an account using the app or the website (https://www.inaturalist.org/home)
- Transmit your user information to Alexandre Changenet by email (alexandre.changenet@slu.se).

[3] Please ask Dr Alexandre Changenet for details if needed, via email (alexandre.changenet@slu.se)

Once in the field, you should follow the steps depicted in Figure 2 for any species you observe in each quadrat and repeat the process for every seeding subplot (i.e., 4 quadrats per plot). Use the Subplot codes (P11, P12, P13 and P14, see Fig. 2) to identify them as in Table 5's 'Unique subplot code' (Fig. 3). More information can be found on the web (https://www.inaturalist.org/pages/getting%252Bstarted) or checking the tutorials of the iNaturalist App (https://www.inaturalist.org/pages/video%252Btutorials) where explanations are given on how to add an observations using different devices or the website.

Figure 3: How to make an observation using iNaturalist (adapted from iNaturalist.org)

Some advice to follow:

- Get the quadrat code right, so that the information can be crossed with other data: **The step 3b is the most important step that will allow to match any observation you add to a given plot, subplot and stands even if your automatic localisation is poorly detected**.
- Number of pictures: We recommend you take at least two pictures from different angle for each plant you find in any subplot. This would help the community to identify your observation with confidence and discriminate between several close species (see also this link: https://vimeo.com/167341998).
- Internet connection: You do not need an internet connection while you make an observation as long as you click the upload/sync button. The observation will be added online when an internet connection is established on your mobile phone.
- Unidentified species: It is better to have a good or approximate idea of the species observed, whether by identifying them *in situ* or using the species suggested by the computer vision algorithm. However, species that cannot be identified using either of these options should be added in the app with as such taxonomic detail as possible. Their picture as well as their approximate cover % within the subplot should be stored in the sheet label 4_Non_tree_understory_species for subsequent identification (Optional), unless they are rare within the given sampling unit.

Table 6: Ground vegetation inventory (Label '4_Non_tree_understort_species'; Opt. denotes fields that are non-compulsory.

Variable	Description	Format Example
Plotcode	Unique generated plotcode	"ES_01_01"
Subplot code	Subplot code	"P11"
Unique subplot code	Plotcode + subplot code	"ES_01_01_P11"
Species	Latin name of the observed species (if possible):	"*Arabidopsis thaliana*"
iNaturalist record	Picture(s) of the observed species	
Cover (Opt.)	Cover of the species in the quadrat if unidentified and abundant	80%
Comments	Free hand	"character-string"