Handbook for Sustainable Forest Management

Deliverable: Handbook for SFM per each species considered

While silvicultural systems do have an impact on fungal communities, their effect is often overshadowed by stronger influences of location and bedrock when accounted for. The significant effects of these variables suggest that local environmental conditions and regional differences are crucial determinants of fungal diversity and community structure. Consequently, while management practices are important, they should be considered alongside these other influential factors for effective conservation and management of fungal biodiversity.

When examining beta diversity, which reflects changes in fungal community composition across different sites, the analysis revealed that bedrock type plays a critical role in shaping both the total fungal community and the EcM community (Figure 3.4.2.5).

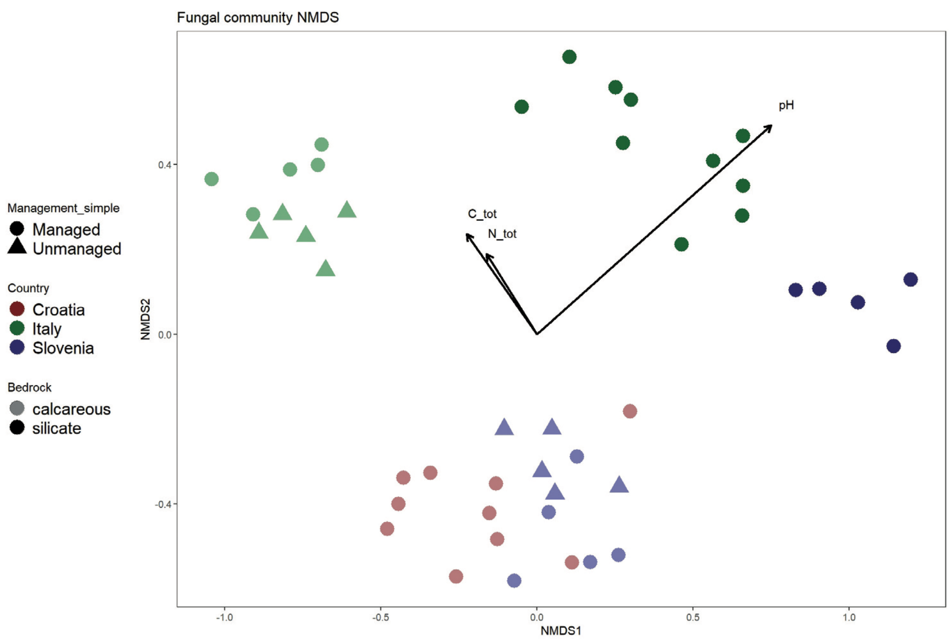

Figure 3.4.2.5. NMDS based on Bray-Curtis distance (stress=0.1050) for communities of all fungi as affected by the bedrock, location and management (unmanaged vs. managed).

PERMANOVA results showed that bedrock significantly influenced the composition of these communities, suggesting that the underlying geology and soil chemistry are among key drivers of fungal community composition. This influence was more pronounced than that of silvicultural practices, highlighting the foundational impact of abiotic factors on fungal communities. For the active EcM community, while silvicultural practices did affect community composition, the effects of bedrock remained substantial, underscoring its primary influence.

3.5 GenBioSilvi model

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Measuring genetic diversity is crucial to understand the health status of forest ecosystems in response to climatic change as well as supporting conservation and management efforts.

Based on the results obtained, we can assume that there is high genetic diversity in all sites, but we can't conclude that there is significant genetic diversity between the sites even though they differ in management types. Analyzing the pattern of genetic diversity distribution based on SSRs data, we observed that old-growth forests have a complex and heterogeneous spatial genetic structure. The spatial genetic structures observed in old-growth beech forests can be attributed to the non-random mating between closely related individuals. Most beech seeds germinate close to mother trees, thus contributing to the formation of such family structures. The management can affect the population demography.

From the results obtained for each management type (see the deliverable Action B2 GenBioSilvi model), it was possible to observe a complex spatial genetic structure similar to that reported for old-growth forests at sites managed with individual tree selection thinning. Site 02 - Baldo's Forest, monospecific beech stands, reported the most complex spatial genetic structure among the managed sites. Observing the various stands managed according to the uniform and irregular shelterwood, we observed a trend of simplified spatial genetic structure. The complexity of the old-growth forest and Site 02 - Baldo's forest implies a dynamic and adaptable ecosystem capable of responding to environmental changes by generating new genetic variability through recombination and gene flow between subpopulations. In addition, we observed a high number of SNPs correlated with current environmental conditions across sites. The presence of these allelic variants associated with bioclimatic indicators that best characterize the local environment is important. We found that Site 02 - Baldo's forest presented a higher number of SNPs correlated with bioclimatic indicators and a complex spatial genetic structure. Based on our results, we assumed that better conditions are found in old-growth forests and individual tree selection system sites. Stand structure is a key element in assessing ecological functions and services in forest ecosystems.

To describe biodiversity, we observed dendrometric data to define the forest structure of the analyzed sites. Thanks to this data, we can assume that the best structure observed is that characteristic of a multi-layered uneven-aged forest. The sites that presented these characteristics are Site 02 - Baldo's Forest, Site 11 - Fonte Novello, and Site 25 - Rajhenavski Rog. A multi-layered uneven-aged population supports the presence of natural regeneration because it shows gaps in canopy cover that create ideal conditions for the establishment of natural regeneration. Furthermore, a multi-layered forest increases the probability of sporadic species occurrence. In addition, multi-layered forest allows high pollen dispersal, promoting genetic diversity. Therefore, based on the best parameters used to define forest structure, we observed that sites characterized by multilayered uneven-aged forest structure also exhibit complex spatial genetic structure and high genetic diversity.

Deadwood plays crucial functional roles such as in nutrient cycling and as a carbon sink. The presence of deadwood can promote germination and seedling development of tree species, acting as nursery sites and thus contributing to forest renewal.

Regarding the amount of deadwood, the best situation is observed in unmanaged sites that showed a higher volume of deadwood.
Deadwood provides an important microhabitat for the development and conservation of species important to the forest ecosystem. In addition to deadwood, we observed other indicators related to saproxylic microhabitats. The greatest number of microhabitats was detected at sites where there are century-old individuals with stem deformations and cavities. The frequency of epixylic microhabitats is lower than saproxylic in all observed populations. Epixylic are used as indicators to assess ecosystem conditions. The presence of these microhabitats is an important source of biodiversity. Based on the obtained results, management types that allow for complex forest structures characteristic of uneven-aged and multilayered stands increase the probability of observing different microhabitat forms.

The majority of analyzed sites are pure beech stands. Some sites such as Site 29 - Gorski kotar, Vrbovsko, Site 25 - Rajhenavski Rog, and Site 12 - Venacquaro present sporadic species such as *Abies alba* Mill., *Prunus avium* L., *Acer* spp. L., and *Fraxinus* spp. L. Sporadic species should be maintained and where they exhibit natural regeneration this should be preserved and conserved and/or stimulated.

Forest management practices, especially those involving tree harvesting, influence the soil community, pivotal components for nutrient cycling, and the well-being of trees. These practices alter subsoil microbial dynamics, potentially leading to a reduction in ectomycorrhizal fungal diversity. This decline can hamper tree growth and compromise the overall functionality of forest ecosystems. Consequently, understanding these effects is imperative for fostering sustainable forest management.

The marked and significant differences observed in bacterial, ectomycorrhizal, and fungal community compositions between close-to-nature, unmanaged, and medium intensity management strategies are attributable to a variety of factors. Each management approach represents a distinct level of disturbance to the forest ecosystem. Close-to-nature management aims to emulate natural disturbances with minimal human interference, while unmanaged forests experience no human intervention. Medium intensity management, however, may involve more intensive silviculture systems, thereby introducing greater disruption to the ecosystem. In conclusion, we assumed that better soil diversity is present in less impact and in old-growth forest-managed sites.

Analysing results, we observed that the condition that conserves and/or increases diversity is the managed site with individual tree selection. This type of management is less impactful moreover it mimics conditions normally found in old-growth forests and unmanaged forests. The removal of a few individuals based on phenotype and position results in the formation of gaps in the tree cover that encourages the growth of natural regeneration. Compared to old-growth forests, where regeneration is predominantly on the borders, in sites managed with individual tree system, natural regeneration is also stimulated within the stand. This type of management increases the complexity of the forest structure presenting a multi-layered pattern, a typical characteristic of an uneven-aged forest. This allows better pollen dispersal -high gene flow- since fewer barriers are present. This promotes genetic diversity and increases spatial genetic complexity, leading to a greater occurrence probability of new allelic variants that are essential in responding to climate change. In addition, a key aspect of forest stand resilience is the presence of high biodiversity. Through our results, we have observed that stands that exhibit higher genetic diversity also exhibits higher biodiversity at the ecosystem and species levels.

Based on the results obtained during the analyses, through the observation of these indicators it is possible to simulate the genetic diversity status of the stand and guide users toward sustainable management to conserve and/or increase the genetic diversity present.

Considering the results obtained from the analysis of all biodiversity indicators, we developed a model that describes the current status of genetic resources within the site. This model was developed to help forest users for checking the current status of stand biodiversity and providing guidelines for sustainable management. To develop a user-friendly suitable model, we observed that it is possible to identify a set of key indicators that are more representative. The indicators at the basis of the model can indirectly describe the genetic diversity status of the stand, as seen from the results obtained. In addition, it is also possible to identify some indicators that are more representative of biodiversity in terms of deadwood, microhabitat, and species diversity. For this reason, we decided to exclude in the form developed for users the data collection on genetic diversity and soil diversity that are difficult to observe. In this regard, we have developed a model that involves the observation of some key indicators that describe the current status of the analyzed stand. The selected indicators are shown in Table 3.5.1.

Table 3.5.1. Description of selected indicator useful for users to describe the status of the stand.

Categories	Indicators	Description
Forest structure	DBH standard deviation	Variability in tree DBH within the stand
	Percentage of trees in regeneration layer	Presence of the target species natural regeneration
	DBH class distribution curve	Complexity of horizontal and vertical forest structure
	No. of population strata	
Deadwood	Standing deadwood presence	Description the presence of deadwood functioning as microhabitat
	Coarse woody debris	
Species diversity	Species richness	Number of all species present in the stand regarding both the presence of adults' individuals and regeneration
	Percentage of non-target individuals regeneration	
Microhabitat	Percentage of individuals with cavities	Presence of key microhabitat form for biodiversity
	Percentage of individuals with Injuries and wounds	
	Percentage of individuals with Deformation	

The model involved the production of a form that requires the compilation of certain parameters that can be easily observed in the field by users. Based on our results, we have chosen value thresholds for each selected indicator. The annotation of the actual real data for each indicator will produce a score based on the selected thresholds. The final score is associated with the identification of the current status of the stand analyzed. For each final score, indications are provided regarding possible actions to be taken to implement sustainable management of the stand (Figure 3.5.1). Below is the example of the form we produced for compilation (Figure 3.5.2). Instead, Figure 3.5.3 shows the compiled form based on the actual data obtained from the Site 02 - Baldo's forest.

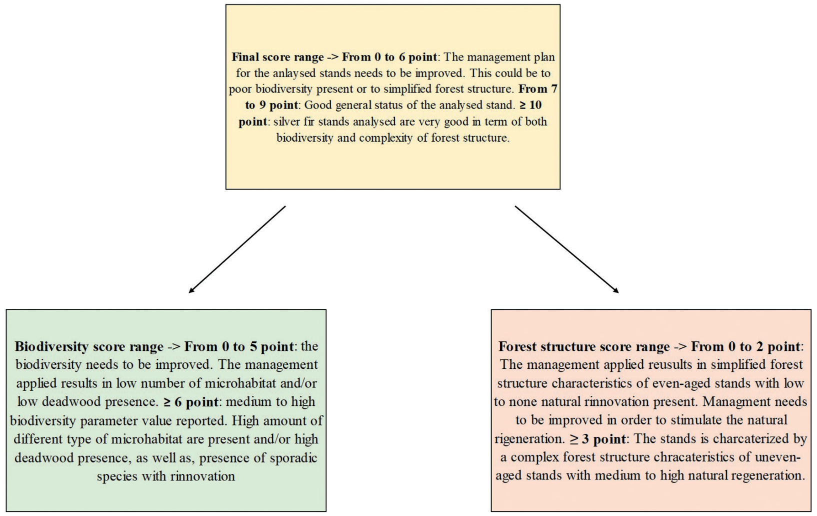

Figure 3.5.1. Guideline for forest management based on the final score obtained after forest assessment forest form compilation.

Forest stand evaluation form

Forest managment		Real Data		Implication for Managment
Forests should be managed in a way to preserve their multifunctional role (ecological, social and productive forest functions). This can be achieved only through maintenance of healthy forests and their biodiversity, protection of its natural fertility and water sources as well as other beneficial functions of forests in the water and carbon cycle, sustainable supply of wood and other products from forest, profit and employment.				
Forest structure indicator	**Structural indicator**	**Real Data**	**Indicator-specific score**	**Implication for Horizontal and Vertical Forest sturcture**
Forest structure is both a product and driver of ecosystem processes and biological diversity. Changes in forest structure as a result of management for timber production have undesirable consequences for other components of forest ecosystems	DBH Standar deviation		☑ Score 1 (DBH SD < 5) ☐ Score 2 (5 ≤ DBH SD ≤ 15) ☐ Score 3 (DBH SD > 15)	**Results from annotated parameters** ☐ Score 1 (Simple forest structure without rinnovation) - From 4 to 6 ☐ Score 2 (Simplified forest structure with rinnovation or Complex forest structure without rinnovation) - From 7 to 8 ☐ Score 3 (Complex forest structure with rinnovation) - From 9 to 11 ☐ Score 4 (Complex forest structure with rinnovation present in the total area) - From 12 to 13
	Referes to % of trees in regeneration layer (considering DBH less than 10 cm)		☑ Score 1 (% Rinn < 15) ☐ Score 2 (15 ≤ % Rinn. < 30) ☐ Score 3 (30 ≤ % Rinn. < 50) ☐ Score 4 (% Rinn. ≥ 50)	
	Curve of DBH class distribution		☐ Score 1 (Bell-shaped) ☐ Score 2 (Multi-modal) ☐ Score 3 (J-shaped)	
	N° of strata (startification of population)		☐ Score 1 (Mono-stratified) ☐ Score 2 (Bi-stratified) ☐ Score 3 (Tri or Multi-stratified)	
Productivity indicators		**Real data**		**Implication for population biodiversity**
Forest site productivity is the production that can be realized at a certain site with a given genotype and a specified management regime. Site productivity depends both on natural factors inherent to the site and on management-related factors.	Growing stock (m³/Ha)			In managed stands, the minimum growing stock should be around 300-350 m³/ha. This might be applicable for shade tolerant species
Biodiversity indicators	**Deadwood indicators**	**Real data**	**Indicator-specific score**	**Implication for stand biodiversity**
	Standing deadwood (including snags) presence		☐ Score 1 (Absence of standing deadwood) ☐ Score 2 (Presence of standing deadwood)	**Results from annotated parameters** ☐ Score 1 (Total absence of deadwood) - 2 point

Biodiversity conservation is a key objective for sustainable forest management, but the multi-dimensional and multi-scale character of biodiversity renders full assessment difficult at large scale. Therefore, indicators are often used to monitor biodiversity. The quantity and quality of deadwood are commonly used in nature conservation as indicators of forest biodiversity. Additionally, the presence of species different from the target species as well as the presence of specific type of microhabitat are also used to monitor bioidiversity in forest stand.	Coarse woody debris		☐ Score 1 (Absence of Coarse woody debris) ☐ Score 2 (Presence of Coarse woody debris)	☐ Score 2 (Presence of standing deadwoodor Coarse woody debris) - 3 point ☐ Score 3 (Presence of various type of deadwood) - 4 point
	Species diversity indicators		**Indicator-specific score**	**Implication for stand biodiverity**
	Species richness (presence of individual of non-target species)		☐ Score 1 (Absence of other species) ☐ Score 2 (Presence of other species)	**Results from annotated parameters** ☐ Score 1 (Monospecific site) - 2 point ☐ Score 2 (Sporadic species with none or low regeneration) - 3 point ☐ Score 3 (Sporadic species with high regeneration) - 4 to 6 point
	% of non-target individuals in the smallest diamteric class (10 cm)		☑ Score 1 (% Rinn < 15) ☐ Score 2 (15 ≤ % Rinn. < 30) ☐ Score 3 (30 ≤ % Rinn. < 50) ☐ Score 4 (% Rinn. ≥ 50)	
	Microhabitat indicators	**Real data**	**Indicator-specific score**	**Implication for stand biodiverity**
	% of individuals with cavities		☑ Score 1 (% Ind. ≤ 15%) ☐ Score 2 (15% < % Ind. ≤ 50%) ☐ Score 3 (% Ind. > 50%)	**Results from annotated parameters** ☑ Score 1 (Absence of low number of microhabitat) - 3 point ☐ Score 2 (Sporadic to consistent presence of microhabita) - 4 to 6 point ☐ Score 3 (High presence of microhabitat) - 7 to 9 point
	% of individuals with injuries and wound		☑ Score 1 (% Ind. ≤ 15%) ☐ Score 2 (15% < % Ind. ≤ 50%) ☐ Score 3 (% Ind. > 50%)	
	% of individuals with deformation		☑ Score 1 (% Ind. ≤ 15%) ☐ Score 2 (15% < % Ind. ≤ 50%) ☐ Score 3 (% Ind. > 50%)	
				Final Score: 1

Figure 3.5.2. Forest population assessment form structure.

Forest population assessment sheet - Simulation Site 02 (Baldo's forest)				
Forest managment		**Real Data**		**Implication for Managment**
Forests should be managed in a way to preserve their multifunctional role (ecological, social and productive forest functions). This can be achieved only through maintenance of healthy forests and their biodiversity, protection of its natural fertility and water sources as well as other beneficial functions of forests in the water and carbon cycle, sustainable supply of wood and other products from forest, profit and employment.		Single tree selection thinning		
Forest structure indicator	**Structural indicator**	**Real Data**	**Indicator-specific score**	**Implication for Horizontal and Vertical Forest sturcture**
Forest structure is both a product and driver of ecosystem processes and biological diversity. Changes in forest structure as a result of management for timber production have undesirable consequences for other components of forest ecosystems	DBH Standar deviation	9,55	☐ Score 1 (DBH SD < 5) ☑ Score 2 (5 ≤ DBH SD ≤ 15) ☐ Score 3 (DBH SD > 15)	**Results from annotated parameters** ☐ Score 1 (Simple forest structure without rinnovation) - From 4 to 6 ☐ Score 2 (Simplified forest structure with rinnovation or Complex forest structure without rinnovation) - From 7 to 8 ☐ Score 3 (Complex forest structure with rinnovation) - From 9 to 11 ☑ Score 4 (Complex forest structure with rinnovation present in the total area) - From 12 to 13
	Referes to % of trees in regeneration layer (considering DBH less than 10 cm)	83,54	☐ Score 1 (% Rinn < 15) ☐ Score 2 (15 ≤ % Rinn. < 30) ☐ Score 3 (30 ≤ % Rinn. < 50) ☑ Score 4 (% Rinn. ≥ 50)	
	Curve of DBH class distribution	J-shaped	☐ Score 1 (Bell-shaped) ☐ Score 2 (Multi-modal) ☑ Score 3 (J-shaped)	
	N° of strata (startification of population)	Tri-stratified	☐ Score 1 (Mono-stratified) ☐ Score 2 (Bi-stratified) ☑ Score 3 (Tri or Multi-stratified)	
Productivity indicators		**Real data**		**Implication for population biodiversity**
Forest site productivity is the production that can be realized at a certain site with a given genotype and a specified management regime. Site productivity depends both on natural factors inherent to the site and on management-related factors.	Growing stock (m³/Ha)	305 m³/ha		In managed stands, the minimum growing stock should be around 300-350 m³/ha. This might be applicable for shade tolerant species
Biodiversity indicators	**Deadwood indicators**	**Real data**	**Indicator-specific score**	**Implication for stand biodiversity**
Biodiversity conservation is a key objective for sustainable forest management, but the multi-dimensional and multi-scale character of biodiversity renders full assessment difficult at large scale. Therefore, indicators are often used to monitor biodiversity. The quantity and quality of deadwood are commonly used in nature conservation as indicators of forest biodiversity. Additionally, the presence of species different from the target species as well as the presence of specific type of microhabitat are also used to monitor bioidiversity in forest stand.	Standing deadwood (including snags) presence	Presence	☐ Score 1 (Absence of standing deadwood) ☑ Score 2 (Presence of standing deadwood)	**Results from annotated parameters** ☐ Score 1 (Total absence of deadwood) - 2 point ☑ Score 2 (Presence of standing deadwoodor Coarse woody debris) - 3 point ☐ Score 3 (Presence of various type of deadwood) - 4 point
	Coarse woody debris	Absence	☑ Score 1 (Absence of Coarse woody debris) ☐ Score 2 (Presence of Coarse woody debris)	
	Species diversity indicators	**Real data**	**Indicator-specific score**	**Implication for stand biodiverity**
	Species richness (presence of individual of non-target species)	Absence	☑ Score 1 (Absence of other species) ☐ Score 2 (Presence of other species)	**Results from annotated parameters** ☑ Score 1 (Monospecific site) - 2 point ☐ Score 2 (Sporadic species with none or low regeneration) - 3 point ☐ Score 3 (Sporadic species with high regeneration) - 4 to 6 point
	% of non-target individuals in the smallest diamteric class (10 cm)	0	☑ Score 1 (% Rinn < 15) ☐ Score 2 (15 ≤ % Rinn. < 30) ☐ Score 3 (30 ≤ % Rinn. < 50) ☐ Score 4 (% Rinn. ≥ 50)	
	Microhabitat indicators	**Real data**	**Indicator-specific score**	**Implication for stand biodiverity**
	% of individuals with cavities	14,51	☑ Score 1 (% Ind. ≤ 15%) ☐ Score 2 (15% < % Ind. ≤ 50%) ☐ Score 3 (% Ind. > 50%)	**Results from annotated parameters** ☑ Score 1 (Absence of low number of microhabitat) - 3 point ☐ Score 2 (Sporadic to consistent presence of microhabita) - 4 to 6 point ☐ Score 3 (High presence of microhabitat) - 7 to 9 point
	% of individuals with injuries and wound	1,57	☑ Score 1 (% Ind. ≤ 15%) ☐ Score 2 (15% < % Ind. ≤ 50%) ☐ Score 3 (% Ind. > 50%)	
	% of individuals with deformation	7,57	☑ Score 1 (% Ind. ≤ 15%) ☐ Score 2 (15% < % Ind. ≤ 50%) ☐ Score 3 (% Ind. > 50%)	
				Final Score: 8

Figure 3.5.3. Forest population assessment form structure with Site 02-Baldo's forest data.

3.6 Recommendations for Sustainable Forest Management

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Overview of silvicultural systems

Sustainable and close to nature forestry uses forest management methods that promote conservation of nature and forests in such a way that they are preserved as natural ecosystems with all their diverse life forms and the relationships that exist within them. It is based on detailed forest management planning, adapted to individual site and stand conditions as well as forest functions, and considering natural processes and structures specific to natural forest ecosystems. Natural processes are altered as little as possible, while still maintaining the financial profitability and social sustainability of forest management (Veselič, 2008).

Silvicultural systems for beech stands should be carefully selected in order to promote close-to-nature approaches and mimic natural processes in forest stands. Within LIFE SySTEMiC four silvicultural approaches in beech stands were analysed:

- Irregular shelterwood system where forest regeneration takes place in openings and gaps,
- individual tree selection system where trees of different dimensions and age are presented on a small surface area,
- uniform shelterwood where the old stand is removed in a series of cuttings (usually three cuttings in case of beech) for establishment of a new even-aged stand under the shelter of the old one,
- Unmanaged forests, where natural processes in forest are not affected by forest management.

Analysed silvicultural systems are described in detail in the introduction of this handbook.

The LIFE SySTEMiC project analysed twelve beech stands, corresponding to four European Forest Types (EFT) has been studied: 6.6 Illyrian sub-mountainous beech forest; 7.2 Central European mountainous beech forest; 7.3 Apennine-Corsican mountainous beech forest and 7.4 Illyrian mountainous beech forest. Results, described in previous chapters, show that silvicultural systems with reduced impact are more favorable in light of genetic variability preservation, such as individual tree selection and low scale irregular shelterwood system.

Figure 3.6.1. Irregular shelterwood system is a common way for management of beech stands.