DEVELOPMENT AND TESTING OF BIODIVERSITY MONITORING FRAMEWORKS IN BRAZIL

FINAL REPORT

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Title:	Development and Testing of Biodiversity Monitoring Frameworks in Brazil
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Executive Summary

The second work package of the *Fast-Tracking Biodiversity Assessment Project* aimed to develop and test standardized biodiversity monitoring frameworks for FSC-certified plantation forests in Brazil. The initiative responds to the need for consistent, scalable, and outcome-oriented monitoring approaches that can demonstrate the biodiversity outcomes of FSC certification and support the implementation of outcome-oriented Forest Stewardship Standards (FSS).

Two biodiversity monitoring frameworks were developed, focusing on key intended outcomes under the Brazilian FSS: (1) the conservation of rare and threatened species (Criterion 6.4), and (2) the conservation and restoration of native ecosystems (Criterion 6.5). The frameworks were designed through a structured process that included the definition of intended outcomes, a systematic literature review, co-development with local experts, and feasibility assessments with certificate holders.

Each framework integrates both remote sensing and field-based metrics to balance scalability and ecological accuracy. For rare and threatened species, monitoring combines **Relative Connectivity (RC)**—a proxy metric derived from geospatial data—and the **Density Dynamic Difference Index (DDDI)**, which captures structural changes in rare and threatened plant species over time. For native ecosystems, the frameworks apply the **Ecological Similarity Index (ESI)**—a proxy metric that compares their ecological conditions to reference ecosystems using remote sensing—and the **Integrated Shannon–Species Evenness Difference Index (ISSED)**, a field-based metric that compares their plant diversity to reference conditions.

The frameworks were tested across five management units in three major Brazilian biomes (Pampa, Atlantic Forest, and Cerrado) using both remote sensing and field-based methods. The results indicate that the assessed FSC-certified management units generally perform well in conserving rare and threatened (tree) species, while also showing moderate to high similarity between the (tree) diversity in native ecosystems within the management units and that of ecological reference conditions.

Despite these positive findings, some considerations were identified. Remote sensing approaches depend on data quality and consistency, while field-based monitoring is constrained by limited historical data, lack of permanent plots, and variability in sampling intensity. In addition, some methodological components—such as parameter selection and reference ecosystem identification—introduce subjectivity.

This report concludes that outcome-oriented biodiversity monitoring is feasible through hybrid frameworks that integrate remote sensing with field-based data. However, their effectiveness depends

on improving data quality, standardization, and the establishment of long-term monitoring systems to ensure greater comparability, consistency, and robustness.

Finally, this study recommends that biodiversity monitoring in the tropics should prioritize ecosystem-level outcomes (Criterion 6.5), and that monitoring frameworks should adopt hybrid approaches combining scalable remote sensing with targeted field validation within adaptive management systems. This requires closer collaboration with certificate holders, the development of standardized, centralized monitoring systems and cost-effective, practical designs for long-term implementation. Clear communication and sustained stakeholder engagement are also essential for building credibility and demonstrating measurable biodiversity outcomes of FSC certification.

Introduction

Forests are among the most biologically diverse ecosystems on Earth, providing habitat for countless species and playing a crucial role in maintaining global ecological balance. Conserving biodiversity is essential for sustaining key ecosystem services—such as carbon sequestration, water regulation, and soil health—that underpin environmental stability and human well-being.

In response to accelerating deforestation and biodiversity loss worldwide, the Forest Stewardship Council (FSC) has established a globally recognized standard for responsible forest management that promotes healthy and resilient forests. To better demonstrate the positive outcomes of FSC certification, FSC International, WWF, and IKEA launched the *Fast-Tracking Biodiversity Assessment Project*. This initiative comprises two work packages and focuses on three countries: Brazil, Sweden, and Finland.

The first work package mapped biodiversity monitoring efforts among FSC certificate holders. The results showed that FSC Forest Stewardship Standards (FSS) complement national legislation by introducing additional requirements, including biodiversity monitoring, the promotion of landscape connectivity, and the establishment of set-aside areas. Field evidence suggested that FSC certification enhance connectivity between native ecosystems, and support the conservation of rare and threatened species and their habitats. However, the wide variety of monitoring methods used by certificate holders restricts the aggregation of data and hinders the ability to measure progress towards FSC intended biodiversity outcomes at a larger scale.

Based on these findings, the second work package aimed to develop and test examples of biodiversity monitoring frameworks that can be applied consistently across FSC certificate holders within a defined FSS scope. The results were expected to inform the ongoing deployment of outcome orientation within FSS[1] by illustrating how monitoring frameworks can be developed, the roles that different stakeholders can play in their development and implementation, and the types of evidence such frameworks could generate to improve understanding of progress toward the achievement of FSC intended outcomes.

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[1] The <FSC-PRO-60 -006 The Development and Revision of FSC Country Requirements> and <FSC-PRO-60-006a Structure and Content of FSC Forest Stewardship Standards> present the requirements for developing outcome-oriented FSS, while <FSC-GUI-60-006 Guidance to make Forest Stewardship Standards outcome-oriented> provides a more detailed guidance for their implementation.

Purpose

This final report on the implementation of the second work package of the *Fast-Tracking Biodiversity Assessment Project* in Brazil aims to:

1. Present examples of biodiversity monitoring frameworks developed for the FSC Forest Stewardship Standard for Plantations in Brazil (FSC-STD-BRA-1.1-2025-Plantations) together with the approaches used for their development;

2. Summarize the main findings from testing these monitoring frameworks across FSC-certified management units of certificate holders in Brazil; and

3. Provide high-level conclusions and recommendations relevant to the development and implementation of monitoring frameworks as part of the deployment of outcome orientation in Forest Stewardship Standards (FSS).

Accordingly, the report is structured into three main sections. Section 1 presents approach taken to develop the examples of biodiversity monitoring frameworks, as well as a description of the elements of these frameworks and the rationale behind their definition. Section 2 summarizes the key findings from testing these frameworks. Finally, Section 3 presents the main conclusions and recommendations relevant to the deployment of outcome orientation in FSS.

Disclaimer

The second work package of the *Fast-Tracking Biodiversity Assessment Project* was not intended to test the deployment of outcome orientation within FSS. Rather, it used real-life examples to explore how monitoring frameworks could be developed, what roles local stakeholders could play in their implementation, and what type of evidence the implementation of such frameworks could generate about the progress towards FSC intended outcomes.

Terms and Definitions

Data collection methods: A precise description of the methods and tools required to collect data (Source: <FSC-PRO-60-006a Structure and Content of Forest Stewardship Standards>).

Data reporting: A description of the data to be reported, of standardization needs for metrics and units, and of tools and frequency of reporting to ensure data compilation is consistent and data are comparable for their analysis (Source: <FSC-PRO-60-006a Structure and Content of Forest Stewardship Standards>).

Expected analytical findings: A description of the learnings or insights expected to be gained from the analysis of data collected from monitoring indicators. They articulate how the data are expected to contribute to understanding the effectiveness of selected requirements for forest management certification and guide how quantitative results should be interpreted in that regard (Source: <FSC-PRO-60-006a Structure and Content of Forest Stewardship Standards>).

Key intended outcome: Intended outcome for which the implementation of normative requirements and progress monitoring are prioritized (Source: <FSC-PRO-60-006a Structure and Content of Forest Stewardship Standards>).

Intended outcome: The likely or achieved short-term and medium-term results from the implementation of FSC requirements (Adapted from OECD Glossary, 2002).

Monitoring framework: Set of elements designed to track the progress made towards achieving a key intended outcome. It defines what should be monitored, which monitoring indicator(s) and metrics to apply, how to collect, analyse and report data, and how to interpret results. It comprises *monitoring requirements* and *additional information*.

a) *Monitoring requirements*: The subset of normative requirements of the monitoring framework that are referenced in the FSS. These include the monitoring indicator(s), data collection methods, sampling, data reporting and additional data needs when relevant.
b) *Additional information*: The subset of elements of the monitoring framework that are not referenced in the FSS but are relevant for the design of the monitoring requirements and the interpretation of the results. These include the expected analytical findings and additional data needs when these are expected from the expert.

(Source: <FSC-PRO-60-006a Structure and Content of Forest Stewardship Standards>.)

Monitoring indicator: 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 (Source: <FSC-PRO-60-006a Structure and Content of Forest Stewardship Standards>).

Metric: A system or standard of measurement that is quantifiable and is used to track, compare, and assess monitoring indicators (adapted from Nature Positive, 2024).

Representative sample areas: Portions of the management unit delineated for the purpose of conserving or restoring viable examples of an ecosystem that would naturally occur in that geographic region. (Source: <FSC-STD-60-004 V2-0>)

Sampling: A clear and precise specification of the subset of units, or samples, selected from the overall population to ensure that the data collected are sufficient, relevant, and appropriate to arrive to the expected analytical findings. The sampling design shall be defined in a manner that ensures consistency, representativeness, and reliability of results.

The sampling description shall include, as a minimum: A) location or geographic scope of data collection; B) time period covered by the data collection; and C) frequency at which data are collected (Source: <FSC-PRO-60-006a Structure and Content of Forest Stewardship Standards>).

1. Examples of biodiversity monitoring frameworks

1.1. Description of approach to develop monitoring frameworks

The <FSC-PRO-60-006 The Development and Revision of FSC Country Requirements> and <FSC-PRO-60-006a Structure and Content of FSC Forest Stewardship Standards> requires that, during the development or revision of Forest Stewardship Standards (FSS), experts appointed by the responsible body shall establish monitoring frameworks to evaluate progress toward key intended outcomes identified by the working group, in close coordination with it. However, as this project was not designed as a formal pilot on outcome orientation, the working group was neither involved in the selection of key intended outcomes nor in the design of the monitoring framework. Instead, the project served as an exercise to demonstrate how experts could develop such monitoring frameworks. Accordingly, the four steps undertaken to develop the monitoring frameworks—implemented in collaboration with local biodiversity monitoring experts and certificate holders—are described in greater detail below.

1.1.1. STEP 1: Definition of biodiversity-related intended outcomes

First, we reviewed the recently approved *Forest Stewardship Standards for Plantations for Brazil* (FSC-STD-BRA-1.1-2025-Plantations) to identify criteria related to biodiversity. Subsequently, the two criteria considered most relevant for the Brazilian context—6.4 and 6.5, as identified under Work Package 1 of the project—were selected for further analysis.

These criteria were then examined to define their intended outcomes based on their wording, considering both explicit objectives and implied effects on biodiversity. Building on this analysis, a simplified Theory of Change was developed for each criterion, illustrating the causal relationships between required inputs, management activities, expected outputs, and the intended biodiversity outcomes of the standard. The resulting Theories of Change are presented in Figures 1 and 2 below.

Figure 1: Theory of change developed for Criterion 6.4.

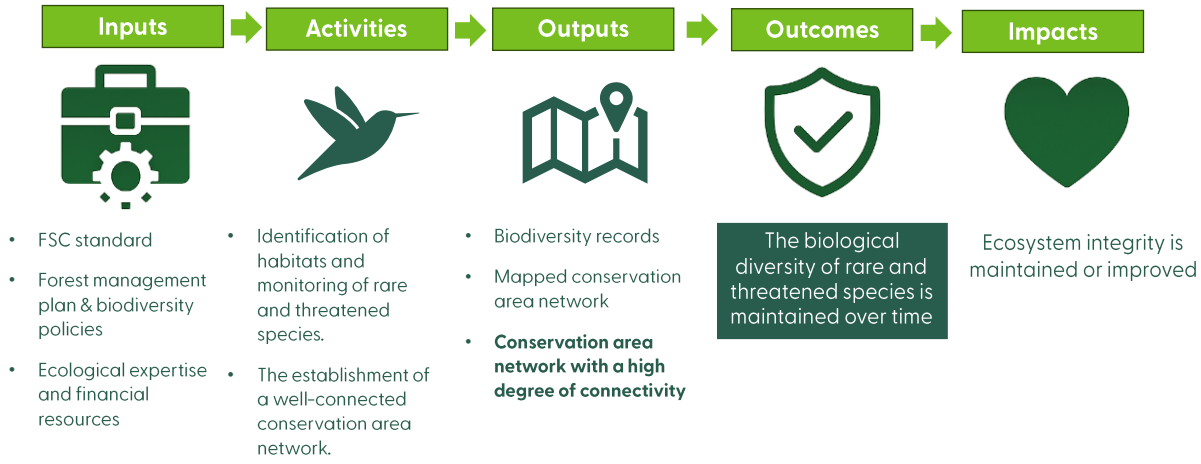
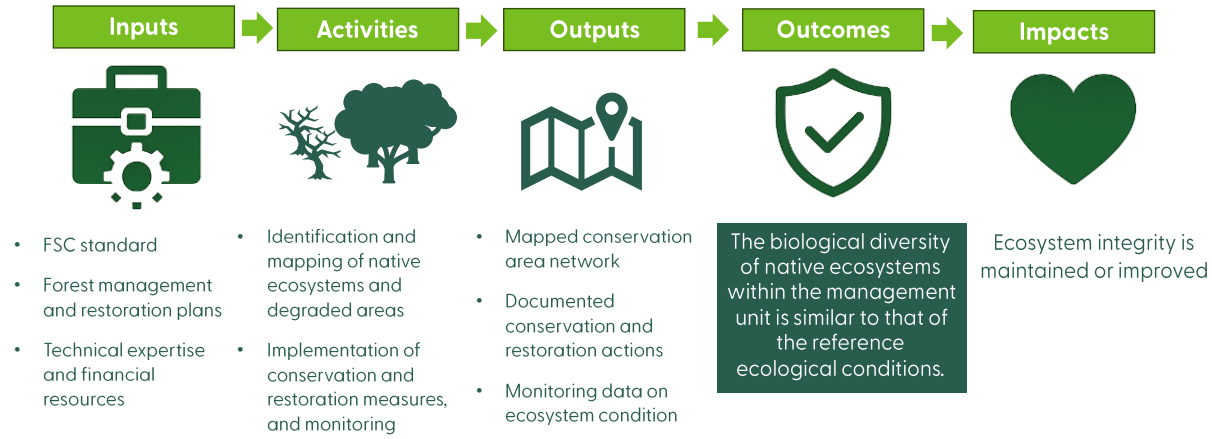


Figure 2: Theory of change developed for Criterion 6.5



1.1.2. STEP 2: Literature review on biodiversity monitoring.

Once the Theories of Change had been developed and the intended outcomes clearly defined, a systematic literature search was undertaken using the academic databases Scopus and Web of Science. Relevant publications were identified through tailored search strings that combined keywords associated with each intended outcome with terms referring to tropical regions, ensuring both thematic and geographic relevance. To further strengthen the evidence base, this search was complemented with curated literature drawn from FSC resources, including the FSC Impact Dashboard and the FSC Research Portal, which provided additional context-specific and practice-oriented studies relevant to monitoring biodiversity outcomes.

Following the compilation of the initial pool of records, all titles and abstracts were systematically screened to identify studies with clear relevance to the monitoring of the defined biodiversity outcomes. This screening process applied the following predefined inclusion criteria to ensure consistency and rigor: (i) the studies are peer-reviewed scientific articles; (ii) they aim to monitor the selected intended biodiversity outcomes; and (iii) they are conducted in native ecosystems within the tropics. Articles that met these criteria were subsequently selected for full-text review. The aim of this in-depth analysis was to identify and extract robust monitoring indicators, as well as methodological approaches and tools, that could be used to assess progress toward the selected intended outcomes. Particular attention was given to approaches that are applicable, feasible, and scalable within the context of Brazilian plantation forestry, ensuring that the resulting recommendations are both scientifically grounded and operationally relevant.

1.1.3. STEP 3: Co-development of monitoring frameworks local experts

Following the identification of robust data sources and potential approaches for monitoring the selected biodiversity intended outcomes, a series of six online workshops was organized with Brazilian biodiversity monitoring experts from academia, certification bodies, and private consultancies. These workshops pursued two main objectives. First, to validate the relevance and contextual appropriateness of the selected criteria and intended biodiversity outcomes for FSC-certified plantation forestry in Brazil. Second, to jointly assess and refine a set of monitoring indicators and methodologies—both those identified in the literature review and additional expert-suggested approaches—that could support a standardized monitoring framework.

Through this collaborative and iterative process, complemented by targeted individual consultations, the first comprehensive versions of the monitoring frameworks were co-developed with the local experts. These frameworks included a structured set of indicators and methodologies, along with clear justifications for their selection, ensuring both scientific robustness and practical applicability within the Brazilian context.

1.1.4. STEP 4: Feasibility assessment with certificate holders

As a final step to further refine the monitoring frameworks, a feasibility assessment of the practical implementation of these frameworks was conducted through a combination of desk review and engagement with certificate holders. This process evaluated several key aspects: whether existing monitoring practices align with the proposed framework, the extent to which local expertise is available to support its application (for example, knowledge of rare and threatened plant species monitoring), and whether the associated costs fall within a range considered acceptable by certificate holders.

The desk review primarily drew on findings from Work Package 1 of the *Fast-Tracking Biodiversity Project*, which systematically mapped current biodiversity monitoring practices among certificate holders in Brazil. In parallel, targeted consultations were carried out with key stakeholders, including representatives from one of Brazil's largest plantation industry associations: Iba, as well as specific certificate holders interested in providing feedback on the biodiversity monitoring frameworks. As a result of this process, robust and context-sensitive monitoring frameworks were finalized.

1.2. Biodiversity monitoring frameworks for FSC-certified plantations in Brazil

As mentioned above, two monitoring frameworks were developed for the Forest Stewardship Standard for Plantations for Brazil (FSC-STD-BRA-1.1-2025-Plantations). The first of these is a monitoring framework designed to assess the conservation of rare and threatened species. This framework aims to evaluate progress towards the key intended outcome defined under Criterion 6.4: *'The biological diversity of rare and threatened species is maintained over time.'* The second framework assesses the conservation and restoration of native ecosystems and aims to evaluate progress towards the key intended outcome defined under Criterion 6.5: *'The biological diversity of representative sample areas of native ecosystems resembles that of ecological reference conditions.'*. The following subsections present all elements of these frameworks and the rationale behind their definition.

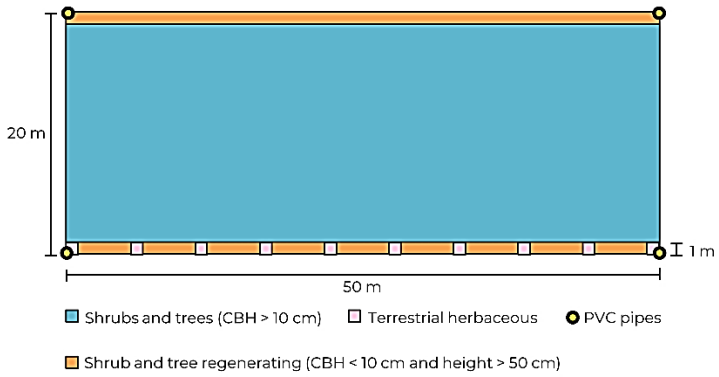
1.2.1. Framework to assess the conservation of rare and threatened species (Criterion 6.4.)

Element	Description	Rationale for the definition of the element
1. Key intended outcome	The biological diversity of rare and threatened species is maintained over time	Brazil hosts some of the world's most biodiverse and threatened ecosystems, many of which overlap with commercial forestry plantations. These plantations are frequently located within or adjacent to highly threatened biomes such as the Atlantic Forest and the Cerrado, where forest management practices can significantly influence the conservation of rare and threatened species through habitat protection and restoration, as well as the maintenance of landscape connectivity. Reflecting this importance, Criterion 6.4[2] emphasizes the identification, protection, and monitoring of rare and threatened species. Therefore, the conservation of rare and threatened species was selected as a key intended outcome of the FSC Forest Stewardship Standard for Plantations for Brazil.
2. Expected analytical findings	Forest management activities required by indicators 6.4.1–6.4.5 allow the diversity of rare and threatened plant species in the management unit to be maintained over time.	Focusing on rare and threatened plant species offers several practical and scientific advantages for outcome-oriented biodiversity monitoring. Unlike many animal species, plants are stationary, which makes them easier to detect, identify, and monitor consistently over time, reducing uncertainty linked to movement or seasonal behaviour. Monitoring plant species is generally less resource-intensive and more cost-effective, and it can draw on extensive existing knowledge, including national red lists, floristic inventories, and habitat assessments, as well as strong local expertise in plant identification and monitoring methods. In addition, rare and threatened plant species often reflect

[2] Criterion 6.4.: The Organization shall protect rare species and threatened species and their habitats in the management unit through conservation zones, protection areas, connectivity and/or (where necessary) other direct measures for their survival and viability. These measures shall be proportionate to the scale, intensity, and risk of management activities and to the conservation status and ecological requirements of the rare and threatened species. The Organization shall take into account the geographic range and ecological requirements of rare and threatened species beyond the boundary of the management unit, when determining the measures to be taken inside the management unit.

		broader ecosystem conditions, as they are closely linked to habitat quality, structure, and management practices. For these reasons, the current focus is placed on rare and threatened plant species, as they provide a feasible, reliable, and informative entry point for assessing biodiversity outcomes and monitoring progress under FSC-certified forest management.
3. Monitoring indicators	Monitoring indicator: Degree of maintenance of the diversity of rare and threatened plant species	The monitoring indicator is broad and reflects the type of evidence needed to produce the expected analytical findings and assess progress toward the selected key intended outcomes. Two metrics can be used to evaluate this indicator. *Relative Connectivity* is a proxy metric that assumes higher connectivity among representative sample areas of native ecosystems within the management unit is associated with better conservation of rare and threatened plant species over time. The *Density Dynamics Difference Index* is a field-based measure that assesses changes in the absolute density and dominance of rare and threatened plant species over time.
	Metric 1 (Remote sensing): Relative Connectivity (%)	Relative Connectivity shows how close the habitat network is to a single-patch fully connected system. It measures the ratio between the Equivalent Connected Area (ECA) and the total habitat area in the network (Saura et al., 2017; 148). The ECA is a structural connectivity metric that characterizes an entire habitat system by assessing both i) the size of individual patches and ii) their connectivity, represented through nodes and edges, respectively. It can be thought of as the equivalent single-patch area that would provide the same ecological capacity as the dispersed patches (Saura et al., 2011)
	Metric 2 (Field): Density Dynamic Difference Index (No unit) for arboreal, shrub, and herbaceous strata	Density Dynamic Difference Index (DDDI) is a metric that synthesize changes in the structural parameters of rare and threatened species between monitoring periods. The DDDI integrates normalized differences in absolute density and absolute dominance of rare and threatened plant species, two widely used phytosociological metrics that describe both the abundance and the structural contribution of such species within plant communities (Dengler, 2013).
4. Data collection methods	For Metric 1 – Relative Connectivity a) The boundary of the management unit and the representative sample areas of native ecosystems within it shall be georeferenced using WGS 1984.	Data collection methods for this metric were based on Saura et al. (2017),with novelty introduced through the use of MapBiomas land-use data and the explicit assignment of resistance values. Land-use and land-cover raster from MapBiomas were selected as they provide the most current and reliable satellite-derived representation of the study area. Habitat patches smaller than 10 ha were excluded based on the assumption that such small fragments are

	b) The determination of land-use classes across the management unit shall be done using the latest land-use raster available from MapBiomass. c) Habitat patches shall be created by processing the land-use raster in GraphHab using 4-connexity. d) Habitat patches smaller than 10ha shall be removed. e) The following resistance values shall be assigned to the land use classes: i. Water, mining and urban area: 9; ii. Farming/crops: 5; iii. Forest plantations: 3; and iv. Forest formation, Savanna formation, Grassland, Wooden sandbank, and Wetland: 1. f) Habitat Link set shall be created and Equivalent Connected Area for the representative sample areas of native ecosystems within the management unit shall be calculated based on Saura et al. (2011).	unlikely to sustain viable populations or contribute meaningfully to functional connectivity for rare or threatened species. Resistance values were assigned according to the presumed capacity of each land-use class to provide habitat or facilitate movement: native ecosystems—forest formation, savanna formation, grassland, wooded sandbank, and wetland—were assigned a resistance value of 1 due to their high ecological integrity, while forest plantations and agricultural areas were assigned values of 3 and 5, respectively, reflecting increasing land-use intensification and ecological simplification. Water bodies, mining areas, and urban land uses were assigned the highest resistance value (9), representing environments with minimal suitability and high resistance to movement for rare and threatened species.
For Metric 2 - Density Dynamic Difference Index a) 20mx50m sampling plots shall be established by demarcating their vertices with PVC pipes and their boundaries with nylon string. The following subplots shall be established within each plot: i. Two 1mx50m subplots for sampling shrub species; and ii. Ten 1mx1m subplots for sampling herbaceous vegetation. See plot configuration bellow:	Data collection methods for this metric were informed by a combination of peer-reviewed research and local expert knowledge. The size of the sampling plots was selected based on recommendations by (Yang et al., 2019), who advocate the use of 0.1 ha rectangular plots to assess plant species composition in species-rich forests. Rectangular plots of this size are considered sufficiently large to capture canopy and sub-canopy diversity and spatial heterogeneity, while remaining operationally feasible for field implementation and long-term monitoring. In addition, the size and spatial arrangement of subplots used to assess shrub species and herbaceous vegetation were defined in consultation with local experts, considering site conditions, vegetation structure, and practical constraints related to fieldwork efficiency and data consistency. This nested design allows for the effective sampling of different vegetation strata within the boundaries of the larger plot.	



b) Phytosociological data shall be recorded for rare and threatened species across the arboreal, shrub, and herbaceous strata:

i. In the arboreal stratum, all individuals with a circumference at breast high (CBH) > 10 cm and height > 1.3 m shall be identified to species, measured for CBH, had their height estimated, and be permanently tagged. When bamboo clumps with multiple culms occur within the plot, mean CBH and height shall be estimated from a subset of culms and extrapolated to the total number of culms counted.

ii. In the shrub stratum, all individuals with CBH < 10 cm and height > 50 cm shall be recorded, including species identification and crown diameter.

iii. In the herbaceous stratum, the percentage cover of each species within the plot, or of individuals with a height < 50 cm, shall be estimated.

c) Density and dominance of rare and threatened plant species per strata shall be calculated using the

The methods used to collect phytosociological data for rare and threatened species across the arboreal, shrub, and herbaceous strata were based on established phytosociological approaches described by Turchetto et al. (2017), complemented by guidance from local experts to ensure methodological feasibility and ecological relevance in the local context.

	corresponding formulas from Mueller-Dombois & Ellenberg (1974); and Magurran & McGill (2011).	
5. Sampling	For Metric 1 – Relative Connectivity: Not applicable	Sampling does not apply to this metric, as connectivity among all patches of representative sample areas of native ecosystems within the management unit—that is, the entire population—was analysed.
	For Metric 2 - Density Dynamic Difference Index a) Sampling method: Systematic stratified approach. i. Representative sample areas of native ecosystems within the management units shall be stratified according to their ecological characteristics, including vegetation type (based on the IBGE, 2012 classification), conservation stage (initial, intermediate, advanced, and primary forest, according to CONAMA), and land use class (e.g., native vegetation, restoration areas, and managed native forest), using information provided by Certificate Holders or MapBiomas. ii. A grid of 100 × 100 m cells shall be overlaid on the total area of each management unit, and only grid cells fully contained within representative sample areas of native ecosystems must be retained. iii. The location of sampling plots shall be randomly selected from the retained cells but proportionally distributed according to the area occupied by each stratum. b) The sampled area shall be calculated as the square root of the total area of the representative sample areas of native ecosystems (in hectares), multiplied by 0.03. c) Nr of sampling plots shall be calculated by multiplying the sampled area by 10. The maximum number of plots to be stablished within a management unit is 50. d) The frequency of data collection shall be 5 years	Sampling for this metric was designed to focus specifically on representative sample areas of native ecosystems within each management unit, as these areas have the highest probability of hosting rare and threatened plant species. A systematic stratified sampling approach was selected to ensure effective coverage of ecological variability while maintaining consistency and comparability across management units. The total sampled area and the number of sampling plots were defined in consultation with local experts to strike an appropriate balance between ecological representativeness, statistical robustness, and operational feasibility, thereby limiting the number of plots established and ensuring that long-term monitoring remains practical. Finally, a five-year data collection frequency was adopted to align with the certification cycle, allowing for the collection of at least two data points per certificate holder—at the beginning and end of the certification cycle—which is essential for assessing changes over time and evaluating the effectiveness of the relevant criteria.

6. Additional data needs	For Metric 1 – Relative Connectivity a) Baseline value: Not applicable b) The Relative Connectivity for the management unit shall be calculated as the ratio between the Equivalent Connected Area of the representative sample areas of native ecosystems within the management unit; and the total area of representative sample areas of native ecosystems within the management unit.	This metric does not have a baseline value, as it is a proxy for the conservation status of rare and threatened plant species rather than a direct measure of species diversity. Consequently, higher relative connectivity values indicate that connectivity is higher, and that rare and threatened plant species are better conserved over time. The calculation of Relative Connectivity was based on Saura et al (2017). The Equivalent Connected Area is a structural connectivity metric that characterizes an entire habitat system by assessing both i) the size of individual patches and ii) their connectivity, represented through nodes and edges, respectively (Saura et al., 2011)
	For Metric 2 - Density Dynamic Difference Index a) The following baseline values shall be calculated: i. Absolute density of rare and threatened species in the arboreal, shrub, and herbaceous strata from the *previous monitoring period* (individuals/ha) ii. Absolute dominance of rare and threatened species in the arboreal, shrub, and herbaceous strata from the *previous monitoring period* (m2/ha) The calculation of these values shall be based on (Magurran & McGill, 2011) b) The Density Dynamic Difference Index shall be calculated using the following formula:	A baseline value was needed for this metric as the calculation of the Density Dynamic Difference Index needs values from the previous monitoring period. Such values were absolute density and dominance of rare and threatened plant species per strata, and their calculation was based on (Magurran & McGill, 2011) The formula to calculate the Density Dynamic Difference Index (DDDI) is novel and built on well-researched phytosociological measures—absolute density and dominance—to capture changes in rare and threatened plant species between monitoring periods. By integrating normalized differences in these parameters, the DDDI reflects both demographic presence and structural relevance within plant communities. Normalization ensures scale independence and comparability across monitoring cycles, supporting consistent interpretation of population trends (Magurran & McGill, 2011)

	$\Delta DEN_{RTE} = \frac{DEN_{RTEcurrent} - DEN_{RTEprevious}}{DEN_{RTEcurrent} + DEN_{RTEprevious}}$ $\Delta DOM_{RTE} = \frac{DOM_{RTEcurrent} - DOM_{RTEprevious}}{DOM_{RTEcurrent} + DOM_{RTEprevious}}$ $DDDI = \frac{\Delta DEN_{RTE} + \Delta DOM_{RTE}}{2}$ Where: $DEN_{RTEcurrent}$= density of RTE species in the current monitoring cycle $DEN_{RTEprevious}$= density of RTE species in the previous monitoring cycle $DOM_{RTEcurrent}$= dominance of RTE species in the current monitoring cycle $DOM_{RTEprevious}$= dominance of RTE species in the previous monitoring cycle	
7. Data reporting	For Metric 1 – Relative Connectivity a) The following values shall be reported: i. Area of representative sample areas of native ecosystems within the management unit (ha) ii. Equivalent Connected Area of representative sample areas of native ecosystems within the management unit (ha) iii. Relative Connectivity (%) b) Reporting frequency shall be every 5 years during the main evaluation. c) The reporting method shall be the digital audit report prepared by the accredited certification bodies.	The selection of the reported values was based on the relevance of aggregating data to demonstrate the outcomes of FSC certification on a large scale. In this regard, aggregating the total area of representative sample areas of native ecosystems will provide information on the extent of conserved areas; the aggregation of the equivalent connected area will provide information on the ecological capacity of these areas; and aggregating relative connectivity will provide information on the progress towards the ideal value of 100%. The reporting frequency was chosen to ensure that there are at least two data points per certification cycle. The reporting method selected was the digital audit report, as this facilitates the transfer of data between certificate holders and the FSC by using auditors from accredited certification bodies as intermediaries.
	For Metric 2 - Density Dynamic Difference Index a) The following values shall be reported: i. Absolute density of rare and threatened species in the arboreal, shrub, and herbaceous strata from the previous monitoring period (individuals/ha)	The selection of the reported values was based on the relevance of aggregating data to demonstrate the outcomes of FSC certification on a large scale. In this regard, aggregating the absolute density and dominance of rare and threatened species in previous and current monitoring periods will provide information on how these values changed over time, while the Density Dynamic

	ii. Absolute dominance of rare and threatened species in the arboreal, shrub, and herbaceous strata from the previous monitoring period (m2/ha) iii. Absolute density of rare and threatened species in the arboreal, shrub, and herbaceous strata from the current monitoring period (individuals/ha) iv. Absolute dominance of rare and threatened species in the arboreal, shrub, and herbaceous strata from the current monitoring period (m2/ha) v. Absolute density and dominance of rare and threatened species in the arboreal, shrub, and herbaceous strata from the current monitoring period vi. Density Dynamic Difference Index (No unit) b) Reporting frequency shall be every 5 years during the main evaluation. c) The reporting method shall be the digital audit report prepared by the accredited certification bodies.	Difference Index will provide information on the progress towards the ideal value of 0. The reporting frequency was chosen to ensure that there are at least two data points per certification cycle. The reporting method selected was the digital audit report, as this facilitates the transfer of data between certificate holders and the FSC by using auditors from accredited certification bodies as intermediaries.

1.2.2. Framework to assess the conservation and restauration of native ecosystems (Criterion 6.5.)

Element	Description	Rationale
1. Key intended outcome	The biological diversity of representative sample areas of native ecosystems within the management unit resembles that of ecological reference conditions.	Brazil hosts a wide diversity of native ecosystems that are highly heterogeneous and increasingly fragmented due to land-use change. In this context, remnants of native ecosystems within managed forestry plantations play a critical role in conserving habitats, maintaining species diversity, and supporting ecological processes at the landscape level. Ensuring that the biological diversity of these native ecosystems resembles ecological reference conditions is essential for maintaining ecosystem structure, composition, and function, and for providing benchmarks to assess the impacts of forest management. Reflecting this importance, Criterion 6.5[3] emphasizes the protection representative sample areas of native ecosystems within the management unit and their restoration to more natural conditions. Therefore, the conservation and restoration of native ecosystems to reflect ecological reference conditions was selected as a key intended outcome of the FSC Forest Stewardship Standard for Plantations for Brazil.
2. Expected analytical findings	Forest management activities required by indicators 6.5.1–6.5.5 allow the diversity of plant species to be similar to that of ecological reference conditions.	Focusing on plant species offers clear practical and scientific advantages for outcome-oriented biodiversity monitoring. As immobile organisms, plants can be detected, identified, and monitored consistently over time, reducing uncertainty associated with movement or seasonal behaviour. Plant-based monitoring is generally less resource-intensive and cost-effective, and it benefits from extensive existing knowledge, floristic inventories, and habitat

[3] Criterion 6.5. The Organization shall identify and protect representative sample areas of native ecosystems and/or restore them to more natural conditions. Where representative sample areas do not exist or are insufficient, The Organization shall restore a proportion of the Management Unit to more natural conditions. The size of the areas and the measures taken for their protection or restoration, including within plantations, shall be proportionate to the conservation status and value of the ecosystems at the landscape level, and the scale, intensity and risk of management activities

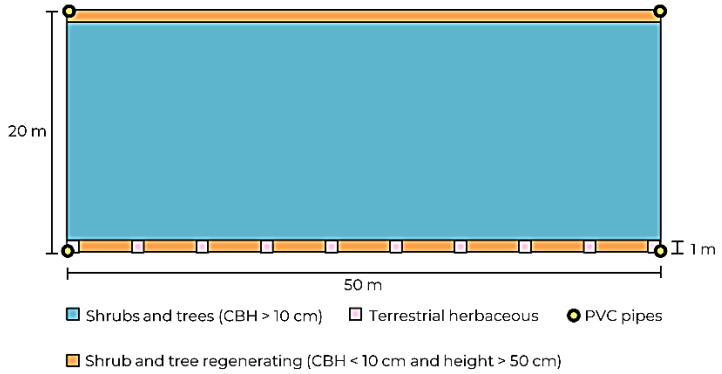
		assessments, supported by strong local expertise. Moreover, plant species are sensible to habitat quality, structure, and management practices, making them effective indicators of broader ecosystem condition. For these reasons, plant species provide a feasible, reliable, and informative basis for assessing biodiversity outcomes and tracking performance under FSC-certified forest management.
3. Monitoring indicators	Monitoring indicator: Degree of similarity in the diversity of plant species in relation to reference ecological conditions	The monitoring indicator is intentionally broad, reflecting the type of evidence required to generate the expected analytical findings and assess progress toward the selected key intended outcome. Two complementary metrics can be used to evaluate this indicator. The *Ecological Similarity Index* measures the similarity between ecological parameters— derived from remote sensing—of representative sample areas of native ecosystems within management units and those of reference ecosystems. The *Integrated Shannon–Species Evenness Difference Index* is a field-based metric that assesses the similarity of plant biodiversity parameters between representative sample areas of native ecosystems within management units and reference ecosystems.
	Metric 1 (Remote sensing): Ecological Similarity Index (No unit)	The Ecological Similarity Index (ESI) synthesizes the degree of similarity between key ecological parameters—namely aboveground biomass, NDVI performance, and canopy height—of representative sample areas of native ecosystems within the management unit and those of reference ecosystems. To ensure meaningful comparisons, similarity is assessed at the land-use class level. This approach avoids comparing fundamentally different ecosystem types (e.g., native grasslands versus native forests). Instead, comparisons are conducted within the same ecosystem categories, such as native forests within the management units with native forest in reference ecosystems and native grasslands within the management unit with native grasslands in reference ecosystems.
	Metric 2 (Field): Integrated Shannon–Species Evenness Difference Index (No unit)	The Integrated Shannon–Species Evenness Difference Index (ISSED) is a composite metric designed to capture how closely the biodiversity characteristics of a managed native ecosystem align with those of a reference or undisturbed ecosystem. It integrates key ecological indicators—primarily the Shannon diversity index, which reflects both species richness and abundance distribution, and species richness itself—to evaluate differences

		in community composition and structural balance. By synthesizing these parameters, ISSED provides a more holistic measure of ecological similarity, highlighting not only the presence or absence of species but also the degree to which species are evenly distributed within the ecosystem. This makes it particularly useful for assessing ecological integrity, restoration success, or management effectiveness, as it quantifies deviations from reference conditions and helps identify whether biodiversity patterns within the management unit are converging toward or diverging from desired natural benchmarks.
4. Data collection methods	For Metric 1 – Ecological Similarity Index a) The boundary of the management unit and the representative sample areas of native ecosystems within it shall be georeferenced using WGS 1984. b) The representative sample areas of native ecosystems shall be classified by land-cover type (e.g., forest formation, grasslands, etc.) using the MapBiomas land-use classification raster. c) Key ecological variables shall be compiled, including aboveground biomass, canopy height, and NDVI performance (vegetation greenness and trends). d) All variables shall be normalized to a 0-1 scale (after outlier control) and combined into a composite Ecological Index (EI) score for each pixel. e) Pixel-level EI scores shall be generated for the representative sample areas of native ecosystems within the management unit.	The selection of this data collection method is justified by its ability to deliver consistent, spatially explicit, and scalable measurements of ecosystem condition using widely validated geospatial and remote sensing tools. Georeferencing ensures accurate spatial alignment and reproducibility across assessments, while the use of standardized land-cover datasets such as MapBiomas provides a reliable and regionally harmonized basis for classifying ecosystem types. The integration of variables like aboveground biomass, canopy height, and NDVI allows for a comprehensive characterization of ecosystem structure, productivity, and vegetation health, capturing key dimensions of ecological integrity. Normalizing these variables to a common scale reduces biases associated with differing units and data ranges, enabling their robust aggregation into a single index. Additionally, the pixel-level approach enhances sensitivity to spatial variability and supports high-resolution monitoring, making the method particularly suitable for detecting changes over time and comparing management outcomes against reference conditions.
	For Metric 2 - Integrated Shannon–Species Evenness Difference Index a) 20mx50m sampling plots shall be established by demarcating their vertices with PVC pipes and their	Data collection methods for this metric were informed by a combination of peer-reviewed research and local expert knowledge. The size of the sampling plots was selected based on recommendations by (Yang et al., 2019), who advocate the use of 0.1 ha rectangular plots to assess plant species composition in species-rich forests. Rectangular plots of this

boundaries with nylon string. The following subplots shall be established within each plot:

i. Two 1mx50m subplots for sampling shrub species; and
ii. Ten 1mx1m subplots for sampling herbaceous vegetation.

See plot configuration bellow:



b) Phytosociological data shall be recorded for all plant species across the arboreal, shrub, and herbaceous strata:

i. In the arboreal stratum, all individuals with a circumference at breast high (CBH) > 10 cm and height > 1.3 m shall be identified to species, measured for CBH, had their height estimated, and be permanently tagged. When bamboo clumps with multiple culms occur within the plot, mean CBH and height shall be estimated from a subset of culms and extrapolated to the total number of culms counted.

size are considered sufficiently large to capture canopy and sub-canopy diversity and spatial heterogeneity, while remaining operationally feasible for field implementation and long-term monitoring. In addition, the size and spatial arrangement of subplots used to assess shrub species and herbaceous vegetation were defined in consultation with local experts, considering site conditions, vegetation structure, and practical constraints related to fieldwork efficiency and data consistency. This nested design allows for the effective sampling of different vegetation strata within the boundaries of the larger plot.

The methods used to collect phytosociological data for plant species across the arboreal, shrub, and herbaceous strata were based on established phytosociological approaches described by Turchetto et al. (2017), complemented by guidance from local experts to ensure methodological feasibility and ecological relevance in the local context.

	ii. In the shrub stratum, all individuals with CBH < 10 cm and height > 50 cm shall be recorded, including species identification and crown diameter. iii. In the herbaceous stratum, the percentage cover of each species within the plot, or of individuals with a height < 50 cm, shall be estimated. c) Richness and Shannon Index of plant species per strata shall be calculated using the corresponding formulas from Magurran & McGill (2011)	
5. Sampling	For Metric 1 – Ecological Similarity Index Not applicable	Sampling does not apply to this metric, as connectivity among all patches of representative sample areas of native ecosystems within the management unit—that is, the entire population—was analysed.
	For Metric 2 - Integrated Shannon–Species Evenness Difference Index a) Sampling method: Systematic stratified approach. i. Representative sample areas of native ecosystems within the management units shall be stratified according to their ecological characteristics, including vegetation type (based on the IBGE, 2012 classification), conservation stage (initial, intermediate, advanced, and primary forest, according to CONAMA), and land use class (e.g., native vegetation, restoration areas, and managed native forest), using information provided by Certificate Holders or MapBiomas. ii. A grid of 100 × 100 m cells shall be overlaid on the total area of each management unit, and only grid cells fully contained within representative sample areas of native ecosystems must be retained. iii. The location of sampling plots shall be randomly selected from the retained cells but proportionally	This sampling was designed to ensure that biodiversity data are representative, statistically robust, and operationally feasible across heterogeneous management units. The systematic stratified approach captures ecological variability by accounting for differences in vegetation type, conservation stage, and land-use class, improving the relevance and comparability of results. The use of a regular grid combined with random plot selection reduces spatial bias while maintaining statistical rigor, and proportional allocation ensures adequate representation of each stratum. The scaling of sampling effort based on total area allows for consistent application across sites of different sizes while maintaining practicality through a cap on the number of plots. Finally, the five-year monitoring interval balances the need to detect ecologically meaningful changes in plant communities with cost-effectiveness and long-term feasibility of monitoring efforts.

	distributed according to the area occupied by each stratum. b) The sampled area shall be calculated as the square root of the total area of the representative sample areas of native ecosystems (in hectares), multiplied by 0.03. c) Nr of sampling plots shall be calculated by multiplying the sampled area by 10. The maximum number of plots to be stablished within a management unit is 50. d) The frequency of data collection shall be 5 years	
6. Additional data needs	For Metric 1 – Ecological Similarity Index a) Baseline value: To calculate the baseline values, the following steps shall be taken i. Reference areas are selected from the IUCN Protected Areas database and filtered to (i) match the same RESOLVE ecoregion, (ii) be located within 100 km, and (iii) be represented as polygons. ii. Selected reference areas are classified by land-cover type (e.g., forest formations, grasslands) using the MapBiomas land-use classification raster. iii. Key ecological variables are compiled for the reference areas, including aboveground biomass, canopy height, and NDVI performance (vegetation greenness and trends). iv. These variables are normalized to a 0–1 scale (after outlier control) and	The additional data needed for the Ecological Similarity Index was designed to ensure a transparent, consistent, and ecologically meaningful estimation of baseline conditions and subsequent comparison with representative sample areas of native ecosystems within the management units. By deriving baseline values from carefully selected reference areas—filtered by ecoregion, proximity, and spatial representation—the approach ensures that benchmarks are both environmentally comparable and context-specific. Classifying reference areas by land-cover type further strengthens ecological relevance by enabling like-for-like comparisons across ecosystem types. The use of multiple ecological variables (aboveground biomass, canopy height, and NDVI) captures complementary dimensions of ecosystem structure, function, and productivity, while normalization and aggregation into a composite Ecological Index (EI) provide a standardized measure across datasets. Finally, computing the Ecological Similarity Index (ESI) as the difference between managed and reference conditions produces an intuitive, bounded metric that clearly indicates the degree to which management units align with natural ecosystem conditions, thereby supporting the assessment of progress toward intended biodiversity outcomes.

combined into a composite Ecological Index (EI) score for each pixel. v. Mean EI values (reference values) are calculated by land-cover class within the reference areas. b) The ESI value shall be computed for each land use type by comparing the mean EI values of the representative sample areas of native ecosystems within the management units and the corresponding reference areas, producing a value ranging from -1 to 1.	
For Metric 2 - Integrated Shannon–Species Evenness Difference Index a) Reference value To calculate the reference values, the following steps shall be undertaken: i. Reference areas are selected based on a bibliographic review, following the principle of best available scientific information. ii. Priority is given to areas that (i) are geographically close to the management units; (ii) share the same vegetation types as the representative sample areas within the management unit; (iii) are in good conservation condition or formally designated as protected areas; (iv) show no significant anthropogenic disturbance; and (v) provide phytosociological data derived from comparable sampling designs and clearly documented methodologies.	The additional data needed for the Integrated Shannon–Species Evenness Difference Index were designed to ensure that reference values for the Integrated Shannon–Species Evenness Difference Index are ecologically meaningful, scientifically robust, and comparable to field data collected in management units. Selecting reference areas through a bibliographic review based on best available scientific information allows the use of established, peer-reviewed knowledge where primary data may not be accessible. Prioritizing sites that are geographically close, share similar vegetation types, and are in good conservation condition ensures that comparisons are context-specific and reflect realistic ecological benchmarks. Excluding disturbed areas and favoring studies with compatible sampling designs and clear methodologies reduces bias and improves the reliability of comparisons. The use of species richness and the Shannon diversity index across vegetation strata captures both compositional and structural dimensions of biodiversity, while the application of standardized methods (Magurran & McGill, 2011) ensures consistency, transparency, and scientific credibility. Together, this approach supports a defensible and practical assessment of how biodiversity in managed areas compares to expected conditions in well-conserved ecosystems.

	iii. The following reference values are calculated: a) Species richness for the arboreal, shrub, and herbaceous strata (expressed as number of species per hectare); and b) Shannon diversity index for the arboreal, shrub, and herbaceous strata. The calculation of these values shall be based on Magurran & McGill (2011) b) The Integrated Shannon–Species Evenness Difference Index shall be calculated using the following formula: **Diferença Normalizada no Índice de Shannon** $$\Delta H' = \frac{H'_{Atual} - H'_{Referência}}{H'_{Atual} + H'_{Referência}}$$ **Diferença Normalizada na Riqueza** $$\Delta S = \frac{S_{Atual} - S_{Referência}}{S_{Atual} + S_{Referência}}$$ **Índice Final:** $$ISSED = \frac{(\Delta H' + \Delta S)}{2}$$	
7. Data reporting	For Metric 1 – Ecological Similarity Index a) The following values shall be reported: i. Area of representative sample areas of native ecosystems within the management unit (ha) ii. Mean Ecological Index per land use class of the reference areas (no unit)	Data reporting for the Ecological Similarity Index was designed to ensure transparency, comparability, and practical usability of results for assessing ecological condition over time. Reporting the extent of representative sample areas provides essential spatial context, allowing interpretation of results relative to the scale of native ecosystems under management. Presenting mean Ecological Index (EI) values for reference areas by land-use class establishes clear and ecologically relevant benchmarks, while reporting Ecological Similarity Index (ESI) values both by land-use class and at the aggregated level enables analysis at different levels of detail—supporting

iii. Mean Ecological Similarity Index per land use class of representative sample areas of native ecosystems within the management unit (no unit) iv. Mean Ecological Similarity Index for all representative sample areas of native ecosystems within the management unit (no unit) b) Reporting frequency shall be every 5 years during the main evaluation. c) The reporting method shall be the digital audit report prepared by the accredited certification bodies.	both targeted management decisions and overall performance evaluation. The five-year reporting frequency aligns with the temporal dynamics of ecosystem change and balances the need to detect meaningful trends with operational feasibility. Finally, using standardized digital audit reports prepared by accredited certification bodies ensures consistency, traceability, and credibility of the reported data within the FSC system.
For Metric 2 - Integrated Shannon–Species Evenness Difference Index a) The following values shall be reported: i. Richness of plant species in the arboreal, shrub, and herbaceous strata in the representative sample areas of native ecosystems within the management unit (nr of species/ha) ii. Richness of plant species in the arboreal, shrub, and herbaceous strata in reference area (nr of species /ha) iii. Shannon Index plant species in the arboreal, shrub, and herbaceous strata in the representative sample areas of native ecosystems within the management unit (no unit) iv. Shannon Index of plant species in the arboreal, shrub, and herbaceous strata in reference area (individuals/ha) v. Integrated Shannon–Species Evenness Difference Index (No unit)	This reporting framework is intended to ensure a comprehensive, transparent, and ecologically meaningful assessment of biodiversity conditions in managed areas relative to reference ecosystems. Reporting species richness and Shannon diversity indices across the arboreal, shrub, and herbaceous strata captures both the compositional and structural dimensions of plant biodiversity, recognizing that different vegetation layers contribute distinctly to overall ecosystem integrity. Including values for both the representative sample areas and the reference areas enable direct, like-for-like comparison, which is essential for interpreting the degree of deviation from expected ecological conditions. The inclusion of the Integrated Shannon–Species Evenness Difference Index provides a single, synthesized metric that facilitates interpretation and communication of results while retaining the underlying ecological detail. A five-year reporting interval is appropriate given the relatively slow dynamics of plant communities, allowing meaningful changes to be detected while maintaining operational feasibility. Finally, the use of standardized digital audit reports prepared by accredited certification bodies ensures consistency, and traceability of the reported information within the FSC system.

	b) Reporting frequency shall be every 5 years during the main evaluation. c) The reporting method shall be the digital audit report prepared by the accredited certification bodies.	

2. Key findings from testing the biodiversity monitoring frameworks

Two complementary tests were conducted: remote sensing tests and field tests. The remote sensing tests evaluated metrics derived from satellite and geospatial data and were implemented by staff from the Monitoring and Evaluation (M&E) team together with the Technology and Innovation Unit at FSC International, covering five management units. In parallel, field tests assessed metrics based on direct on-site measurements and were carried out by the Brazilian consulting team from Casa da Floresta Ltda in three management units.

The selection of partner certificate holders (CHs) and management units (MUs) was guided by the objective of ensuring representative, feasible, and meaningful testing conditions for the monitoring frameworks developed. Priority was given to CHs operating in regions where the majority of FSC-certified plantations are concentrated, thereby maximizing relevance across key biomes. Additionally, only management units large enough to support statistically robust sampling—meeting a minimum requirement of four plots—were included.

The selected units represent a gradient of plantation and native vegetation compositions, ensuring the applicability of the methodology across diverse landscape contexts and management realities. Specifically, the management units are located in the Pampa, Atlantic Forest, and Cerrado biomes, encompassing vegetation types such as seasonal deciduous forest, mixed ombrophilous and semideciduous forests, and Cerrado sensu stricto. Together, these units provide a balanced representation of ecological conditions, supporting the validation of monitoring approaches across varying biodiversity profiles while ensuring that the results are both scalable and relevant to FSC. Further details are provided in Table 1.

Table 1: Main characteristics of the five management units included in the tests.

MU	Biome	Area of the MU included in the test (ha)	Tests	
			Remote sensing	Field
1	Transition Pampa/Atlantic Forest	10 262	X	
2		3 815	X	
3		8 560	X	X
4	Atlantic Forest	120 285	X	X
5	Cerrado	16 783	X	X

2.1. The conservation of rare and threatened species

To assess the effectiveness of the key intended outcome under Criterion 6.4—namely, that the diversity of rare and threatened species is maintained over time—two metrics were applied: Relative Connectivity, a proxy that assumes that high connectivity leads to a good maintenance of the diversity of rare and threatened plant species, and the Dynamic Density Difference Index, which synthesizes temporal changes in two structural parameters of rare and threatened plant species: density and dominance.

The key results of testing these metrics using remote sensing and field-based methodologies, summarized below, reflect how these indicators contribute to evaluating whether current management practices are effectively progressing towards the mentioned key intended biodiversity outcome.

2.1.1. Relative Connectivity (RC)

The analysis of the Relative Connectivity indicates that **representative sample areas of native ecosystems within the assessed FSC-certified management units exhibit a high degree of connectivity, with an average relative connectivity of 86%, exceeding the global benchmark** (provided by Saura et al., 2017). See Figure 3. This finding suggests that, overall, habitat continuity within the management units remains strong, supporting ecological processes such as the maintenance of the biological diversity of rare and threatened species.

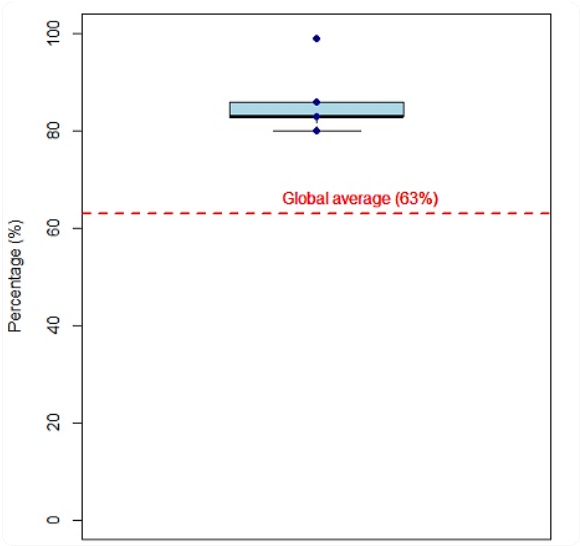
At the management unit (MU) level, connectivity values ranged from 80% to 99%, demonstrating consistently high performance across sites despite differences in size and the proportion of representative sample areas of native ecosystems. Management Units 1, 2, and 3 showed relatively similar connectivity levels (83%, 86%, and 83% respectively), while MU4 presented a slightly lower value (80%), potentially reflecting its larger spatial extent and landscape configuration. In contrast, MU5 exhibited the highest connectivity (99%), indicating near-complete linkage between native ecosystem patches.

These results suggest that, regardless of variations in RSA area (ranging from 1,463 ha to 46,566 ha) and proportional coverage (23% to 39%), the spatial arrangement and management of native vegetation within the assessed units are effective in maintaining a well-connected landscape. This high level of connectivity is a positive indicator for the conservation of biodiversity, particularly for rare and threatened species that depend on habitat continuity.

While the findings provide useful insights, several methodological limitations should be considered when interpreting the results. First, the effective application of remote sensing approaches depends on

the timely and consistent submission of data by certificate holders. E.g., all of the management units evaluated were subsets of the total certified area. Additionally, widely used datasets such as MapBiomas present constraints for detailed or long-term analyses, including potential classification errors and changes in methodology over time that can introduce inconsistencies in the results. Finally, certain parameters—such as resistance values applied in connectivity analyses—rely partly on expert judgment, which introduces an element of subjectivity. Together, these factors may influence the precision and reproducibility of the outcomes and should be considered when drawing conclusions or scaling the approach.

Figure 3: Relative Connectivity values across the five management units assessed



2.1.2. Density Dynamic Difference Index (DDDI)

The analysis of the Density Dynamic Difference Index (DDDI) indicates that **native ecosystems within the assessed FSC-certified management units have maintained similar structural parameters of rare and threatened plant species in the arboreal stratum compared to previous monitoring campaigns**. See Figure 4. Overall, these findings suggest that current management practices are effective in conserving these species over time.

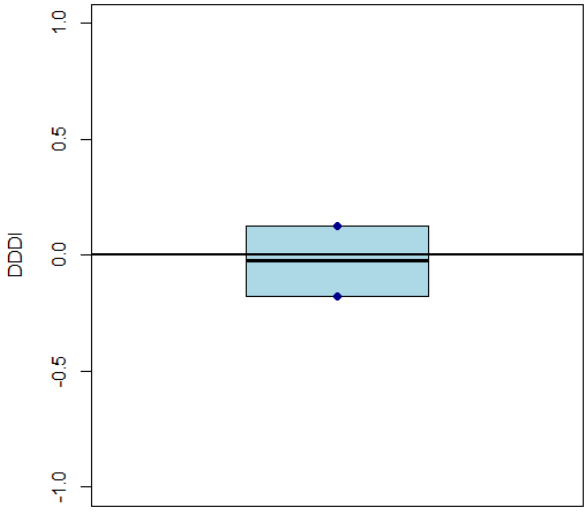
At the management unit (MU) level, results show some variation in density and dominance patterns. In MU4, species density increased substantially from 78.75 ind/ha in previous monitoring to 105 ind/ha in the FSC test monitoring, while dominance decreased from 6.70 m²/ha to 2.27 m²/ha, resulting in a slightly negative DDDI value (-0.1755). This indicates a shift toward higher numbers of individuals with lower overall dominance, which may reflect structural changes in the arboreal stratum. In contrast, MU5 showed a slight decrease in density (from 15 ind/ha to 12.5 ind/ha) but an increase in dominance

(from 0.2087 m²/ha to 0.4336 m²/ha), producing a positive DDDI value (0.1296), suggesting consolidation in the structural presence of species.

Despite these differences, the structural parameters of rare and threatened plant species in the arboreal stratum remained broadly consistent across monitoring periods. This overall stability highlights that, while localized shifts in density and dominance may occur, the ecological structure of these species are being maintained over time. Together, these results support the conclusion that the assessed management units are effectively contributing to the conservation of rare and threatened plant species.

While the methodology applied is generally appropriate for detecting rare and threatened species—particularly through stratification and well-designed sampling plots—some limitations should be considered. Ideally, the analysis would rely on historical data from the same permanent plots; however, due to time constraints related to project implementation, it draws instead on data from previous monitoring at the management unit level, which may be inconsistent or incomplete across native ecosystem areas, thereby limiting the robustness of temporal comparisons. Additionally, the historical monitoring focus on the arboreal stratum and High Conservation Value (HCV) areas may overlook important ecological dynamics in other vegetation layers. Consequently, the findings should be interpreted with caution, and future applications would benefit from the systematic use of permanent plots and more comprehensive data collection across a wider diversity of ecosystems.

Figure 4: Density Dynamic Difference Index (DDDI) values for the arboreal stratum across two management units



Note: Although three management units and three strata were included in the test, only results for two units and the arboreal stratum are presented here, as complete historical data for the remaining cases were not available to support the calculation of DDDI values.

2.2. The conservation and restauration of native ecosystems

To assess the effectiveness of the key intended outcome under Criterion 6.5—namely, that the diversity of native ecosystems within the management unit is comparable to reference ecological conditions—two complementary metrics were applied: the Ecological Similarity Index, which serves as a proxy under the assumption that similar ecological parameters reflect comparable species biodiversity, and the Integrated Shannon–Species Evenness Difference Index (ISSED), which captures the degree of similarity in plant species richness and diversity (Shannon index) between representative sample areas of native ecosystems and corresponding reference ecosystems.

The key results from testing these metrics—using a combination of remote sensing and field-based methodologies—are summarized below. Together, they demonstrate how these indicators support the evaluation of whether current management practices are effectively progressing toward the intended biodiversity outcome under this criterion.

2.2.1. The Ecological Similarity Index (ESI)

The analysis of the Ecological Similarity Index indicates that **native ecosystems within the assessed FSC-certified management units generally exhibit moderate to high ecological similarity to their respective reference areas**, with values closer to 0 representing greater similarity and deviations toward -1 or 1 indicating lower similarity. See Figure 5. Overall, the results suggest that the ecological characteristics of these ecosystems are broadly aligned with expected reference conditions, supporting the effectiveness of current management approaches.

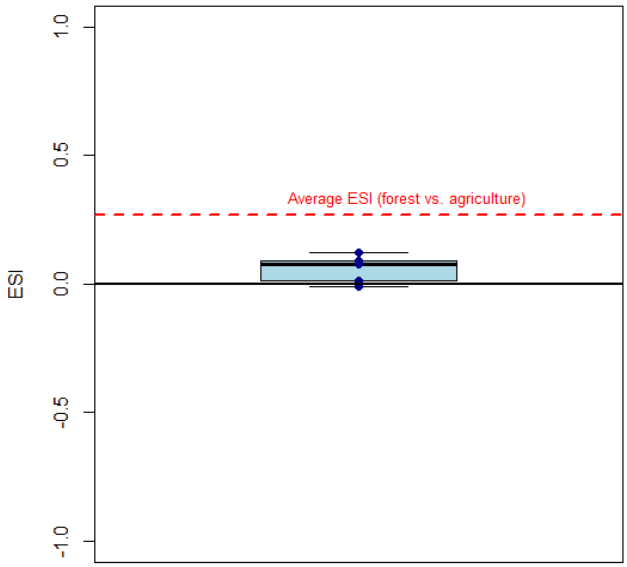
At the level of individual management units, values remain relatively close to zero, indicating limited deviation from reference conditions despite some variability. MU1 recorded the value closest to zero (0.014), reflecting the highest similarity, followed by MU3 (0.076), MU4 (0.092), and MU2 (0.123), all showing only moderate deviations. In contrast, MU5 exhibited a slightly negative value (-0.010), which still indicates high similarity, though with a minor divergence in ecological characteristics.

Despite this variation, the overall pattern demonstrates that all management units are closely aligned with their reference ecosystems, as reflected by index values concentrated near zero. These findings reinforce that FSC-certified management practices are broadly effective in maintaining ecosystem composition and function, while also highlighting minor deviations that may benefit from targeted adaptive management.

While the findings provide valuable insights, some methodological limitations should be considered in their interpretation. The effectiveness of the approach depends in part on the timely and consistent

submission of remote sensing data by certificate holders. E.g., all of the management units evaluated were subsets of the total certified area. Additionally, both ecological datasets and sources such as MapBiomas present constraints for detailed and long-term analyses, including potential classification errors and methodological changes over time that may affect consistency. The selection of reference ecosystems, while informed by local knowledge, was not fully automated, introducing a degree of subjectivity into the process. As a result, the findings should be interpreted with caution, as these factors may influence the precision, comparability, and reproducibility of the results across management units.

Figure 5: Ecological Similarity (ESI) values for the arboreal stratum across the five management units assessed



Note: The ESI reference value (forest vs. agriculture) refers to the average ESI value obtained when comparing different land uses, such as forests and agriculture. The purpose is to use this value as a benchmark for assessing the degree of similarity between the representative sample areas of native ecosystems within the management unit and the reference areas as part of the testing process.

2.2.2. The Integrated Shannon-Species Evenness Difference Index (ISSED)

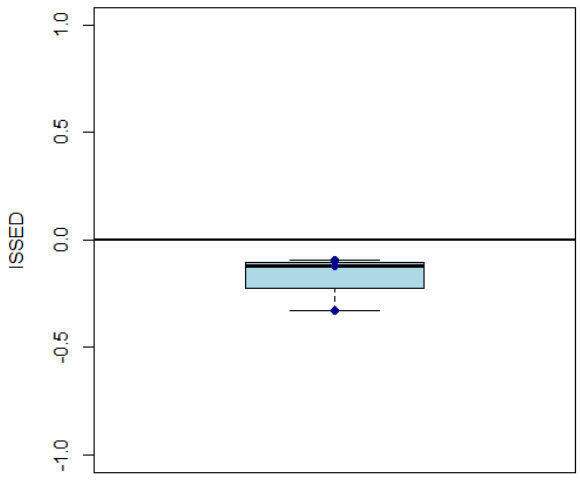
The analysis of the Integrated Shannon–Species Evenness Difference Index (ISSED) indicates that **native ecosystems within the assessed FSC-certified management units generally exhibit biodiversity patterns in the arboreal stratum that are comparable to reference conditions**, with values closer to 0 representing greater similarity and deviations toward -1 or 1 indicating increasing divergence. See Figure 6. While all assessed units show some variation, the ISSED values remain relatively close to zero, suggesting that overall biodiversity attributes are being maintained.

At the management unit level, MU3 showed an increase in species richness from 37 to 45 species, alongside a notable decrease in the Shannon diversity index from 3.72 to 1.73, resulting in the largest deviation from reference conditions (ISSED = -0.330). This reflects a shift toward lower species evenness despite higher richness. MU4 experienced declines in both richness (140 to 118 species) and diversity (4.10 to 2.99), with an ISSED value of -0.120, indicating a moderate deviation. In contrast, MU5 remained the closest to reference conditions, with a slight increase in richness (69 to 71 species) despite a reduction in Shannon diversity (3.33 to 2.25), yielding an ISSED value of -0.092.

Overall, although all units present negative ISSED values—indicating some degree of departure from reference conditions—the magnitude of these deviations remains moderate and relatively close to zero. This suggests that biodiversity in the arboreal stratum of representative sample areas of native ecosystems in the management units is being successfully conserved or restored.

While the methodology applied is generally appropriate for assessing plant diversity—particularly through the use of stratification and well-designed sampling plots—some limitations should be considered when interpreting the results. The sampling effort remains limited, which may constrain the representativeness of the findings and the detection of finer-scale variability within native ecosystems. In addition, the analysis relies on data from reference ecosystems that are themselves limited in scope and availability, potentially affecting the robustness and comparability of the benchmarking process. As a result, the findings should be interpreted with caution, and future applications would benefit from increased sampling intensity and a more comprehensive and consistent set of reference data.

Figure 6: Integrated Shannon–Species Evenness Difference Index (ISSED) values for the arboreal stratum across the three management units assessed



3. Conclusions and recommendations

The conclusions and recommendations presented in this section are informed by both the implementation of the project and the results outlined above, as well as by the feedback and insights provided by members of FSC Brazil and FSC International staff during the debriefing events held in São Paulo and Bonn on 13 and 25 May of 2026, respectively.

3.1. Conclusions

The two developed monitoring frameworks integrate landscape-scale proxies with field-based ecological measurements, enabling a multidimensional and operationally feasible assessment of the selected biodiversity outcomes. Their application across diverse ecological contexts demonstrates broad methodological robustness; however, their overall reliability remains constrained by cross-cutting challenges related to data availability, consistency, and standardization. In particular, the inherent trade-off between scalable remote-sensing approaches and more precise but resource-intensive field methods underscores the need for methodological refinement. Strengthening long-term monitoring systems—such as the systematic use of permanent plots—harmonizing datasets, and reducing subjectivity in parameterization and reference selection will be critical to enhancing the comparability, reproducibility, and scalability of the frameworks. More detailed conclusions are presented below.

3.1.1. Relative Connectivity (RC)

The Relative Connectivity metric demonstrates strong methodological value as a scalable, landscape-level proxy for biodiversity conservation, particularly suited to assessing habitat continuity relevant to rare and threatened species. Its consistent performance across management units with varying sizes and compositions indicates robustness and comparability, making it well suited for large-scale application within certification systems. However, its reliability is influenced by the quality and consistency of remote sensing data inputs, as well as by the use of expert-defined parameters such as resistance values, which introduce subjectivity. As such, while RC is an efficient and practical indicator, its methodological rigor would be strengthened through improved data harmonization and more standardized parameterization.

3.1.2. Density Dynamic Difference Index (DDDI)

The Density Dynamic Difference Index (DDDI) provides a methodologically sound and ecologically meaningful approach to capturing temporal changes in the structure of rare and threatened species populations, particularly by integrating density and dominance measures. Its strength lies in its ability

to detect subtle structural dynamics that are not captured by simpler indicators. However, its application is currently limited by the lack of consistent longitudinal data, especially the absence of permanent plots and reliance on heterogeneous historical datasets. This reduces the robustness and comparability of temporal analyses. Therefore, while DDDI is conceptually strong, its methodological reliability depends on the establishment of standardized, long-term monitoring systems and more comprehensive data collection across ecological strata.

3.1.3. Ecological Similarity Index (ESI)

The Ecological Similarity Index offers a clear and operationally useful framework for comparing managed ecosystems to reference conditions, supporting the evaluation of conservation and restoration outcomes. Its ability to combine ecological and remote sensing data enhances its scalability and applicability across large areas. The consistently low deviation values observed suggest that the metric is stable and interpretable across diverse contexts. Nevertheless, methodological limitations arise from the partially subjective selection of reference ecosystems and the dependence on variable-quality datasets, which may affect reproducibility and comparability. Strengthening the objectivity and standardization of reference selection would significantly enhance the methodological robustness of this metric.

3.1.4. Integrated Shannon–Species Evenness Difference Index (ISSED)

The ISSED provides a comprehensive and sensitive measure of biodiversity by integrating species richness and evenness, allowing for nuanced comparisons with reference ecosystems. Its methodological strength lies in its capacity to capture shifts in community structure that go beyond simple species counts, making it particularly relevant for assessing ecological integrity. However, its effectiveness is constrained by limited sampling intensity and the restricted availability of robust and representative reference datasets, which can affect both precision and interpretability. To improve its methodological reliability, future applications should increase sampling effort and develop more consistent and extensive reference baselines.

3.2. Recommendations

3.2.1. For the design and implementation of biodiversity monitoring frameworks for FSC-certified plantations in the tropics

Overall, future biodiversity monitoring frameworks in the tropics should move toward standardized, outcome-oriented, and hybrid systems, supported by clear reference baselines, improved data quality, and stronger integration of biodiversity dimensions, ensuring both ecological robustness and operational feasibility at scale. More detailed recommendations are presented below.

3.2.1.1. Focus on the assessing progress towards ecosystem-level intended outcomes

Monitoring frameworks should be explicitly designed to assess progress in conserving and restoring native ecosystems (Criterion 6.5), prioritizing ecosystem-level attributes rather than focusing narrowly on the diversity of specific species groups. In highly complex and biodiverse systems such as tropical biomes, an emphasis on rare and threatened species (Criterion 6.4) alone can be limiting due to detection challenges and high natural variability. Instead, broader ecological indicators should form the foundation of monitoring, providing more consistent, scalable, and comparable insights, while species-specific assessments can serve as a complementary layer.

3.2.1.2. Integrate wildlife monitoring in plantation landscapes

While current indicators effectively track plant diversity in native ecosystems, monitoring frameworks should incorporate more integrative biodiversity measures that assess both native ecosystems and plantation landscapes, including those dominated by exotic species. In particular, wildlife monitoring within plantations should be systematically included to evaluate ecological functionality, habitat use, and landscape connectivity. Integrating fauna-based indicators will help demonstrate the broader ecological value of plantations, provide a more comprehensive picture of biodiversity outcomes, and contribute to addressing perceptions of plantations as "green deserts."

3.2.1.3. Provide cost-effective and adaptable monitoring frameworks

Monitoring approaches should be simple, clear, and adaptable to the operational capacities of different certificate holders. Sampling designs must balance scientific robustness with cost-efficiency, ensuring feasibility for long-term implementation without compromising data quality. Flexibility is essential to accommodate varying ecological conditions and management contexts.

3.2.1.4. 5. Combine remote sensing with field validation

The most effective approach is a hybrid system combining remote sensing and field-based methods. Remote sensing enables scalability and regular monitoring, while field data ensures ecological accuracy and calibration. Strengthening collaboration with certificate holders is key to improving data availability, validation, and ownership of the monitoring process.

3.2.1.5. Support adaptive management and continuous improvement

Monitoring should be embedded within an adaptive management framework, where results are regularly used to refine management practices. Feedback loops between data collection, analysis, and decision-making should be formalized to ensure continuous improvement of both biodiversity outcomes and monitoring systems.

3.2.2. For the deployment of outcome orientation in Forest Stewardship Standards

Overall, outcome-oriented monitoring within Forest Stewardship Standards should evolve toward collaborative, scalable, and evidence-based systems that integrate remote sensing with field validation, are co-developed with key stakeholders, and are supported by clear communication mechanisms. This approach will ensure that monitoring not only generates robust data but also effectively demonstrates impact, supports adaptive management, and strengthens the credibility of FSC certification. More detailed recommendations are presented below.

3.2.2.1. Engage certificate holders early and continuously

Engage certificate holders from the outset in the design and implementation of monitoring frameworks, leveraging their local ecological knowledge and operational experience. Identifying and supporting "monitoring champions" among certificate holders can facilitate testing, calibration, and continuous methodological improvement, while also ensuring feasibility and ownership.

3.2.2.2. Develop centralized remote sensing-based monitoring systems

Establish centralized monitoring systems based on remote sensing that allow for consistent, scalable, and comparable assessments across management units. These systems should be systematically calibrated using field data collected in collaboration with certificate holders. In addition, they should incorporate local ecological knowledge and existing spatial data (e.g., maps), complemented where appropriate by AI-based tools, to address methodological gaps such as the identification of reference ecosystems and land-use classification challenges.

3.2.2.3. Support adaptive management

Ensure that monitoring frameworks are explicitly designed to inform and support adaptive management. Monitoring outputs should be directly linked to decision-making processes, allowing certificate holders to adjust management practices based on evidence and observed trends. This requires the establishment of clear feedback loops, where results are regularly reviewed, interpreted, and translated into actionable recommendations. Providing guidance, tools, and capacity-building support can help certificate holders effectively use monitoring data to improve forest management outcomes over time. By embedding monitoring within a continuous learning cycle, the framework can enhance responsiveness to changing ecological conditions, risks, and management objectives.

3.2.2.4. Strengthen communication of results

Develop clear, transparent, and audience-specific communication strategies to convey monitoring results effectively. Monitoring findings should be translated into accessible, credible, and decision-

relevant messages tailored to different stakeholders, including certificate holders, policymakers, market actors, and the broader public. This may involve the use of visual tools, dashboards, summary reports, and storytelling approaches that highlight trends, impacts, and progress toward intended outcomes. Strengthening communication not only supports internal learning and accountability but also demonstrates the effectiveness and added value of FSC-certified forest management, thereby enhancing credibility, stakeholder trust, and market recognition.

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