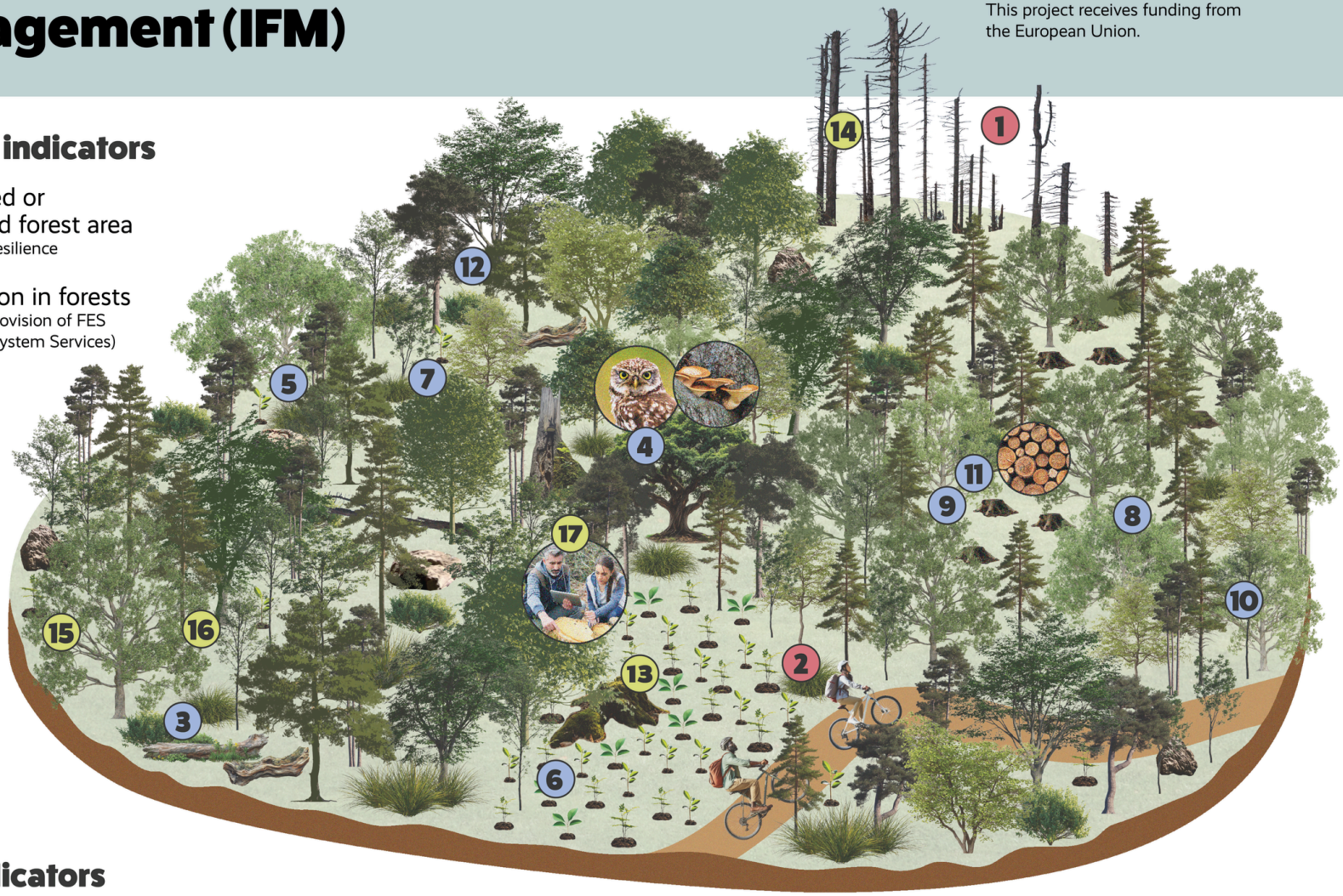
Key Indicators for Integrative Forest Management (IFM)

Funded by the European Union

This project receives funding from the European Union.

TRANSFORMIT



Pressure indicators

1. Disturbed or damaged forest area
   IFM goal: Resilience
2. Recreation in forests
   IFM goal: Provision of FES (Forest Ecosystem Services)

Response indicators

13. Plan for the retention of valuable structures in forests
    IFM goal: Biodiversity conservation
14. Forest risk mitigation and climate change adaptation plan
    IFM goal: Resilience / Adaptive capacity
15. Forest management plan
    IFM goal: Provision of FES
16. Protected forest area
    IFM goal: Provision of FES
17. Education and training
    IFM goal: Provision of FES

*FES (Forest Ecosystem Services)
*IFM (Integrated Forest Management)

State indicators

3. Dead wood
   IFM goal: Biodiversity conservation
4. Habitat trees
   IFM goal: Biodiversity conservation
5. Tree species abundance & distribution
   IFM goal: Biodiversity conservation
6. Regeneration
   IFM goal: Adaptive capacity
7. Native and non-native tree species/ provenances and which of them are site-adapted
   IFM goal: Adaptive capacity
8. Timber production potential
   IFM goal: Provision of FES
9. Management intensity in forest area available for wood supply
   IFM goal: Provision of FES
10. Forest carbon
    IFM goal: Provision of FES
11. Revenue of forest enterprises
    IFM goal: Provision of FES
12. Forest structure
    IFM goal: Provision of FES / Resilience

Indicators for Integrative Forest Management

DISTURBED OR DAMAGED FOREST AREA

TRANSFORMIT

IFM* goal: Enhancing forest resilience

FES*: Resilience; Biodiversity; Carbon sequestration

Importance for IFM assessment

Monitoring forest disturbance and damage is essential for IFM as it enables timely and effective responses to threats. IFM can mitigate disturbances or damages through integrated damage management practices, which include promoting diverse forest structures and site-adapted, mixed tree species compositions. Such diversity enhances ecosystem resilience, making forests less susceptible to abiotic and biotic threats. Regular monitoring allows forest managers to detect early signs of disturbance or damage, assess the severity, and implement appropriate interventions promptly (Patacca et al., 2023). This proactive approach not only guards forest health and productivity but also biodiversity and other ecosystem services.



Characteristics

- ***Pressure indicator***
- Can *predict* higher disturbances or damages with increasing climate change
- *Reporting* on forest ecosystem health
- *Communicating* forest pressures through disturbance or damage
- *Decision-making* regarding damage mitigation and resilience-building measures

Trade-offs

- Accepted natural disturbance (tree mortality) ≠ Damage (monetary or socio cultural impact of disturbance on human values)
- Damaged forest area ≠ Timber production
- Damaged forest area ≠ Ecosystem services provision
- Clear-up damaged areas and reforest with site-adapted species as fast as possible ≠ Wait for native/site-adapted natural regeneration

Regionalisation

- Damages by storm, wind and snow mainly affect the North, South-East and Central-East European regions.
- Large forest fires mostly affect the Mediterranean region.
- Forest area damaged by wildlife was highest in North Europe and lowest in South-East Europe.
- Extensive forest dieback caused by bark beetle outbreaks in Central Europe.

Indicator references

- Global Core Set 6
- Forest Europe 2.4

Local measurement units

Area (ha) and share of forest area disturbed/ damaged (%) by:

- insects and diseases
- extreme weather events
- fire
- other biotic agents like wildlife and grazing

National measurement units

Area (ha) and share of forest area disturbed/ damaged (%) by:

- insects and diseases
- extreme weather events
- fire
- other biotic agents

Target or threshold and desired direction

EU target:
Reduce deforestation and forest degradation (Deforestation Regulation, EP and Council, 2023).

Proposed threshold:
>10% forest area affected = damaged forest area with potential economic and habitat loss (Köhl et al., 2024; Robertson et al., 2024).

Direction: Decrease damaged forest area through IFM to avoid economic and habitat loss.

National-level data sources

- NFI
- Copernicus C3S Burnt Area dataset
- DFDE, Database on Forest Disturbances
- EFFIS, European Forest Fire Information System
- Forest Europe
- ICP Forests (for defoliation)
- INForest Database
- Landsat satellites


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*IFM- Integrated Forest Management *FES: Forest Ecosystem Services

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Indicators for Integrative Forest Management

RECREATION IN FORESTS

TRANSFORMIT

IFM* goal: Provision of forest ecosystem services

FES*: Recreation; Aesthetic value

Importance for IFM assessment

Tourism and income from paid services can significantly contribute to forest owners' incomes. However, tourism and recreational uses increasingly put pressures on forest owners, forest ecosystems and wildlife. Threats to forest biodiversity from tourism include the use of bikes off-road, skiing off-slope, the round-the-clock/nonstop presence of recreationalists in forests, damage of regeneration, littering and excessively collecting non-wood forest products. Forests with tall and old trees are preferred by recreationalists and generate high recreational values (Giergiczny et al., 2021) but might generate less revenues from harvesting if social pressure is put on forest owners to omit harvesting activities. In some countries forest owners are responsible for the safety of roads and paths and might have high additional expenses to remove dead branches and unstable stems to ensure visitor safety.

Characteristics

- ***Pressure indicator***
- Can *predict* higher pressure on forest ecosystems with increasing number of recreationalists
- *Reporting* on recreational use and its impacts
- *Communicating* forest pressures through access for leisure
- *Decision-making* regarding balancing recreational use and IFM goals



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Trade-offs

- Use of wood ≠ Recreational and aesthetic values
- Valuable structures in forests ≠ Safety of visitors
- Open forests can enhance both recreational opportunities and biodiversity, but this often requires active management, such as cutting trees.

Regionalisation

In North Europe, almost all forests are available for public recreation, in CW and CE Europe it is more than half and in Southern Europe it is less than 40%.

Indicator references

Forest Europe 6.10

Local measurement units

Public access to forest area (ha, %) for

- hiking,
- biking, horse riding, cross-country skiing, others
- Expenses to provide services (EUR/ha)
- Expenses to remove litter and damages (EUR/ha)
- Loss of income (EUR/ha)
- Earnings from recreationists (EUR/ha)
- Length of pathways that require specific management activities to guarantee security

National measurement units

- Forest area with access for the public in ha;
- Share of forest area in %
- Earnings from recreation in EUR and EUR/ha
- Expenses for the compensation of the various pressures in EUR/ha

National-level data sources

- Some NFI
- Forest Europe

Target or threshold and desired direction

EU Target:
Access limitations to sensitive nature conservation areas (EC Guidelines on Closer-to Nature Forest Management, EC, 2023)

Proposed targets:

- Access limitations to sensitive habitats like protected forest areas, regeneration areas and old-growth forests
- Implement visitor guidance tools
- Compensation payments for management for recreation purposes

Direction: Decrease pressure from recreation



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3

Indicators for Integrative Forest Management

DEADWOOD

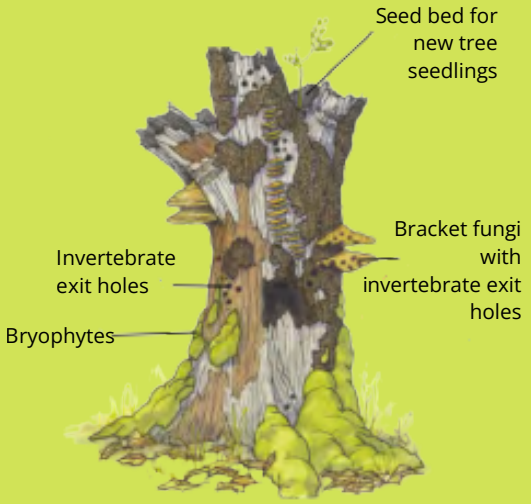
TRANSFORMIT

IFM* goal: Biodiversity conservation **FES*:** Biodiversity; Habitat provision; Carbon sequestration

Importance for IFM assessment

Monitoring the presence and quantity of deadwood is an important integrative measure as deadwood enhances structural diversity and provides essential habitat for many, particularly endangered forest species. It can be used as a wood product and depending on the type/dimension is a fuel for potential forest fires. Deadwood contributes to nutrient cycling, carbon storage, water retention, and fosters regeneration on or next to lying deadwood (Bauhus et al., 2018; Hagge et al., 2019; Müller & Bütler, 2010). Monitoring deadwood helps forest managers track changes due to interventions or disturbances and implement proper measures for deadwood enhancement or reduction.





Characteristics of standing deadwood
Humphrey, J., & Bailey, S. (2012)

Characteristics

- ***State indicator***
- *Predictor* of species diversity of wood inhabiting fungi and beetles
- Can *predict* higher fire risk with increasing climate change depending on type and dimension of deadwood
- *Reporting* on biodiversity aspects
- *Communicating* forest biodiversity status
- *Decision*-making regarding biodiversity management, habitat preservation, fire precaution

Trade-offs

- Fine fuel deadwood might increase fire danger ≠ Large-scale deadwood might inhibit fire danger.
- Habitat for endangered species, water retention, carbon sequestration ≠ For pest precaution, it may be necessary to remove high shares of deadwood.
- Habitat for endangered species, water retention, carbon sequestration ≠ Fire precaution.
- Deadwood retention ≠ Salvage logging.
- Safety concerns with standing deadwood next to paths and roads. In some countries, the road keeper is liable for safety on the roads.
- Strict forest legislations request spruce deadwood with bark to be removed.
- Harvesting standing deadwood is not economically profitable.

Regionalisation

Lying deadwood is the predominant structural component in forests in most pan-European countries. Total deadwood ranged in 2015 from 5.8 m^3/ha in SW Europe to 18.4 m^3/ha in CW Europe. Over the last 25 years, the amount of deadwood increased in all European regions except CE Europe. This increase is highly dynamic, often resulting from increased disturbances.

Indicator references

- Forest Europe 4.5
- FISE - the Forest Information System for Europe
- EU Nature Restoration Regulation
- Guidelines for Defining, Mapping, Monitoring and Strictly Protecting EU Primary and Old-Growth Forests
- FSC 6.6.5
- Part of Index of Biodiversity Potential

Local measurement units

- Lying and standing deadwood incl. stumps in m^3/ha if >10 cm in diameter and by
  - Forest type
  - Coniferous, broadleaved or more detailed tree species
  - Decay classes
- Lying and standing deadwood in percent of the growing stock (%)

National measurement units

- Standing deadwood: m^3/ha by forest type (>10cm in diameter, >1,3 m height)
- Lying deadwood: m^3/ha by forest type (>10cm in diameter)

National-level data sources

- NFI
- Forest Europe
- FAO FRA

Target or threshold and desired direction

EU target:
Optimise deadwood retention (Guidelines on Closer-to-Nature Forest Management)

Proposed target:
Remain 5-10% of the volume of the growing stock as deadwood in the forest (site and stand age dependent)

Direction:
Increasing for natural forest regeneration and forest biodiversity, decreasing for fire precaution.



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Indicators for Integrative Forest Management

HABITAT TREES

TRANSFORMIT

IFM* goal: Biodiversity conservation

FES*: Habitat for forest species

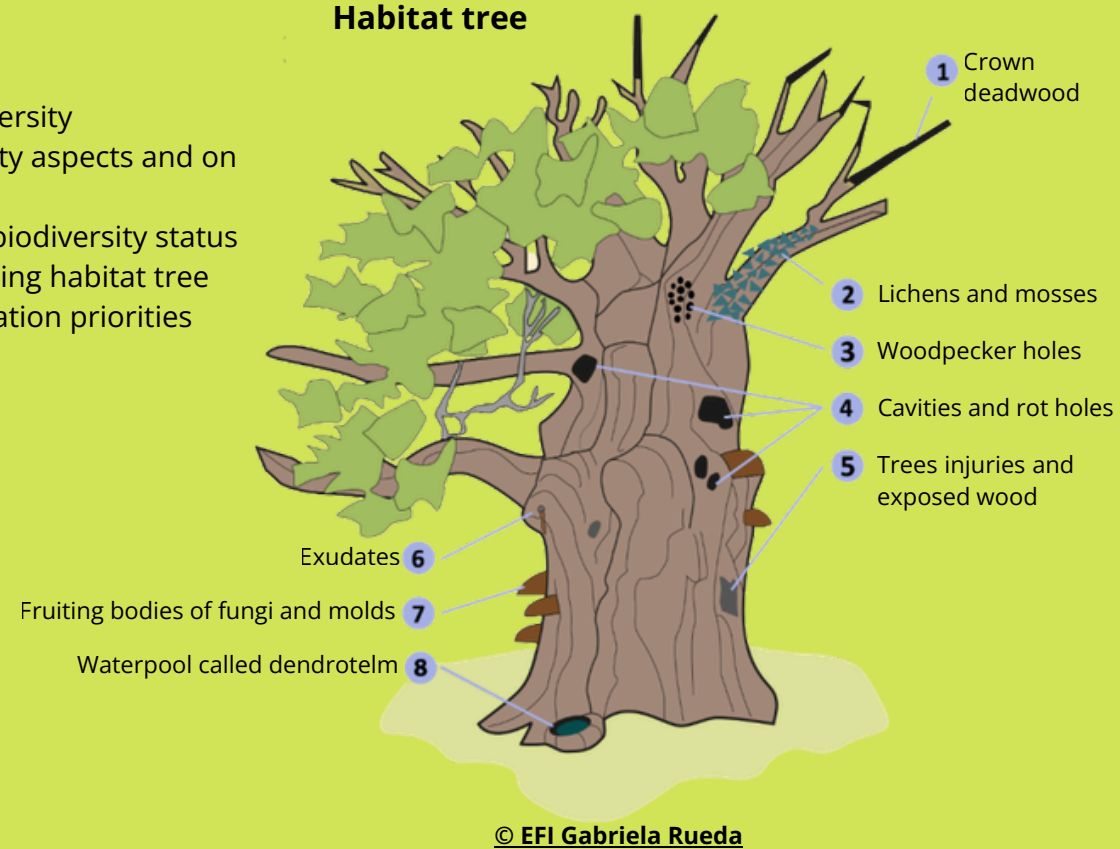
Importance for IFM assessment

Habitat trees are usually large, old, living or dead microhabitat-bearing trees that provide essential resources or play a crucial role in the life cycle of many dwelling species in managed forests like beetles, fungi, lichens, bats, small mammals, and insects. Also, younger trees which will be allowed to develop micro-habitats and to reach their senescence can be assigned and conserved as habitat trees. The conservation of trees that are of ecological, cultural or aesthetical interest has a long tradition in European forests and is now systematically applied under integrative approaches in Forest Management. By identifying and preserving habitat trees, IFM strives to enhance habitat quality, habitat diversity, structural complexity, and compositional heterogeneity in forests, thereby promoting natural tree dynamics (Asbeck et al., 2021; Bütler et al., 2013; Kraus et al., 2016; Larrieu et al., 2022; Mölder et al., 2020).

Characteristics

- ***State indicator***
- *Predictor* of species diversity
- *Reporting* on biodiversity aspects and on aesthetic values
- *Communicating* forest biodiversity status
- *Decision-making* regarding habitat tree selection and conservation priorities

Habitat tree



© EFI Gabriela Rueda

Trade-offs

- Large habitat trees ≠ High value timber
- Stem with microhabitats ≠ High timber value
- Potential habitat trees, which are allowed to develop microhabitats in time, are often already large trees, which are economically attractive (Spînu et al., 2022, 2024) and therefore difficult to convince forest owners to leave them developing as habitat trees.

Regionalisation

No pan-European wide data available so far.

Indicator references

- Guidelines for Defining, Mapping, Monitoring and Strictly Protecting EU Primary and Old Growth Forests
- FSC 6.6.5
- Part of Index of Biodiversity Potential

Local measurement units

- Number of trees/ha which are harmless from a phytosanitary and safety point of view (for instance, for workers or for visitors, next to hiking paths) with:
  - >40 cm DBH (in boreal forests and in regions where the trees are rather young e.g. after huge disturbances)
  - >45 cm DBH
  - >60 cm DBH
- Number of trees/ha which will be allowed to reach their senescence and form tree microhabitats in the future
- Share of trees older than half of their lifespan (%)


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National measurement units

Number/ha

National-level data sources

- NFI
- Biodiversity monitoring

Target or threshold and desired direction

Proposed target:
5-10 trees/ha with at least >45 cm DBH (40 cm DBH in boreal forests).

Direction:
Increasing the number of habitat trees at least up to 10 trees/ha for biodiversity maintenance and enhancement (Kraus & Krumm, 2013; Niedermann-Meier et al., 2010).

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Indicators for Integrative Forest Management

TREE SPECIES ABUNDANCE & DISTRIBUTION

TRANSFORMIT

IFM* goals: Biodiversity conservation; Adaptive capacity to climate change

FES*: Biodiversity; Habitat provision; Aesthetic value

Importance for IFM assessment

Monitoring the abundance of tree species provides insights into forest ecosystem dynamics, helping to detect shifts in species dominance, succession patterns, or disturbances like climate change and pest outbreaks. This information is important for IFM decisions, including species selection for regeneration and interventions to maintain ecosystem stability and biodiversity. Assessing tree species also reveals the diversity and complexity of forest habitats. Forests with more tree species are more resilient to disturbances and climate change, offering a range of ecological niches and resources. Economically, species diversity influences market demand and resilience to damaging agents. Additionally, stands with diverse tree species provide ecosystem services such as water regulation, soil stabilization, and recreation, enhancing the socio-economic value of the forest.


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Characteristics

- ***State indicator***
- *Predictor* of species diversity and forest resilience
- *Reporting* on tree species composition and distribution
- *Communicating* forest-biodiversity status
- *Decision-making* regarding species selection and forest management activities (e.g. thinning)

Trade-offs

- Climate change-adapted or more diverse tree species ≠ Demand on the timber market

Regionalisation

In Nordic countries and at higher elevations tree diversity is lower than in temperate forest ecosystems.

Indicator references

- Forest Europe 4.1
- EU Nature Restoration Reg.

Local measurement units

- Share of forest area with
  - 1, 2-5, 6+ tree species occurring (%)
  - shrubs
  - %/spp
- Abundance of each tree species/ha
- Change of abundance of each tree species
- Dominant tree species/ha
- Shannon Diversity Index
- Gini coefficient

National measurement units

Share of forest area (%) with

- 1
- 2-5
- 6+ tree species occurring
- shrubs

National-level data sources

- NFI
- Forest Europe
- FAO FRA

Target or threshold and desired direction

EU targets:
Promote the mixing of species (Guidelines on Biodiversity friendly Afforestation, Reforestation and Tree Planting). Increase tree species richness (including in specific cases the introduction of pioneer species that are more resilient and better adapted to long-term climate change) (Guidelines on Closer-to-Nature Forest Management) Maintain and increase genetic variation within tree species (Guidelines on Closer-to-Nature Forest Management).

Proposed target:
≥ 3 tree species in each stand (Krumm et al., 2020; Larsen et al., 2022)

Direction:
Increase species diversity



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6

Indicators for Integrative Forest Management

REGENERATION

TRANSFORMIT

IFM* goal: Adaptive capacity to climate change

FES*: Biodiverity

Importance for IFM assessment

Monitoring regeneration of native or non-native species is essential for IFM as it provides an important ecological and economical background. Site-adapted natural regeneration is cost-effective, fosters self-thinning and leads to uneven aged, structurally stable, more resilient forests with high carbon mitigation potential (Crouzeilles et al., 2020; König et al., 2022; Zerbe, 2002). However, in areas where natural regeneration may not be successful or is not site-adapted, planting or seeding can be valuable. While costly, planting or seeding help
diversify tree species, accelerate stand development, and enable the selection of site-adapted tree species to provide forest ecosystem services in the face of climate change. Planting native tree species to replace non-native natural regeneration (e.g., spruce in Central Europe) is an effective measure to promote biodiversity and naturalness. Fostering site-resilient species/saplings after disturbances, whether naturally regenerating or planted, enhances the forest's ability to sequester carbon and aid ecosystem recovery and resilience, creating healthier, more stable forest ecosystems. Monitoring natural regeneration that is not site-adapted provides critical feedback on potential mismatches between tree species and changing site conditions, impacting forest resilience, carbon sequestration and revenue from the forest. An increase of different tree species in the regeneration layer will lead to more structured, stable and healthier stands.



Characteristics

- ***State indicator***
- *Predictor* of species diversity and of adaptability of forests to climate change
- *Reporting* on regeneration success and species composition
- *Communicating* adaptation measures
- *Decision-making* regarding species selection, biodiversity management and adaptation measures

Trade-offs

- Natural regeneration is free of costs ≠ Planting is expensive
- Natural regeneration is not necessarily site-adapted
- Several decades old inventories of the potential natural vegetation are outdated due to climate change
- Planting of exotic trees as a chance to economically compensate for the natural decline ≠ risk of biotic invasion (Krumm et al., 2020)
- High dominance of invasive species can hinder native tree regeneration
- Damage by large ungulates hinder the natural forest regeneration and make any afforestation impossible. This leads to high costs for planting and tree-protecting activities and severely complicates measures for adaptation to climate change (EEA, 2016)
- Planting broadleaves is 10 times more expensive than planting conifers

Regionalisation

In all regions except Central-East Europe, more than 60% of the total forest area was established by natural regeneration except in Central-East Europe (48.3%).

Natural regeneration is slightly increasing in all European regions, except in Northern Europe, where planting is most common.

In mountainous and boreal forest eco-systems forests stands are naturally composed of only one to a few different tree species.

Indicator references

- Forest Europe 4.2
- FSC 10.2.2
- FSC 10.2.5

Local measurement units

Regeneration type in ha, share of in %:

- natural regeneration
- site-adapted
- planted/seeded regeneration
  - native tree species
    - site-adapted
  - non-native tree species
    - site-adapted
- coppice sprouting
  - native tree species
    - site-adapted
  - non-native tree species
    - site-adapted
    - invasive

Number of tree species regenerated:

- Share of regeneration area (%) with
  - 1
  - 2-5
  - 6+ tree species or provenances occurring
  - shrubs
- Share of regeneration area (%)/spp
- Share of dominant species in the regeneration layer (%)

National measurement units

- Regeneration type (natural, seeded, planted, coppice), site-adapted in ha, %
- Share of regeneration area (%) with
  - 1
  - 2-5
  - 6+ tree species or provenances occurring
  - shrubs
  - dominance of invasive species

National-level data sources

- NFI
- Forest Europe
- FAO FRA

Target or threshold and desired direction

EU target:
Promote diversity and natural forest processes (Guidelines on Closer-to-Nature Forest Management, (EC, 2023))

Proposed targets:

- ≥ 3 tree species in the regeneration of each stand (Krumm et al., 2020; Larsen et al., 2022)
- >⅔ of the area in mature stands carries advanced regeneration
- Promote natural regeneration wherever possible, elsewise seeding or planting of site-adapted species.

Direction:

- Decrease invasive species in regeneration until 0%
- Decrease non-site-adapted regeneration until 0%
- Increase site-adapted regeneration up to 100%

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Indicators for Integrative Forest Management

NATIVE & NON-NATIVE TREE SPECIES/PROVENANCES AND WHICH OF THEM ARE SITE-ADAPTED

TRANSFORMIT

IFM* goals: Adaptive capacity to climate change; Enhancing forest resilience

FES*: Biodiversity

Importance for IFM assessment

Monitoring native and non-native tree species, as well as their provenances and site-adapted characteristics, is important for IFM as native tree species provide essential habitat, food, and shelter for diverse local organisms, contributing significantly to biodiversity and carbon sequestration. Understanding which native species are resilient to climate change helps in selecting trees that enhance the adaptive capacity of forest ecosystems to changing conditions. Site adapted species, whether native or non-native, are specifically suited to local environmental conditions such as soil type, moisture levels, and elevation. These species can enhance ecosystem resilience and productivity, optimizing tree growth, health, and the provision of ecosystem services (Krumm & Vitkova, 2016). Monitoring these species ensure that Forest Management practices are tailored to promote ecosystem stability, functionality and wood production. It allows forest managers to make informed decisions about species selection and management strategies.



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Characteristics

- ***State indicator***
- *Can predict* the adaptability of forest ecosystems to climate change
- *Reporting* on species suitability and site adaptation
- *Communicating* biodiversity status
- *Decision-making* regarding species selection and site-specific management

Trade-offs

Promoting biodiversity and naturalness by prioritizing native tree species ≠ enhancing forest resilience to climate change by introducing site-adapted tree species to secure ecosystem services. While native tree species may not always be the best suited to future climatic conditions, site-adapted species - whether native or non-native - can improve resilience. However, the use of non-native species carries the risk of invasiveness.

Regionalisation

No pan-European wide data available so far.

Indicator references

- EU Nature Restoration Regulation
- Guidelines for Defining, Mapping, Monitoring and Strictly Protecting EU Primary and Old-growth Forests
- Part of Index of Biodiversity Potential

Local measurement units

- Area covered (ha)
- Share of area covered (%)
  - native tree species
    - in overstorey
    - in understory
    - site-adapted
  - non-native tree species/provenances
    - in overstorey
    - in understory
    - site-adapted

National measurement units

- Area covered (ha)
- Share of area covered (%)
  -Native
  -Non-native/ provenances
  -Site adapted

National-level data sources

NFI

Target or threshold and desired direction

EU target:
Avoid introducing invasive alien species (Guidelines on Biodiversity-Friendly Afforestation, Reforestation and Tree Planting)

Proposed targets:

- >⅔ of the forest cover consists of native species
- >⅓ of tree species in overstory are site-adapted
- >⅔ native tree species
- <⅓ non-native tree species which should be adapted to site conditions and climate change (Krumm et al., 2020)

Direction:
Increase the share of site-adapted species



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Indicators for Integrative Forest Management

TIMBER PRODUCTION POTENTIAL

(GROWING STOCK ON FOREST AREA AVAILABLE FOR WOOD SUPPLY)

TRANSFORMIT

IFM* goal: Provision of forest ecosystem services

FES*: Timber and wood products; Carbon sequestration

Importance for IFM assessment

By knowing the timber production potential, forest managers can make informed harvesting plannings that meet timber demands without overexploitation. This indicator helps ensure that forests remain productive, while also maintaining critical ecosystem services like carbon sequestration, biodiversity, and soil and water protection. It is particularly important in adapting to climate change, allowing managers to balance growing stock and introduce site-adapted species where needed, ensuring that forests remain resilient, multifunctional, and sustainable over the long term (Mantau et al., 2010).


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Characteristics

- ***State indicator***
- *Predictor* of harvesting capacities
- *Reporting* on forest productivity
- *Communicating* timber production potential
- *Decision-making* regarding harvesting planning and carbon sequestration strategies

Trade-offs

- Increasing growing stock and high canopy closure ≠ maintaining forest clearings and increasing early successional light demanding (rare) species.
- Growing stock as a predictor for wood supply is of economic importance for the rural area ≠ conservation goals.
- High growing stock/ha may indicate also potential of biodiversity relevant characteristics.
- Decrease of growing stock might be necessary for conversion measures to adapt to climate change.
- Enhancement of bioeconomy for the replacement of fossil fuels ≠ protection of forests for biodiversity

Regionalisation

The Central-East and Central-West European regions have the highest growing stock densities.

Central-West Europe has the highest share of forest area available for wood supply (FAWS) (92%), SE Europe the lowest share (53%). The area of FAWS has been increasing since 1990, only in North-Europe has it declined.

Indicator references

- SDG 15.2.1
- Global Core Set 8
- Forest Europe 1.1
- Forest Europe 1.2

Local measurement units

m^3/ha
- on FAWS

National measurement units

m^3/ha
- on FAWS

Target or threshold and desired direction

EU target:
Keep growing stock volume low to minimise economic loss due to disturbances (Guidelines on Closer-to Nature Forest Management).

Proposed target:
10% of the growing stock will not be harvested but will instead be set aside as habitat trees, special habitats, or dead wood.

Direction:
Overall growing stock should increase particularly on landscape level, though on a stand scale there is a limitation to an increase particularly in young stands.

National-level data sources

- Forest Europe
- FAO FRA



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Indicators for Integrative Forest Management

MANAGEMENT INTENSITY (INCREMENT/ FELLINGS) IN FOREST AREA AVAILABLE FOR WOOD SUPPLY

TRANSFORMIT

IFM* goal: Provision of forest ecosystem services

FES*: Timber and wood products; Carbon sequestration

Importance for IFM assessment

By monitoring increment/fellings on forest areas available for wood supply, managers can make informed decisions to optimize both economic returns and ecosystem resilience. Monitoring the harvesting and removal of wood, including salvage logging, provides essential information for IFM on economic goals, which must be carefully managed to avoid compromising biodiversity conservation and carbon sequestration. A utilization rate below 100% ensures that timber harvests do not exceed forest growth. However, in cases of natural disturbances or facing the need to adapt to climate change, rates larger than 100% might be acceptable. Management intensity is not related to the area but rather to temporary intensity, which can vary periodically. High management intensity could be regular every few years, allowing for adaptive management practices that respond to changing conditions. Monitoring these rates helps forest managers assess the balance between timber production and ecological sustainability, ensuring that harvesting practices do not compromise forest health, biodiversity, or carbon sequestration.



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Characteristics

- ***State indicator***
- *Reporting* on forest productivity
- *Predictor* of sustainable harvesting levels
- *Reporting* on forest productivity
- *Communicating* sustainable harvesting practices
- *Decision-making* regarding harvesting intensity

Trade-offs

- High management intensity ≠ Biodiversity conservation goals
- Carbon sink in forests ≠ Fellings
- There is an increased pressure for increased timber production under global changes and substitution of steel, concrete and fossil fuels.
- Retention of deadwood and habitat trees are important parts of any IFM intervention to be considered

Regionalisation

The utilisation rate was highest in North Europe and Central-West Europe, and lowest in South East Europe

Indicator references

- Part of Global Core Set 9
- Forest Europe 3.1
- FSC 5.2.2
- FSC 5.2.4

Local measurement units

- m^3/ha (increment)
- m^3/ha (fellings)
- Share of increment harvested (%)
- Selected harvesting
  - Single tree
  - Group selection
  - Shelterwood systems
- Clearcutting <1 ha
- Clearcutting >1 ha
- Salvage logging

National measurement units

- m^3/ha (increment)
- m^3/ha (fellings)
- Share of increment harvested (%)

National-level data sources

- NFI
- Forest Europe
- FAO FRA

Target or threshold and desired direction

EU target:

- Ensure that the share of forest-based bioenergy … remains within the limits of sustainability (New EU Forest Strategy 2030)
- Increase domestic wood production (New EU Forest Strategy for 2030)

Proposed target:

- <100%, with exceptions (Mönkkönen et al., 2024; Nabuurs et al., 2018)
- Exceptions: e.g. damaging events, conversion measures


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*IFM- Integrated Forest Management *FES: Forest Ecosystem Services

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10

Indicators for Integrative Forest Management

FOREST CARBON

TRANSFORMIT

IFM* goal: Provision of forest ecosystem services

FES*: Carbon sequestration

Importance for IFM assessment

The capacity of sequestering carbon is a key metric in Forest Management, as it enables forest managers to ensure that activities such as thinning or harvesting do not compromise the forest's ability to sequester carbon. Furthermore, an understanding of carbon dynamics in forests is pivotal in achieving a balance between economic objectives and ecological sustainability, thereby ensuring that timber production does not compromise carbon sink capabilities. Moreover, data on carbon sink is integral to the carbon credit market. Forests that effectively sequester carbon can gene rate carbon credits, which can be sold to offset emissions from other sectors. This provides a financial incentive for IFM practices. Participation in the carbon credit market enables forest managers to generate additional revenue.

Characteristics

- ***State indicator***
- *Predictor* of carbon sequestration potential
- *Reporting* on carbon storage and sequestration capacity
- *Communicating* the role of forests in climate change mitigation
- *Decision-making* regarding carbon sequestration strategies and sustainable harvesting practices



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Trade-offs

- Carbon sink ≠ Biomass extraction
- Carbon sink ≠ Increased disturbance from climate change
- Old forest with low C sink strength have typically accumulated much fuel and thus bear a higher risk for uncontrolled fires.
- Younger coniferous forests with high C sink strength may have lower crowns and then we may have a higher risk for crone fires.
- Policy over-emphasises the use of forests for energy production instead of increasing forest for carbon storage (EASAC, 2017).

Regionalisation

Carbon stored in biomass per ha is the highest in CW and CE Europe, whereas forests in the Southern regions and North Europe contain half of that quantity. Least amounts of dead-wood are available in SW Europe, highest in CW Europe with corresponding carbon sink capacities.

Indicator references

- Forest Europe 1.4
- EU Nature Restoration Regulation

Local measurement units

Tons C/ha/year in

- above-ground living biomass
- below-ground living biomass
- deadwood
- forest soil
- litter

National measurement units

Tons C/ha/year in

- above-ground living biomass
- below-ground living biomass
- deadwood
- forest soil
- litter

Target or threshold and desired direction

EU targets:
Increase carbon storage….roll-out of carbon farming practices (New EU forest Strategy 2030, EU Green Deal, LULUCF Reg., UN Paris Agreement, UN Strategic Plan for Forests 2017-2030, Bonn Challenge)

Target at national/European level:
Maintain or increase forest carbon sequestration at ≥ 2.5–3.5 t CO_2/ha/year, depending on country and harvest levels, to achieve climate neutrality by 2050 (LULUCF Reg., ; Pilli et al., 2022).

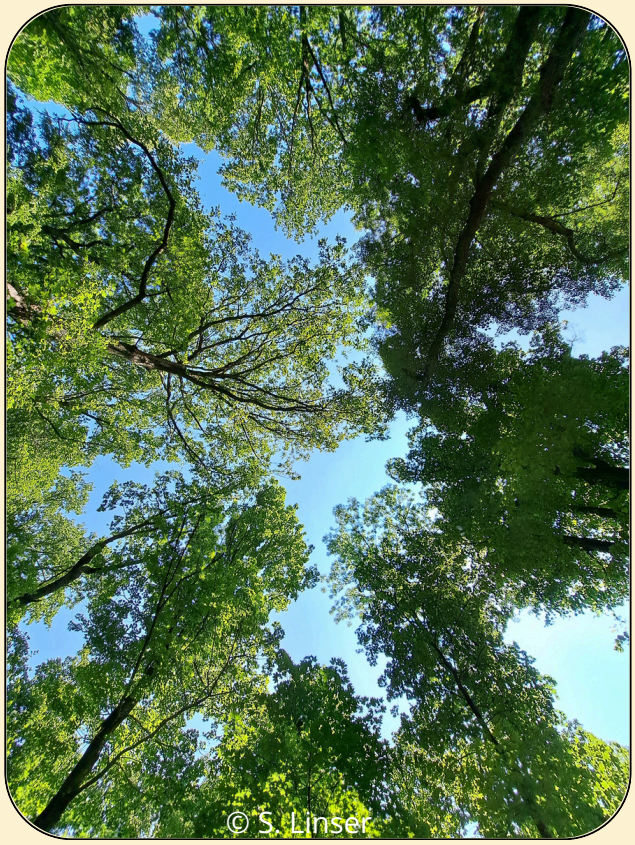
National target on total forest sink contribution:
Forests should contribute at least 310 Mt CO_2eq/year by 2030 across the EU (Based on EU's 2030 LULUCF target under the "Fit for 55" package).

Proposed target at stand/local level:
Maintain or increase living biomass carbon stocks at ≥ 100 tC/ha, depending on the forest type, age, management practices, and regional conditions (Calvin et al., 2023) and if compatible with forest fire prevention plans.

Direction:
Increase carbon sink, particularly on landscape level

National-level data sources

- Forest Europe
- FAO FRA



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11

Indicators for Integrative Forest Management

REVENUE OF FOREST ENTERPRISES

TRANSFORMIT

IFM* goal: Provision of forest ecosystem services

FES*: Revenue of forest enterprises

Importance for IFM assessment

Revenue from timber and non-timber products is crucial for integrated Forest Management in forest enterprises because it supports economic sustainability while promoting the provision of various ecosystem services. Timber sales provide core income for investments in sustainable practices, while mainly extensively produced NWFPs such as fruits, mushrooms, or game diversify revenue streams and support regional demand. Additional income from services like clean water, hunting licenses, recreation, and entrance fees to cultural or recreational sites further enhances economic resilience. By balancing income generation with the maintenance of ecosystem services, IFM strengthens the viability of forest enterprises, supports local economies, and promotes long-term ecological and social benefits.

Characteristics

- ***State indicator***
- *Predictor* of economic sustainability and forest enterprise viability
- *Reporting* on economic aspects of IFM
- *Communicating* the economic benefits of IFM
- *Decision-making* regarding income generation strategies and balancing economic and ecological goals



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Trade-offs

- Forest visitors take NWFP and services granted for free ≠ willingness to pay.
- Maximizing several ecosystem services simultaneously within a single stand or enterprise ≠ inherent trade-offs between different ecosystem services (Kraus & Krumm, 2013).
- IFM can cause lower revenues and additional costs as for example, by preserving old trees and leaving large amounts of deadwood in the forest. Additional costs can also arise when applying more expensive timber harvesting methods to support soil protection (Krumm et al., 2020).
- Money from the timber pays for biodiversity conservation.

Regionalisation

The main share of factor income was generated in North and Central-West Europe (Data availability for other countries was low).

Data quality on NWFP and services is too low for valid regional assessments.

Indicator references

- Forest Europe Indicators 3.3, 3.4, 6.3
- EUROSTAT
- UNECE

Local measurement units

EUR/ha for

- timber products
- NWFP
- services
- other

National measurement units

EUR/ha for

- timber products
- NWFP
- services

Target or threshold and desired direction

EU target:
An increase of revenue should lead to the economic viability and sustainability of forest enterprises (Aggestam et al., 2020; EC, 2021; Krumm et al., 2020).

Proposed target:
Forest owners should get fair prices for products from their forests that exceed costs for management and harvesting. This also accounts for small scale owners that however might be organised in associations or similar to effectively deal with the cost

Direction:
Increase of revenue

National-level data source

Forest Europe



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12

Indicators for Integrative Forest Management

FOREST STRUCTURE

TRANSFORMIT

IFM* goals: Enhancing forest resilience; Provision of forest ecosystem services

FES*: Biodiversity; Habitat provision; Aesthetic value; Resilience

Importance for IFM assessment

Information on forest structure combines the assessment of even or uneven-aged age structure and diameter distribution with multi-layeredness. By monitoring stand age and diameter distribution, managers can obtain accurate increment data, enabling timber production planning and sustainable harvest scheduling. Additionally, maintaining diverse vertical structures through a mixture of tree ages and dimensions addresses ecological and economic management objectives like increasing habitat diversity, enhancing resilience against natural disturbances and climate change impacts, improving the quality and value of individual trees, ensuring regeneration, and supporting economic viability by providing optimized, regular revenues while minimizing costs of artificial regeneration (Gao et al., 2014; Messier et al., 2014; Puettmann et al., 2009).

Characteristics

- ***State indicator***
- *Predictor* of harvesting capacities and of resilience against natural disturbances
- *Reporting* on forest structure and its implications for biodiversity and resilience
- *Communicating* the importance of structural diversity for resilience and biodiversity
- *Decision-making* regarding structural diversity, and resilience-building measures



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Trade-offs

Rich structured forests ≠ economies of scale in harvesting that favour clear cutting (Aggestam et al., 2020)

Regionalisation

For Europe as a whole, more than 70% of FAWS is reported as even-aged, in which the inter-mediate development phase dominates (>60%), while mature and regeneration phases amount to about 18% each. Uneven-aged forests with multiple layers cover almost 30% of the FAWS area all over Europe. SE Europe has the highest share of forests (47%) where multiple layers may occur. Regions where clear-cutting and replanting are more common in Europe have less uneven-aged forests.

Indicator references

- Forest Europe 1.3
- EU Nature Restoration Regulation
- Guidelines for Defining, Mapping, Monitoring and Strictly Protecting EU Primary and Old-Growth Forests
- Part of Index of Biodiversity Potential

Local measurement units

- Age-class distribution in even-aged stands (%)
- Volume (m^3) per age class in FAWS
- Area (ha) per development phase (regeneration phase, intermediate phase, mature phase, unspecified),
- Volume (m^3) per development phases in FAWS
- Diameter distribution in uneven-aged stands
- Volume/ha by diameter class (≤20 cm; 21-40 cm; >41-60 cm; >60; unspecified)
- Share of shrubs (%)

National measurement units

- Age-class distribution in even-aged stands (%)
- Diameter distribution in uneven-aged stands
- Share of shrubs (%)

National-level data sources

- NFI
- Forest Europe
- FAO FRA

Target or threshold and desired direction

EU target:
Increase structural complexity (Guidelines on Closer-to Nature Forest Management)

Proposed target:
Multi-layered forest structure on >⅔ of the forest area if compatible with forest fire prevention plans

Direction:
Increase structural complexity


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13

Indicators for Integrative Forest Management

PLAN FOR THE RETENTION OF VALUABLE STRUCTURES IN FORESTS

TRANSFORMIT

IFM* goal: Biodiversity conservation

FES*: Habitat provision; Biodiversity; Aesthetic value; Stewardship

Importance for IFM assessment

Retaining valuable structures like bushes, pioneer species, deadwood and habitat trees is ecologically important as these elements provide essential habitats for a wide range of species. Deadwood is a critical resource for decomposers that recycle nutrients back into the soil, enhancing forest health and productivity. Bushes and habitat trees offer nesting sites and food sources. Planning for deadwood retention can also help avoid or reduce salvage logging, which often disrupts habitat creation and ecological processes. While retaining or creating these valuable structures may require short- to mid-term investments, the long-term benefits are significant. Structurally diverse and vital forests are more resilient to threats such as climate change, pests, and diseases. Economically, these investments pay off in the long term by more resilient forest ecosystems safeguarding timber resources and reducing the costs of managing degraded forests. Socially, structurally diverse forests offer recreational opportunities and aesthetic values, contributing to human well-being.



Characteristics

- ***Response indicator***
- *Predictor* of biodiversity and habitat quality
- *Reporting* on structural diversity and habitat provision
- *Communicating* to care about valuable structures in forests
- *Decision-making* regarding retention priorities

Trade-offs

- Deadwood retention ≠ Salvage logging to increase resilience against bark beetles and forest fires.
- Retaining valuable structures in forests may reduce short-term revenues from timber.

Regionalisation

No pan-European wide data available so far.

Indicator references

New indicator developed within TRANSFORMIT

Local measurement units

Plan or equivalent with following planned measures:

- Regular monitoring of deadwood
- Retaining deadwood crowns, low-quality stems, branches and stumps after thinning or harvesting
- Designation of zones where any deadwood removal is prohibited if compatible with fire prevention plans
- Designation of habitat trees

National measurement units

Share of forest area with activities conducted within the last 10 years:

- Deadwood monitoring
- Designation of habitat trees (at least 5/ha)

National-level data sources

- NFI
- National Forest Strategy
- National Biodiversity Strategy

Target or threshold and desired direction

Proposed target:
> ⅔ of the area covered by a plan or equivalent which contains > ⅔ of the measures.

Direction:
Plan or equivalent available for the whole forest area covering > ⅔ of the measures.



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14

Indicators for Integrative Forest Management

FOREST RISK MITIGATION AND CLIMATE CHANGE ADAPTATION PLAN

TRANSFORMIT

IFM* goals: Enhancing forest resilience; Adaptive capacity to climate change

FES*: Stewardship, Pest and disease control; Erosion control; Genetic diversity

Importance for IFM assessment

A forest risk management planning is essential for maintaining forest health, resilience, and productivity and should consider precautionary measures and countermeasures to address risks aligning with conservation and economic objectives (Krumm et al., 2020). The climate change adaptation planning should go beyond changing forestry practices to new site conditions. New objectives and structures must be defined to enhance the resilience and adaptability of forests to new, often unpredictable environmental realities.


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Characteristics

- ***Response indicator***
- *Predictor* of forest resilience and adaptive capacity
- *Reporting* on planned risk mitigation and adaptation measures
- *Communicating* the importance of planned risk mitigation, preventive and adaptation measures
- *Decision-making* regarding priorities on countermeasures, preventive measures or adaptation measures

Trade-offs

- Risk mitigation and climate change adaptation activities might be resource intensive and costly.
- Precautionary and containment activities may have unintended environmental impacts like deadwood removal for risk reduction.
- Disturbances may provide temporary habitats for a high number of species, depending on size and intensity of affected area (Kraus & Schuck, 2017).

Regionalisation

Southern European countries have already advanced fire management systems due to their history of forest fires and the associated risks.

Indicator references

New indicator developed within TRANSFORMIT

Local measurement units

Plan or equivalent with following measures:

- Regular monitoring of presence and spread of invasive species, calamities, diseases and other damaging agents
- Precautionary and containment activities (mechanical, chemical, biological)
- Implementation of anti-soil erosion measures to prevent soil degradation
- Measures to reduce game and cattle damages
- Application of Forest Management practices to enhance resilience and adaptability to new environmental realities incl. transformation of high-risk stands
- Monitoring of stands requiring regeneration and regeneration planning
- Tending and thinning to promote site-adapted tree species
- Tending and thinning to enhance the diversity of tree species e.g. by promoting minority or pioneer tree species
- Restoration of degraded forest ecosystems.

Target or threshold and desired direction

Proposed target:
> ⅔ of the area covered by a plan or equivalent which contains > ⅔ of the measures covered.

Direction:
Plan or equivalent available for the whole forest area covering > ⅔ of the measures.

National measurement units

- Share of forest area with activities conducted within the last 10 years:
  - National soil survey
  - National forest risk monitoring
  - Large-scale forest site classifications as basis for site-adapted Forest Management.
- RS application available to detect forest risks like forest fires, storm damages or defoliation.
- Availability of air force to combat forest fire.
- International co-operation on forest fire fighting.

National-level data sources

- National Forest Strategy
- Respective ministries or agencies



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15

Indicators for Integrative Forest Management

FOREST MANAGEMENT PLAN

TRANSFORMIT

IFM* goals: Provision of forest ecosystem services; Biodiversity conservation; Enhancing forest resilience; Adaptive capacity to climate change

FES*: Stewardship

Importance for IFM assessment

IFM is typically documented in a Forest Management plan that outlines the objectives and practices for IFM including ecological (e.g. reducing fragmentation, increasing connectivity), economic (e.g. sustainable harvesting), and social (e.g. staff health care, recreational use) considerations. These plans serve as a critical tool for guiding the implementation of IFM, ensuring that Forest Management aligns with sustainability goals while balancing multiple ecosystem services and stakeholder interests. In an ideal case, a Forest Management plan should incorporate additional objectives from other sectors, such as nature conservation and urban planning, to reduce the risk of trade-offs and conflicts.

Characteristics

- ***Response indicator***
- *Predictor* of management effectiveness
- *Reporting* on management objectives and practices
- *Communicating* about management activities and forest inventory details
- *Decision-making* about management measures



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Trade-offs

- Management plans may have trade-offs with plans with different objectives, like plans for nature conservation or plans for urban development that exist in the same area.
- Large unfragmented forest areas are beneficial for biodiversity, but a Forest Management plan must also consider creating fragmentation, if necessary, to help regulate forest fires, bark beetles and pests spreading over larger areas.

Regionalisation

In South-East Europe nearly 100% of the forest area are under management plans, in North Europe 88%, South-West Europe has the lowest share.

Indicator references

- SDG 15.2.1
- Global Core Set 19
- Forest Europe qualitative Indicator under Criterion 3
- FSC 7.1.2

Local measurement units

Plan or equivalent with following planned measures:

- IFM as management objectives
- Planned thinning operations
- Planned harvesting operations
- Regular monitoring of standard forest parameters
- Identification of ecologically sensitive or valuable area for special management
- Active management of protected forest areas
- Promote or restore forest ecosystem connectivity and avoid fragmentation

National measurement units

Share of forest area with Forest Management plan available

National-level data sources

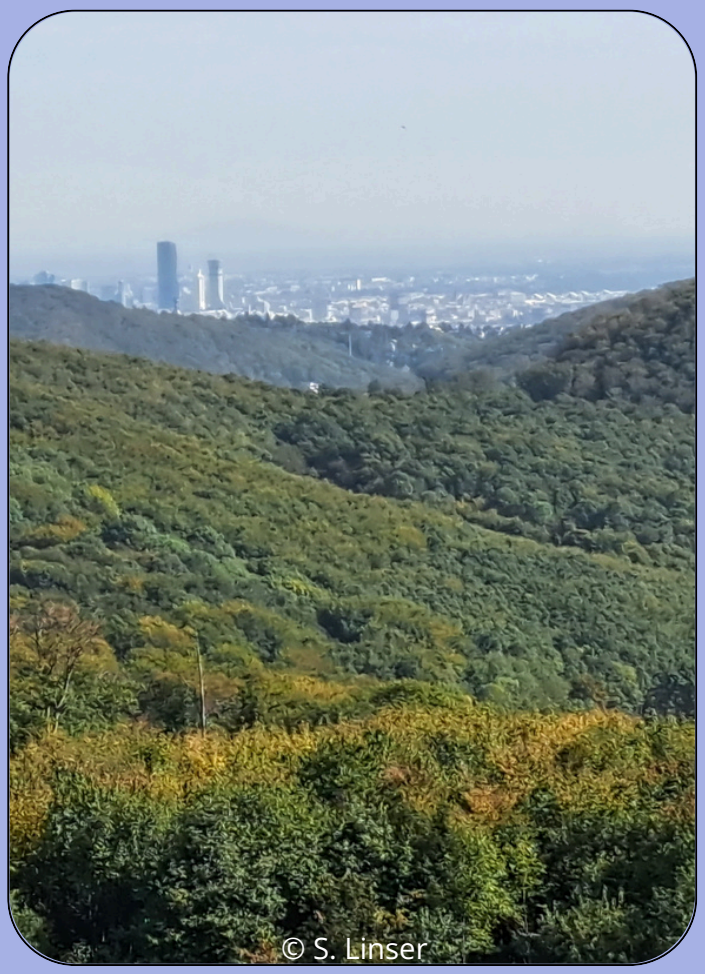
- NFI
- National Forest Reports
- Forest Europe

Target or threshold and desired direction

EU target:
The share of forest areas covered by Forest Management plans should cover all managed public forests and an increased number of private forests. (New EU Forest Strategy 2030)

Proposed target:
Management plan or equivalent in place for forest areas >10 ha and which contains > ⅔ of the measures.

Direction:
Increasing shares of forest areas covered by plan or equivalent covering > ⅔ of the measures.


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16 Indicators for Integrative Forest Management

PROTECTED FOREST AREA

(DESIGNATED BY LAW OR BY VOLUNTARY TEMPORARY CONTRACTS TO PROTECT BIODIVERSITY OR OTHER FOREST ECOSYSTEM FUNCTIONS)

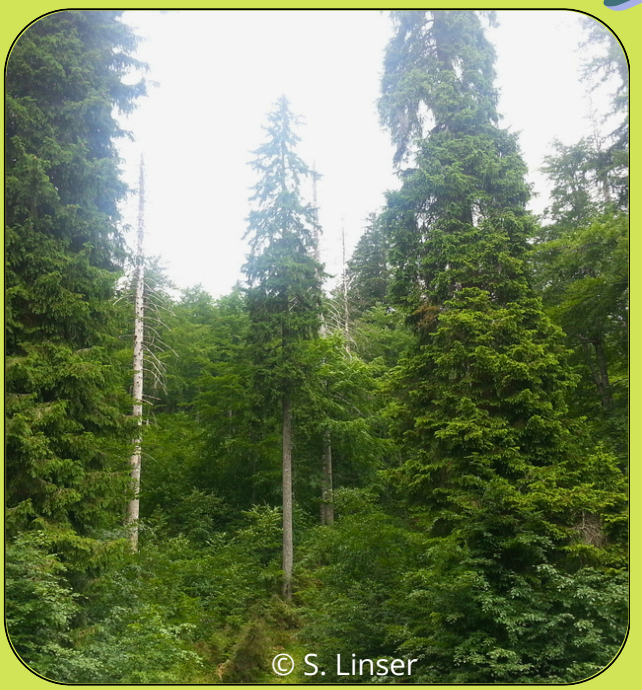
TRANSFORMIT

IFM* goals: Biodiversity conservation; Provision of forest ecosystem services

FES*: Stewardship; Biodiversity; Habitat provision

Importance for IFM assessment

In legally protected forest areas (PFA) but also in forest areas under voluntary contractual nature conservation where harvesting is restricted, IFM may focus on conservation measures to maintain and enhance biodiversity and other ecosystem functions. Temporary contractual nature conservation fosters collaboration between forest owners, forest administration, research and environmental NGOs incentivising the temporary (usually 20 years) decommissioning of high-value forest areas to conserve biodiversity.


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Characteristics

- ***Response indicator***
- *Predictor* of species diversity and ecosystem functions
- *Reporting* on protected areas and conservation measures
- *Communicating* the importance of protected areas
- *Decision-making* regarding conservation management

Trade-offs

- Unmanaged protected forest ≠ Managed forests with timber extraction
- Establishment of additional protected areas ≠ Reduced forest available for wood supply (FAWS) with competing management goals (Kraus & Krumm, 2013)
- Protective forests (which need to be managed to maintain their protective functions) ≠ Protected forests

Regionalisation

The protection of forest biodiversity varies considerably within Europe: while minimal or no intervention in PFA dominate in NE and SW Europe, larger PFA with active conservation management are in CE. Forest areas protected for landscapes and specific natural elements are mainly in CW Europe

Contractual nature conservation is primarily a privilege of wealthier European regions, as only richer countries have funds to provide compensation payments.

Most of the designated protective forest stands are in mountainous areas.

Indicator references

- SDG 15.2.1
- Global Core Set 4
- Forest Europe 4.9
- SEBI 007
- FSC 6.5.4

Local measurement units

Area (ha) and share of forest area (%) set aside through:

- national designation or protection
- voluntary, temporary contracts

National measurement units

Area (ha) and share of forest area (%) set aside through:

- national designation or protection
- voluntary, temporary contract

Target or threshold and desired direction

EU targets:

- Legally protect a minimum of 30% of the EU's land area and strictly protect at least a third of the EU's protected areas (EU Biodiversity Strategy for 2030)
- Protect all remaining EU primary and old-growth forests (EU Biodiversity Strategy for 2030, New EU Forest Strategy 2030)

Proposed target:
Set aside 5% forest area <100 ha
Set aside 10% forest area >100ha

Direction:
Protect the ecologically valuable forest ecosystems, e.g. according to Habitats Directive Annex 1

National-level data sources

- NFI
- National Forest
- Reports
- Forest Europe



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17 Indicators for Integrative Forest Management

EDUCATION AND TRAINING

TRANSFORMIT

IFM* goal: Provision of forest ecosystem services

FES*: Educational and scientific value

Importance for IFM assessment

Education and training of the workforce are essential for IFM because they equip the staff with the knowledge and skills to apply integrative management practices which facilitate to adapt to climate change and conserve biodiversity among other ES. Trained staff can also effectively use advanced/new technologies, comply with regulations, and engage with stakeholders to manage ecosystem services and to balance the IFM goals.


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Characteristics

- ***Response indicator***
- *Predictor* of quality of Forest Management
- *Reporting* on social aspects and workforce development
- *Communicating* the importance of education and training for sustainable Forest Management
- *Decision-making* regarding workforce development and capacity-building initiatives

Trade-offs

No trade-offs identified.

Regionalisation

No pan-European wide data available so far.

Indicator references

New indicator developed within TRANSFORMIT

Local measurement units

- Training days/year/full-time staff equivalent -
- Presence of adequate facilities (Marteloscopes etc.)
- Expenses for forest enterprise in EUR/year

National measurement units

Publicly offered education and training programmes for forest workforce (Training days/person/ year)

Target or threshold and desired direction

Proposed targets:

- All employees take part in regular education and training programmes
- 2-5 days/year as paid work

Direction:
Life-long learning

National-level data sources

- Chamber of Agriculture
- Forest training centers





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1 Indicators for Integrative Forest Management
DISTURBED OR DAMAGED FOREST AREA

IFM* goal: Enhancing forest resilience

FES*: Resilience; Biodiversity; Carbon sequestration

Importance for IFM assessment

Monitoring forest disturbance and damage is essential for IFM as it enables timely and effective responses to threats. IFM can mitigate disturbances or damages through integrated damage management practices, which include promoting diverse forest structures and site-adapted, mixed tree species compositions. Such diversity enhances ecosystem resilience, making forests less susceptible to abiotic and biotic threats. Regular monitoring allows forest managers to detect early signs of disturbance or damage, assess the severity, and implement appropriate interventions promptly (Patacca et al., 2023). This proactive approach not only guards forest health and productivity but also biodiversity and other ecosystem services.


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Characteristics

- ***Pressure indicator***
- *Can predict* higher disturbances or damages with increasing climate change
- *Reporting* on forest ecosystem health
- *Communicating* forest pressures through disturbance or damage
- *Decision-making* regarding damage mitigation and resilience-building measures

Trade-offs

- Accepted natural disturbance (tree mortality) ≠ Damage (monetary or socio cultural impact of disturbance on human values)
- Damaged forest area ≠ Timber production
- Damaged forest area ≠ Ecosystem services provision
- Clear-up damaged areas and reforest with site-adapted species as fast as possible ≠ Wait for native/site-adapted natural regeneration

2 Indicators for Integrative Forest Management
RECREATION IN FORESTS

IFM* goal: Provision of forest ecosystem services

FES*: Recreation; Aesthetic value

Importance for IFM assessment

Tourism and income from paid services can significantly contribute to forest owners' incomes. However, tourism and recreational uses increasingly put pressures on forest owners, forest ecosystems and wildlife. Threats to forest biodiversity from tourism include the use of bikes off-road, skiing off-slope, the round-the-clock/nonstop presence of recreationalists in forests, damage of regeneration, littering and excessively collecting non-wood forest products. Forests with tall and old trees are preferred by recreationalists and generate high recreational values (Gierańczyk et al. 2021) but might generate less revenues from harvesting if social pressure is put on forest owners to omit harvesting activities. In some countries forest owners are responsible for the safety of roads and paths and might have high additional expenses to remove dead branches and unstable stems to ensure visitor safety.



Characteristics

- ***Pressure indicator***
- *Can predict* higher pressure on forest ecosystems with increasing number of recreationalists
- *Reporting* on recreational use and its impacts
- *Communicating* forest pressures through access for leisure
- *Decision-making* regarding balancing recreational use and IFM goals

Trade-offs

- Use of wood ≠ Recreational and aesthetic values
- Valuable structures in forests ≠ Safety of visitors
- Open forests can enhance both recreational opportunities and biodiversity, but this often requires active management, such as cutting trees.

3 Indicators for Integrative Forest Management
DEADWOOD

IFM* goal: Biodiversity conservation

FES*: Biodiversity; Habitat provision; Carbon sequestration

Importance for IFM assessment

Monitoring the presence and quantity of deadwood is an important integrative measure as deadwood enhances structural diversity and provides essential habitat for many, particularly endangered forest species. It can be used as a wood product and depending on the type/dimension is a fuel for potential forest fires. Deadwood contributes to nutrient cycling, carbon storage, water retention, and fosters regeneration on or next to lying deadwood (Bauhus et al., 2018; Hagge et al., 2019; Müller & Bütler, 2010). Monitoring deadwood helps forest managers track changes due to interventions or disturbances and implement proper measures for deadwood enhancement or reduction.





Characteristics of standing deadwood
Humphrey, J. & Bailey, S. (2012)

Characteristics

- ***State indicator***
- *Predictor* of species diversity of wood inhabiting fungi and beetles
- *Can predict* higher fire risk with increasing climate change depending on type and dimension of deadwood
- *Reporting* on biodiversity aspects
- *Communicating* forest biodiversity status
- *Decision-making* regarding biodiversity management, habitat preservation, fire precaution

Trade-offs

- Fine fuel deadwood might increase fire danger ≠ Large-scale deadwood might inhibit fire danger.
- Habitat for endangered species, water retention, carbon sequestration ≠ For pest precaution, it may be necessary to remove high shares of deadwood.
- Habitat for endangered species, water retention, carbon sequestration ≠ Fire precaution.
- Deadwood retention ≠ Salvage logging.
- Safety concerns with standing deadwood next to paths and roads. In some countries, the road keeper is liable for safety on the roads.
- Strict forest legislations request spruce deadwood with bark to be removed.
- Harvesting standing deadwood is not economically profitable.

4 Indicators for Integrative Forest Management
HABITAT TREES

IFM* goal: Biodiversity conservation

FES*: Habitat for forest species

Importance for IFM assessment

Habitat trees are usually large, old, living or dead microhabitat-bearing trees that provide essential resources or play a crucial role in the life cycle of many dwelling species in managed forests like beetles, fungi, lichens, bats, small mammals, and insects. Also, younger trees which will be allowed to develop micro-habitats and to reach their senescence can be assigned and conserved as habitat trees. The conservation of trees that are of ecological, cultural or aesthetical interest has a long tradition in European forests and is now systematically applied under integrative approaches in Forest Management. By identifying and preserving habitat trees, IFM strives to enhance habitat quality, habitat diversity, structural complexity, and compositional heterogeneity in forests, thereby promoting natural tree dynamics (Kuback et al. 2021; Butler et al. 2013; Kraus et al. 2016; Larrieu et al. 2022; Mölder et al. 2020).

Characteristics

- ***State indicator***
- *Predictor* of species diversity
- *Reporting* on biodiversity aspects and on aesthetic values
- *Communicating* forest biodiversity status
- *Decision-making* regarding habitat tree selection and conservation priorities

Habitat tree



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Trade-offs

- Large habitat trees ≠ High value timber
- Stem with microhabitats ≠ High timber value
- Potential habitat trees, which are allowed to develop microhabitats in time, are often already large trees, which are economically attractive (Golivu et al., 2022, 2024) and therefore difficult to convince forest owners to leave them developing as habitat trees.

5 Indicators for Integrative Forest Management
TREE SPECIES ABUNDANCE & DISTRIBUTION

IFM* goals: Biodiversity conservation; Adaptive capacity to climate change

FES*: Biodiversity; Habitat provision; Aesthetic value

Importance for IFM assessment

Monitoring the abundance of tree species provides insights into forest ecosystem dynamics, helping to detect shifts in species dominance, succession patterns, or disturbances like climate change and pest outbreaks. This information is important for IFM decisions, including species selection for regeneration and interventions to maintain ecosystem stability and biodiversity. Assessing tree species also reveals the diversity and complexity of forest habitats. Forests with more tree species are more resilient to disturbances and climate change, offering a range of ecological niches and resources. Economically, species diversity influences market demand and resilience to damaging agents. Additionally, stands with diverse tree species provide ecosystem services such as water regulation, soil stabilization, and recreation, enhancing the socio-economic value of the forest.


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Characteristics

- ***State indicator***
- *Predictor* of species diversity and forest resilience
- *Reporting* on tree species composition and distribution
- *Communicating* forest-biodiversity status
- *Decision-making* regarding species selection and forest management activities (e.g. thinning)

Trade-offs

- Climate change-adapted or more diverse tree species ≠ Demand on the timber market

6 Indicators for Integrative Forest Management
REGENERATION

IFM* goal: Adaptive capacity to climate change

FES*: Biodiversity

Importance for IFM assessment

Monitoring regeneration of native or non-native species is essential for IFM as it provides an important ecological and economical background. Site-adapted natural regeneration is cost-effective, fosters self-thinning and leads to uneven aged, structurally stable, more resilient forests with high carbon mitigation potential (Crouzeilles et al., 2020; Könik et al., 2022; Zerbe, 2020). However, in areas where natural regeneration may not be successful or is not site-adapted, planting or seeding can be valuable. While costly, planting or seeding help diversify tree species, accelerate stand development, and enable the selection of site-adapted tree species to provide forest ecosystem services in the face of climate change. Planting native tree species to replace non-native natural regeneration (e.g., spruce in Central Europe) is an effective measure to promote biodiversity and naturalness. Fostering site-resilient species/saplings after disturbances, whether naturally regenerating or planted, enhances the forest's ability to sequester carbon and aid ecosystem recovery and resilience, creating healthier, more stable forest ecosystems. Monitoring natural regeneration that is not site-adapted provides critical feedback on potential mismatches between tree species and changing site conditions, impacting forest resilience, carbon sequestration and revenue from the forest. An increase of different tree species in the regeneration layer will lead to more structured, stable and healthier stands.



Characteristics

- ***State indicator***
- *Predictor* of species diversity and of adaptability of forests to climate change
- *Reporting* on regeneration success and species composition
- *Communicating* adaptation measures
- *Decision-making* regarding species selection, biodiversity management and adaptation measures

Trade-offs

- Natural regeneration is free of costs ≠ Planting is expensive
- Natural regeneration is not necessarily site-adapted
- Several decades old inventories of the potential natural vegetation are outdated due to climate change
- Planting of exotic trees as a chance to economically compensate for the natural decline ≠ risk of biotic invasion (Krumm et al., 2020)
- High dominance of invasive species can hinder native tree regeneration
- Damage by large ungulates hinder the natural forest regeneration and make any afforestation impossible. This leads to high costs for planting and tree-protecting activities and severely complicates measures for adaptation to climate change (EEA, 2019)
- Planting broadleaves is 10 times more expensive than planting conifers

7 Indicators for Integrative Forest Management
NATIVE & NON-NATIVE TREE SPECIES/PROVENANCES AND WHICH OF THEM ARE SITE-ADAPTED

IFM* goals: Adaptive capacity to climate change; Enhancing forest resilience

FES*: Biodiversity

Importance for IFM assessment

Monitoring native and non-native tree species, as well as their provenances and site-adapted characteristics, is important for IFM as native tree species provide essential habitat, food, and shelter for diverse local organisms, contributing significantly to biodiversity and carbon sequestration. Understanding which native species are resilient to climate change helps in selecting trees that enhance the adaptive capacity of forest ecosystems to changing conditions. Site adapted species, whether native or non-native, are specifically suited to local environmental conditions such as soil type, moisture levels, and elevation. These species can enhance ecosystem resilience and productivity, optimizing tree growth, health, and the provision of ecosystem services (Krumm & Vitkova, 2016). Monitoring these species ensure that Forest Management practices are tailored to promote ecosystem stability, functionality and wood production. It allows forest managers to make informed decisions about species selection and management strategies.


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Characteristics

- ***State indicator***
- *Can predict* the adaptability of forest ecosystems to climate change
- *Reporting* on species suitability and site adaptation
- *Communicating* biodiversity status
- *Decision-making* regarding species selection and site-specific management

Trade-offs

Promoting biodiversity and naturalness by prioritizing native tree species ≠ enhancing forest resilience to climate change by introducing site-adapted tree species to secure ecosystem services. While native tree species may not always be the best suited to future climatic conditions, site-adapted species - whether native or non-native - can improve resilience. However, the use of non-native species carries the risk of invasiveness.

8 Indicators for Integrative Forest Management
TIMBER PRODUCTION POTENTIAL
(GROWING STOCK ON FOREST AREA AVAILABLE FOR WOOD SUPPLY)

IFM* goal: Provision of forest ecosystem services

FES*: Timber and wood products; Carbon sequestration

Importance for IFM assessment

By knowing the timber production potential, forest managers can make informed harvesting plannings that meet timber demands without overexploitation. This indicator helps ensure that forests remain productive, while also maintaining critical ecosystem services like carbon sequestration, biodiversity, and soil and water protection. It is particularly important in adapting to climate change, allowing managers to balance growing stock and introduce site-adapted species where needed, ensuring that forests remain resilient, multifunctional, and sustainable over the long term (Mantau et al., 2010).


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Characteristics

- ***State indicator***
- *Predictor* of harvesting capacities
- *Reporting* on forest productivity
- *Communicating* timber production potential
- *Decision-making* regarding harvesting planning and carbon sequestration strategies

Trade-offs

- Increasing growing stock and high canopy closure ≠ maintaining forest clearings and increasing early successional light demanding (rare) species.
- Growing stock as a predictor for wood supply is of economic importance for the rural area ≠ conservation goals.
- High growing stock/ha may indicate also potential of biodiversity relevant characteristics.
- Decrease of growing stock might be necessary for conversion measures to adapt to climate change.
- Enhancement of bioeconomy for the replacement of fossil fuels ≠ protection of forests for biodiversity

9 Indicators for Integrative Forest Management
MANAGEMENT INTENSITY (INCREMENT/FELLINGS) IN FOREST AREA AVAILABLE FOR WOOD SUPPLY

IFM* goal: Provision of forest ecosystem services

FES*: Timber and wood products; Carbon sequestration

Importance for IFM assessment

By monitoring increment/fellings on forest areas available for wood supply, managers can make informed decisions to optimize both economic returns and ecosystem resilience. Monitoring the harvesting and removal of wood, including salvage logging, provides essential information for IFM on economic goals, which must be carefully managed to avoid compromising biodiversity conservation and carbon sequestration. A utilization rate below 100% ensures that timber harvests do not exceed forest growth. However, in cases of natural disturbances or facing the need to adapt to climate change, rates larger than 100% might be acceptable. Management intensity is not related to the area but rather to temporary intensity, which can vary periodically. High management intensity could be regular every few years, allowing for adaptive management practices that respond to changing conditions. Monitoring these rates helps forest managers assess the balance between timber production and ecological sustainability, ensuring that harvesting practices do not compromise forest health, biodiversity, or carbon sequestration.


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Characteristics

- ***State indicator***
- *Reporting* on forest productivity
- *Predictor* of sustainable harvesting levels
- *Reporting* on forest productivity
- *Communicating* sustainable harvesting practices
- *Decision-making* regarding harvesting intensity

Trade-offs

- High management intensity ≠ Biodiversity conservation goals
- Carbon sink in forests ≠ Fellings
- There is an increased pressure for increased timber production under global changes and substitution of steel, concrete and fossil fuels.
- Retention of deadwood and habitat trees are important parts of any IFM intervention to be considered

10 Indicators for Integrative Forest Management
FOREST CARBON

IFM* goal: Provision of forest ecosystem services

FES*: Carbon sequestration

Importance for IFM assessment

The capacity of sequestering carbon is a key metric in Forest Management, as it enables forest managers to ensure that activities such as thinning or harvesting do not compromise the forest's ability to sequester carbon. Furthermore, an understanding of carbon dynamics in forests is pivotal in achieving a balance between economic objectives and ecological sustainability, thereby ensuring that timber production does not compromise carbon sink capabilities. Moreover, data on carbon sink is integral to the carbon credit market. Forests that effectively sequester carbon can gene rate carbon credits, which can be sold to offset emissions from other sectors. This provides a financial incentive for IFM practices. Participation in the carbon credit market enables forest managers to generate additional revenue.


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Characteristics

- ***State indicator***
- *Predictor* of carbon sequestration potential
- *Reporting* on carbon storage and sequestration capacity
- *Communicating* the role of forests in climate change mitigation
- *Decision-making* regarding carbon sequestration strategies and sustainable harvesting practices

Trade-offs

- Carbon sink ≠ Biomass extraction
- Carbon sink ≠ increased disturbance from climate change
- Old forest with low C sink strength have typically accumulated much fuel and thus bear a higher risk for uncontrolled fires.
- Younger coniferous forests with high C sink strength may have lower crowns and then we may have a higher risk for crone fires.
- Policy over-emphasises the use of forests for energy production instead of increasing forest for carbon storage (EASAC 2017).

11 Indicators for Integrative Forest Management
REVENUE OF FOREST ENTERPRISES

IFM* goal: Provision of forest ecosystem services

FES*: Revenue of forest enterprises

Importance for IFM assessment

Revenue from timber and non-timber products is crucial for integrated Forest Management in forest enterprises because it supports economic sustainability while promoting the provision of various ecosystem services. Timber sales provide core income for investments in sustainable practices, while mainly extensively produced NWFPs such as fruits, mushrooms, or game diversify revenue streams and support regional demand. Additional income from services like clean water, hunting licenses, recreation, and entrance fees to cultural or recreational sites further enhances economic resilience. By balancing income generation with the maintenance of ecosystem services, IFM strengthens the viability of forest enterprises, supports local economies, and promotes long-term ecological and social benefits.



Characteristics

- ***State indicator***
- *Predictor* of economic sustainability and forest enterprise viability
- *Reporting* on economic aspects of IFM
- *Communicating* the economic benefits of IFM
- *Decision-making* regarding income generation strategies and balancing economic and ecological goals

Trade-offs

- Forest visitors take NWFP and services granted for free ≠ willingness to pay.
- Maximizing several ecosystem services simultaneously within a single stand or enterprise ≠ inherent trade-offs between different ecosystem services (Kraus & Krumm, 2013).
- IFM can cause lower revenues and additional costs as for example, by preserving old trees and leaving large amounts of deadwood in the forest. Additional costs can also arise when applying more expensive timber harvesting methods to support soil protection (Krumm et al., 2020).
- Money from the timber pays for biodiversity conservation.

12 Indicators for Integrative Forest Management
FOREST STRUCTURE

IFM* goals: Enhancing forest resilience; Provision of forest ecosystem services

FES*: Biodiversity; Habitat provision; Aesthetic value; Resilience

Importance for IFM assessment

Information on forest structure combines the assessment of even or uneven-aged age structure and diameter distribution with multi-layeredness. By monitoring stand age and diameter distribution, managers can obtain accurate increment data, enabling timber production planning and sustainable harvest scheduling. Additionally, maintaining diverse vertical structures through a mixture of tree ages and dimensions addresses ecological and economic management objectives like increasing habitat diversity, enhancing resilience against natural disturbances and climate change impacts, improving the quality and value of individual trees, ensuring regeneration, and supporting economic viability by providing optimized, regular revenues while minimizing costs of artificial regeneration (Gao et al., 2014; Messier et al., 2014; Puettmann et al., 2009).


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Characteristics

- ***State indicator***
- *Predictor* of harvesting capacities and of resilience against natural disturbances
- *Reporting* on forest structure and its implications for biodiversity and resilience
- *Communicating* the importance of structural diversity for resilience and biodiversity
- *Decision-making* regarding structural diversity, and resilience-building measures

Trade-offs

Rich structured forests ≠ economies of scale in harvesting that favour clear cutting (Argestam et al., 2020)

13 Indicators for Integrative Forest Management
PLAN FOR THE RETENTION OF VALUABLE STRUCTURES IN FORESTS

IFM* goal: Biodiversity conservation

FES*: Habitat provision; Biodiversity; Aesthetic value; Stewardship

Importance for IFM assessment

Retaining valuable structures like bushes, pioneer species, deadwood and habitat trees is ecologically important as these elements provide essential habitats for a wide range of species. Deadwood is a critical resource for decomposers that recycle nutrients back into the soil, enhancing forest health and productivity. Bushes and habitat trees offer nesting sites and food sources. Planning for deadwood retention can also help avoid or reduce salvage logging, which often disrupts habitat creation and ecological processes. While retaining or creating these valuable structures may require short to mid-term investments, the long-term benefits are significant. Structurally diverse and vital forests are more resilient to threats such as climate change, pests, and diseases. Economically, these investments pay off in the long term by more resilient forest ecosystems safeguarding timber resources and reducing the costs of managing degraded forests. Socially, structurally diverse forests offer recreational opportunities and aesthetic values, contributing to human well-being.


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Characteristics

- *Response indicator*
- *Predictor* of biodiversity and habitat quality
- *Reporting* on structural diversity and habitat provision
- *Communicating* to care about valuable structures in forests
- *Decision-making* regarding retention priorities

Trade-offs

- Deadwood retention ≠ Salvage logging to increase resilience against bark beetles and forest fires.
- Retaining valuable structures in forests may reduce short-term revenues from timber.

14 Indicators for Integrative Forest Management
FOREST RISK MITIGATION AND CLIMATE CHANGE ADAPTATION PLAN

IFM* goals: Enhancing forest resilience; Adaptive capacity to climate change

FES*: Stewardship; Pest and disease control; Erosion control; Genetic diversity

Importance for IFM assessment

A forest risk management planning is essential for maintaining forest health, resilience, and productivity and should consider precautionary measures and countermeasures to address risks aligning with conservation and economic objectives (Krumm et al., 2020). The climate change adaptation planning should go beyond changing forestry practices to new site conditions. New objectives and structures must be defined to enhance the resilience and adaptability of forests to new, often unpredictable environmental realities.



Characteristics

- *Response indicator*
- *Predictor* of forest resilience and adaptive capacity
- *Reporting* on planned risk mitigation and adaptation measures
- *Communicating* the importance of planned risk mitigation, preventive and adaptation measures
- *Decision-making* regarding priorities on countermeasures, preventive measures or adaptation measures

Trade-offs

- Risk mitigation and climate change adaptation activities might be resource intensive and costly.
- Precautionary and containment activities may have unintended environmental impacts like deadwood removal for risk reduction.
- Disturbances may provide temporary habitats for a high number of species, depending on size and intensity of affected area (Kraus & Schuck, 2017).

15 Indicators for Integrative Forest Management
FOREST MANAGEMENT PLAN

IFM* goals: Provision of forest ecosystem services; Biodiversity conservation; Enhancing forest resilience; Adaptive capacity to climate change

FES*: Stewardship

Importance for IFM assessment

IFM is typically documented in a Forest Management plan that outlines the objectives and practices for IFM including ecological (e.g. reducing fragmentation, increasing connectivity), economic (e.g. sustainable harvesting), and social (e.g. staff health care, recreational use) considerations. These plans serve as a critical tool for guiding the implementation of IFM, ensuring that Forest Management aligns with sustainability goals while balancing multiple ecosystem services and stakeholder interests. In an ideal case, a Forest Management plan should incorporate additional objectives from other sectors, such as nature conservation and urban planning, to reduce the risk of trade-offs and conflicts.



Characteristics

- *Response indicator*
- *Predictor* of management effectiveness
- *Reporting* on management objectives and practices
- *Communicating* about management activities and forest inventory details
- *Decision-making* about management measures

Trade-offs

- Management plans may have trade-offs with plans with different objectives, like plans for nature conservation or plans for urban development that exist in the same area.
- Large unfragmented forest areas are beneficial for biodiversity, but a Forest Management plan must also consider creating fragmentation, if necessary, to help regulate forest fires, bark beetles and pests spreading over larger areas.

16 Indicators for Integrative Forest Management
PROTECTED FOREST AREA
(DESIGNATED BY LAW OR BY VOLUNTARY TEMPORARY CONTRACTS TO PROTECT BIODIVERSITY OR OTHER FOREST ECOSYSTEM FUNCTIONS)

IFM* goals: Biodiversity conservation; Provision of forest ecosystem services

FES*: Stewardship; Biodiversity; Habitat provision

Importance for IFM assessment

In legally protected forest areas (PFA) but also in forest areas under voluntary contractual nature conservation where harvesting is restricted, IFM may focus on conservation measures to maintain and enhance biodiversity and other ecosystem functions. Temporary contractual nature conservation fosters collaboration between forest owners, forest administration, research and environmental NGOs incentivising the temporary (usually 20 years) decommissioning of high-value forest areas to conserve biodiversity.


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Characteristics

- *Response indicator*
- *Predictor* of species diversity and ecosystem functions
- *Reporting* on protected areas and conservation measures
- *Communicating* the importance of protected areas
- *Decision-making* regarding conservation management

Trade-offs

- Unmanaged protected forest ≠ Managed forests with timber extraction
- Establishment of additional protected areas ≠ Reduced forest available for wood supply (FAWS) with competing management goals (Kraus & Krumm, 2013)
- Protective forests (which need to be managed to maintain their protective functions) ≠ Protected forests

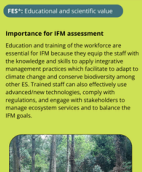
17 Indicators for Integrative Forest Management
EDUCATION AND TRAINING

IFM* goal: Provision of forest ecosystem services

FES*: Educational and scientific value

Importance for IFM assessment

Education and training of the workforce are essential for IFM because they equip the staff with the knowledge and skills to apply integrative management practices which facilitate to adapt to climate change and conserve biodiversity among other ES. Trained staff can also effectively use advanced new technologies, comply with regulations, and engage with stakeholders to manage ecosystem services and to balance the IFM goals.


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Characteristics

- *Response indicator*
- *Predictor* of quality of Forest Management
- *Reporting* on social aspects and workforce development
- *Communicating* the importance of education and training for sustainable Forest Management
- *Decision-making* regarding workforce development and capacity-building initiatives

Trade-offs

No trade-offs identified.