



LUONTOA

Biodiversity outcome monitoring frameworks

**Report on the development and testing of outcome
monitoring frameworks for biodiversity in Finland and
Sweden**

Final report

Luontoa Ltd

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Executive summary

FSC's current certification system for forest management relies primarily on conformance with prescriptive activity-based requirements, such as minimum thresholds for set-aside areas, conservation of High Conservation Value forests, or applying due processes for addressing land-use rights (e.g., FPIC). While these rules are important, they do not demonstrate whether the intended or implicit outcomes of responsible forest management are achieved. This project was carried out in Finland and Sweden to test practical ways of bridging this gap by developing and testing outcome-oriented frameworks. This framework is currently being developed to increase the effect and credibility of FSC. The outcomes were focused solely on biodiversity, and much of the content reviewed for the purposes of this project focused on FSC P&C Principle 6.

Biodiversity loss has been identified as one of the greatest global risks, and in the Nordic region, forestry is a major driver. For FSC, credibility increasingly depends on showing measurable contributions to halting biodiversity decline. At the same time, markets and policymakers expect certification schemes to provide reliable outcome data rather than reporting only on conformance with normative requirements.

In this project, two intended outcomes were defined as the most relevant/important expected results for biodiversity for the FSC Forest Stewardship Standards for Finland and Sweden: first, that the presence of fire-dependent rare and threatened species is maintained over time; and second, that representative forest stands maintain or increase dead wood volumes towards natural reference levels. To test these intended outcomes, three complementary methods were applied. Environmental DNA analysis was used to detect fungal bioindicators in burned sites. Remote sensing was used to calculate standing dead wood volumes. Finally, a series of field inventories were conducted to provide qualitative data on dead wood, including species and decay stages.

The results are encouraging. eDNA analysis proved both effective and scalable. Across twenty burned sites, 683 fungal taxa were detected, including twenty-one pyrophilous (fire-dependent) species and seven red-listed fungi. Significant detections included *Phellodon secretus* and *Hydnellum gracilipes*, both globally listed as vulnerable. The eDNA method consistently distinguished fire-affected sites and demonstrated its potential for outcome verification within certification. Remote sensing analysis provided robust information on dead wood volumes. Across more than 2600 FSC-certified stands, mean standing dead wood volume was 5.0 m³ per hectare. Set-aside stands held 101 percent more standing dead wood than special

management stands (6.2 versus 3.1 m³ per hectare). However, reference levels for ensuring adequate conditions for dead wood-dependent species are 20–30 m³ per hectare, showing that these current FSC averages remain well below ecological thresholds. A time series approach to the use of aerial imagery further demonstrated the potential of remote sensing for monitoring, with increases of around 7.5 m³ per hectare recorded over a six-year period in a selected set of management units. Field inventories added some qualitative and ecological depth to the remote sensing results. In Finland, spruce dominated dead wood with some variance in decay stages, whereas in Sweden pine dominated and most downed dead wood was in late stages of decay.

Together, these findings demonstrate that outcome monitoring for biodiversity in FSC-certified forests is both possible and practical. Proven and scalable methods already exist, and their integration into certification would provide FSC with a stronger evidence base to revise its forest management standards and for its communication. This in turn would enhance credibility and help FSC meet the growing demand from markets and policymakers for measurable outcomes.

In summary, this project shows that FSC can move beyond a rules-only approach towards outcome-oriented certification. By embedding cost-efficient monitoring tools into its system, FSC can provide credible, science-based evidence of its impact on biodiversity, and strive for continuous monitoring of the outcomes of FSC certification globally. This represents a critical step for maintaining FSC's reliability and relevance in a rapidly evolving policy and market landscape, where environmental claim validity is not only measured in historical trust, but quantified and verified impact data.

1. Introduction

Biodiversity – the variety of species, ecosystems and genetic resources – provides the foundation for a healthy planet, ecosystem services, viability and resilience of various production systems. Biodiversity is being impacted by humans. This happens directly through land-use, land-use change as well as pollution, and indirectly through climate change and invasive species. Loss of biodiversity has been identified as the third most severe risk the humanity faces in the next decade by the [World Economic Forum](#).

Governments have taken action to address the rate of biodiversity loss, and to mitigate impacts it poses to societies, economy and the environment. This is especially evident following the adoption of agreements such as the [Kunming-](#)

[Montreal Global Biodiversity Framework \(GBF\)](#) and [Bringing nature back into our lives – EU 2030 Biodiversity Strategy](#). Failure to reverse the trend on biodiversity loss could amount to extraordinary economic impacts, with global GDP forecasted to endure impacts to be measured in trillions of USD by 2030. This impact extends beyond governments to businesses, organisations and societies.

Companies and organisations are also facing increasing demand to define their sustainability objectives and be able to monitor and report them clearly. Global, regional and national regulation and legislation are becoming increasingly conscious and demanding regarding the identification, mitigation and reporting on environmental risks, opportunities and impacts. This also applies to voluntary third-party certification schemes aimed at ensuring environmentally appropriate practices in the land-use and management, resource extraction and production of commerce. FSC's value proposition to the global markets is contingent with it being able to ensure that its responsible forest management brand is actively contributing to the sustainable management and use of global certified forest land. To be able to contribute to the global agreements and regulatory pressure, as well as national and organizational targets on halting nature loss, FSC should provide means for establishing clear and monitorable intended outcomes for responsible forest stewardship and management as part of certification.

This entails a need for change for FSC both on international and national levels. Currently the system is designed to provide a standardized framework for establishing national indicators for responsible forest management but lacks the consistent data collection and evaluation of data that could provide means for monitoring of change or progress against established baselines or targets. An activity-based certification scheme fails to provide the necessary solutions for companies, organizations or governments to effectively evaluate the effectiveness of actions to address biodiversity loss.

A total of 44,000 species are documented currently as being at risk of extinction through a [study](#) funded by International Union for Conservation of Nature (IUCN) and conducted by the Global Environment Facility. FSC considers the existence of rare and endangered species as well as their habitats in its national Forest Stewardship Standards, but currently many of the national FSS lack the necessary requirements and means for monitoring and quantification of changes or outcomes related to the activity-based requirements. The [lack of monitoring and primary data production](#) that would allow for quantification, proper scientific tracking of progress towards outcomes, has been made evident in the first part of FSC's project 'Fast-tracking biodiversity impact assessment'.

2. Important terms and definitions for this document

This chapter introduces the important terms and definitions that pertain to this document. The terms and definitions have been adopted from the FSC-GUI-60-006 (currently in development).

Expected insights: A description of the learnings or information expected to be gained from the analysis of data collected from monitoring indicators and other existing reporting activities (e.g. Forest Management evaluation).

Key intended outcome: Selected outcome for which the implementation of normative requirements and progress monitoring is prioritized.

Metric: A system or standard of measurement that is quantifiable and is used to track, compare, and assess monitoring indicators.

Monitoring framework: For the purposes of this project, the term 'monitoring framework' is specified. It is not a term currently used in FSC normative documents, and it is necessary to define. The term encompasses all monitoring needs and approaches taken in order for a given intended outcome to be monitored. Specifically, it covers the following:

- Set of monitoring requirements that are intended to be covered by the FSS in the future;
- Additional monitoring and evaluation needs that are envisioned to complement the FSS. For example data collection and analysis methods hosted centrally by FSC that are not imposed as requirements to FM certificate holders through the FSS.

Monitoring indicator: Quantitative or qualitative factor or variable that provides a simple and reliable means to measure achievement of, or progress towards, key intended outcomes. A quantitative or qualitative factor or variable that provides a simple and reliable means to measure the performance against the key intended outcomes, including positive or negative trends. An indicator can be measured through one or multiple metrics.

3. Purpose

The aim of this project is to test the development and implementation of outcome monitoring frameworks (including both requirements for field monitoring and remote sensing approaches) as part of FSC forest management certification in Finland and Sweden. [Finland](#) and [Sweden](#) serve as good testing grounds for key

intended outcome monitoring in FSC as in both countries' forestry is the biggest or one of the biggest reasons for biodiversity loss, and FSC-certified forests are relatively common offering feasible opportunities to considering various forest conditions and conduct field tests. FSC-certified forests cover 12% (2,5MHa) of Finnish productive forests, and 53% (11,9MHa) in Sweden.

To achieve this, we developed frameworks that defined key intended outcomes, expected insights, and monitoring indicators, as well as the data needs necessary to measure progress. These frameworks were then piloted through field testing and analysis, combining environmental DNA surveys of fungal communities in prescribed burning stands, remote sensing-based assessments of standing dead wood, and qualitative field inventories of dead wood.

The report documents this process and the results of testing, providing both scientific insights and practical recommendations for how FSC could integrate outcome monitoring into its certification system. It also reflects on the role of certificate holders, external service providers, and stakeholders in implementing such approaches in practice. The overarching aim was to provide FSC with tested evidence and actionable recommendations on how outcome-oriented monitoring can complement and strengthen the current certification framework.

By completing this work, we were able to move from a conceptual outline of monitoring frameworks to tested approaches applied in real FSC-certified forests. The next section describes in detail how these frameworks were developed, including the methodological steps taken to define intended outcomes, identify suitable indicators, and select data collection methods that could be applied within the certification context.

Disclaimer

This project is not intended to act as a formal testing of the guidance FSC-GUI-60-006 and the requirements related to outcome orientation in FSC-PRO-60-006 that are in development at the time of implementing this project. However, the methodology closely follows the proposals being made in these documents. The focus of this project is to evaluate, through real-life examples, how outcome monitoring could be applied and what type of roles could FM certificate holders and other stakeholders play in co-developing and applying these frameworks. Finally, the project intends to provide recommendations as to how the outcome-orientation concept could be further adopted into the FSC normative framework in the future.

Although outcome orientation and the need for outcome monitoring pertains to all sustainability issues being addressed through FSC, this project exclusively focuses on biodiversity. This is done in with the intention of focusing on an urgent and important global issue for FSC, certificate holders and stakeholders. The project does intentionally not consider other environmental or socio-economic aspects of forest management.

4. Description of approaches to defining outcome monitoring requirements

The development of outcome monitoring requirements in this project was guided by FSC's draft guidance (*FSC-GUI-60-006 VI-0 Guidance to Develop Outcome-Oriented Forest Stewardship Standards VI-0, Draft 1-0*). To support the adaptation of the guidance into a concrete project plan, relevant background materials, the normative framework, and the Finnish and Swedish Forest Stewardship Standards (FSS) were also reviewed. Our aim was to design approaches that reflected the objectives of the FSS while ensuring that the resulting frameworks were scientifically robust and feasible to implement in practice.

The starting point was to identify the key drivers of biodiversity loss in Finland and Sweden and to assess how FSC requirements could contribute to addressing them. From this analysis, intended outcomes were formulated so that they could be linked to specific FSC Principles and Criteria. The frameworks were designed to translate broad sustainability goals into practical and measurable outcomes, and to clarify what changes certification should be able to demonstrate.

Each set of requirements was structured to allow for the detection of change in multiple ways: by tracking shifts in species assemblages, monitoring specific habitats, and measuring biomass or structural features of forests. Depending on the outcome, the monitoring relied on either field-based data (e.g., soil sampling for eDNA), large-area data (e.g., remote sensing of dead wood), or a combination of both. The use of complementary methods was intended to provide FSC with options that vary in cost, scalability, and level of detail.

Finally, stakeholder engagement played a role in shaping the monitoring requirements. Members of FSC Finland and Sweden, certificate holders and certification bodies were informed and consulted upon through webinars and meetings. Additionally, inputs from a TWG were considered in the drafting of the project plan.

The flow chart below was adopted from the *FSC-GUI-60-006 VI-0 Guidance to Develop Outcome-Oriented Forest Stewardship Standards (Draft 1-1)*. It demonstrates the overall approach to the design and structure of the outcome monitoring frameworks for this project.



Figure 1. Flow chart of the process for defining outcome monitoring frameworks

4.1. Stakeholder engagement

The FSC standards are developed based on a chamber-balanced representation of economic, environmental and social interests. This unique decision-making structure and process ensures that all three interests are equally represented and consulted when considering the impacts and objectives of forest management certification.

Stakeholders have been invited to participate and provide feedback to ensure scientifically sound and practical monitoring approaches in the context of FSC certification without a specific decision-making role. Perspectives of FSC membership, certificate holders, certification bodies, researchers, and specifically the technical working group has been gathered via meetings where the approach of this project has been presented. The members of FSC Finland and Sweden were provided with informative webinars on 3rd and 11th of April 2025. The aim of these webinars was to inform and seek inputs to the testing of the monitoring frameworks.

and the anticipated role of outcome orientation in shaping the future of FSC and the Fast-tracking biodiversity assessment project and the testing of this approach in Finland and Sweden was presented to the members. A final webinar for members was hosted for the FSC membership of Finland and Sweden on the 17th of December 2025. The stakeholder outreach towards the FSC members was coordinated with the national offices of the respective countries. Members were also offered one on one meetings with Luontoa to go through the project in more details.

5. Outcome monitoring requirements tested in this project

This section illustrates how the outcome monitoring requirements were developed for the purposes of running the field-testing in Finland and Sweden.

[The red list of Finnish species \(2019\)](#) evaluated that the primary causes for forest species being threatened are:

Primary cause of threat for forest-dwelling rare or endangered species	% of species
Decline of old-growth forests and large trees	21 %
Regeneration activities and silviculture	19 %
Decline in dead wood volume	19 %
Changes in tree species dynamics	13 %
Overgrowth of open areas	10 %
Construction	4 %
Random factors	3 %
Decline in burnt areas and other early stages of natural succession	3 %
Adverse chemical effects	2 %
Clearing land for cultivation	1 %
Climate change	1 %
Other	4 %

Table 1. Primary causes of threat for forest-dwelling species in Finland

The amount of dead wood is [widely used](#) as an indicator for successful sustainable forest management. This applies to also [Finland](#) and [Sweden](#) where loss of dead

wood and heterogeneity of dead wood are some of the [main drivers](#) for forest species decline.

Forest fires are a critically important factor in the succession of many fire-dependent species in Finland and Sweden. Both in [Sweden](#) and [Finland](#), the number of forest fires and area affected by forest fires has declined since the beginning of 1900. This has led to decline of fire-adapted habitat types and species, many of which have become red-listed. Sweden on the other hand has experienced decrease in forest fires similarly to Finland but also some extreme cases of wildfires in [2018](#). Decline of forest fires also plays role in the decline of dead wood.

Building on the approaches outlined in previous chapters and to the protection of threatened species and their habitats, two set of outcome monitoring requirements were developed and tested in FSC-certified forests in Finland and Sweden. Each set was linked to a key intended outcome derived from the national Forest Stewardship Standards, namely:

1. the maintenance of rare and threatened fire-dependent species over time, and (related to FI&SE: C6.4)
2. the maintenance or increase of dead wood as a critical habitat resource (related to FI: 6.5.3, SE: 6.5.2).

The below sub-sections 5.1 and 5.2 each introduce a specific intended outcome and the approach for defining the associated monitoring requirements (expected insights, outcome-oriented indicators, data needs and data compilation methodologies that were deployed).

- Chapter 5.1 relates to fire-dependent species.
- Chapter 5.2 relates to dead wood volumes and quality.

5.1. Example of monitoring framework for rare and threatened species and their habitats

This section of this work report presents an example of an outcome monitoring framework and how it is tested. The example focuses on the maintenance of rare and threatened species, using fire-dependent fungal taxa as a representative group.

Rare and threatened species are essential indicators of forest ecosystem integrity and biodiversity health. Their presence reflects the capacity of forest landscapes to provide suitable habitats, sustain ecological processes, and recover from disturbances. In managed boreal forests, species that depend on disturbance-

related or late-successional habitats have declined substantially over the past century, largely due to changes in fire regimes, intensive silviculture, and loss of structural diversity.

Within the FSC Forest Management certification, the conservation of rare and threatened species and their habitats is embedded in Principle 6 and its associated Criteria. However, the current approach focuses on management prescriptions rather than measurable outcomes. Transitioning to outcome monitoring offers a way to evaluate whether these requirements truly support the existence of threatened species in certified forests.

The following subsections outline the rationale for selecting this topic to define a key intended outcome, describe the associated indicators and expected insights, and detail how monitoring can be implemented in practice through environmental DNA (eDNA) analysis and related data collection methods.

Step 1. Key intended outcome

One of the core aims of the Finnish and Swedish Forest Stewardship Standards is to safeguard rare and threatened species and their habitats as stated in the [Finnish FSS criterion 6.4](#). Forestry has led to changes in available resources and habitats to species, such as the decrease in the amount of dead wood, changes in the tree species composition and decrease in large and old trees.

Fire on the other hand plays a crucial ecological role in boreal forest dynamics, shaping habitats for many specialized organisms that rely on burned or charred wood or soil.

Intensive forest management has also led to the decreased events of wildfires in both Finland and Sweden. [The decrease of forest fires](#) is especially detrimental to fire-dependent species, many of which have become rare or endangered as a result.

Prescribed burning can be used as a restoration measure to promote diversity of threatened species in boreal forests. Furthermore, [fires create](#) large quantities of dead wood which is even more important for many endangered species than the fire event itself. It is also notable that the [appearance of red-listed species](#) also depends on the vicinity of suitable source areas, from which the species can disperse to the actively disturbed areas.

For the purposes of this project, and how it may give more clarity to the quantifiable outcomes of applying Forest Stewardship Standard management requirements in forestry, the species community of fungi in prescribed burning areas was studied.

The scope of the key intended outcome was further specified to meet the local conditions and context of the applicable FSS in Finland and Sweden. This was done using the metric measurement indicators and monitoring indicators.

Note: According to the approach proposed by the FSC Secretariat and the working group of FSC-PRO-60-006 for outcome orientation, a key intended outcome that refers to a specific Criterion of the FSC Principles and Criteria (FSC-STD-01-001 V5-3) must be defined. In this case the selected Criterion was 6.4. The intended outcome was built on the premise that C6.8 requires forest management certificate holders to implement prescribed burning on mesic and poorer habitats proportionate to the total area of regeneration felling (3% in Finland, 5% in Sweden).

The key intended outcome was formulated as follows:

The presence of rare and threatened species is maintained over time.



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Step 2. Indicators

The indicators suggested for the key intended outcome that aims for the maintenance of rare and threatened species over time are as follows:

- The Organization ensures that there is an increase in the total area of the forests treated with prescribed burning on a 5-year cycle as compared with the area from previous certification cycle.

Related activity-based requirements currently in force for implementing prescribed burning from the respective FSS for Finland and Sweden:

FI (6.8.2): Large forest owners: The Organization maintains the habitats of the forest fire-dependent species by performing prescribed burning on an area of at least 3% of the regeneration felling area situated in sites suitable for prescribed burning (mesic and poorer habitats) during a 5-year period. The aim is to produce at least 20 fire-damaged stems per hectare in the burnt area that meet the retention tree diameter requirement (6.6.2.1).

SE (6.8.4): Large forest owners: An area equivalent to at least 5 % of the regeneration area on dry and mesic forest land is burned over a rolling five-year period. Felling is adapted and burning is carried out with the goal of promoting species favoured by fire.

Step 3. Expected insights

This monitoring framework relies on the assumption that prescribed burning requirements will create suitable habitats for fire-dependent species. Therefore, the data collected according to the monitoring requirements and their analysis are expected to create insights about whether the FSS requirements on establishing areas treated with prescribed burning effectively contribute to the maintenance of rare and endangered species in this specific case, obligate and pyrophilous fungi species.

A more locally adapted version of the intended outcome is as follows:

The presence of rare and threatened indicator species is maintained in sites treated with prescribed burning.

Prescribed burning promotes the abundance of certain fire obligates and pyrophilous species. Obligates meaning species that require fire, pyrophiles meaning species that are more likely to thrive in a fire-cured environment and none meaning no known connection to fire. These species include polyphore species. The indicator species were selected as being obligate or pyrophilous rare and endangered fungi. By assessing the occurrence of fire obligate and pyrophilous fungi in prescribed burning sites, this framework demonstrates how monitoring indicators can be applied to identify biodiversity outcomes linked to specific FSC requirements.

- **Specifically, it is expected that:** As the number and area of burnt forests increase, more suitable habitats for fire-dependent species are established

on a country level, and the numbers of rare and threatened species would increase over time.

Note: In this project the data is collected on a single occasion, hence the temporal change is not studied.

Step 4. Monitoring indicators

Monitoring indicators for this project are developed so that they define the exact data to be collected to allow measuring the occurrence of fire-dependent species (FI/SE: C6.8), and the continued maintenance of fire continuum areas (FI: C6.5).

Key intended outcome:	Expected insight	Monitoring indicator	Metric
The presence of rare and threatened species is maintained over time.	Positive influence on the numbers of rare and threatened species over time on country level	Total forest area treated with fire.	ha
	Species occurrence of rare and threatened obligate and pyrophilous fungi is maintained over time.	Number and share of rare and threatened pyrophilous and fire obligate fungi species including possible rare and threatened species.	
	Positive influence on the numbers of rare and threatened species over time on a country level.	The maintenance of fire continuum on prescribed burning areas.	yes/no

Table 2. Outcome-oriented indicators for fire-dependent species monitoring

Step 5. Data collection method

For the purposes of this project to gain information on fire obligate and pyrophilous species an environmental DNA (eDNA) and sampling-based method was selected as the primary data collection method. This decision was made in aim to create a reliable, cost-effective and scalable method for studying the presence of selected indicator species in fire-treated areas.

DNA extraction was carried out by Puro Analytics' partner laboratory utilizing proprietary DNA-extraction methodologies. Taxonomic assignment was performed against a reference database. From the identified taxa, species known from literature to be fire-adapted or characteristic of post-fire habitats were tagged as obligates, pyrophiles or none.

Step 6. Sampling

In this example of the framework and for the purposes of this project two forest management certificate holders from Finland and one from Sweden took part in the project by providing information about prescribed burnings.

Each certificate holders provided information of their forest sites where prescribed burning was done. 10 areas altogether, all burnt less than 5 years ago, were selected for each country. This timing was selected for the purpose of this project as [studies](#) have shown that the effects of fire decrease over time. Ten subsamples were collected from each fire cured area, regardless of the area's size, the extent of burned ground, or the amount of burned biomass. These subsamples were pooled into one collection sample per each site. EDNA analysis for fungi species was carried out for each site.

Sampling was conducted in June 2025 for sites located in Finland and August 2025 for sites in Sweden during time when soil was unfrozen.

In this project, soil samples collection was conducted by Luontoa with detailed instruction provided by Puro Analytics (*deliverable 1*). Additionally, with instructions, Puro Analytics provided Luontoa with the hardware needed to conduct the sampling.

The analysis involved taking into consideration geographic coverage and representativeness of sampling with regards to the structure of the forest prior to burning (FI/SE FSS), retained biomass prior to burning (FI/SE FSS), potential existence of continuously managed fire continuum areas (FI FSS) and other environmental considerations (FI/SE FSS).

Prior to the DNA sampling the data was collected from CHs to define the area of stands treated with prescribed burning.

The data in this project included a qualitative description for each stand as follows:

- Location (shapefile)
- Recency of treatment, in other words the timing of the prescribed burning (years), all less than five years ago
- Retained wood biomass prior to treatment (as an estimated percentage)

Step 7. Additional data needs

To conduct a reliable analysis of the effects of FSC certification on rare and threatened species (in this case, rare and threatened obligate and pyrophilous fungal species) over time it would be good to consider sampling at least once in five years.

Step 8. Data reporting

The data should be reported every five years synchronized with forest management evaluation period. This report should include results for each defined monitoring indicator. The additional data collected in this project (such as retained biomass) was done for the purpose of evaluating the examples tested on this example of the framework use.

5.2. Example of a monitoring requirements for benefits of dead wood for biodiversity

This section presents the outcome monitoring requirements developed and tested for dead wood in FSC-certified forests in Finland and Sweden.

Dead wood plays a fundamental role in maintaining forest biodiversity and ecological functions. It provides habitat and resources for a wide range of organisms, including fungi, insects, lichens, and cavity-nesting birds. The presence and diversity of dead wood are widely recognized as key indicators of forest ecosystem integrity and state of naturalness. In managed forests, dead wood volumes are often reduced compared to natural reference conditions. This significantly affects biodiversity, especially among saproxylic species that depend on decaying wood for all or part of their life cycle.

Within the FSC framework in Finland and Sweden, dead wood is directly linked to the implementation of Principles 6 and 10, which address the conservation of biodiversity and the maintenance of ecosystem services and natural forest attributes. Dead wood is identified as a central ecological attribute that can serve as both a key intended outcome and a proxy indicator for monitoring biodiversity outcomes.

The work focused on assessing whether FSC certification contributes to maintaining or increasing dead wood volume levels towards ecologically meaningful thresholds and whether current management requirements are demonstrating to be sufficient to achieve these. Additionally, qualitative aspects of dead wood were assessed and degree of decay as well as species composition of dead wood were monitored. Remote sensing, field inventories, and statistical analyses were combined to generate data that can inform both certification processes and national standard development group discussions about outcomes of FSC forest management certification.

Step 1. Key intended outcome

Dead wood provides a critical resource for many dead wood dependent species in Swedish and Finnish forests, and is widely used as an [indicator](#) for sustainable forest management. Approximately 7500 species across the Nordic countries [have been known](#) to be dependent on dead wood during part or wholly throughout their lifecycle. This amounts to roughly 20-25% of all forest-dwelling species.

Dead wood volumes in managed forests across Sweden (8-10m³/ha) and Finland (6-7m³/ha) are significantly lower than the volumes encountered in [natural forests](#)

(41-170m³/ha) and hence there are too little resources and necessary habitat conditions for dead wood dependent species in Finnish and Swedish forests.

The intended outcome was formulated to produce a high-level intended outcome that may be applicable globally since it should reflect the scope and intent of the Criterion 6.5.

The quality of the areas of native ecosystems restored resemble that of reference native ecosystem

This key intended outcome introduces an active restoration action to designated areas. In both the Finnish and Swedish FSS, there are several indicators that suggest that a specified environmental objective dictates the outcomes of management activities in specified areas. Active promotion and establishment of dead wood in each FSS is mentioned as a plausible option to conform with requirements of the C6.5 and meeting with the requirement of upholding a minimum of 10% land area for conservation area networks and 'special sites' (FI: 6.5.3, SE: 6.5.2).

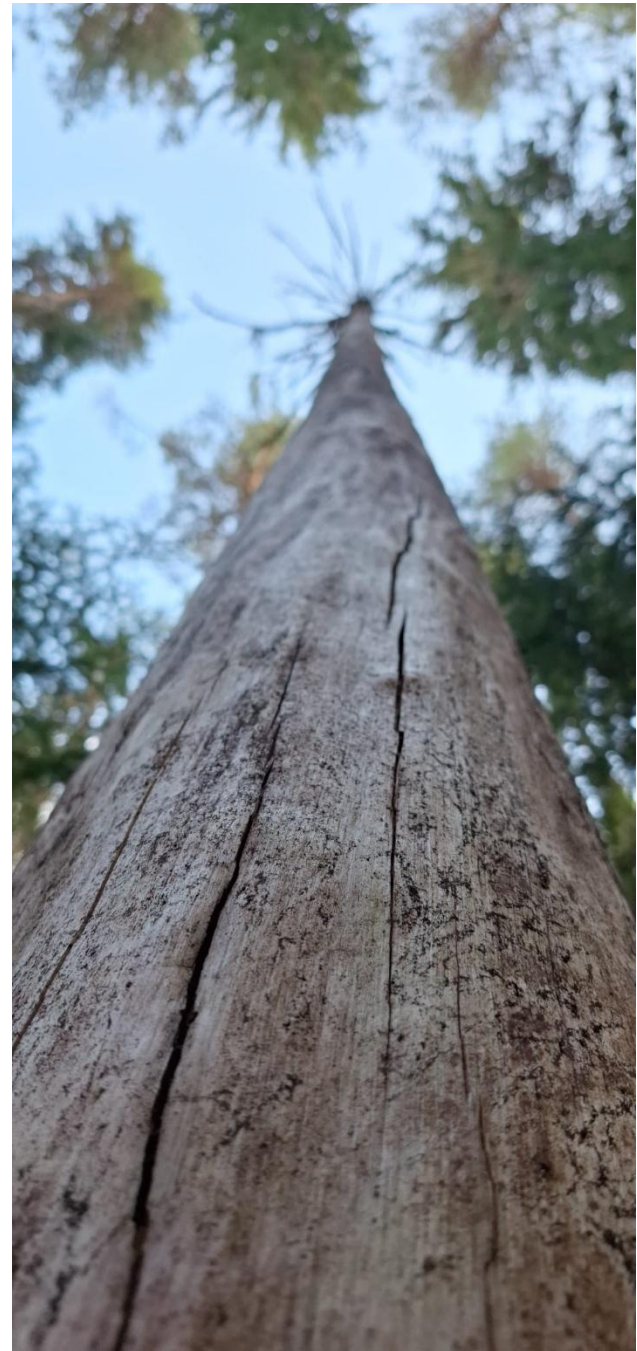
Studies support the idea that the dead wood volume can largely be considered an indicator of forest biodiversity, however, dead wood quality attributes are also critically [important](#).

For the purposes of this project, the key intended outcome was further refined as follows:

The quality of the areas of native ecosystems restored resemble that of reference native ecosystem through maintenance and increase of dead wood.

As the key intended outcome suggests, the aim was to focus on designated areas that have either been identified as set-aside areas (FI: 6.5.1, SE: 6.4.1/6.5.1) or 'special sites' (FI: 6.5.3, SE: 6.5.2) with a specific emphasis on the volume of dead wood.

Dead wood volumes in Finland and Sweden



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In Sweden, the current average volume for dead wood in production forests is roughly [8-10m³/ha](#), whilst in Finnish production forests the corresponding volume is [6-7m³/ha](#). For conservation forests, the dead wood volume is on average [16m³/ha](#) in Sweden and [20m³/ha](#) in Finland. In natural-state forests, the dead wood volumes range between [41-170m³/ha](#).

There is no one figure that would be applicable for dead wood objectives across all types of forests, in different botanical regions and different countries. Studies suggests that a more natural reference state for dead wood volume in conservation areas should be at least in the region of 20-50m³/ha to hold a sufficient habitat and resources to maintain the majority of saproxylic species. A study by Ranius, T. & Fahrig, L. (2006) suggests that it has been difficult to establish forest policies that would share a strictly biological aim in establishing a dead wood volume or quality target in Sweden (this also applies for Finland). The study also suggests that if all dead wood dependent species are to be conserved in the forest landscapes, there is a need to maintain dead wood levels equalling 'old growth forests' to achieve this. This further suggests that the current dead wood volumes are insufficient in general – including conservation areas, not just in production forests.

National forest policies promote the establishment of more dead wood, but the means in both the Swedish and Finnish forest policy lack in effectiveness. The policies entail loose support without concrete tools or active willingness to conduct any type of progress assessments by the governing bodies outside of the regular National Forest Inventory work. The Finnish and Swedish Forest Stewardship Standards promote the maintenance and increase of dead wood in forests. Generally, through the establishment of set-aside areas, it may be expected that over time these areas will generate increasing amounts of dead wood that may be monitored and compared with the expected volumes of dead wood for a reference native ecosystem – e.g., conservation forests.

Step 2. Indicators

The Finnish and Swedish FSS have requirements aimed to always preserve forests rich in dead wood (FI: 6.5.1.3, SE: 6.4.1) or manage them with an aim to increase this critical and scarce resource for forest species without a set-aside status (FI: 6.5.3, SE: 6.5.2). However, the volume and quality of dead wood in these stands is not monitored regularly by certificate holders, and likely very little data is available to effectively monitor the dead wood volumes or gain any meaningful insights over the quality or degree of decay of the dead wood. To gain more information on how the FSS can benefit the ecological status of Finnish and Swedish forests, it is

important to build an outcome monitoring protocol for dead wood volume and quality.

The Finnish and Swedish FSS outline 'representative sample areas' where dead wood is the main environmental management objective under the following requirements in the respective standards:

- FI: 6.5.1 and 6.5.3
- SE: 6.4.1, 6.5.1 and 6.5.2

The Swedish FSS, 6.4.1a states the following:

The following habitats are exempt from all management activities other than management required to maintain or promote natural biodiversity or biodiversity conditioned by traditional land use practices:

- a) natural, conspicuously uneven-aged and stratified forests with an abundance of old/large trees and a high frequency of coarse dead woody debris in different stages of decomposition [...]

Note: The Swedish indicator 6.4.1 seems to be more related to the IGI 6.5.1 than C6.4. In this instance, the decision is made that the Swedish indicator 6.4.1 is treated equally to the indicator 6.5.1 of the Finnish FSS (below).

The Finnish FSS, 6.5.1.3 states the following:

6.5.1.3 Other sites to be always preserved:

- [...] b) Specified forests rich in dead wood* in accordance with Annex 5 (of the Finnish FSS).

Step 3. Expected insights

This monitoring framework relies on the assumption that requirements related to the maintenance of dead wood, as well as the requirements to establish set-aside areas, will result in specified forest areas evolving towards a reference native ecosystem.

Therefore, the data collected according to the monitoring requirements and their analysis are expected to create insights about whether the FSS requirements on representative sample areas are contributing to progression towards threshold values of a reference native ecosystem.

As the intended outcome discusses a reference state as being 'reference native ecosystem' for the representative sample areas, this needed to be defined for the purposes of this project. As the focus was on dead wood, the more natural condition

also relates to conditions that do not exist in production forests, but are grounded on reference values for dead wood volumes that sustain native forest-dwelling species and associated ecosystem functions.

As the project focused on areas where the dead wood volume is specifically being maintained or enhanced, a relevant threshold value was set to align with volumes that are expected to be sufficient to offer resources and habitat conditions for most saproxylic species.

For the purposes of this project, a reference state for the 'reference native ecosystem' was established using studies and data from the national forest inventories. A threshold value for European coniferous forests for dead wood has been estimated to be around [20-30 cubic meters per hectare](#). If the amount goes below this the species dependent on dead wood do not survive in the area. This could be used as a benchmark value for FSC. Strictly for the purposes of this project, a volume threshold of **25m³/ha** was chosen for the 'representative sample areas'.

The volume threshold is used to assess the progression of set-aside areas towards a reference native ecosystem with regards to the monitored volume and quality of dead wood.

As managed forests include less dead wood than reference native ecosystems, their species composition is more restricted and decay stages of dead wood is [more skewed towards early-stage decay](#). The use of qualitative descriptions of decay classes and species of dead wood, allow the assessment of progress towards reference native ecosystem conditions from an alternative perspective.

Specifically, it is expected that:

- a) Areas are identified continuously where dead wood volumes have triggered set-aside action (6.4.1/6.5.1) or actions have been taken to designate areas with special environmental objectives for the stand to be established (6.5.2/6.5.3);
- b) Set-aside areas contain on average more dead wood than special management sites;
- c) Special management sites contain on average more dead wood than certified productive forest land;
- d) Dead wood volumes are determined for standing dead wood in all identified areas (above) and to which extent the volumes of dead wood resemble that of the reference volume threshold (25m³/ha of dead wood);

- e) The qualitative descriptions (e.g., share of decay classes and species composition) of dead wood demonstrate progression towards reference native ecosystem in sample areas, ensure dead wood continuum and increasingly produce dead wood in varying stages of decay.

Note: The reference volume thresholds are arbitrary in this exercise, but such should be developed by the national standard development group for set-aside areas, and special management stands. Set-aside areas (6.4.1/6.5.1) should be set with a threshold that would correspond with natural-state reference, whereas more flexibility could be used when determining a reference volume threshold for special management stands (6.5.2/6.5.3).

Step 4. Monitoring indicators

The following table introduces the suggested monitoring indicators. These indicators were used tentatively in the process of collecting and analysing the data for the purposes of this project. As a temporal assessment was not carried out, the use of the monitoring indicators to detect changes against a baseline or prior data analysis results could not be conducted. The aim was to test the feasibility of the monitoring activities and suggest any changes or improvements for future monitoring applications.

Monitoring indicator	Indicator to be featured under P8	Metric
Quality of dead wood.	The Organization monitors the quality of dead wood in a designated sample area of x% of areas designated with an abundance or quality of dead wood as being the trigger for set-aside or special management regime.	CWD inventory: <ul style="list-style-type: none"> • Stage of decay • Species • Orientation • Volume (diameter, length, intactness)
Volume of dead wood.	The Organization monitors the dead wood volumes in specified areas according to the monitoring requirements.	m ³ /ha

Table 3. Outcome-oriented indicators for dead wood volume and quality

Step 5. Data collection methods

Two data sets were compiled about the quantity of monitored dead wood volumes. One data set was compiled through the use of remote sensing. Another was collected through field inventories, and it was complemented with a qualitative

assessment of dead wood in each field sample area. The use of field observations for stand-level data for dead wood may be too costly to implement for a wide selection of stands, but it may open possibilities of utilizing field observations as proxy data to cover larger areas.

The compilation of quantitative data on dead wood was done by Luontoa and its service provider KOKO Forest. Certificate holders were only requested to share shapefile data over specified forest areas.

Data collection from certificate holders

Data collection began with the participating certificate holders, who provided spatial information on the forest management units (MUs) and individual stands relevant for dead wood monitoring. Each organization identified stands designated as set-aside areas or special management sites under the national Forest Stewardship Standards (FSS) where dead wood abundance or specific environmental objectives had triggered special management actions.

For each identified stand, polygon data (and metadata) were compiled, including:

- The FSS clause under which the stand was designated (e.g., FI: 6.5.1, SE: 6.4.1 or 6.5.2);
- Stand location and boundaries (GIS shapefiles provided by certificate holders);
- Stand type (set-aside, special management, or other);
- Basic forest attributes where available (dominant tree species, age class, and site type).

This information formed the spatial baseline for applying both remote sensing and field-based data collection methods.

Remote sensing data collection (KOKO Forest)

Remote sensing was used to estimate the volume of standing dead wood in all identified stands. The analysis was carried out by KOKO Forest using high-resolution aerial and satellite imagery, supported by national forest inventory data.

The method is based on computer vision algorithms to detect individual standing dead trees based on canopy reflectance and spectral characteristics, and to derive stand-level dead wood volumes. The method is based on the well-established ecological and spectral principle that standing dead trees differ clearly from living trees in both canopy structure and near-infrared (NIR) reflectance, particularly during the leaf-on season. By directly observing individual dead trees from above and linking those observations to stand-level forest data, the method moves

beyond indirect proxies and enables explicit mapping and quantification of standing dead wood. The approach combined:

- Detection of dead trees from multispectral aerial or satellite imagery (sub-meter resolution, including near-infrared bands);
- Estimation of mean tree volume from national forest inventory data (average live-tree volume per stand);
- Computation of dead wood volume by multiplying detected dead-tree counts by mean tree volume, with a corrective factor applied (1.3×) to account for canopy bias (since only overstory dead trees are visible from above).

Remote sensing was applied across 13,294 ha of forest land in Finland and Sweden, covering both set-aside and special management stands. The analysis enabled consistent large-scale quantification of standing dead wood and provided data for statistical comparison between stand types.

Field inventories

To complement the remote sensing analysis, field inventories were conducted in sample areas to provide qualitative data on downed and standing dead wood, including species composition and decay stages.

Within each sample plot, all coarse wood debris (CWD) was recorded and measured. The following parameters were assessed:

- Tree species (identified visually);
- Orientation and position (standing, lying, or leaning);
- Diameter and length (measured with tape measure and measuring scissors);
- Stage of decay (estimated using a knife penetration test and visual classification, decay stages 1–4);
- Condition (intact or fragmented).

This inventory protocol was designed so that it could be replicated by certificate holder staff (e.g., procurement or planning personnel) with basic field equipment, ensuring practicality for future monitoring cycles.

Field data were used to:

- Verify the qualitative accuracy of the remote sensing analysis;
- Provide information on downed dead wood not detectable by remote sensing;

- Characterize the variation in dead wood decay stages and tree species composition.

A detailed field protocol and data template are provided in Annex 3 of this report.

Step 6. Sampling

A standing dead wood inventory was conducted to stands allocated with a set-aside or special management ('special site') label as a result of dead wood abundance. A sample-based compilation of qualitative data from 20 forest stands (10 from Sweden and 10 from Finland) was conducted. Each stand contained 5 sub sample areas. See [Annex 3](#) for field protocol.

To be defined for an FSS

- What is a relevant scale of conducting sampling for representative sample areas?
Note: for the purposes of this study, a relatively small sample size was applied.
- Sampling should consider different types of forest areas (set-aside vs. special management site; stand maturity; stand composition; etc).
- Field work season: field work should be conducted outside of frost-season to allow for ground dead wood detection and effective assessment of decay stages.

Step 7. Additional data needs

Forest inventory data is required as an additional data source to obtain information over the forest type and age classes. This is relevant when deriving the dead wood volumes by combining detected dead tree counts with national forest inventory data at stand level. The inventory data may be used to provide an accurate volume estimate for each standing dead tree based on the stand-specific mean tree volume.

Step 8. Data reporting

The data should be reported every five years synchronized with the certification cycle. This report should include results for each defined monitoring indicator.

6. Results of the field testing and data analysis

This section outlines the results of the field testing conducted by Luontoa, remote sensing data analysis conducted by KOKO Forest and eDNA analysis conducted by

Puro Analytics. The spatial forest data used in the testing was provided by five FSC forest management certificate holders in Finland and Sweden.

Results for testing the two following key intended outcomes are described in the sections 6.1. and 6.2.

1. The presence of rare and threatened species is maintained (6.1); and
2. The quality of the areas of native ecosystems restored resemble that of reference native ecosystem through maintenance and increase of dead wood (6.2)

6.1. The maintenance of the presence of rare and threatened species using pyrophilous and fire obligate fungi species as bioindicators

6.1.1. Overview of sites treated with prescribed burning

All the sites in Sweden and Finland were burnt between 2022 and 2024. Most sites in Finland were burnt after logging and all sites had retention tree groups. Most sites in Sweden were burnt with lot of standing wood so the volume of burnt biomass was high. All but one site in Finland were dry heath forests with pine as a main tree or mixed with spruce. Ground vegetation was either very scarce due to recent fire or dominated with hay with patchy moss cover.

More detailed description of sites can be found from Annex 6.

6.1.2. The results of the eDNA analysis

eDNA recovered distinct assemblages of fungi species known to be associated with fire-cured environments with several previously documented post-fire indicator taxa consistently detected in all burned sites.

Across the 10 sampling sites in Finland, we detected a total of 21 pyrophilous species, meaning fungi species that benefit from fire. These accounted for approximately 4.6% of all taxa identified to species level across all sampled sites. The number of detected pyrophilous species in Finland ranged from 2 to 11 at each site. The share of pyrophilous species ranged from 1.4% to 8.1% out of all species detected for each site. Fire obligate species were found from each site and the total number of obligate species detected ranged from 1 to 7 for each site.

In terms of the number of DNA reads in Finnish sites, pyrophilous species amounted to 3.7% of the total number of reads of taxa identified to species level.

eDNA analysis revealed 683 distinct fungal taxa, of which 456 could be confidently assigned to species level, including 21 pyrophilous species and 7 red-listed fungi for

Finland with 314 species not previously recorded in Finland (according to The Finnish Biodiversity Information Facility (FinBIF)).

Among the most significant findings were *Phellodon secretus* and *Hydnellum gracilipes*, both globally listed as Vulnerable (VU) in the IUCN Red List.

In Sweden, pyrophilous species were detected in all of the sites and their share of all detected species ranged from 1.1% to 5.3%. Two species were classified as fire-obligates bringing the total number of obligate species in the project to 23. There were nine species listed in Sweden’s Red List, although none of these were fire obligates.

Share of pyrophilous and fire obligate fungi species in Finland

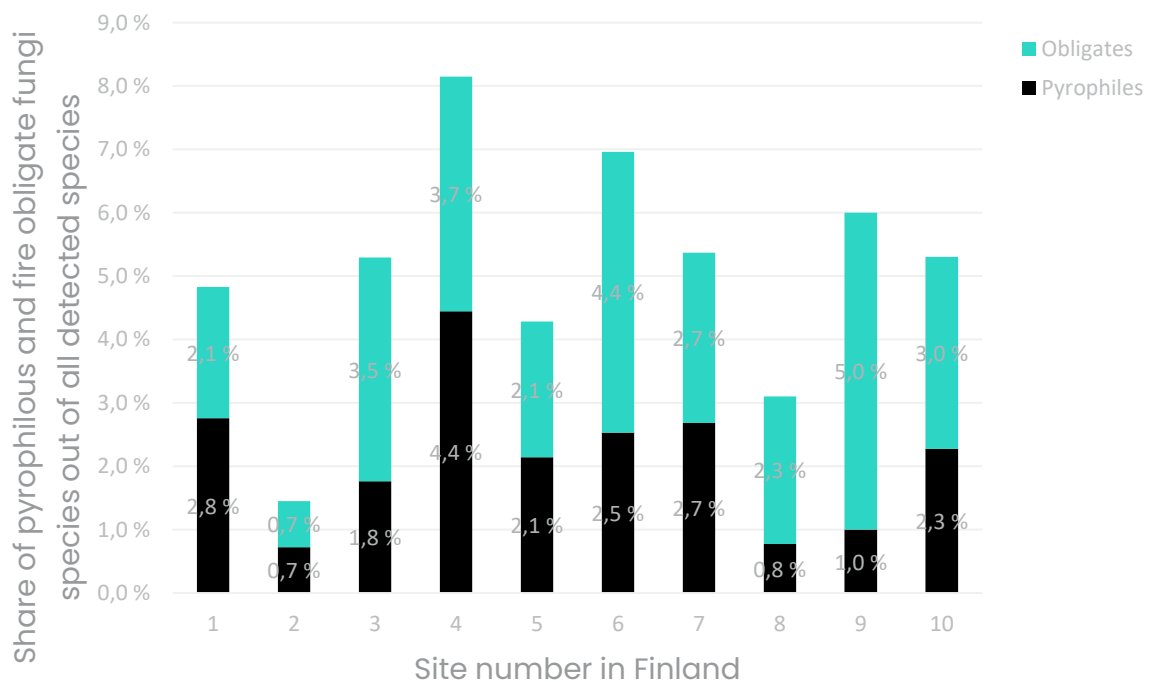


Figure 2. Share of pyrophilous and fire obligate species per site (Finland)

Share of pyrophilous and fire obligate fungi species in Sweden

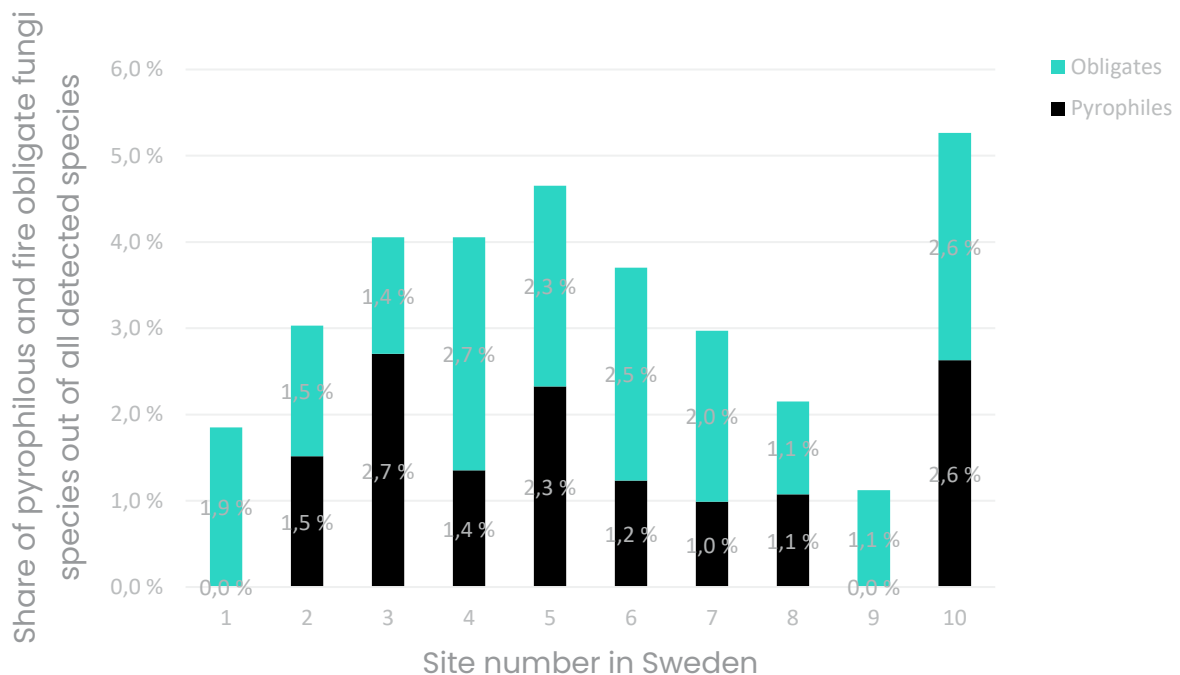


Figure 3. Share of pyrophilous and fire obligate species per site (Sweden)

6.2. The quality of the areas of native ecosystems restored resemble that of reference native ecosystem through maintenance and increase of dead wood

The monitoring requirements related to dead wood was evaluated through a combination of remote sensing and field inventories. Remote sensing was applied to more than 13,200 hectares of certified forests in Finland and Sweden to estimate standing dead wood volumes, while targeted field inventories provided qualitative data on downed dead wood, decay stages, and species composition. Together, these data made it possible to assess whether FSC-certified stands maintain or increase dead wood towards levels that support biodiversity, and to evaluate the effectiveness of FSS requirements in practice.

In Sweden the sampled sites consisted of dry heath forests and mesic heath forests whereas in Finland half of the sites were mesic heath forests and half herb rich heath forests. In Finland the main species of ground dead wood was spruce whereas in Sweden the main species was pine. In Finland the inventory includes 189 dead wood specimens and in Sweden the number was 118.

6.2.1. Dead wood volumes in Finland from remote sensing analysis

2,604 FSC-certified stands were used for conducting the remote sensing-based inventory, covering a total area of 11,045 ha, including 8,821 ha of set-aside stands and 2,225 ha of special management stands. On average, the volume of standing dead wood on the stands was 5.00 m³/ha with a standard deviation of 11.7 m³/ha. There was a statistically significant difference in standing dead wood volume between the set-aside stands and special management stands. For the set-aside stands, the mean stand-level standing dead wood volume was 6.16 m³/ha with a standard deviation of 13.65 m³/ha. Considering the special management stands, the corresponding values were 3.07 m³/ha and 6.98 m³/ha. Thus, the finding is that set-aside stands had 101 % more standing dead wood than the special management stands, which is in line with the expected insights established for this analysis.

Most stands contained less than 6 m³/ha of standing dead wood, whereas some had over 50 m³/ha, reaching a maximum of 258.2 m³/ha for a single stand.

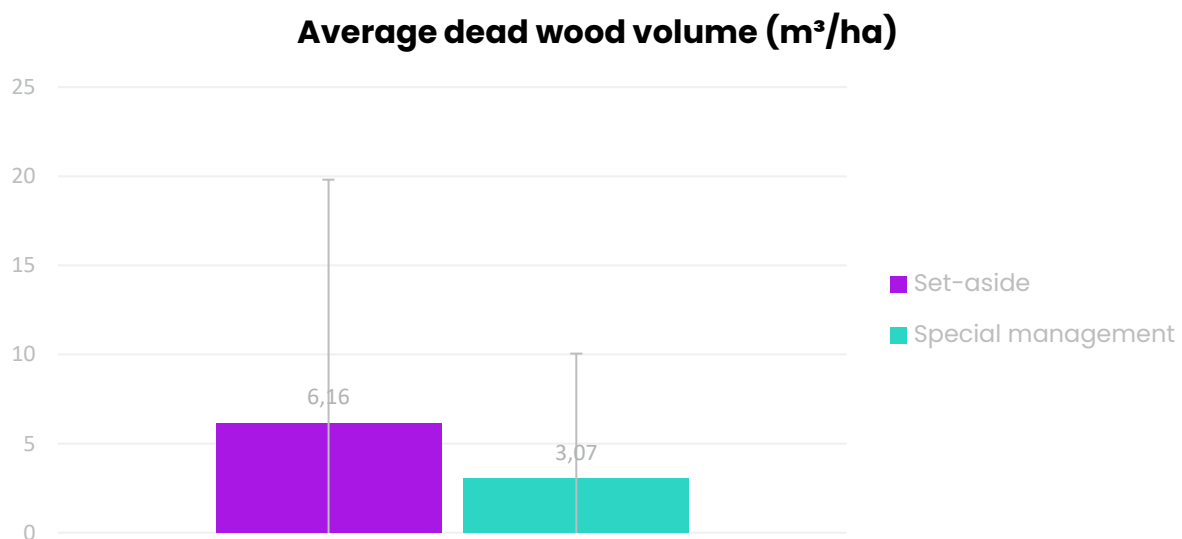


Figure 4. Average dead wood volumes per stand type (Finland)

6.2.2. Dead wood volumes and qualitative assessment in Finland from field data analysis

In Finland the field inventory from 10 sites contained 189 dead wood specimens of which 142 were downed dead wood and 47 were standing trees. The main tree species was Norway spruce (157 specimen), with other coniferous trees only accounting to 2 hits (Scots pine). Deciduous trees amounted to a combined total of only 12 dead wood observations. Calculated quantities for the dead wood and coarse wood debris (CWD) further emphasized the heavily skewed results towards

spruce (92,2% of total volume share). Over-emphasis of a single species, in this case spruce, is largely explained with the sites being established through regenerative planting and selective forest management regimes that favour single species stands. By chance, all of the sample areas in Finland were managed previously as spruce monocultures. Most FSC set-aside areas have a recent history of being production forests, with all of the special management stands still holding this status. Introduction of naturally generated trees and more diverse species composition requires time but is expected to ultimately produce more diverse type of dead wood as a result (in line with the expected insights). In a reference native ecosystem, a much more [diverse species composition and diversity](#) is expected than compared with mature production forests. No immediate qualitative reference thresholds were established for the reference native ecosystem in this study, but progression should be observable across all other species types than Norway spruce, and other commercially viable species more prominent in other areas (e.g., Scots pine). Additionally, the distribution of dead wood in is expected to increase in later stage decay classes.

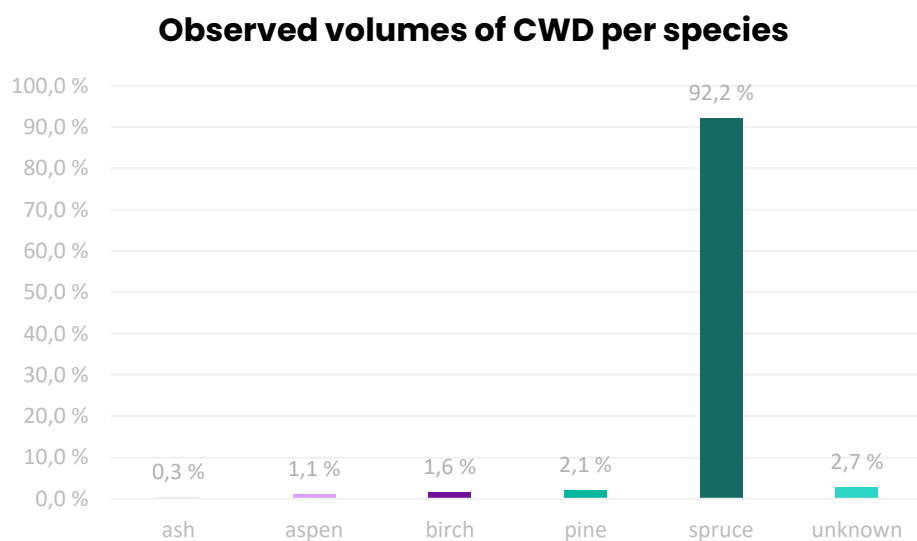


Figure 5. Observed volumes of CWD per species (Finland)

Standing dead wood was observed to be completely of decay stage 1 meaning early stages of decay whereas in downed dead wood there was a lot of variances between stages 1-4. This supports the expected insights of this project. It would be beneficial for FSC, certificate holders and stakeholders to monitor the changes taking place with regards to the volume of dead wood in set-aside areas, but most importantly, what changes take place with regards to species diversity of dead wood and whether improvements may be detected in the distribution of dead wood in latter stage decay classes.

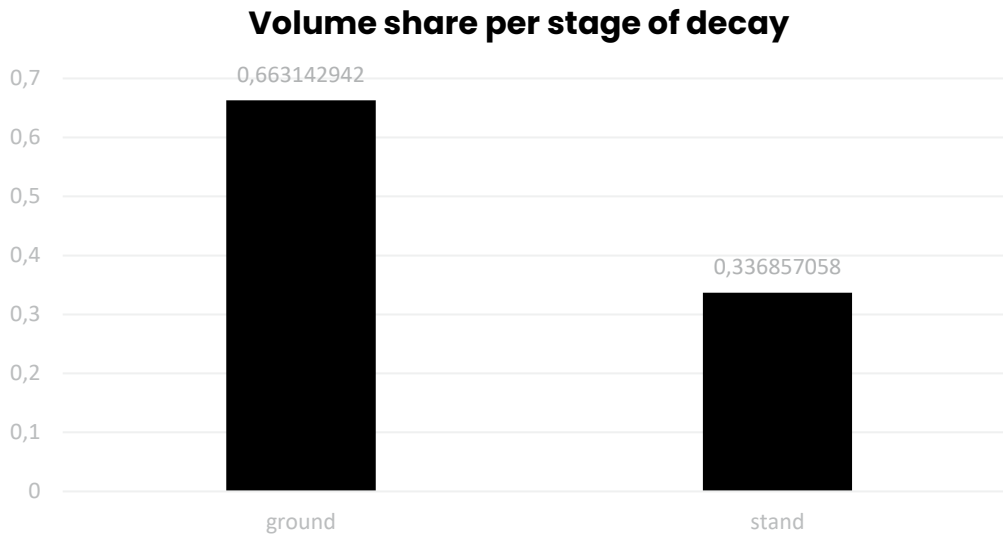


Figure 6. Volume share per stage of decay (Finland)

When assessing the distribution of dead wood stages of decay for each of the sample areas, it is noticeable that a majority of the dead wood volume detected in field observations is in decay stages 1 and 2 (71% and 7% respectively). Decay stages 3 and 4 amount to a combined 21% of the total dead wood volume monitored.

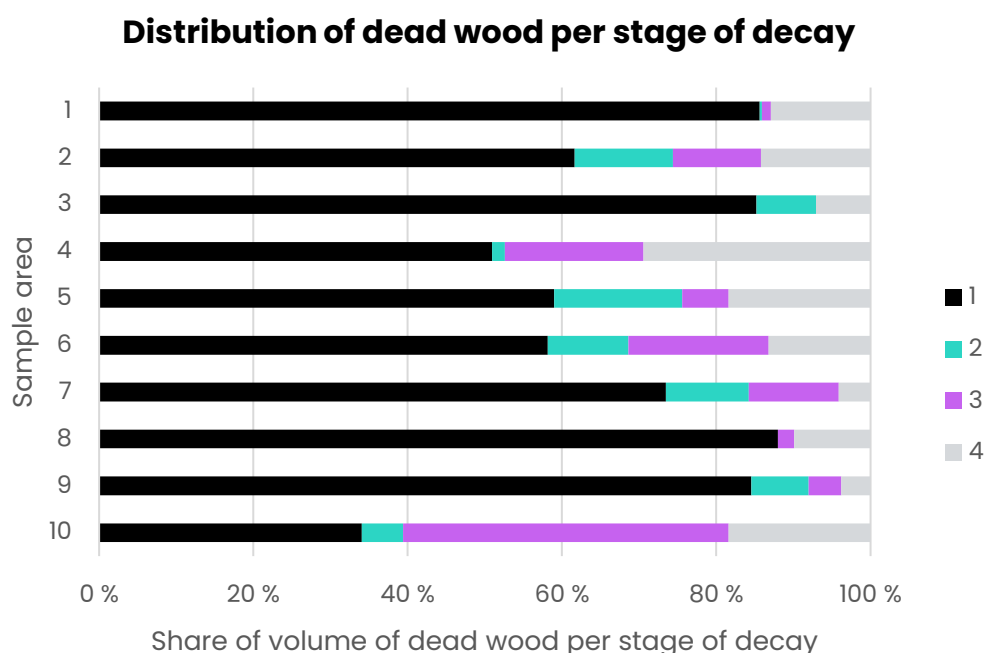


Figure 7. Distribution of dead wood per stage of decay (Finland)

The sample areas in Finland were observed to be relatively mature stands, but such where forest management had left still visible marks on the forests. The stand compositions were similar to that of typical production forests, which may be observed through the domination of Norway spruce with observed species of dead

wood. Over time, there will be progression in terms of further decaying dead wood in each of the sample areas and dead wood volumes shifting from one decay stage to another. It is also expected that as the stand is set aside from active management, the species composition will also diversify, and more species will contribute to the dead wood volumes.

6.2.3. Dead wood volumes in Sweden from remote sensing analysis

In Sweden, the remote sensing-based dead wood detection covered a total of 2249 hectares in Sweden. The area consisted only of set-aside stands. The detected dead wood volumes were on average of 2.58 m³/ha in the designated set-aside areas with a standard deviation of 7.26 m³/ha. There was considerable variation in the amount of standing dead wood between individual stands. A maximum of 76.8 m³/ha of standing dead wood was identified for a single stand, whereas the minimum values found were close to zero.

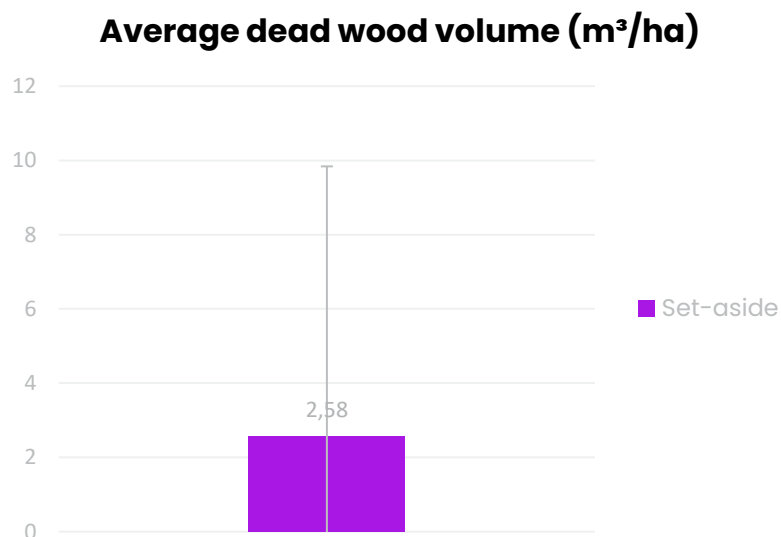


Figure 8. Average dead wood volumes for set-aside areas (Sweden)

6.2.4. Dead wood volumes and qualitative assessment in Sweden from field data analysis

In Sweden the field inventory allowed to record 118 dead wood specimens with 94 of the specimens being downed dead wood and 24 being standing trees. The main tree species was pine (103 specimens), with other coniferous trees amounting to only 6 hits (spruce). Deciduous trees amounted to a combined total of only 2 dead wood detections (birch).

Standing dead wood had more variance than in Finland the main stages being 1 and 2. Rot degree of downed dead wood was mainly the last stage of decay (4).

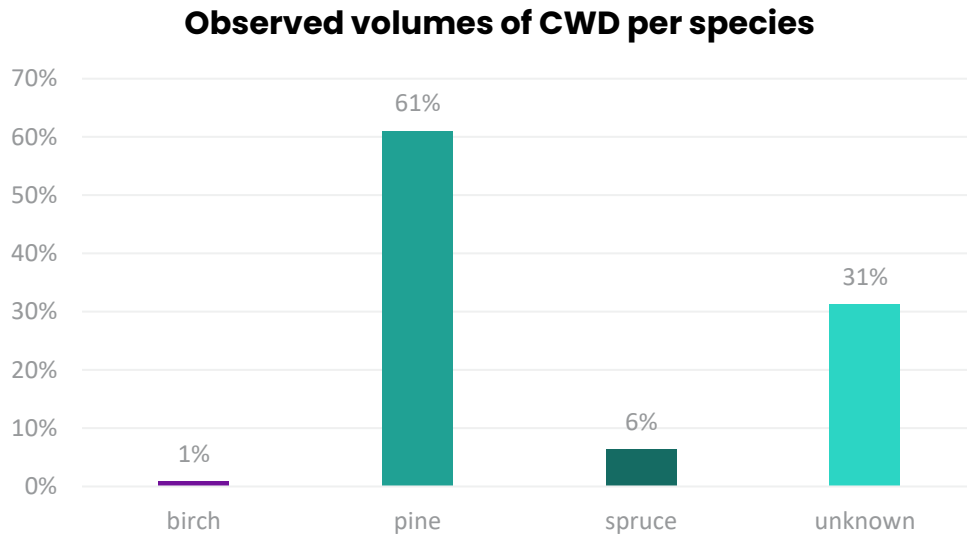


Figure 9. Observed volumes of CWD per species (Sweden)

There was much variation between decay stages across the detected dead wood specimen. The dead wood detected as downed dead wood were highest with stage 4 of decay (36%). Standing dead wood also demonstrated a variety of each of the stages of decay, with stage 1 being the most prominent one.

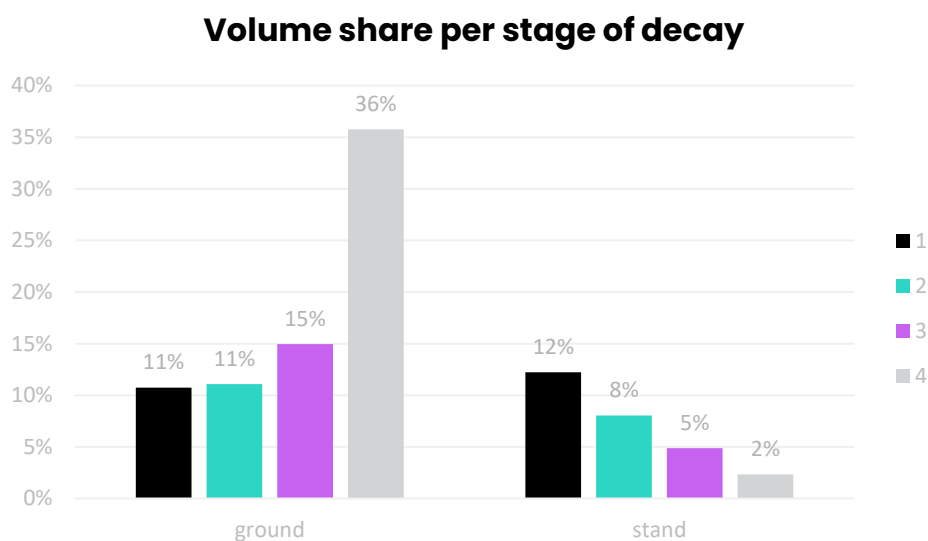


Figure 10. Volume share per stage of decay (Sweden)

When assessing the distribution of dead wood stages of decay for each of the sample areas in Sweden, it is noticeable that dead wood is relatively evenly distributed across the various decay stages. Decay stages 3 and 4 amount to a combined 58% of the total dead wood volume monitored, whilst earlier decay stages 1 and 2 amount to a combined total of 42% of the total volume of monitored dead wood.

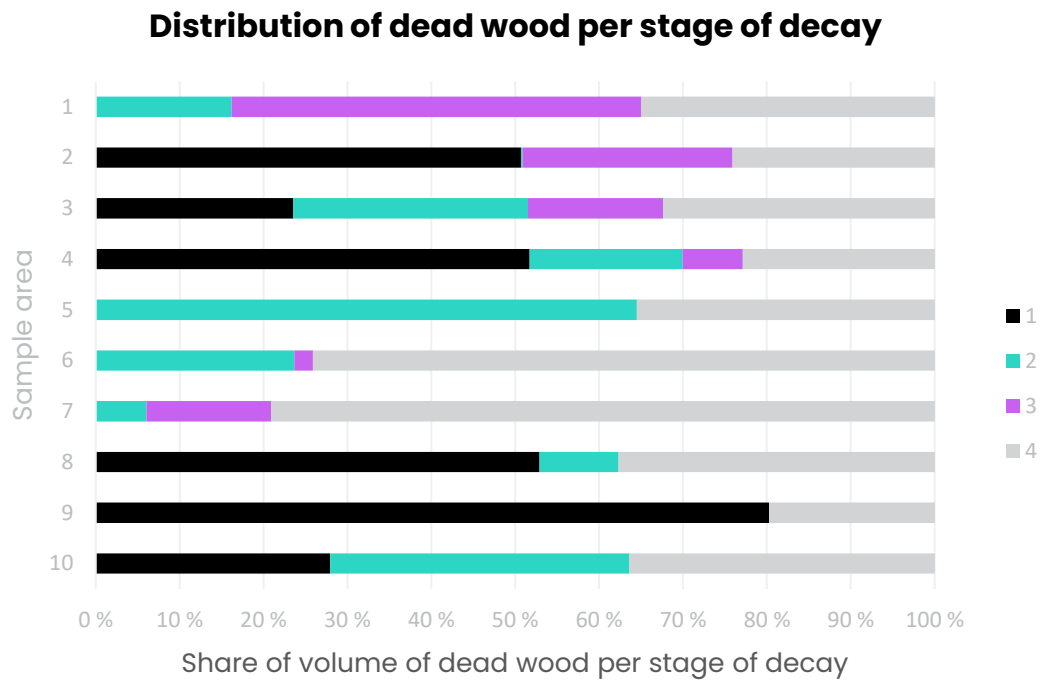


Figure 11. Distribution of dead wood per stage of decay (Sweden)

Overall, the sample areas in Sweden were observed to be areas where human disturbance through forest management had been very limited in the past decades. Dead wood had been accumulating without extraction for more than 15 years. The species composition and share of later decay stage dead wood are showcasing progression towards reference native ecosystem conditions.

7. Discussion

7.1. Effectiveness of FSC forest management requirements in Finland and Sweden for the maintenance of rare and threatened species using pyrophilous fungi species as bioindicators

In this project the results indicate consistent findings of pyrophilous fungi in areas where prescribed burning has been conducted. It can be argued that the number and proportions of these species are elevated compared to unburned sites, where such taxa are generally absent or only detected at negligible levels (Bruns et al., 2020; Packard et al., 2023). This tends to confirm the relevance and effectiveness of FSC forest management requirements in the FSS for Finland and Sweden for the maintenance of rare and threatened species.

The results also align with earlier research, confirming that pyrophilous taxa are reliably elevated both in terms of species richness and sequencing reads in burned sites. At the same time, it should be noted that this assessment did not include control sites where prescribed burning has not been conducted, which limits the ability to make direct comparisons between burned and unburned conditions. Future monitoring would benefit from incorporating such controls to establish stronger baselines.

Currently, the Finnish and Swedish Forest Stewardship Standards do not include explicit requirements to improve fire-dependent species occurrences in stands managed with prescribed burning, nor do they require the establishment of fire continuum areas. Looking ahead, the focus on further developing this example into a requirement in monitoring framework could be on monitoring not only the presence of species but also the expansion and continuity of fire-treated habitats. Setting explicit targets for the area under prescribed burning could serve as a practical and valuable indicator for sustaining fire-dependent biodiversity.

Further, from a more practical standpoint, eDNA proved to be a capable and effective method for detecting pyrophilous fungi from soil samples. This demonstrates strong potential for using eDNA as a tool to verify and monitor prescribed burning activities and their impacts to species dependent on specific disturbances as part of certification. Beyond this, the analyses revealed that eDNA can generate highly detailed insights into fungal communities more broadly, highlighting differences in biodiversity composition. eDNA does also offer a proven and valuable tool for ecological assessments that extend beyond that of assessing the impacts of prescribed burning to fungi.

By enabling robust and replicable assessments, this approach strengthens the capacity to make data-driven decisions for responsible forest management and support FM evaluations. As this use case for eDNA has demonstrated sufficiency, it would be useful for FSC to continue experimentation with eDNA for other use cases.

Due to the nature of this one-off field test project, data have not been collected at different points in time, and we are not able to provide insights related to the maintenance of species in time. However, the method and analysis shown would simply need to be repeated over time to be able to track the trends in the number and proportion of overtime and across FSC-certified forests.

In Finland there were two sites out of ten which clearly differed in the numbers of pyrophilous species found in the samples (sites 2 and 9). These sites differed from the rest in that they were forest fire sites with more trees and smaller percentage of area burnt (site 2 only ca. 5% and site 9 ca. 30%). Site 2 was a mature forest stand with no immediate harvest history, and site 9 being a young pine stand where a lightning strike had kindled a forest fire.

In Sweden there was less variation in numbers of pyrophilous species found likely due to very similar sampling sites. The variation in share of pyrophilous fungi in all fungi species found had similar variation that the one in Finland. Altogether there were less pyrophilous species found in Sweden than in Finland probably due to very different forest types in these two countries. Both pyrophilous and fire obligates were found in all the sites in Sweden.

Variation in taxa and species detected through soil eDNA surveys can arise from several interacting factors. These can be broadly grouped into three categories: 1) local ecological characteristics, 2) eDNA dynamics and substrate effects, and 3) biogeographical and climatic context.

Local ecological characteristics influence both biodiversity and the amount of DNA present in soils. Differences in vegetation cover, tree biomass and diversity, habitat structure, and land use shape the diversity and activity of soil organisms, which in turn affect how much DNA is deposited and detected. In forest environments, factors such as canopy density, litter input, and disturbance history contribute to site-specific variation. Past fire events may also play a role by altering vegetation composition and microhabitat structure, indirectly influencing the diversity of taxa detectable in soil.

eDNA dynamics and substrate effects determine how well DNA is retained and preserved within soils. Soil texture, organic matter content, moisture, and pH all influence DNA binding and degradation rates. Soils richer in organic material or clay

tend to preserve DNA longer, whereas coarse or nutrient-poor soils may allow faster breakdown. In previously burned areas, changes in organic matter and pH could affect DNA persistence, leading to differences in detection independent of true species richness.

Biogeographical and climatic context provides the broader framework for biodiversity patterns across regions. Climatic gradients, soil formation history, and large-scale vegetation zones influence the species pool and the composition of local communities. In northern forest systems, differences in temperature, precipitation, and productivity shape both biological communities and soil properties, contributing to spatial variation in taxa detected with eDNA methodologies

7.2. Representative samples of natural ecosystems are similar to that of reference native undisturbed ecosystems, using dead wood as a bioindicator

The results showcased that the dead wood volume inventories and qualitative aspects may be effectively monitored in designated set-aside and special management sites. In Finland, set-aside areas consistently contained more standing dead wood than special management stands, with mean volumes of 6.16 m³/ha and 3.07 m³/ha respectively. In Sweden, set-aside areas contained an average of 2.58 m³/ha of dead wood. Although the overall mean dead wood volume (5.0 m³/ha in Finland, and 2.58 m³/ha in Sweden) across the FSC-certified stands is still relatively low, there is high variability (standard deviation = 11.7 m³/ha in Finland and 7.26 m³/ha in Sweden). This suggests that while dead wood is generally scarce, certain individual stands make disproportionately large contributions to overall habitat availability for dead wood dependent species.

This is, however, not an ideal situation for maintaining spatial dead wood continuum and availability of the resources for dead wood dependant species. The aim of the FSS should be to make sure that alongside of these dead wood hotspots created for example by storms there would be an adequate amount of dead wood resources available throughout the landscape.

Compared to the latest [forest inventory](#) data, the sites (assigned with either a 'set-aside' or 'special management site' label) in the project area had more dead wood than productive forest land in the municipal regions where the remote sensing was conducted. Production forests typically hold 2-3m³ of dead wood per hectare. Although the current methods for utilizing remote sensing for the detection of dead wood are limited to standing trees, downed dead wood becomes detectable at the

moment it is downed. Historical downed dead wood may not be currently detected with certainty, and accurate dead wood monitoring will still require a combination of remote sensing and field observations. For the purposes of conducting qualitative assessments of the dead wood, sample-based field observations are a necessary part of the analysis, and should be incorporated as part of any dead wood-related monitoring activities.

The data analysis provides insights about the effectiveness of criterion 6.5 on the maintenance of dead wood volumes and quality. Based on the data collected and the results obtained about dead wood and associated biodiversity values, the results provide insights about the effectiveness of the FSS requirements for the maintenance of dead wood dependant biodiversity. Standing dead wood is more abundant in set-aside areas and downed dead wood in various decay stages was inventoried in most sample sites.

The assumption was that the volume of dead wood maintained per hectare and its quality are good indicators of the FSS contributing to the resource needs of dead wood dependent species in FSC-certified forests. The periodic assessment of the accumulation of dead wood (volume) as well as the varying decay stage, variation in species and other qualitative aspects in coarse wood debris in certified forests should be used to generate insights about the effectiveness of FSC FM requirements to ensure suitable habitats and resources for thousands of dead wood dependent species.

The results from the much more prominent variation of stages of decay in the Swedish field inventory sites suggests that these areas have been accumulating dead wood for a much longer period time than the field inventory sites in Finland. The Swedish inventories showcased an abundance of dead wood in its final stages of decay. The Finnish field inventory sites showcased a relative over-representation of fresh dead wood (decay stage 1), which could be an indication of storm or insect or other biotic or abiotic disturbances to the forest.

Quantity does not supersede quality when it comes to dead wood. A dead wood continuum, with dead wood in various stages of decay omnipresent in the same site, is considered an important factor in ensuring necessary resources and habitats for dead wood dependent species. Closer attention should be paid to ensuring that designated areas in FSC certified forests would hold dead wood in various decay stages, whilst also ensuring adequate quantities may be reached.

7.3. On the usability of key intended outcome in the FSC standard framework

This project provides insights into both the technical and practical aspects of developing outcome monitoring frameworks for FSC certification. The experience confirmed that outcome monitoring is not only scientifically feasible but also operationally realistic, if methods are carefully selected and adapted to the certification context. The usability of the chosen methods is likely to be affected by the price trend of both remote sensing and eDNA analysis as the unit price will decrease.

One of the most important lessons was the value of combining complementary methods. Remote sensing offered a cost-efficient way to capture dead wood data at scale, while field inventories added ecological depth by identifying species, decay stages, and qualitative habitat features that remote sensing cannot yet detect. eDNA analysis proved to be a powerful and scalable tool for detecting fire-dependent fungi. Together, these approaches demonstrated that outcome monitoring can generate both breadth and depth of information in a way that is directly applicable to certification.

Another key lesson was that outcome monitoring requires clear benchmarks to be meaningful. In the case of dead wood, comparing current volumes in certified stands with ecological thresholds revealed a significant gap between present conditions and the levels needed to sustain biodiversity. This highlighted the importance of linking outcome data to reference conditions or target values, so that FSC can assess not only whether rules are followed but also whether ecological outcomes are being achieved.

Stakeholder engagement also provided important learning. The webinars and consultations in Finland and Sweden showed that members and certificate holders are open to the idea of outcome monitoring, but practical questions remain about cost, responsibilities, and the role of auditors. It became clear that outcome monitoring will require cooperation between certificate holders, FSC, and accredited service providers to ensure both scientific credibility and operational feasibility.

Annex 2 will be developed specifically for the development of recommendations for the national FSS revision processes.

8. Recommendations

At the time of writing this report, the FSC-PRO-60-006 is under revision and there are proposals for including outcome monitoring into the scope of Forest Stewardship Standards. The results of this project show that outcome monitoring for biodiversity in FSC-certified forests is both feasible and valuable. During the project, Luontoa has

applied the draft contents of the FSC-GUI-60-006 and implemented FSC's planned approaches to outcome monitoring in practise. The project and its results confirm that the plan to introduce outcome monitoring into the FSC system is feasible and may be conducted at a reasonable cost.

The use of eDNA for species detection, remote sensing for large-scale dead wood assessment, and field inventories for qualitative validation provide FSC with a concrete steps for linking its requirements to measurable biodiversity outcomes. Building on these insights, we recommend a set of actions for FSC at the global, national, and practical implementation levels. These recommendations are intended to provide further improvements and opportunities for uptake in the national Forest Stewardship Standard level.

8.1. Recommendations for FSC International

At the global level, FSC could more integrally introduce outcome monitoring into its certification framework. The ongoing revision of the FSC Principles and Criteria (P&C) and the International Generic Indicators (IGIs) offers an opportunity to integrate measurable outcomes alongside existing management requirements. Monitoring indicators, such as the presence of a specified subset of pyrophilous species in burned areas or quantified levels of dead wood, would strengthen FSC's ability to demonstrate its contribution to halting biodiversity loss. The measurable outcomes and monitoring practices could be determined at national levels as part of the FSS revision processes.

This shift would also align FSC with broader international frameworks and broader aspirations among forest and wood products industry companies. The Kunming-Montreal Global Biodiversity Framework and the EU 2030 Biodiversity Strategy both emphasize measurable progress towards measurable biodiversity targets. By adopting outcome monitoring, FSC may demonstrate that its certification scheme contributes directly to these global commitments. In doing so, FSC will strengthen its credibility with governments and markets, showing that certification is not only a compliance mechanism but also a driver of positive biodiversity outcomes.

FSC should determine what level of detail and how broadly the outcome monitoring should be incorporated into the FSS. Incorporating new monitoring requirements will undoubtedly increase the costs of certification, if the requirements for conducting the monitoring activities is assigned directly to the certificate holders. The study already suggests ways for FSC to obtain necessary data through external service providers, and by adopting this as a default option, FSC could bear the cost of data collection and analysis by itself. Indirect increases to certification costs could be

more acceptable, than the introduction of more costly requirements and practices for outcome monitoring that would be rolled out on top of the existing certification requirements for certificate holders.

A key enabler of this transition could be the recognition of external service providers. FSC should establish mechanisms for accrediting service providers – laboratories, remote sensing companies, and other technical experts who can deliver standardized, verifiable outcome data and data analysis services. This would allow certificate holders and auditors, as well as FSC, to access high-quality data without bearing the full technical, data collection and analysis burden themselves.

8.2. Recommendations for national application in the Nordics

The national Forest Stewardship Standards of Finland and Sweden provided the pilot context for this project. Both countries have explicit requirements related to prescribed burning and dead wood, but they currently lack mechanisms for verifying whether these requirements are transferred into changes seen in field.

We recommend that the next revision of the Finnish and Swedish standards incorporate monitoring indicators to complement existing management rules. This could be done by continuing the work done in this project and/or by piloting with other possible key intended outcomes. Following the effect of work done also gives FSC credibility on affecting biodiversity in certified forests. Hence it answers for example to the demands of providing credible and verifiable information regarding their environmental impact, ensuring that claims are in fact true. This also plays into building consumer trust and further could positively contribute to the demand for certified products.

For the moment outcome-oriented indicators could include prescribed burning (this could involve the use of eDNA surveys to verify the presence of fire-dependent fungal species in burned sites) and amount of dead wood. For dead wood the standards could introduce a benchmark volume ([example of 20–30 m³ as potentially feasible](#)) per hectare in designated stands as an ecological threshold, with progress monitored through remote sensing. Field inventories could continue to play a role in validating qualitative attributes such as decay stages and species composition.

In the longer term, the national forest stewardship standards could be a mix of monitoring indicators and rule-based standard as they currently are.

Both standards should also require certificate holders to make basic spatial data available, such as stand and MU polygons for areas designated as set-aside or

special management. This would enable more efficient use of remote sensing and ensure that monitoring results are comparable across the certification landscape.

8.3. Practical recommendations

Practical steps are needed to make outcome monitoring operational within the certification process. Monitoring should be aligned with the five-year certification cycle, allowing outcome indicators to be assessed periodically alongside conformance evaluations. Remote sensing offers a cost-efficient way to generate data at scale. eDNA sampling protocols are simple enough to be carried out by trained staff or contracted field teams, making these also scalable across regions.

In the short term, FSC could encourage certificate holders to further pilot eDNA and remote sensing approaches voluntarily, with support from accredited service providers. In the medium term, selected outcome indicators could be introduced into national standards because of normal standard revision processes, with guidance on methods and thresholds continuously provided by FSC International. In the long term, outcome monitoring should become a standard part of FSC's global certification framework, with aggregated (national or sub-national) results reported publicly to help demonstrate FSC's biodiversity impact. Specific, and product-based LCA or EPD claims are also sought after by certificate holders, and their suitability for outcome monitoring should be carefully assessed.

Outcome monitoring should not be seen as an additional burden but as an evolution of FSC certification model. By combining rules-based requirements with measurable outcomes, FSC can provide stronger assurance to markets and policymakers about the system's core outputs, while also delivering valuable outcome and impact data globally with aggregated results.

9. Concluding remarks

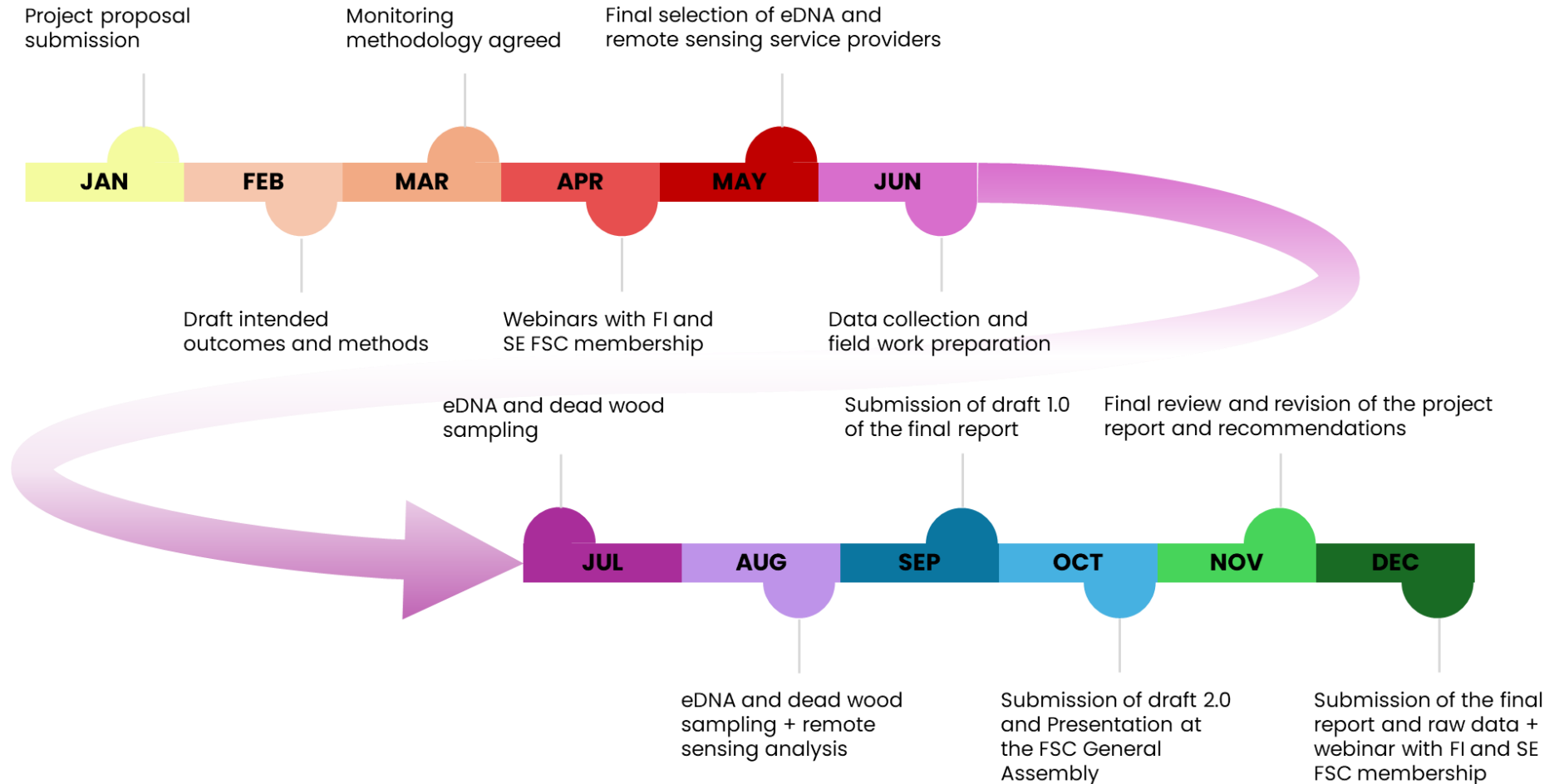
To test the outcome monitoring requirements related to fire-dependent species, soil samples were collected from recently burned stands in Finland and Sweden and analyzed using eDNA metabarcoding. This approach allowed us to detect fungal communities associated with fire and to evaluate whether prescribed burning requirements in the national FSS are contributing to the obligate fire related species or presence of rare and threatened species. The results provide the first systematic evidence that eDNA can capture pyrophilous and red-listed species in certified forests and therefore offer a practical tool for monitoring biodiversity outcomes and contributing to the maintenance of the presence of rare and threatened species.

The project demonstrates that by using the outcome monitoring framework investing in the maintenance of the habitats of fire dependent forest species by performing prescribed burnings the FSS application leads to the maintenance of species occurrences in certified forests by introducing specific habitats otherwise not available.

The outcome monitoring requirements for the purpose of monitoring changes to dead wood volumes and qualitative aspects proved feasible. Targeted monitoring of designated representative sample areas of high dead wood volume stands with remote sensing technologies, may be used to effectively monitor incremental changes to dead wood volumes. Furthermore, conducting targeted sampling and field inventories to assess changes to decay stages and other qualitative aspects of dead wood, may further provide opportunities for understanding FSC specific outcomes.

This project has demonstrated that outcome monitoring is technically feasible and operationally realistic to be integrated into FSC FM certification. The recommended actions outlined provide a pathway for FSC to move beyond a 'rules-based system' and towards demonstrating tangible contributions and outcomes to maintenance and improvements towards biodiversity in FSC certified forests. By making outcome monitoring and integral part of the system will strengthen FSC's position as the leading certification system for responsible forest management and ensure its continued relevance in a world that increasingly demands measurable evidence of environmental impact.

Annex 1 – General timeline of the project



Annex 2 – Summarized examples for national Standard Development Groups

This section of the document will be used to outline what elements are needed to be considered for the implementation of outcome monitoring frameworks in the FSS. The section specifically considers the need for guidance to the revision of FSS, as well as what are the practical requirements that should be incorporated into the revised FSS to ensure effective and appropriate outcome monitoring as part of FSS implementation.

Step 1: Define key intended outcomes

The working group is to define a minimum of three and a maximum of five key intended outcomes for the entire FSS, aligned with its intended validity period and scope of application.

In this project those were:

Rare and threatened species

The presence of rare and threatened *pyrophilous fungi* species is maintained over time.

Refers to criterion 6.4 in the FSC-STD-01-001 V5-3.

Dead wood

The quality of the areas of native ecosystems restored resemble that of reference native ecosystem *through maintenance and increase of dead wood*.

Refers to criterion 6.5 in the FSC-STD-01-001 V5-3.

NOTE: The part in italics has been a further adaptation of the generic key intended outcome.

Step 2: Define indicators

The working group should define indicators so that they specify forest management activities clearly contributing to achieving or progressing toward the key intended outcomes.

In this project those were:

Rare and threatened species

The Organization ensures the area treated with prescribed fire increases on a 5-year cycle as compared with the area from previous certification cycle and the fire continuum is maintained by prescribed burning every five years.

Refers to indicators: FI (6.8.2) SE (6.8.4)

Dead wood

Set-aside areas are established in areas with high dead wood volumes. Dead wood is retained and stands are assigned with a special environmental objective of increasing dead wood volumes.

Refers to indicators: FI (6.5.1 and 6.5.3), and, SE (6.4.1, 6.5.1 and 6.5.2)

Step 3: Define expected insights

The Expert should define expected insights for each key intended outcome that are actionable discoveries derived from data analysis, going beyond simple findings to reveal deeper understanding and potential solutions.

NOTE: The FSC-GUI-60-006 suggests a designated expert is to be used for steps 3-8, whilst the SDG retains the decision-making role over the final outputs.

In this project those were:

Rare and threatened species

As the number and area of burnt forests increase, more suitable habitats for fire-dependent species are established on a country level. The expectation is that this influences positively on the numbers of rare and threatened species over time.

Dead wood

Continuous identification of areas where dead wood volumes have led to set-aside designation or special environmental objectives.

Quantified assessment of standing dead wood volumes in these areas and

Species occurrences of rare and threatened pyrophilous indicator species may be detected in established burnt areas over time.

their proximity to the ecological benchmark of 25 m³/ha.

Cumulative insights into the progress of qualitative aspects related to dead wood in sample areas by type, quality, and decay stage.

Step 4: Define Monitoring indicators

The expert should define monitoring indicators for each of the selected key intended outcomes. Monitoring indicators should provide a simple, reliable, and replicable mean to measure progress towards, and/or the achievement of, key intended outcomes.

In this project those were:

Rare and threatened species

The organization monitors the development of the forest area treated with fire.

The Organization monitors the presence of rare and threatened obligate and pyrophilous fungi species on prescribed burning sites.

The Organization monitors the maintenance of a fire continuum on prescribed burning areas.

Dead wood

The Organization conducts a dead wood inventory on a designated sample area of x% of areas designated with an abundance or quality of dead wood as being the trigger for set-aside or special management status.

The Organization ensures the dead wood volumes in specified areas (conforming with requirements specified under C6.4 and C6.5 in Finnish and Swedish FSS), are progressing against the set reference threshold of 25m³/ha (threshold to be determined separately).

The Organization monitors the dead wood volumes in specified areas

according to the monitoring requirements.

Step 5: Define data collection method

The expert should define data collection methods for each monitoring indicator. These should be replicable and cost effective.

In this project those were:

Rare and threatened species

eDNA analysis for specified subset of rare/threatened/endangered fungi species.

Dead wood

Remote sensing based dead wood inventory (requiring polygon data).

Field inventories for the qualitative assessment of dead wood.

Step 6: Define sampling

The expert should define the sampling method and timing for each monitoring indicator.

In this project those were:

Rare and threatened species

20 fire-cured sites 10 sub-samples to be collected and pooled into a single representative soil sample of each site.

Sampling of the soil in forest stands burned less than four years ago in June to August. DNA extraction to be carried out by specialized DNA-

Dead wood

A standing dead wood inventory to be conducted through remote sensing technologies to all stands allocated with a set-aside or special management ('special site') status.

A sample-based compilation of qualitative data from 0,5% of specified forest stands. Each stand contains 5 sub

extraction laboratory. Taxonomic assignment to be performed against a reference database.

sample areas. The sites amount to a sample size of 0,5% of the total pool of relevant stands.

NOTE: The sample size in this project has been identified as too small, and a larger sample size is suggested.

Step 7: Define additional data needs

The expert should define any additional data needs for key intended outcomes and to specify a reference value.

In this project those were:

Rare and threatened species

N.A.

Dead wood

Determining a feasible reference value for dead wood volume in reference native ecosystem.

Step 8: Define data reporting

The expert should define data reporting needs for each intended outcome such as reporting frequency and units.

In this project those were:

Rare and threatened species

Reporting is needed every five years for the development of fire treated area, fire continuum and species occurrence of fire obligate and pyrophilous fungi species.

Dead wood

Reporting on remote sensing based dead wood volume inventories may be done on an annual basis or per certification cycle.

Field inventories and qualitative findings should be compiled every five years, or per certification cycle.

Annex 3 – Field inventory survey for dead wood

This annex introduces a field inventory method and survey used in this project.

The surveyors will also be provided access to the Finnish forest industries’ collective guidance on dead wood evaluation form¹ The associated guidance provides the basic tools to understanding how the measurements are to be taken. A complementary sampling guidance will be provided by Luontoa. This annex is adapted from this existing guidance.

stand-level field inventories were conducted with 5 random scatter plots per each stand – each plot area being one are. The inventories were developed utilizing a predetermined format.

The field inventory resulted in a categorization of each CWD identified from the sample plots:

- Counting/defining CWD items
- Identifying CWD wood species
- Measuring breadth from chest height
- Estimating length
- Estimating degree of rot with knife
- Determination of dead wood volume per species

The aggregated data demonstrates, for each stand, the:

- Calculated total volume of dead wood per species, per decay stage, standing/downed

Field survey: Dead wood						
Surveyor/organization: Cadastral unit and stand number:			Date: Observations:			
Measurement data						
CWD number	Species	DBH	CWD length	Intact/ Fragm.	Orient./ Position	Degree of rot
[...]						

¹ [Field inventory guide of Tapio](#)

Annex 4 – Sample collection for eDNA analysis

This annex introduces the sample collection method as utilized in the soil sample collection of this project.

Step-by-step instructions for sample collection

At arrival to a new site disinfect reusable equipment (knife and hammer) and boots, carry reusable equipment separately in a new (site specific) plastic bag (to avoid contamination of sampling equipment)

At arrival to a subsampling spot

Clear sampling spot from detritus and vegetation. Use a knife or other provided tools to dig soil at a depth of 0–5cm. Collect ~2 tablespoons of soil per subsample for fungal eDNA analysis. Use a spoon to scoop soil into the sample bag. Collect subsamples from 2 types of sampling sites:

- Close (0–50cm) from wood trunks (living or rotten)
- Open soil distant from wood trunks (living or rotten)

Collecting soil samples and recording necessary information

1. Record metadata (Use your smartphone/GPS to log coordinates of each subsample site, e.g. Site A, subsample 1, N=6861208.096, E=488396.007)
2. Wear new gloves
3. Choose undisturbed soil (avoid recently trampled or contaminated spots (e.g., visible animal faeces) and avoid stepping onto sampling spots)
4. Take the sample e.g., collect ~2 tablespoons of soil (0–5cm deep) into a clearly labelled sample bag (site ID, date, name of the person collecting the samples)
5. Use a sterile spoon or disinfected knife/hammer to dig the soil if needed. Wipe the tools used with a paper towel after usage to avoid spreading the soil, no thorough disinfection needed between subsampling sites
6. Seal and cool in the freezer (Seal the bag for moving to next subsampling site and place it into the cool box/bag with ice packs (do not leave your samples exposed to sunlight or heat))
7. Repeat steps 1–6 in total of 10 times per sampling location (i.e. each prescribed burning area) for different subsampling locations.

Annex 5 – Raw data of dead wood field inventories in Finland and Sweden

This information will be submitted as a separate annex.

Annex 6 – The raw data of the prescribed burning sites in Finland and Sweden

This information may be submitted as a separate ‘raw data’ excel. A format for summarizing the raw data will be developed also for the final version of the report.

Finland

date	Site #	Site location	sub sample	coordinates	Treated	Forest type	Amount of trees ²	% burnt	other observations
18.6.2025	1	Puumala Mannila	coordinates for 10 sub-plots available upon request	Confidential	2023	dry heath forest, main tree pine	1	20	Lots of ground vegetation present, raspberry, rosebay, hays, stumps
18.6.2025	2	Puumala, Heinlahti	coordinates for 10 sub-plots available upon request	Confidential	2022	dry heath forest, main tree pine mixed with spruce	3	5	standing forest, ground vegetation bilberry, lingonberry, rowan, lily of the valley, wall moss
18.6.2025	3	Ruokolahti	coordinates for 10 sub-plots available upon request	Confidential	2022	mesic heath forest, main tree spruce	2	30	lot of retention trees burnt, mainly pine and spruce, some burnt ground logs, lots of ground vegetation e.g. rosebay, birch, sorrel ferns and hays
18.6.2025	4	Joensuu, Haapovaarantie	coordinates for 10 sub-plots available upon request	Confidential	2023	dry pine forest, main tree pine	1	30	lot of burnt stumps, ground also burnt in places, some ground logs, ground vegetation ca 50% coverage, mainly hays, birch, some rosebays
18.6.2025	5	Joensuu, Revonkylä	coordinates for 10 sub-plots available upon request	Confidential	2023	dry pine forest, main tree pine	1	30	lot of burnt stumps, ground also burnt in places, some ground logs, ground vegetation ca 50%

² 1 = clear cut area with some retention trees, 2 = less than 50% of biomass retained prior to burning, 3 = no harvest activity

									coverage, mainly hays, birch, some rosebays
19.6.2025	6	Joensuu, Särkkäniemi	coordinates for 10 sub-plots available upon request	Confidential	2023	dry pine forest, main tree pine	2	30	
19.6.2025	7	Kaavi, Lyly1	coordinates for 10 sub-plots available upon request	Confidential	2023	dry heath forest, main tree pine mixed with birch	1	70	ground vegetation scarce, soil preparation done
19.6.2025	8	Kaavi, Lyly2	coordinates for 10 sub-plots available upon request	Confidential	2023	dry heath forest, main tree pine mixed with birch	2	70	ground vegetation scarce, mainly rosebay and hey, burnt stums
19.6.2025	9	Kaavi, Koski	coordinates for 10 sub-plots available upon request	Confidential	2024	young pine stand, dry	3	30	young pine stand with few bigger pines, ground vegetation mainly rowan, birch, lingonberry, haircap moss, heather
19.6.2025	10	Äänekoski	coordinates for 10 sub-plots available upon request	Confidential	2024	dry heath forest, main tree pine mixed with spruce	2	70	burnt ground logs, ground vegetation scarce mainly fire heather, hays

Sweden

date	Site #	Site location	sub sample	coordinates	Treated	Forest type	Amount of trees ³	% burnt	other observations
11.8.2025	1	Dalarna	coordinates for 10 sub-plots available upon request	Confidential	2024	dry heath forest, main tree pine	3	80	All trees burnt to ca two meter up the trunk, soil burnt in patches, ground vegetation scarce, mainly

³ 1 = clear cut area with some retention trees, 2 = less than 50% of biomass retained prior to burning, 3 = no harvest activity

									blueberry and lingonberry, plenty of boulders
11.8.2025	2	Dalarna	coordinates for 10 sub-plots available upon request	Confidential	2023	dry heath forest, main tree pine	3	80	All trees burnt to ca two meter up the trunk, soil burnt in patches, ground vegetation scarce, mainly blueberry and lingonberry, plenty of boulders
11.8.2025	3	Dalarna	coordinates for 10 sub-plots available upon request	Confidential	2023	dry heath forest, main tree pine	3	80	All trees burnt to ca two meter up the trunk, soil burnt in patches, ground vegetation scarce, mainly blueberry and lingonberry, plenty of boulders
11.8.2025	4	Dalarna	coordinates for 10 sub-plots available upon request	Confidential	2023	dry heath forest, mixed stand with pine and spruce	3	60	Stand next to a clear cut that was also burnt, one sub sample taken from the border of these two stands, ground vegetation present, mainly blueberry, some young alnus, hays and wall moss
12.8.2025	5	Dalarna	coordinates for 10 sub-plots available upon request	Confidential	2022	dry heath forest, main tree pine	3	60	All trees burnt to ca meter up the trunk, soil burnt in patches, ground vegetation scarce, mainly blueberry and lingonberry, plenty of boulders
12.8.2025	6	Dalarna	coordinates for 10 sub-plots available upon request	Confidential	2024	dry heath forest, main tree pine mixed with birch	3	70	All trees burnt to ca two meter up the trunk, soil burnt in patches, ground vegetation scarce, mainly blueberry and lingonberry, plenty of boulders
12.8.2025	7	Dalarna	coordinates for 10 sub-plots available upon request	Confidential	2024	dry heath forest, main tree pine	3	40	Trees burnt mainly from the very lowest part of the trunk, soil burnt in patches, ground vegetation present, mainly blueberry and

									lingonberry, plenty of boulders, some moist patches
12.8.2025	8	Dalarna	coordinates for 10 sub-plots available upon request	Confidential	2024	dry heath forest, main tree pine mixed with birch	3	40	Trees burnt mainly from the very lowest part of the trunk, soil burnt in patches, ground vegetation present, mainly blueberry and lingonberry, plenty of boulders, some moist patches
12.8.2025	9	Dalarna	coordinates for 10 sub-plots available upon request	Confidential	2022	dry heath forest, main tree pine mixed with spruce	3	30	Trees burnt mainly from the very lowest part of the trunk, soil burnt in patches, ground vegetation present, mainly blueberry and lingonberry, plenty of boulders, some moist patches
12.8.2025	10	Dalarna	coordinates for 10 sub-plots available upon request	Confidential	2022	dry heath forest, main tree pine	2	20	Very young pine stand next to a clearcut stand, ground vegetation present, young birch, blueberry, moss

Annex 7 – Summary and main information of raw data of eDNA laboratory testing

The raw data from the laboratory testing will be submitted as a separate ‘raw data’ excel. The excel also introduces the analysis utilised for the purposes of this report.

Below is an example pivot table of the taxa identified (Kingdom and Phylum) and how many of the individual species under each taxa level has been previously or newly identified for Finland, and where no ID has been included in the reference database for an individual species.

Count of ASV_IDs Taxa	New to Finland		No ID to species level	Total
	No	Yes		
k__Fungi	144	312		227 683
p__Ascomycota	32	196		139 367
c__Archaeorhizomycetes			1	1
c__Arthoniomycetes			1	1
c__Dothideomycetes	2	22	31	55
c__Eurotiomycetes	3	48	8	59
c__Geoglossomycetes			2	2
c__Lecanoromycetes	3	2	8	13
c__Leotiomycetes	13	33	40	86
c__NA		2	6	8
c__Orbiliomycetes		1	1	2
c__Pezizomycetes	8	3	6	17
c__Pezizomycotina_cls_Incertae_sedis		1		1
c__Saccharomycetes		5	2	7
c__Sordariomycetes	3	79	32	114
c__Xylonomycetes			1	1
p__Basidiomycota	112	76	65	253
c__Agaricomycetes	111	38	50	199
c__Cystobasidiomycetes		2	1	3
c__Dacrymycetes	1			1
c__Exobasidiomycetes		2		2
c__Geminibasidiomycetes			1	1
c__GS25			1	1
c__GS27			1	1
c__Microbotryomycetes		14	5	19
c__NA			1	1
c__Tremellomycetes		19	4	23
c__Tritirachiomycetes		1	1	2
p__Chytridiomycota		2	6	8
c__Chytridiomycetes		2	5	7

c__NA			1	1
p__Mortierellomycota			1	1
p__Mucoromycota	37		9	46
c__Endogonomycetes			3	3
c__Glomeromycetes			2	2
c__Mortierellomycetes	24		1	25
c__Mucoromycetes	7		1	8
c__Umbelopsidomycetes	6		2	8
p__NA			1	1
p__Olpidiomycota			1	1
p__Rozellomycota			5	5
p__Zoopagomycota	1			1
c__Basidiobolomycetes	1			1
Total	144	312	227	683

Annex 8 – Methodological overview and results of dead wood remote sensing

This information will be submitted as a separate annex.



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