D 7.1 - First draft on policy recommendation framework

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List of acronyms and abbreviations

ACRONYM	Description
AP	Action Point
API	Application Programming Interface
CA	Consortium Agreement
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
CTNFM	Closer-to-Nature Forest Management
DoA	Description of Action
DX.Y	Deliverable X. Y (X refers to the WP and Y to the deliverable in the WP)
EAB	External Advisory Board
EC	European Commission
ECAS	European Commission Authentication Service
EFI	European Forest Institute
EU	European Union
EIM	Exploitation and IP Manager
ELGA	Hellenic Agricultural Insurance Agency
ELSTAT	Hellenic Statistical Authority
EROS	Earth Resources Observation and Science
ESA	European Space Agency
FAOSTAT	Food and Agriculture Organization of the United Nations
FCover	Fractional Vegetation Cover
FDP	Forest Development Phases
GA	General Assembly
IPCC	Intergovernmental Panel on Climate Change
IPRs	Intellectual Property Rights
KoM	Kick-off Meeting
KPI	Key Performance Indicators
MA	Millennium Ecosystem Assessment
MESMA	Multiple Endmember Spectral Mixture Analysis
NRM	Natural Resource Management
PAC	Project Administrative Coordinator
PM	Project Manager

PQP	Project Quality Plan
RP	Reporting Period
SC	Steering Committee
QAC	Quality Assurance Coordinator
QAM	Quality Assurance Manager
QAP	Quality Assurance Plan
SIC	Scientific and Innovation Coordinator
TL	Team Leader
ToC	Table of Contents
VSI	Vegetation Sensitivity Index (VSI)
WP	Work Package
WPL	Work Package Leader
WRM	World Rainforest Movement

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Executive Summary

This document is the deliverable D7.1, entitled "First draft on policy recommendation framework". The scope of D7.1 is to provide a comprehensive mapping of current policies and practices related to forest management, with a focus on sustainable forest management, forest resilience, post-fire forest restoration, and forest governance. It discusses EU policies related to the climate crisis, biodiversity management, wildfire policy, forest strategy and provides related key points for the next steps, in order to support the process of developing new policies or enhancing current policies related to wildfires prevention and mitigation.

Definitions and roles of forests are discussed, as well as EU policies for the climate crisis, including the EU Green Deal and wildfire policy. The document presents sustainable forest management as a holistic approach, including traditional and multifunctional forest management and the new approach of closer-to-nature forest management as well. The topic of forest resilience is addressed, including the assessment of forest resilience and the data that support it. Moreover, post-fire forest restoration is discussed, including pre- and ongoing fire impact assessment, consequences of wildfires, long-term restoration and forest resources performance. Finally, forest governance models are explored and concluding preliminary remarks, with future work recommendations are given.

The deliverable emphasizes the importance of healthy forests and the various ecosystem services that are provided by the forest, but also the multiple negative impacts of wildfires are highlighted, including environmental, economic, and social effects. Collected evidence highlights the need for effective forest management practices to promote resilience and adaptation in the face of climate change and other stressors, while balancing the competing interests of different stakeholders.

Various examples of successful wildfire prevention and restoration strategies, including both passive and active restoration approaches are presented. The importance of using site-appropriate species and management techniques is stressed. It is concluded that promoting sustainable forest management practices and reducing vulnerability to future wildfires should be a top priority in forest policies, and that participatory processes and stakeholder involvement are critical for successful implementation of these policies.

1 Introduction

Climate change has been one of the major factors in increasing the risk and extent of wildfires in Europe in recent decades, especially in the Mediterranean region, causing rippling effects in ecological, social and economic conditions and services. The 2018 special report of the Intergovernmental Panel on Climate Change (IPCC) concluded that human-induced warming has already reached around 1°C above pre-industrial levels and if this pace of warming continues, would reach 1.5°C around 2040, unless there are dramatic reductions in carbon emissions (IPCC, 2018). In the technical report of Eberle et al. (2021/2022) it is stated that in the summer of 2021 a record-breaking heat of up to 48.8 °C was recorded (mainland Spain), in combination with drought and low humidity, leading to wildfire outbreaks across Mediterranean countries, including Italy, Greece, Algeria and Turkey. During the summer of the same year (in July and August 2021) more than 620,000 ha of land burned. Apart from loses of million hectares of wood- and agriculture land areas, with native species of plants and certain animal life that caused a significant loss on biodiversity, large scales and intensive wildfires are responsible also for human loses. More than hundred people were killed during the 2021 wildfire season in the Mediterranean, including Italy, Greece, Algeria and Turkey (Eberle et. al., (2021/2022). Three people died in Greece, four people died in Italy and at least eight people were killed in Turkey (Sullivan, 2021; Gristwood, 2022). In 2017 as well, wildfires caused the death of 118 people in Portugal (both civilians and firefighters) and in 2018, Greece suffered with 102 deaths from the Mati (Attica) wildfire (EU, 2021). In 2007, 84 people lost their lives in Greece, including several fire fighters. On top of all the above, many more people suffered from fire-related injuries, such as burns and respiratory problems from smoke inhalation (CBS, 2021; Abnett, 2021; Castelfranco, 2021). In addition to fatalities or other direct or indirect public health impacts and ecological disturbances, wildfires also cause major economic consequences at local, regional, national and global scales.

Healthy forests provide a wide range of ecosystem services, including supporting biodiversity, climate and water regulation, provision of food, medicines and material, carbon sequestration and storage, soil stabilisation as well as bringing immense recreational, aesthetic and spiritual benefits to millions of people (Jenkins et al. 2018). Therefore, it is crucial to maintain healthy forest ecosystem, by sustainably managing them and restoring them after hazards, such as wildfires, while increasing their resilience to their typical hazards and their adaptation to climate change or untypical hazards, as they are essential for people lives and livelihoods.

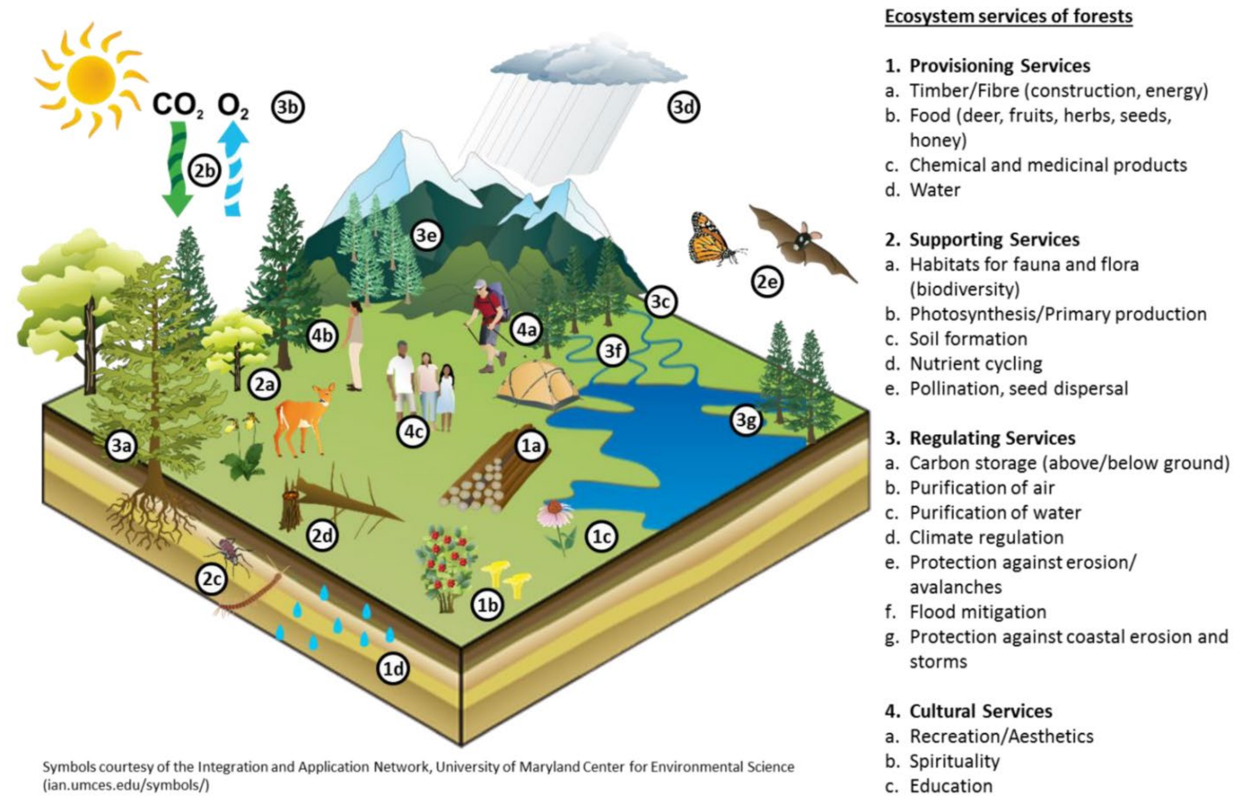

Figure 1: Ecosystem services provided by forests, divided in: provisioning, supporting, regulating and cultural services (Holzwarth et al. 2020).

Traditionally, to restore an area after a wildfire, managers and stakeholders first have to make an analysis of the fire root causes (why, when, where and how fires start and their impacts on forest areas and people). Then the main management objectives need to be defined (definition of goals, i.e., emergency and/or long-term restoration), considering the history, local environmental and social conditions and priorities. Lastly, considering all the above, they have to choose optimal or alternative silvicultural measures in order to achieve the future goals.

The new EU forest strategy for 2030[1] is one of the flagship initiatives of the European Green Deal and builds on the EU biodiversity strategy for 2030. The strategy sets a vision and concrete actions to improve the quantity and quality of EU forests and to strengthen their protection, restoration and resilience. It aims to adapt Europe's forests to the new conditions, weather extremes and high uncertainty brought by climate change. This is a precondition for forests to continue delivering their economic, ecological and socio-cultural functions, and to ensure vibrant rural areas with thriving populations. Also, the guidelines on land-based wildfire prevention call for managing vegetation to avoid the accumulation of fuels on the ground to facilitate fire-fighting.

The EU is working on measures to mitigate the unavoidable impact of wildfires and published the EU Strategy on Adaptation to Climate Change in March 2021. The strategy underlines that adaptation needs to become faster, smarter and more systemic.

[1] https://environment.ec.europa.eu/strategy/forest-strategy_en

1.1 Deliverable Scope

The main goal of this first deliverable under WP7 is to provide a comprehensive mapping of current policies and practices related to forest management, with a focus on sustainable forest management, forest resilience, post-fire forest restoration, and forest governance. The deliverable aims to analyze and evaluate EU policies related to the climate crisis, biodiversity management, wildfire policy, and forest strategy, and to provide recommendations for policy frameworks that can support integrated technological and information platforms for wildfire management.

To achieve this goal, the deliverable utilizes a working methodology that includes literature reviews and use of questionnaires. The deliverable provides a detailed overview of the roles and significance of forests, including an analysis of the main issues in forest management, such as conflicts related to the definition of forests and forest conflict cases. The comparative analysis of traditional forest management practices and closer-to-nature forest management practices are evaluated for their effectiveness in promoting sustainable forest management.

The deliverable also provides an overview of forest resilience, including methodologies for assessing the quantitative and qualitative aspects of forest resilience. Post-fire forest restoration are explored, including pre- and ongoing fire impact assessment, consequences of wildfires on ecosystem biodiversity, post-fire damage quantification and secondary damages, and long-term restoration and forest resources performance. Recommendations for post-fire restoration processes based on close-to-nature forest management principles are identified.

Furthermore, the deliverable analyzes governance models for forest restoration, including traditional forest models, innovative forest models, and economic investment models, and provides recommendations for policy frameworks that can support integrated technological and information platforms for wildfire management.

1.2 Overview of Working Methodology

As aforesaid, the development of this document has followed a twofold approach, which has been based on extensive literature reviews, on one hand, as well as primary research to relevant experts and stakeholders by means of carefully prepared questionnaires, on the other. This first deliverable of WP7 has mostly been based on the literature review through desk research but has also given the opportunity to initiate primary research on focused topics where primary research would make sense (see Section 1.2.2). A more extensive analysis of the evidence collected through the questionnaires will be carried out in the next phases of the project and will be appropriately documented in D7.2 "Second draft on policy recommendation framework".

1.2.1 Literature Reviews

The purpose of having a methodology to conduct literature review is to standardize the outcomes and ensure quality of the results. The use of keywords for literature review is a common practice in research to ensure a systematic approach to searching for relevant literature. However, it is true that the list of keywords provided may not be exhaustive and other relevant keywords could have been included, such as "wildfires" or "wildfire management". The use of additional keywords could have potentially resulted in the identification of more relevant literature on the topic. It is important to note that the table of keywords provided in the methodology is not intended to be a definitive list, but rather a starting point for the literature review. Also, it is important to note that, for several parts, expert knowledge regarding the respective domain is used by the authors, and the literature review is used to supplement or confirm own knowledge (e.g., regarding current EU policies and forest management practices) as well as provide additional background where applicable. As the review progresses, additional keywords can be identified and incorporated into the search strategy as necessary. Overall, it is important to approach literature review systematically and rigorously, using multiple sources and search strategies to ensure a comprehensive review of the relevant literature.

Table 1: Keywords for literature review

	Identify relevant keywords
EU policies for climate crisis	"EU climate policy," "climate change mitigation," and "climate adaptation."
Sustainable forest management practices	"Sustainable forest management", " multifunctional forest management ", "integrative forest management", "nature-based forest management", "closer-to-nature forest management", "continuous cover forestry"
Forest resilience	"Forest resilience," "ecosystem resilience," and "climate resilience."
Post-fire forest restoration	"post-fire forest restoration," "ecosystem recovery," and "forest rehabilitation."
Forest governance	"Forest governance," "forest policy," and "forest management."

After the keyword identification, the methodology comprised the followed:

- Use academic databases such as Web of Science, Scopus, and Google Scholar to identify relevant articles, reports, and policy documents.
- Review the literature to identify:
    - key EU policies related to the climate crisis, such as the EU Green Deal and the EU Climate Law.
    - key sustainable forest management practices, such as ecosystem-based management and adaptive management.
    - methodologies for assessing forest resilience, such as the Resilience Alliance framework and the Stockholm Resilience Centre resilience assessment.
    - post-fire forest restoration practices, such as salvage logging, reforestation, and natural regeneration.
    - different forest governance models, such as top-down governance and participatory governance.
- Analyze and synthesize the literature to identify:
    - trends, challenges, and opportunities related to EU policies for the climate crisis.
    - the effectiveness of different sustainable forest management practices and their impact on forest ecosystems, biodiversity, and socio-economic development.
    - the factors that contribute to forest resilience, such as biodiversity, ecosystem services, and adaptive capacity.
    - the effectiveness of different post-fire forest restoration practices and their impact on forest ecosystems, biodiversity, and socio-economic development
    - the effectiveness of different forest governance models and their impact on forest ecosystems, biodiversity, and socio-economic development
- Develop initial policy recommendations based on the analysis of the literature.

1.2.2 Specification and Use of Questionnaires

In addition to the literature review, the partners of the consortium created a dedicated questionnaire to be shared among the pilots and stakeholders. The questionnaire was created by the domain (forest management) experts of the consortium and was initially distributed internally to be reviewed and approved. After this step, it was shared among the pilot leaders and relevant stakeholders of the pilot countries to be answered. A period of approximately 45 days followed to allow the users to respond. Next the partners analysed the questionnaire responses and synthesized the results which contributed to the next chapters of this deliverable.

What follows is the questionnaire template that was used as an instrument of evidence collection from the pilots and stakeholders. Specifically, the components of the questionnaire have been carefully prepared in order to cover the following five aspects: 1) legal and policy framework (at country level), 2) decision making in forest restoration (at country level), 3) processes of forest restoration (at country level), 4) monitoring and results of forest restoration (at country level), 5) restoration programme case study (at pilot site level).

SILVANUS WP7 QUESTIONNAIRE

Note: PARTS 1-4 concern the Pilot COUNTRY. PART 5 concerns a specific Pilot AREA.

Country or region for which the Questionnaire is filled in:	
Pilot Area for which the Questionnaire is filled in:	

1. CURRENT LEGAL AND POLICY FRAMEWORK

1.1 Please provide -in English- the definition of forest and forested/wooded areas according to your national/state laws and regulations.

Please describe

1.1.1 Is this definition in accordance with the FAO definition?

Yes/No/Not aware

If No:

1.1.2 What are the key differences?

Please describe

1.2 At national (country) level, what is the legal framework (current laws and regulations) that addresses (sustainable) forest management? *Please provide references to applicable laws and regulations and a brief description -in English- of the content of each one.*

Please describe

1.3 At national (country) level, is there any legal framework that defines the conditions that must be fulfilled, in order to take action for the restoration of burned areas?

Yes/No

If Yes:

1.3.1 What is this legal framework? Provide references to applicable laws and a brief description -in English- of the content of each one.

Please describe

1.3.2 According to your opinion, is this legal framework sufficient for the restoration of burned areas (and particularly of forest areas)?

Yes/No

1.3.3 What are the legal gaps (if any) in comparison to the European Union directives?

Please describe

1.3.4 What improvements could be made to the current legal framework?

Please describe

1.4 In your country or region, do Sustainable Forest Management policies give more focus on specific topics or aspects? What are these topics? Are all the topics equally important? *For example: Is there more focus on response or on prevention measures? Are the forest management policies more oriented on wildfire/landscape fire prevention/mitigation/response? Are they more economically driven and/or land use driven?*

Please describe

1.4.1 Do you consider that forest management in your country or region is more segregated (e.g., strictly concerning protected forest areas or economical forest plantation) or integrated (integrated multifunctional forest landscapes)? Do you consider that forest management in your country or region places more focus on specific aspects or follows a more holistic approach?

Please describe

<u>If it is more holistic:</u>

1.4.2 How is this holistic approach to forest management implemented? *Please describe briefly. You can use specific examples if it is convenient.*

Please describe

1.5 What are the funding mechanisms used for the restoration, rehabilitation and maintenance of forests? *Please try to name specific funding programmes and respective objectives (briefly). Please also try to provide funding information in relation to the country's GDP, if possible (e.g., funding for forest sector in 2021 x% of country's GDP).*

Please describe

2. DECISION PROCEDURES FOR FOREST RESTORATION

2.1 Is there any official methodology on the basis of which the decision of the restoration (holistic or partial) is taken?

Yes/No

<u>If Yes:</u>

2.1.1 What is this *official methodology*? Please describe the methodology and provide the relevant literature references if available.

Please describe

<u>If No:</u>

2.1.2 Please describe the *empirical process* that guides the decision about the objectives of the restoration and their prioritization.

Please describe

2.2 Which Entity/ies (actor) is in charge of taking the decision for the objectives of the restoration?

Please describe

2.3 Is there a participatory process that is followed between various administration services and local stakeholders to guide the decision for these objectives?

Yes/No

If Yes:

2.3.1 Please describe the participatory process.

Please describe

2.4 Is there a strategy that is followed to engage with the local stakeholders that will be involved in any part of the restoration (from planification to execution)?

Yes/No

If Yes:

2.4.1 Please describe this strategy.

Please describe

2.4.2 How are the interests of the (local) stakeholders considered?

Please describe

2.5 What are the main factors that trigger the restoration process?

Please describe

2.6 Is chemical analysis of soil, air or water implemented in the burned area?

Please describe

2.7 What are the most common objectives of the restoration process?

Please describe

2.8 Which Entity/ies is responsible for implementing the restoration?

Please describe

2.9 Is there any follow-up or recurrent action if the restoration process fails?

Please describe

3. FOREST RESTORATION PROCESS

3.1 What are the most common actions for the restoration of burned areas (e.g., artificial regeneration, natural regeneration, works for reduction of soil erosion and flood risk, etc.)?

Please describe

3.2 What is the usual sequence (order) of actions and the time extent of each one (e.g., dead tree removal, flood protection works, artificial or natural regeneration)?

Please describe

3.3 Are precaution works or other activities to control soil erosion usually implemented?

Please describe

3.4 Is there any provision during the restoration process on increasing long-term forest resilience? What are the typical measures taken in this direction?

Please describe

3.5 In what time depth are the restoration actions applied (i.e., how many years)?

Please describe

3.6 Do the forest restoration processes involve any (strategic) planning that is related to a future resilient forest model? Please describe, for example, whether the goals is simply to return to a pre-fire ecological status or to an improved one that can mitigate damage/impacts of a potential future event.

Please describe

4. MONITORING AND RESULTS OF FOREST RESTORATION

4.1 Are there any methodologies and associated metrics applied for the evaluation of the restoration's success (i.e., a posteriori evaluation, Key Performance Indicators, such as biodiversity index, etc.)?

Please describe

4.2 Are there any methodologies and/or tools (e.g., technical means) in place for the continuous monitoring of forest restoration?

Yes/No

If Yes:

4.2.1 What are these methodologies and/or tools? *Please describe them providing the relevant literature references if available.*

Please describe

4.2.2 Do you consider that these methods and/or tools are sufficient to achieve the objective of continuous monitoring of forest restoration?

Please describe

5. CASE STUDY OF A RESTORATION PROGRAM IN YOUR PILOT COUNTRY

5.1 Please provide a short description of a pilot area that *is, was or could be* under restoration in your country.

Please describe.
Note that you may either provide a description or simply point us to the most relevant an up-to-date information of a published or draft deliverable. For instance: "DX.Y Chapter Z" and "DA.B Chapter C".
In either case, please make sure that your description contains at least the following information:
- *location of the area, forest type, tree species, topography, climate, available ecosystem services*
- *burned area size (ha), day/month/year of fire, duration of fire, fire-fighting forces that have taken part in fire extinction, fire history (or fire recurrence), physical environment status during disturbance event (season, humidity, temperature, …)*

5.2 Describe the methodology for the decision-making about the restoration and the selection of the objectives.

Please describe

5.3 Describe the restoration actions, their sequence (order) and their duration.

Please describe

5.4 Please provide information about the Total Cost of restoration (including soil protection measures), if available, and also compare it with the total area (cost (€)/ha).

Please describe

5.5 Current state of the restoration program: Has the program ended (successfully, not successfully, why), is it ongoing (how is it going, successfully, not successfully, why), or not yet initiated?

Please describe

5.6 What was the footprint of the program and what is the current state in the area of interest? What are the key lessons learnt?

Please describe

5.7 Please add any complementary information that you consider useful.

Please describe

2 Definitions and Roles of Forests

2.1 Forest Definitions

2.1.1 Definitions

FAO (FRA, 2020) defines:

- ***FOREST***

as a "*Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use*".

Explanatory notes

1. *"Forest is determined both by the presence of trees and the absence of other predominant land uses. The trees should be able to reach a minimum height of 5 meters in situ.*

2. Includes areas with young trees that have not yet reached but which are expected to reach a canopy cover of 10 percent and tree height of 5 meters. It also includes areas that are temporarily unstocked due to clear-cutting as part of a forest management practice or natural disasters, and which are expected to be regenerated within 5 years. Local conditions may, in exceptional cases, justify that a longer time frame is used.

3. Includes forest roads, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of specific environmental, scientific, historical, cultural or spiritual interest.

4. Includes windbreaks, shelterbelts and corridors of trees with an area of more than 0.5 hectares and width of more than 20 meters.

5. Includes abandoned shifting cultivation land with a regeneration of trees that have, or are expected to reach, a canopy cover of 10 percent and tree height of 5 meters.

6. Includes areas with mangroves in tidal zones, regardless whether this area is classified as land area or not.

7. Includes rubber-wood, cork oak and Christmas tree plantations.

8. Includes areas with bamboo and palms provided that land use, height and canopy cover criteria are met.

9. Includes areas outside the legally designated forest land which meet the definition of "forest".

10. ***Excludes*** *tree stands in agricultural production systems, such as fruit tree plantations, oil palm plantations, olive orchards and agroforestry systems when crops are grown under tree cover. Note: Some agroforestry systems such as the "Taungya" system where crops are grown only during the first years of the forest rotation should be classified as forest".*

- ***OTHER WOODED LAND***

"Land not classified as "Forest", spanning more than 0.5 hectares; with trees higher than 5 meters and a canopy cover of 5-10 percent, or trees able to reach these thresholds in situ; or with a combined cover of

shrubs, bushes and trees above 10 percent. It does not include land that is predominantly under agricultural or urban land use".

Explanatory notes

1. "*The definition above has two options:*

- The canopy cover of trees is between 5 and 10 percent; trees should be higher than 5 meters or able to reach 5 meters in situ.

or

2. The canopy cover of trees is less than 5 percent but the combined cover of shrubs, bushes and trees is more than 10 percent. Includes areas of shrubs and bushes where no trees are present.

- Includes areas with trees that will not reach a height of 5 meters in situ and with a canopy cover of 10 percent or more, e.g., some alpine tree vegetation types, arid zone mangroves, etc.".

- ***OTHER LAND***

All land that is not classified as "Forest" or "Other wooded land".

Explanatory notes

1. "For the purpose of reporting to FRA, the "Other land" is calculated by subtracting the area of forest and other wooded land from the total land area (as maintained by FAOSTAT).

2. Includes agricultural land, meadows and pastures, built-up areas, barren land, land under permanent ice, etc.

3. Includes all areas classified under the sub-category "Other land with tree cover".

Other land as "Land not classified as forest or other wooded land as defined above. Includes agricultural land, meadows and pastures, built-on areas, barren land, etc".

United Nations Framework Convention on Climate Change (UNFCCC; 2001): *A minimum area of land of 0.05–1.0 ha with tree crown cover (or equivalent stocking level) of more than 10–30 % with trees with the potential to reach a minimum height of 2–5 m at maturity in situ. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown cover of 10–30 % or tree height of 2–5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest.*

United Nations Convention on Biological Diversity (UN-CBD; 2010): *A land area of more than 0.5 ha, with a tree canopy cover of more than 10 %, which is not primarily under agriculture or other specific non-forest land use. In the case of young forest or regions where tree growth is climatically suppressed, the trees should be capable of reaching a height of 5 m in situ, and of meeting the canopy cover requirement.*

United Nations Convention to Combat Desertification (UN-CCD; 2000): *Dense canopy with multi-layered structure including large trees in the upper story.*

International Union of Forest Research Organizations (IUFRO; 2002): *A land area with a minimum 10 % tree crown coverage (or equivalent stocking level), or formerly having such tree cover and that is being naturally or artificially regenerated or that is being afforested.*

The UNFCCC, CBD, IUFRO and FAO definitions are compatible. They are all based on land use and tree cover. In terms of tree cover, all definitions set thresholds for minimum area, tree height and canopy cover. The CBD and FRA definitions have the same numerical values for the thresholds and they apply universally in all countries. The UNFCCC thresholds differ in that Parties to the Kyoto Protocol can set the numerical values within the ranges given, using their national definitions. Several countries have either adapted their national definitions or converted national data to be comparable with the FAO definition, and this process is expected to continue (Source: SECOND EXPERT MEETING ON HARMONIZING FOREST-RELATED DEFINITIONS FOR USE BY VARIOUS STAKEHOLDERS (fao.org)).

Appendix 10.1 also provides the national definitions of forests in selected countries of SILVANUS.

2.1.2 Comparison of Definitions

FAO (Food and Agriculture Organization) declares that there are over 200 national definitions of forests (Keenan, 2015) that reflect a variety of stakeholders in this matter, in order to have a globally valid, simple and operational categorization of forests. The definition of 'forest' varies because of national context, landcover, land use, administrative or legal unit, private or public property and so on. Whereas, from a territory perspective, these definitions vary from international, to national, to state, province and local scales (Lund, 2007). As stated on national GHG (Greenhouse Gas) inventories that are reported to the UNFCCC (United Nations Framework Convention on Climate Change), the definition of forest differs not only from country to country, following the parameters that have been agreed in the Marrakech Accords, allowing countries to identify different thresholds for a minimum green area, canopy cover, and tree height (Lund, 2002).

However, the diversification of terminology may lead to conflicts or complications. For instance, some definitions may ignore fundamental aspects of forests. Limiting the concept of 'forest' to a cluster of trees could overlook other forms of life (e.g., other types of plants, animals, forest-dependent human communities). Furthermore, after defining a "forest", a minimum area of land cover (following FAO's definition, a forest is a "land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use"), the major sector that benefits from this definition is industrial tree plantation sector; after many millions of hectares of industrial tree plantations. The consequences led to a negative impact on local communities and their forests, as the WRM (World Rainforest Movement) documented in their studies.

By the same token, Sasaki and Putz (2009) argue that a definition of forest should at least differentiate between natural forest and forest plantation, which will promote protecting biodiversity and contribute to sustainable development.

The main objective of stakeholders engaged in the tree plantation sector is the production of timber or fuel wood (it is estimated that about 35% of the global wood supply in 2000 has been provided from plantation, FAO 2011), but some of these activities, have been established to reduce erosion, fix carbon, or provide other environmental, economic, or social benefits (Brockerhoff, 2008).

Such debates may be partially solved by establishing a dialogue between the stakeholders that deal with forest products and services (wood-based industry, local communities, governments, private sector parties, civil society organizations and academia), and by revising FAO's definition from one that reflects the preferences and perspectives of timber, pulp/paper, rubber, and carbon trading companies, to one that reflects ecological realities as well as the views of forest-dependent peoples, as WRM states ("How does the FAO Forest definition harm people and forests? An open letter to the FAO", 2016).

To better address the dialogue issues in forest management, it is indeed critical to identify who are the important actors that deal with forest management. Forest stakeholders are individuals or groups that show interest in forests and the services and resources it provides. There are two classifications for forest stakeholders:

1. Indirect stakeholders: the stakeholders that affect forest management. This cluster of people do not depend on the forest for their livelihood, but their interests are affected by the forest. They include the government, industries, and environmentalists.
2. Direct stakeholders: the stakeholders that get affected by forest management. This group includes the forest dwellers, who depend on the forest for their food, shelter, and livelihood.

The main forest stakeholders that can be identified are:

- The Government and traditional authorities - who manages the forests and sets the rules and regulations for forest use.
- Industries - such as timber, pulp and paper, palm oil, rubber, carbon storage, biomass, etc.
- Environmental groups - who are concerned about the impact of forest use on the environment.
- Local communities - who depend on forests for their livelihood and cultural traditions, such as hunters, farmers, etc.

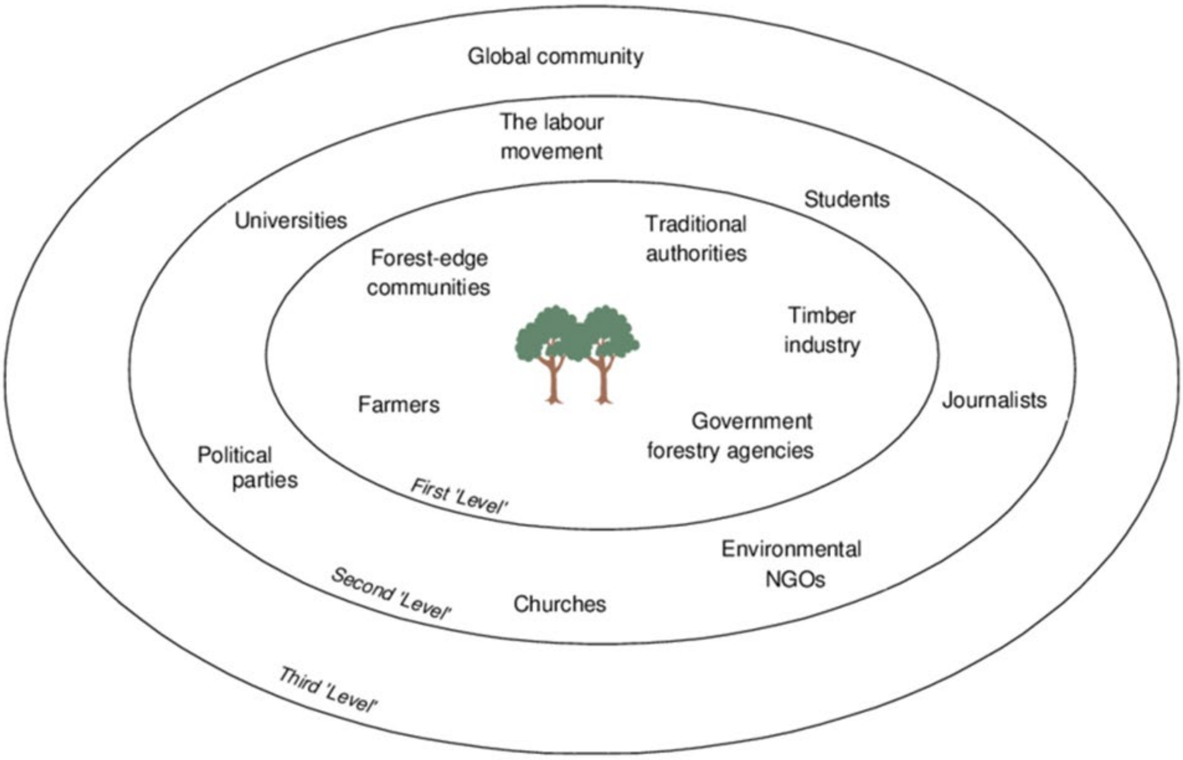

Figure 2: Levels of stakeholders (Mayers, James & Bass, Stephen; 2013)

2.1.3 Forest conflict cases

Natural ecosystems provide a wide range of natural resources, that benefit humans since a long time. The management of these natural resources led to conflicts between different stakeholders, because of differing and competing interests and ideas on how these resources should be carried out (Buckles 1999, Castro and Nielson 2003). Conflicts represent a key and an intrinsic part of natural resource management

(NRM). FAO states that conflicts over natural resource management "occur when there are disagreements and disputes regarding access and management of natural resources" (FAO, 2000).

Since 1950, European forest conflicts have occurred mainly because of three types of development (Hellström and Reunala, 1995):

1. Intensification of forestry operations – manifesting through: (a) overall changes in forest management (e.g. through changes in ownership structure, systems for transportation of wood to industry, changing of planning strategy, and suppression of natural forest fires), (b) changes in silvicultural systems (e.g. modified harvesting such as introducing clear-cutting, shortening of crop rotation times, introduction of exotic species and plantation forestry, installation and/or alteration of drainage systems, and use of fertilizers, pesticides and herbicides), and (c) introduction of new technologies (e.g. new machinery for timber harvesting and treatment of regeneration areas, and new types of forest roads)
2. Increasing recreational needs – e.g., tourism, sport, fishing or hunting can damage natural regeneration and intensify traffic in the area,
3. Increased importance of the environmental movement – e.g., indigenous groups may be affected by timber industry sector, or plantation may be perceived negatively by other forest user.

Additionally, the conflict types can be classified into (Hellström, 2001):

1. forest protection;
2. forest management;
3. forest conservation;
4. forest for amenity use;
5. private forest ownership-related conflicts.

Mola-Yudego and Gritten (2010) classified forest conflict types into 12 categories, as reported in Table 2.

Table 2: Conflict types used for the classification of forest conflicts (Modified from Mola-Yudego and Gritten, 2010)

	Conflict type	*Description*
1	Agriculture	Impact of agriculture on forest use
2	Bioenergy plantations	Establishing bioenergy plantations (for example, palm oil)
3	Conservation	Impact of forest conservation or protection activities
4	Deforestation	Effects of deforestation
5	Genetically modified material	Usage of GM material
6	Illegal logging	Impact of illegal logging on, for example, local communities
7	Indigenous rights	Rights of indigenous people restrained by, for example, timber logging of a private company
8	Forestry industry	Activities of some enterprise causing conflicts
9	Plantations (excluding bioenergy plantations)	Plantations for pulp and paper production
10	Resource extraction	Effects of, for example, coal mining on a forest in a mining area
11	Conflict of stakeholders	Stakeholders having different opinions on forest usage or management
12	Urban forestry	Different perspectives related to forest use in urban areas

In addition to the conflict type, forest conflicts can also be characterised based on the intensity of the actions that occurred in the conflict. If the most significant features of the conflict intensity are known, their transformation can be affected (Glasl, 1999).

Academic sources, publication and databases (Gritten and Mola-Yudego, 2011; Albrecht and Trishkin, 2017; Eurostat, 2020, Protected Forests, 2015) show that in Europe there have been 84 forest conflict cases, as shown in Figure 3 in the period 1999–2020. Distributed by countries, Germany and Poland were the countries with the most significant number of cases (9), followed by Finland (8), the Czech Republic (6) and Denmark (6). The following countries presented at least one case, with the exception of Belgium, Bulgaria, Cyprus, Luxembourg, Malta, and Portugal, where there were not forest conflict cases (Table 3).

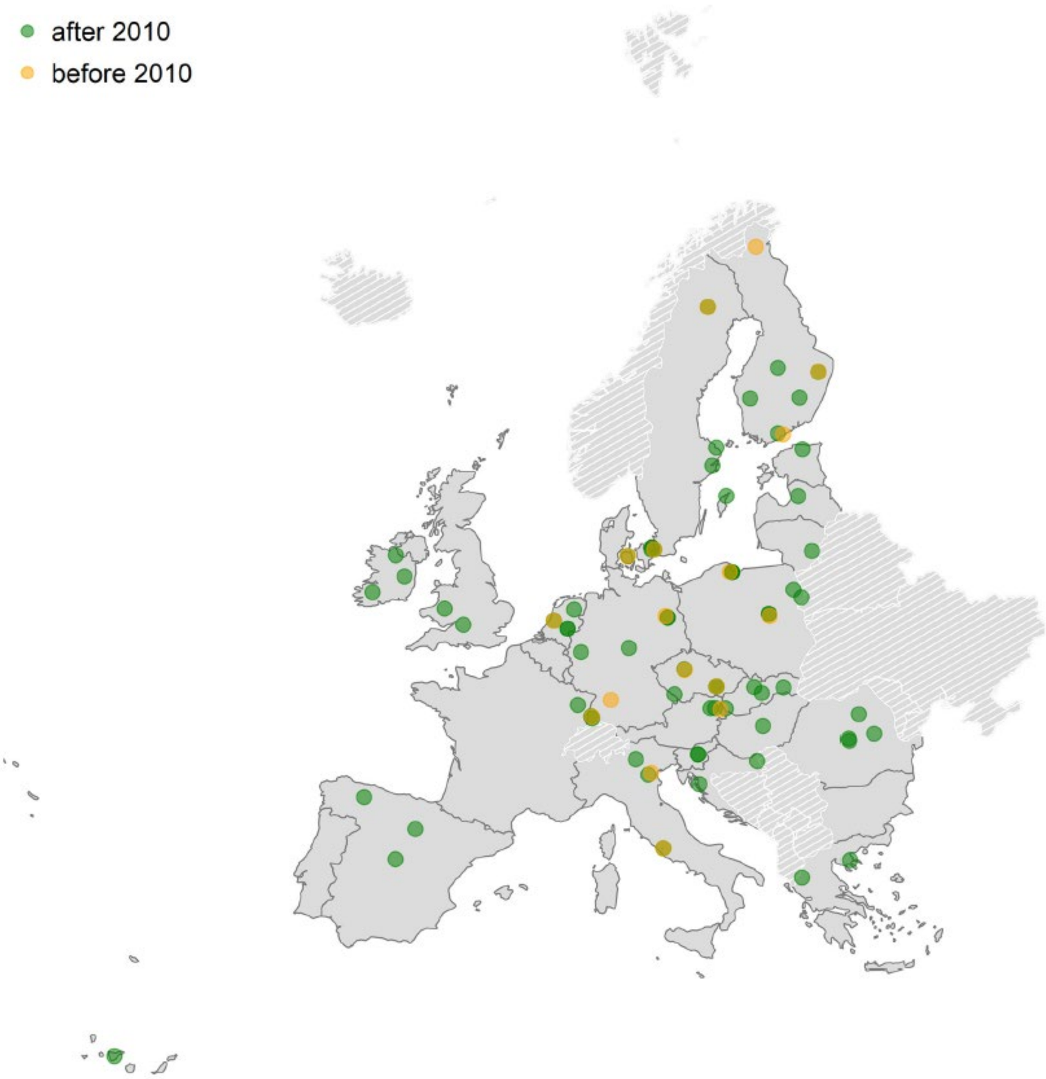

Figure 3: Forest conflicts identified (N = 84) in the period 1999–2020 in Europe (EU27 + UK) based on academic sources. Nousiainen, Daniela, and Blas Mola-Yudego (2022)

Table 3: Comparison of the number of conflicts with country-specific indicators: forest area, forest per capita, protected forests and urban population. There were no clear correlations observed. Nousiainen, Daniela, and Blas Mola-Yudego (2022).

Country	Forest area (x1000 ha)	Forest per capita (ha.cap^{-1})	Protected forests ($\times$1000 ha)	Urban population (%)	Forest conflicts (N)
Austria	3899	0.42	835	58.8	3
Belgium	689	0.06	48	98.1	0
Bulgaria	3893	0.6	578	75.7	0
Croatia	1939	0.65	320	57.6	2
Cyprus	190	0.22	26	66.8	0
Czech Republic	2677	0,26	752	74.1	6
Denmark	628	0.09	124	88.1	6
Estonia	2438	1.92	554	69.2	1
Finland	22,409	4.42	4327	85.6	8
France	17,253	0.23	6180	81.0	1
Germany	11,419	0.13	9264	77.5	9
Greece	3902	0.35	197	79.7	2
Hungary	2053	0.22	874	71.9	1
Ireland	782	0.15	7	63.7	3
Italy	9566	0.15	4706	71.0	5
Latvia	3411	1.81	549	68.3	1
Lithuania	2201	0.81	377	68.1	1
Luxembourg	89	0.16	2	91.5	0
Malta	0.46	< 0.00	NA	94.7	0
Netherlands	370	0.02	92	92.2	5
Poland	9483	0.27	1608	60.0	9
Portugal	3312	0.33	1070	66.3	0
Romania	6930	0.39	539	54.2	4
Slovak Republic	1926	0.41	854	53.8	4
Slovenia	1238	0.57	278	55.1	2
Spain	1857	0.29	5481	80.8	4
Sweden	27,980	2.92	2245	88.0	5
United Kingdom	3190	0.04	290	83.9	2

However, to a limited extent, conflicts have also had positive outcomes: for instance, new agreements over resource management, policy changes and co-management agreements among stakeholders (Castro and Nielson, 2001). In all cases, it is crucial to have a pragmatic plan of conflicts management.

The success or failure of conflict management is determined mainly by the development of adequate conflict capabilities, i.e., the ability to anticipate and deal with conflict constructively in order to accentuate the positive aspects of conflicts and eliminate the negative potential. The key to develop such capabilities is building a solid understanding of conflicts triggers, or the fundamental issues that lead to conflict (Glasl, 1999).

2.1.4 Dealing with conflicts

Niemelä (2005) suggested means that can be adopted to mitigate the damages of conflicts, and to develop the most efficient forest management strategies. These can be divided into three groups:

a. Technical - which may contribute to reduce or solve the conflict acting on the ’substance’ dimension, e.g., silvicultural guidelines, forest planning at or involving a local scale (watershed, community, and farm).
b. Political - which may influence the ‘procedure’ dimension of the conflict establishing principles or rules (e.g., EU regulations, forest acts, national/regional forest and land use planning), providing financial compensation and incentives, and favouring stakeholder participation.
c. Cultural - which may affect the ‘relationship’ dimension of the conflict. The aim should be to improve the ability of stakeholders to communicate with each other. The strategies to implement conflict resolution differ according to the attitude of people in different countries (Hellström, 2001): e.g., education policies aiming at improving the attitude of people to collaborate, and to acknowledge and respect the values of others; specific courses for forest managers to learn communication skills and techniques; advertising campaigns to make the public aware of the problems and to contrast lobbying actions.

There are some cases where it should be necessary to apply multiple approaches for one conflict alone, because the same issue may involve the cultural, political, and technical domain. Generally, it is important to involve several stakeholders in the planning process of conflict management and resolution; it is also critical to inform the local communities about the conflict resolution in progress, create awareness about the different interests and values at stake (Maguire, 1994).

As a result, the keys to better address the insurgence of a forest conflict is the identification of the issues and the triggers, identification of the main actors affected, identification of the domains affecting the issues, and adoption of tailored strategies.

2.2 The Roles and Significance of Forests

Forests are critical for world's biodiversity, landscape, society and economy. In the context of the phenomenon of a rapidly changing climate, people around the world have already recognized many major roles of forests. For example:

a. stability of the biosphere,
b. the maintenance of biodiversity (providing habitats as a host of other species of plants, along with numerous animals and microorganisms),
c. carbon sequestration, several forest resources (timber and non-timber forest products),
d. numerous renewable biobased materials and products and
e. rural livelihoods.

Except all these, forests also:

f. hold the water and control the waterflow over the land,
g. protect the soil from erosion,
h. providing a host of outdoor recreational opportunities,
i. creating jobs and
j. providing food, medicines, materials, etc.

It is a globally accepted fact that forests are already under increasing pressure from economic, environmental and social crises. There are significant biotic and abiotic threats and challenges, in particular from forest disturbance, biodiversity loss, forest and land degradation, damage from wind, insects, ungulate browsing, forest fires and economic factors. In addition, there are new and/or revived demands on forests from citizens.

The UN Sustainable Development Agenda 2030[2], agreed by world leaders in 2015, established 17 Sustainable Development Goals (SDGs) to be achieved by 2030. One of the 17 Sustainable Development Goals (SDGs), Goal 15 "*Life on Land*" refers *to "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss"* (source: https://sdgs.un.org/goals). Global Forest Goal 1 calls reserving the loss of forest cover worldwide through sustainable forest management, including protection, restoration, afforestation and reforestation, and increase efforts to prevent forest degradation and contribute to the global effort of addressing climate change (UN, 2021). Goal 6 address also directly forests. Below are described the two SDGs that directly address forests, with specific targets:

[2] https://www.un.org/sustainabledevelopment/development-agenda/

- Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss;
  - 15.1. By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements;
  - 15.2. By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally;
  - 15.10. Mobilize significant resources from all sources and at all levels to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation.
- Goal 6: Ensure availability and sustainable management of water and sanitation for all;
  - 6.6. By 2020 protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

Figure 4: UN Sustainable Development Goals.

FAO's "State of the World's Forests 2018" confirms that "forests and trees, when managed sustainably, provide a wide range of beneficial products and services, thereby contributing to the achievement of the 17 SDGs" (FAO, 2018).

The new EU Forest Strategy 2030 aims to overcome these challenges and unlock the potential of forests for our future, while fully respecting the subsidiarity principle, the best available science and the requirements of better regulation.

Natural ecosystems provide a wide list of benefits to humans since a long time; in recent years these benefits have been referred to as ecosystem services. The Millennium Ecosystem Assessment (MA) defined ecosystem services in 2005 as "the benefits gained by humans from ecosystems" (M.E.A., 2005), since 2005 research in this context has increase significatively (Kubiszewski et al., 2023). Ecosystem services have been divided in 4 classes, namely:

1. **Provisioning Services**. These are benefits to people that can be extracted from nature, such as food and fibre, fuel, genetic resources, biochemicals, natural medicines and pharmaceutical, ornamental resources and fresh water.
2. **Regulating Services**. These include all the processes that allow the life for people to be possible, working together to make ecosystems sustainable, clean, functional and resilient. These services are obtained by processes that moderate natural phenomena. Regulating services include: air quality maintenance, climate regulation, water regulation, erosion control, water purification and waste treatment, regulation of human diseases, biological control, pollination and storm protection.
3. **Cultural Services**. These services are non-material benefits that people obtain from nature that contribute to their development and cultural advancement through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences. Cultural services, being tightly bound to human values and behaviour, including social, economic and political organization, are likely to differ among individuals and communities, and the way that these services are perceived may strongly vary. Cultural services include: cultural diversity, spiritual and religious values, knowledge systems, educational values, inspirations, aesthetic values, social relations, sense of place, cultural heritage values, recreation and ecotourism.
4. **Supporting Services**. These services are those that are necessary for the production of all the other ecosystem services. Supporting services are different from the other services as their impact on people are often indirect or they occur over a very long time, while changes in the other services cause relatively direct and short-term impacts on people. Some of these services can be both categorised as belonging to this class or to other, e.g., erosion regulation can be both a supporting or regulating services, depending on the scale and immediacy of their impact on people. Supporting services include: soil formation, photosynthesis, primary production, nutrient cycling and water cycling (M.E.A., 2005).

Forest ecosystems are home to several ecosystem services at the same time. Production of timber and other non-wood from forest has been, and currently is, the main use of forest areas. As of today, about 30% of all forest are managed primarily for production of wood and non-wood forest products, including food product, such as fruits, nuts, berries, seeds, and non-food products, such as oils (e.g., palm oil), perfumes and medical plants. 20% of all forests is managed for multiple uses, 10% mainly for conservation of biodiversity and another 10% mainly for protection of soil and water. This distribution changes widely between regions, e.g., more than 50% of forest in Europe is primarily managed for production, while only in South America around 10% of forests is primarily managed for production (FAO, 2020).

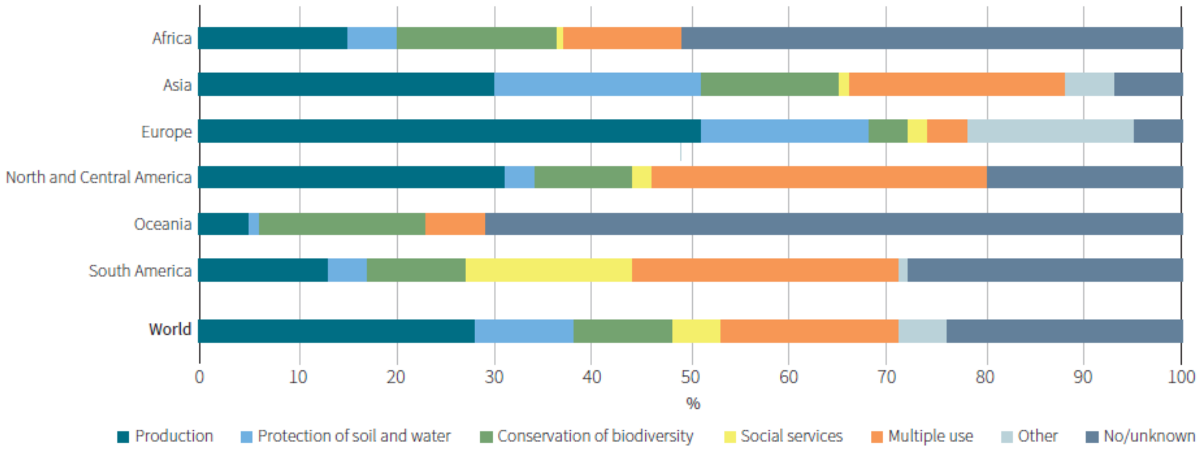

Figure 5: Proportion of total forest area designated for different primary management objectives, per region and globally, 2020. (FAO, 2020)

Among the several services provided by forest areas, biodiversity can be considered as the basis for all the other ecosystem services. Productive activities, such as fishing and forestry, directly depend on healthy ecosystem but also each component of the ecosystem is necessary. Regulating activities also depend on healthy and diverse ecosystem, e.g., some vegetation is able to regulate water levels and water quality, presence of some species of insects and climate conditions are necessary for pollination, micro-organism are able to mobilise nutrients or can support the neutralisation of pollutants in water and soil. Cultural services are also heavily dependent on biodiversity and nature as they are a source of enjoyment and recreation, being invaluable to many (EUSTAFOR and T. Patterson, 2011). The interlinkage that exists between biodiversity and the other ecosystem services provided by forests, underlines the importance of the conservation of biodiversity.

Although lot of forest ecosystem services are important for human societies, the management practices for providing two different ecosystem services can be conflicting. Pohjanmies et al. (2017) studied the conflicts that exist between ecosystem services in boreal production forests, considering timber production, bilberry production, carbon storage and pest regulation and one biodiversity conservation objective defined as availability of deadwood resources. Their result showed that conflicts between different services exist and are of different entities, in particular they defined conflicts between timber production and other objectives to be "typical, severe and difficult to solve", while they defined the conflicts between non-extractive benefits to be easier to reconcile with each other. The study concluded that the diversification of forest management practices can help to mitigate such conflicts. Stakeholders involved in forest management exploits the outputs of different ecosystem services. Because of this, the conflicts between different ecosystem services translate to conflict between the forest management objectives of the different stakeholders involved in the forests, e.g., the timber industry will aim to increase timber production while local communities could be more interested in the conservation of the forest for its aesthetic and cultural heritage value. Conflict between stakeholders will be addressed more deeply in chapter 4.2.2.

The value of the forest varies between communities; the perception and knowledge of ecosystem services provided by forests is different among the citizens. Citizens from different locations (e.g., countries) and of different occupation might have a different perception and knowledge of the importance of the ecosystem services provided by the forest in their area. Pour et al. (2023) highlighted that resident near the Hara Biosphere Reserve in the Persian Gulf valued most highly the cultural services offered by the ecosystem, while provision services were the second most perceived ecosystem service. On the other hand, Hochmalová et al. (2022) find out that in the Czech and Chinese societies that they analysed, provisioning and regulating services were perceived as more important than cultural services, with oxygen production and air purification being the most valued ones. Difference between the two countries was also detected as Chinese respondent demanded more cultural, spiritual, and meditation services (which are associated to their culture), while the Czech valued more highly mushroom picking. Both studies pointed out that there the perception of the ecosystem services varies between different social groups, highlighting the importance of social considerations in forest management.

2.3 Facts about Forests (Europe and Worldwide)

Facts about Forest (Global)

Forests as natural habitats cover a wide range of several ecosystems, which vary greatly in their characteristics. Some of these characteristics are for example:

a. species composition,
b. stand structure (horizontal structure of stands in functional forms and stages of stand development),
c. vertical stand structure (single-storey-, two-storey- or three-storey or multi-storey stands)
d. management systems (high forest, coppice forest, middle forest, coppice forest under conversion),
e. development stages (young growth, thicket, etc.)
f. stand composition, and
g. the extent of modification by humans and by non-human factors.

In the main report of Global Forest Resources Assessment 2020 it is stated that the global forest area in 2020 is estimated at 4.06 billion ha, which is 31% of the total land area. 45% of the world's forests are in the tropical domain, followed by:

- the boreal (27%),
- temperate (16%) and
- subtropical (11%) domains.

Europe accounts for 25 percent (25%) of the world's forest area, followed by:

a. South America (21 %),
b. North and Central America (19 %),
c. Africa (16 %),
d. Asia (15 %) and
e. Oceania (5 %).

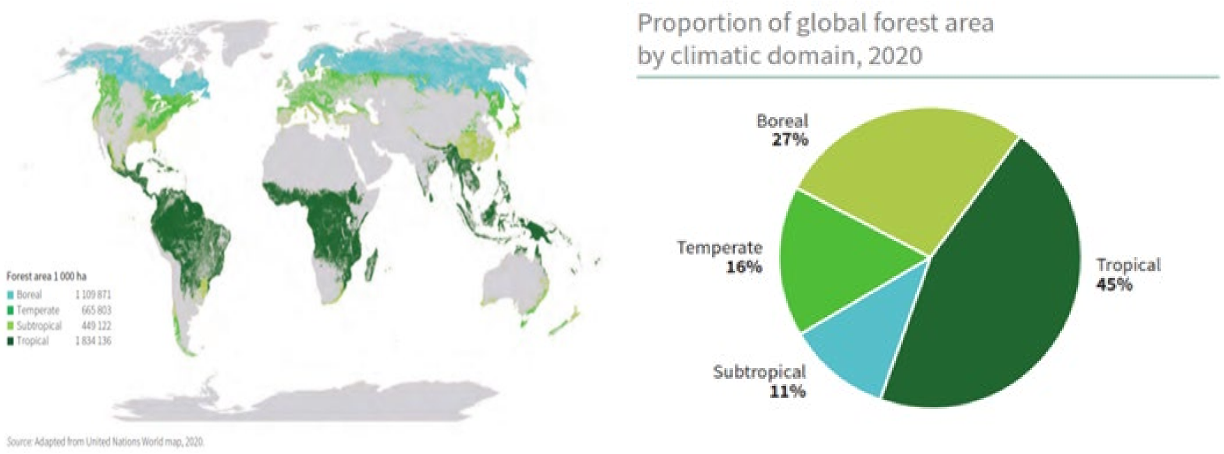

Figure 6: The goal distribution of forests, by climate domain (Source: FRA, 2020)

According to the World Bank database forests around the world are constantly decreasing, from approximately 31.6% of land areas in 1991 to 30.7% in the year 2020 (Figure 6).

In absolute numbers, the area of forests worldwide was equal to 41,282,694.9 sq. km in 1991, while in 2020 this number has decreased to 39,958,245.9 sq. Km.

In Figure 7, the distribution of forests per country around the globe is presented. It is obvious that Canada in North America, Russia in Eurasia and Brazil in South America, have the highest percentage of forested areas. The United States of America and China have significant forest areas, followed by Australia.

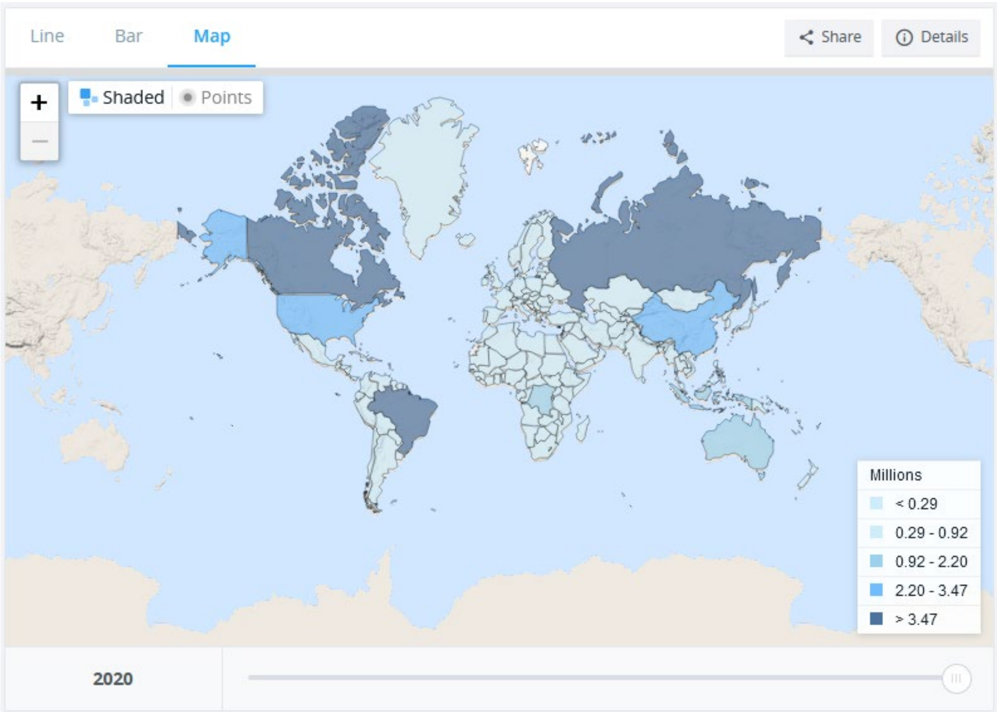

Figure 7: Forested areas in millions of sq. Km around the globe (Source: World Bank) - https://data.worldbank.org/indicator/AG.LND.FRST.K2?end=2020&start=1990&type=shaded&view=map&year=2020).

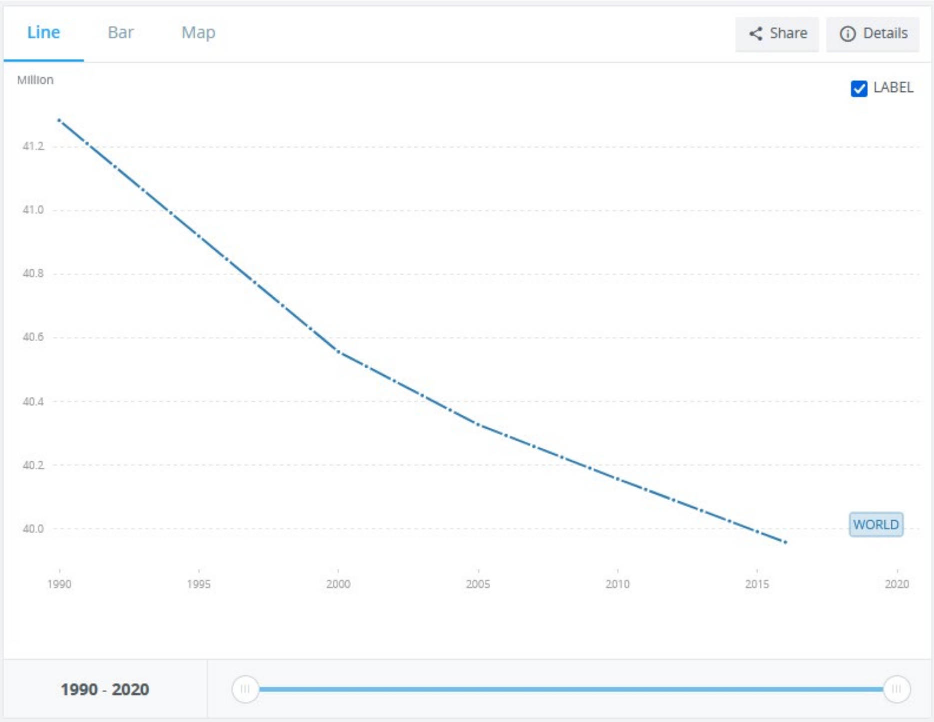

Figure 8: Decrease in the forested areas as a percentage of land area worldwide for the period 1990 - 2020 (Source: World Bank - https://data.worldbank.org/indicator/AG.LND.FRST.K2?end=2020&start=1990&type=shaded&view=chart&year=2020).

FRA 2020 refers that the world has lost a net area of 178 million ha of forest since 1990, which is an area about the size of Libya. In absolute numbers, the rate of net forest loss decreased from 7.8 million ha/year in the decade 1990–2000 to 5.2 million ha per year in 2000–2010 and to 4.7 million ha/year in 2010–2020. The rate of decrease of net forest loss slowed in the most recent decade due to a reduction in the rate of forest expansion (FRA, 2020).

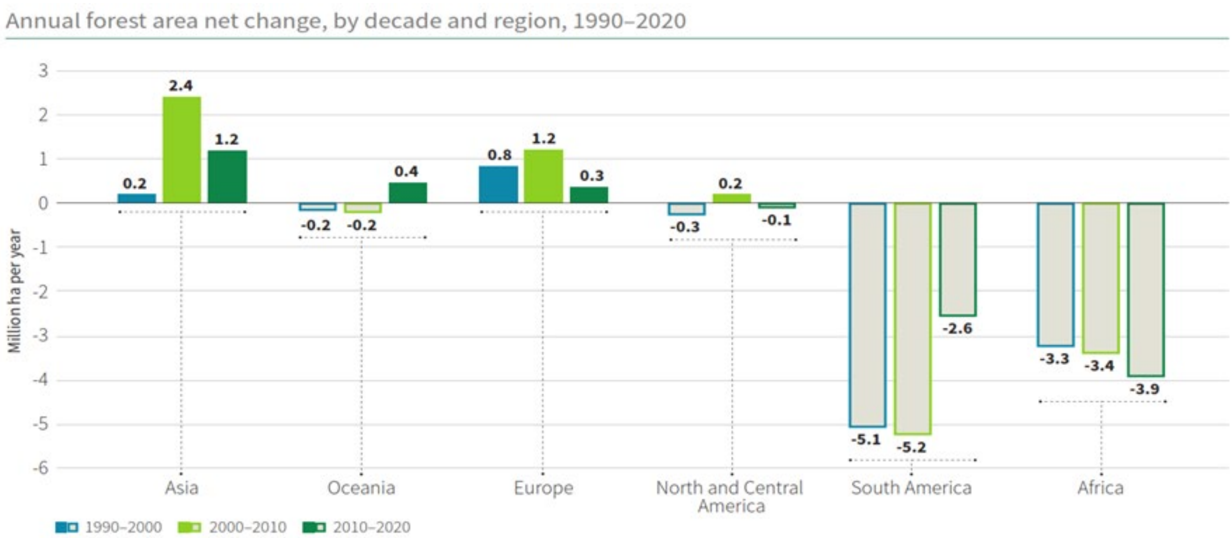

Figure 9: Annual forest area net change, by decade and region, 1990-2020.

The area of naturally regenerating forests decreased by 301 million ha between 1990 and 2020. The total area of planted forests globally is estimated at 294 million ha, which is 7% of the world forest area. Worldwide, there are 131 million ha of plantation forests, which is 45 percent of the total planted forest area. The remainder (55%) is categorized as other planted forest, covering 163 million ha. the area of primary forests worldwide is estimated at 1.11 billion ha.

The world's total forest growing stock is estimated at 557 billion m3.

FRA 2020 received information on forest ownership in 2015 for the main categories (i.e. public, private and unknown/other) from 180 countries and territories representing 97% of the world's forests

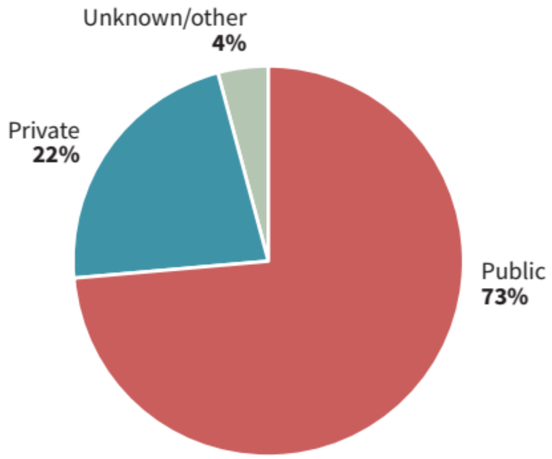

Figure 10: Proportion of total forest area, by three ownership categories, 2015

The total living biomass in the world's forests amounts to almost 606 gigatons (Gt), or about 149 tonnes/ha. The total forest carbon stock (i.e., including all carbon pools) is estimated at 662 Gt (163 tonnes/ha), comprising 300 Gt in soil organic matter, 295 Gt in living biomass and 68 Gt in dead wood and litter.

Soil organic matter constitutes the biggest pool, with 45.2% of the total carbon, followed by above-ground biomass, below-ground biomass, litter and dead wood (FRA, 2020).

Facts about Forests - Europe

In accordance with EUROSTAT, 5% of the world forests are located in the European Union (EU), and despite the worldwide decrease in forested areas, forests of Europe are slightly increasing based on the data from 1990 to 2020 (Figure 11). The area of forests in Europe has increased by 9% over the last 30 years. At 227 million ha of forests, more than one-third of Europe's land surface is forested.

Unfortunately, the recent wildfires in Europe of 2021 and 2022 and their impacts have not yet been included in the European statistics, by the time this document was written and submitted. Only, Portugal and Sweden present a decrease in forested areas for the same time period of approximately 3% and 0.3%, respectively. The highest increase is observed in Ireland, while the highest share of forest to the total country area belongs to Finland, closely followed by Sweden and Slovenia.

Forests are more or less 30% -40% of the country total area for the majority of the EU countries.

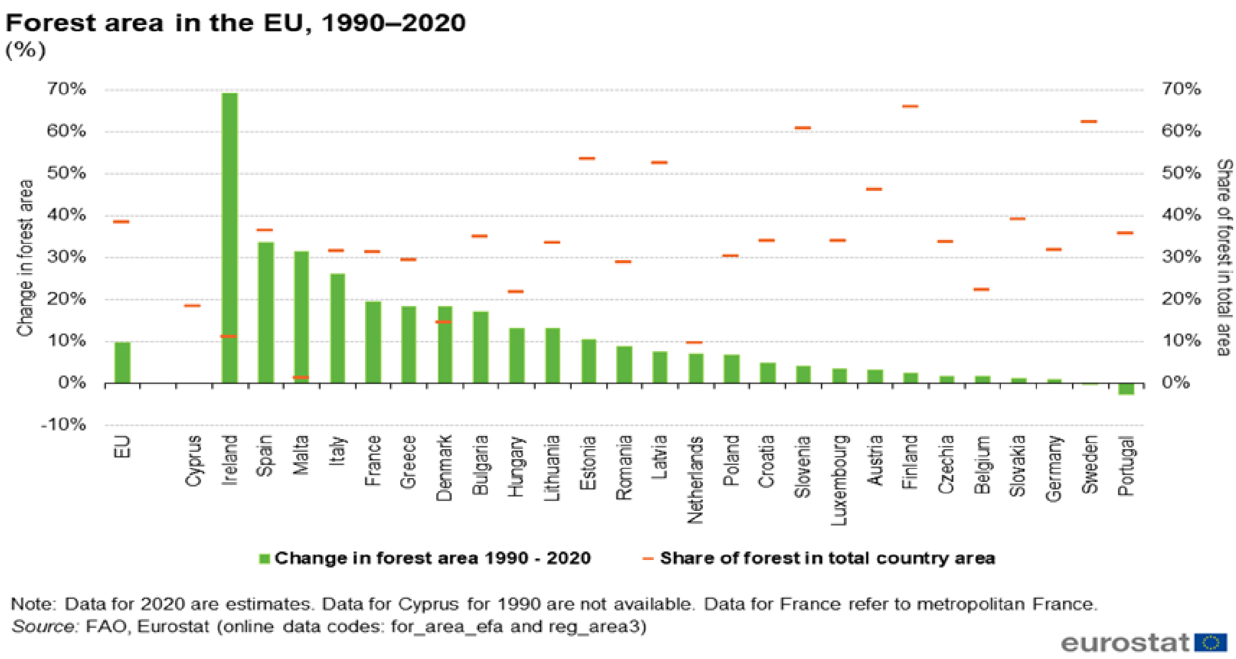

Figure 11: Forest areas in EU for the time period 1990-2020. Changes (green bar) and share of forests in total country area (red dash).

The State of Europe's Forests 2020 report (SoEF 2020) presents below recent official information on European forests, their management, policies, etc. in the FOREST EUROPE signatory countries (Source: FOREST EUROPE, 2020: State of Europe's Forests 2020).

In Europe 227 million ha of forests cover 35% of the total land area. 46% are predominantly coniferous forests, 37% are predominantly broadleaved, and the rest are mixed forest. Sixty-seven per cent (67%) of forests have two or more species and the proportion of single species stands has been decreasing over recent decades. About three-quarters of European forests are even-aged and between 20 and 80 years of age, of which about 64% are beyond the regeneration phase and have not yet reached the mature phase. Nearly a quarter of these forests are of uneven-aged. 66% of the total forest area in Europe was naturally regenerated or resulted from natural expansion, and the share of these forms of establishment is slightly increasing. In 2020, plantations in Europe covered only 3.8%; Forests undisturbed by man cover 2.2% of European forest area (Source: FOREST EUROPE, 2020: State of Europe's Forests 2020).

The total growing stock adds up to 34,900 million m^3 of the European forests, of which about 84% is located in forests available for wood supply. On average, there are 169 m^3 of growing stock per ha, which is 40 m^3/ha more than thirty years ago. The highest values arise in the Central-East Europe region with 254.6 m^3/ha and in the Central-West Europe region with 242.1 m^3/ha; the lowest density results for the South-West Europe region with 59.7 m^3/ha (Source: FOREST EUROPE, 2020: State of Europe's Forests 2020).

In the European region, between 2010 and 2020, the average annual sequestration of carbon in forest biomass reached 155 million tonnes. In the EU-28, sequestration corresponds to around 10% of gross greenhouse gas emissions. In the period 1990-2015, the carbon stock in harvested wood products increased from 2.5 to 2.8 tonnes of carbon per capita, thus contributing to CO2 emission reductions (Source: FOREST EUROPE, 2020: State of Europe's Forests 2020).

The area of forests designated for biodiversity conservation has increased by 65% in 20 years, and the area designated for landscape conservation by 8%. In 2015, the reported protected forest area was 49.3 million ha (23.6% of total forest area in reporting countries) and 4.1 million ha of other wooded land was also protected (20.5% of total other wooded land) in 2015. About 15% (or 31 million ha) of European forests are protected, with the main objective of conserving biodiversity, while about 9% (18 million ha) aim at protection of landscapes and specific natural elements. Forests designated for the protection of soil, water, and other ecosystem services represent about 32% of the forest area (Source: FOREST EUROPE, 2020: State of Europe's Forests 2020).

About 3% of European forests are damaged, mainly by wind, insects, ungulate browsing, and forest fires. There is a clear regional pattern in specific disturbances: fires occur mostly in the Mediterranean region, and windstorms and heavy snowfalls in central and north-western regions. Ungulate browsing is a European-wide disturbance. Damage by insects fluctuates, while damage by wind and snow has increased. However, an apparent shift in disturbances has been observed recently, suggesting extreme droughts and heat waves, more extensive bark beetle outbreaks, and a wider occurrence of forest fires (Source: FOREST EUROPE, 2020: State of Europe's Forests 2020).

About the forest ownership in Europe, the following table describes in total that there are about 53.5% of public and 46.5% of private forests in EU.

Table 4: Share of public and private ownership, by region, 2015

Region	Public		Private	
	1 000 ha	%	1 000 ha	%
North Europe	17 512	29.8	41 268	70.2
Central-West Europe	13 366	37.0	22 778	63.0
Central-East Europe	37 446	85.7	6 241	14.3
South-West Europe	5 352	24.5	16 475	75.5
South-East Europe	29 520	90.5	3 085	9.5
EU-28	56 892	39.3	87 785	60.7
Europe	103 196	53.5	89 847	46.5

Note: Data coverage as % of total regional forest area: NE 83%, C-WE 100%, C-EE 100%, S-WE 70%, S-EE 81%, EU-28 92%, Europe 87%.

A technical report published by EFI in 2013 "Mapping the distribution of forest ownership in Europe" also provides a better knowledge of the distribution of forest ownership in the 47 European countries with the following maps (Figure 12, Figure 13). It is apparent that Western Europe has more private forests than Eastern Europe.

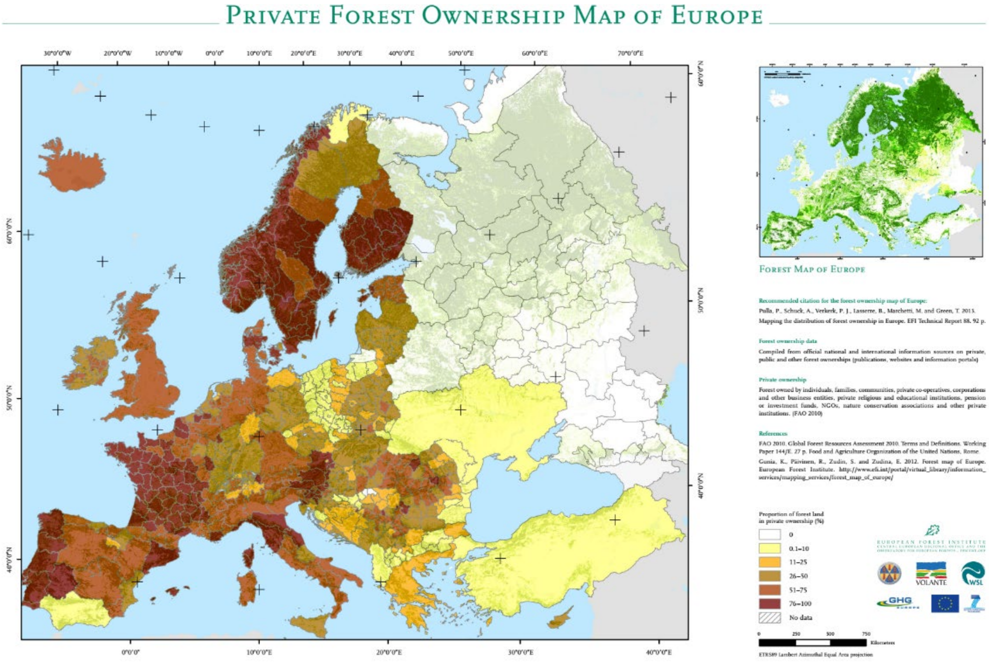

Figure 12: Private forest ownership map of Europe (Source: EFI, 2013)

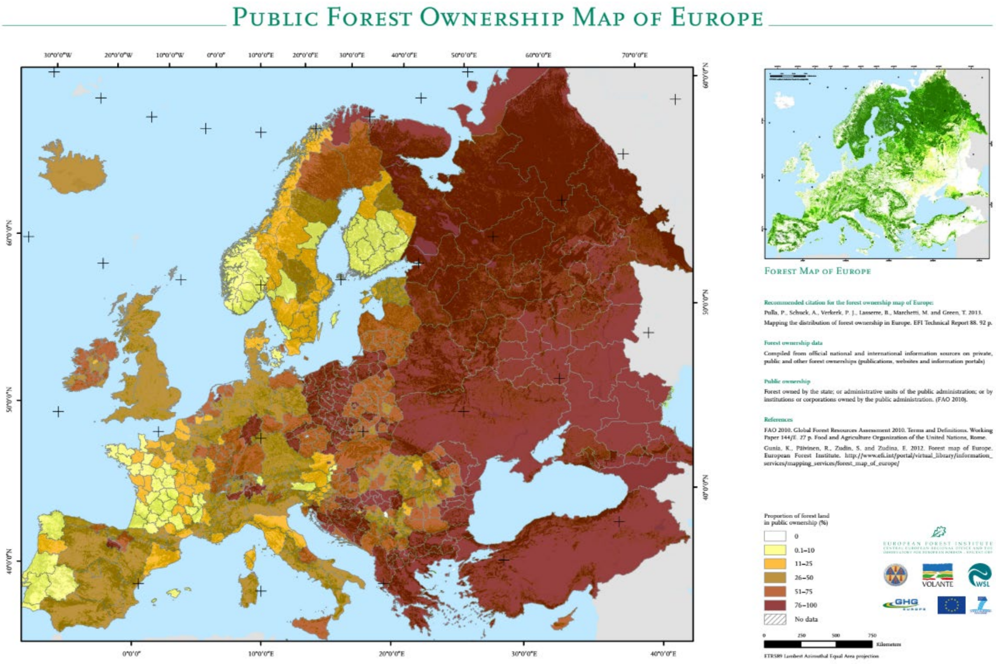

Figure 13: Public forest ownership map of Europe (Source: EFI, 2013)

3 Climate change and forest related EU Policies

In 2015 the Paris Agreement was adopted by United Nations Framework Convention on Climate Change (UNFCCC), to govern emission reductions from 2020 onward. According to Article 4 of the Paris Agreement, each Party shall prepare and publish what post-2020 climate actions they would take under the agreement, known as their successive Nationally Determined Contributions (NDCs). Each NDC defines the targets of a country's reduction emission and the future steps that it will take to address and adapt to the impacts of climate change, i.e., by holding the increase in the global average temperature to well below 2 °C above preindustrial levels, pursuing efforts to limit the temperature increase to 1,5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change and to achieve net zero emissions in the second half of this century.

The new EU Strategy on Adaptation to Climate Change refers that the frequency and severity of climate and weather extremes is increasing**.** This has caused a surge in the number of and damages from, disasters over the last two decades. These extremes range from unprecedented forest fires and heatwaves right above the Arctic Circle to devastating droughts in the Mediterranean region; and from hurricanes ravaging EU outermost regions to forests decimated by unprecedented bark beetle outbreaks in Central and Eastern Europe. Slow onset events, such as desertification, loss of biodiversity, land and ecosystem degradation, ocean acidification or sea level rise are equally destructive over the long term.

Furthermore, the new EU Strategy proposes a coherent and holistic policy framework on European Forests. It aims to accelerate adaptation by developing solutions, moving from planning to implementing adaptation strategies and plans at all levels of governance, also increasing adaptation mainstreaming and a systemic approach for policy development. It identifies three cross cutting priorities, which will affect the forestry sector:

1. integrate adaptation into macro-fiscal policy,
2. promote nature-based solutions for adaptation, including sustainable management of forests, with new financial incentives and certification of carbon removals, and
3. stimulate local adaptation actions to improve the science-based knowledge on climate risks, ecosystem restoration, and sustainable management for minimizing risks, improve resilience, and ensure the continued delivery of vital ecosystem services and features.

Major emphasis will also be put to encourage collaborative, transnational production and transfer of high-quality plant reproductive material through active policies and actions to support adaptation in forestry and land ecosystem management.

In addition, on July 2021, the LULUCF Regulation sets a binding commitment for emission reduction, for the period 2021-2030, for the first time in an EU law. The Regulation extends the accounting of emissions and removals from only forests today to all land uses (including wetlands by 2026). This will support foresters through greater visibility for the climate benefits of wood products, which can store carbon sequestered from the atmosphere and substitute for emission-intensive materials (Source: https://climate-adapt.eea.europa.eu/en/eu-adaptation-policy/sector-policies/forestry).

Promoting and sustainably managing forests will help the adaptation to climate change in a cost-effective way. Sustainable forest management needs to maintain the resilience of forest ecosystems while avoiding abrupt and destructive changes. Research indicates that maintenance of genetic, structural, and functional diversity in forest communities forms a good basis for multifunctional and sustainable forest use (Kraus et al., 2013).

The European Green Deal being a set of policy initiatives that aims to overcome the challenges caused by the climate change by reducing net greenhouse gas, by at least 55% by 2030, and making Europe the first

climate-net continent by 2050 ensuring that no one and no place are left behind, and that economic growth is independent of the use of resources.
The EU Green Deal is a transformation of the EU economy and society towards a sustainable Europe. The EU green Deal works on various aspects of the economy and society aiming to:

- Produce Clean energy;
- Sustainable industry;
- Building and renovation with re-used and eco-friendly materials;
- Food sustainability;
- Elimination of pollution;
- Sustainable mobility;
- Protection of biodiversity;
- Sustainable economies.

3.1 Biodiversity Management Policies

Biodiversity. in brief. is the variety and richness of life on Earth; the number of genes, species, individual organisms within a given species, and biological communities within a defined geographic area, ranging from the smallest ecosystem to the global biosphere. Similarly, biodiversity loss defines the decline in the number, genetic variability, and variety of species, and the biological communities in a given area. The loss in the variety of life on Earth can lead to a breakdown in the functioning of the ecosystem where the decline has happened. Article 2 of CBD states that biological diversity (Syn.: Biodiversity) is "*the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems*". Allen and Hoekstra (1992) defined biodiversity even more broadly to include the variety of life at multiple scales of ecological organization, including genes, species, ecosystems, landscapes, and biomes.

Muys et al. (2002) denotes that biodiversity has different components that correspond to three (3) hierarchical levels of organisation of biodiversity, i.e., genes, species and ecosystems. In order to make biodiversity comprehensible, these three (3) different components can be looked as a triangle from three (3) separate dimensions, specifically its compositional, structural and functional diversity (Figure 14)

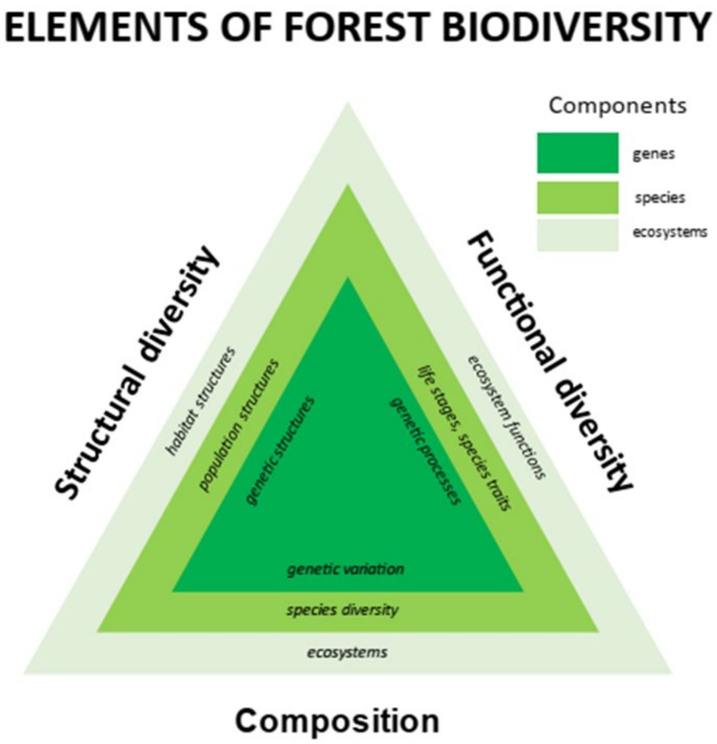

Figure 14: The main elements of forest biodiversity are represented as a triangle with three dimensions (composition, structure and function) that take account of the three hierarchical levels of components (genes, species and ecosystems) (modified after Noss, 19

In EFI report (Larsen et al. 2022) about Biodiversity it is stated that *"Plants, animals, fungi and single-cell organisms interact and are foundations for ecosystem functions and processes (Science for Environment Policy 2021). The provisioning of ecosystem services such as wood production, water purification, carbon sequestration and recreation, and maintenance of multifunctional forests, depend on well-functioning species and species interactions (Krumm et al. 2020). For example, most trees need symbiotic association with fungi (mycorrhiza) to acquire nutrients, and bees and wasps, butterflies, beetles, moths and hoverflies pollinate many herbaceous plants on the forest floor (Kraus and Krumm 2013). Soil biodiversity is less known but is fundamental to the functioning of terrestrial ecosystems through interactions with above-ground biodiversity (Nielsen et al. 2015; Guerra et al. 2020)".*

The climate crisis has a severe and direct impact on biodiversity. Climate change makes ecosystems more fragile and intensifies the effects of other drivers of biodiversity loss, such as habitat loss and fragmentation, pollution, over-exploitation and the spread of invasive alien species. Biodiversity loss and climate change are linked and interdependent. So, climate change and biodiversity loss should be tackled together. Biodiversity loss cannot be addressed without addressing the climate crisis, and climate crises cannot be addressed without biodiversity loss at the same time.

Muys et al., (2022), with reference to Brook, et al. (2008), illustrate with the following figure (Figure 15) the foremost causes of biodiversity loss globally, i.e., pollution, climate change, biological invasions, land-use change and overexploitation (Brook et al. 2008) in European forests. To make these threats even more relevant to forest stakeholders and actors when assessing their negative effects on forest biodiversity, Mys et al., (2022) "distinguish between 'external' threats that are beyond the direct influence of forest owners and managers and 'internal' threats that are directly related to forest management practices".

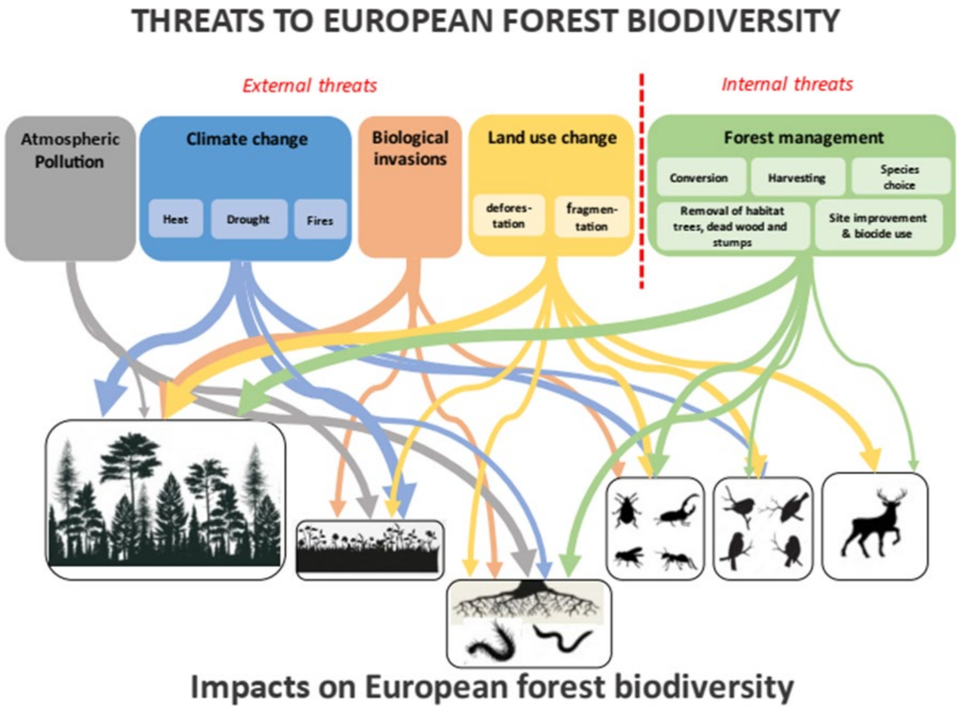

Figure 15: The relationships between major threats to biodiversity in European forests and particular groups of species (from left to right: trees, understory vegetation, soil organisms, insects, birds, mammals). The thickness of the arrows indicates the estimate

The main pressures on biodiversity (plants, animal and fungi) caused by forestry focusing on wood production (internal pressures) and other factors (external pressures), and their consequences for biodiversity as well are presented in Table 5.

Table 5: Main pressures on biodiversity (plants, animal and fungi) caused by forestry focusing on wood production (internal pressures) and other factors (external pressures), and their consequences for biodiversity (Source: Larsen, J.B. et al. 2022)

Internal pressures (forestry for wood production)	Consequences for biodiversity
Harvesting of old-growth forest	Reduces populations of species largely confined to more or less undisturbed and continuous tracts of old forest with high structural variation.
Removal of old, dead and dying trees	Disfavours species depending on big and old trees displaying a wide range of tree-related microhabitats such as hollows, crevices and wounds as well as standing dead wood of different sizes and decay stages and corresponding microhabitats.
Clearcutting with extraction of all trees	Negative for species sensitive to large open areas, including those that need a stable forest-interior climate. A more long-term effect is a dramatic decrease in old trees and dead wood.
Treatment of disturbed forest areas	Disturbances provide forest development stages that are often rare in managed forest landscapes. Structures created by specific disturbance agents (fire, storms, beetles) attracts specialists (e.g., semi-burned trees, root plates or splintered stems) and provide habitat for many species. Complete removal of dead trees prevents

	colonization of saproxylic species. Fast reforestations hinder the occurrence of numerous specialist species e.g., ruderal and thermophile species

External pressures (outside of forestry)	**In addition to organic matter removal, soil perturbations and fertilizer additions, which can affect soil animal and microbial communities, the control of ground vegetation through herbicides or mechanical means reduces plant species richness and hence diversity of insects and provision of related ecosystem services**
Forest type and habitat conversion	Variation in forest types and habitats is fundamental to a rich biodiversity. Forestry impacts tree-species composition, structural and horizontal variation, tree and forest stand ages and alters hydrology. Often small, deviating habitats are removed and transformed into production forests. Thus, conversion of forest has considerable effects on species composition and may cause decrease and loss of species adapted to natural forest landscapes.
Maintenance of dense forests with high growing stocks	High wood volumes imply darker and denser forests with negative response of light-demanding species, many of which are becoming less common today. Higher sensitivity to human-induced disturbances
Introduction of non-native or poorly adapted species/provenances	The use of introduced tree species and ill-adapted provenances may lead to changes in ecological processes such as nutrient dynamics, in turn affecting plants, animals and fungi
Abandonment of traditional forest management approaches (coppice, coppice with standards, wood pasture systems)	The abandonment of traditional practices in many parts of Europe leads to a habitat loss for specialized species of cultural landscapes and open agro-forest conditions.
Climate change	The distribution of species will alter, vulnerable habitats will be lost, species interactions (competition, mutualistic relationships, pests and diseases) will be affected and altered disturbance patterns will change habitats.
Landscape fragmentation	Functional connectivity of a region's forest types is fundamental to long-term maintenance of species and species communities.
High populations of large herbivores. Since forest management partly controls their food resource, they are regulated both by external and internal factors	Herbivores such as deer and moose cause browsing and fraying damage to young trees, which precludes preservation/restoration of less common tree species hosting a rich associated biodiversity.

Eutrophication through nitrogen deposition	Nitrogen addition to forest soils through the atmosphere disadvantages species adapted to nutrient-poor soils, most marked for ground- vegetation but with side-effects for associated species.
Biological invasions	Extinction cascades may be trigged if invasive plants, pests and pathogens are introduced; this may lead to the loss of tree species, which can have a considerable impact if such trees host a rich associated biodiversity with many rare species.

Literature sources: Addison et al. 2019; Bernes et al. 2018; Bernhardt-Römermann et al. 2015; Carpio et al. 2021; EEA 2020; Fahrig 2003; Fedrowitz et al. 2014; Götmark 2013; Gundale 2021; Košulič et al. 2021; Krumm and Vítková 2016; Liebhold et al. 2017; Lindenmayer and Laurance 2017; Lindner et al. 2013; Milad et al. 2011; O'Brien et al. 2021; Plue et al. 2013; Pötzelsberger et al. 2021; Stokland et al. 2012; Thorn et al. 2018, 2020b; Thom and Seidl 2015, 2016; Unrau et al. 2018; Verheyen et al. 2012; Vilén et al. 2016.

On the upside, conserving and restoring biodiversity and ecosystems can make a vital contribution to addressing climate change – so much so that 30% of climate mitigation targets could be met by nature-based solutions, such as restoring forests, soils and wetlands. Addressing behavioural change and consumption patterns, such as intensive exploitation of forests or deforestation, would further reduce pressures on both biodiversity and climate.

- FAO (2022) state that Biodiversity conservation in production forest can be enhanced through the following measures:
- Assessing and managing risks of forest operations to biodiversity.
- Establishing and managing set-aside areas.
- Protecting critical biodiversity resources.
- Sustainable management of timber resources.
- Regulating non-wood forest product (NWFP) harvest.
- Sustainable management of forest genetic resources.
- Managing and controlling invasive species.
- Protecting forests from illegal and unauthorized activities.

Recent EU forest-related policies particularly emphasise the importance for biodiversity conservation and climate change mitigation (European Commission, 2021). The European Green Deal includes several initiatives to halt biodiversity loss above and below ground, including the:

- EU Biodiversity Strategy
- new Common Agricultural Policy (CAP) to protect and restore nature and move to a more sustainable food system,
- Zero Pollution Action Plan to reduce the pollution of our air, water and soil,
- EU Forest Strategy 2030 to ensure healthy, diverse and resilient EU forests and the legislative proposal on deforestation-free products, to reduce the impact of EU's consumption on global deforestation.

The EU Biodiversity Strategy for 2030 recognised forests as hugely important for biodiversity, climate and water regulation, the provision of food, medicines and materials, carbon sequestration and storage, soil stabilisation and the purification of air and water. It includes several measures related to forests.

Amongst other things, in the Biodiversity Strategy the Commission committed to:

- Strictly protect all EU primary and old-growth forests - which are large carbon sinks and are home to many of our animal and plant species.

- Develop guidelines for closer-to-nature forest management - which will lead to a more sustainable use of forest resources, and to healthier, more resilient, and more diverse forests.
- Develop guidelines for biodiversity-friendly afforestation, reforestation and tree-planting - which will ensure that the right tree is planted in the right place at the right time, creating mixed forests adapted to current and future challenges.
- Plant 3 billion additional trees by 2030 - to substantially increase the EU's forest area, store CO_2, and provide more living space for animal and plant species.
- Creating payment schemes for forest owners and managers for the provision of ecosystem services

The Biodiversity Strategy also puts forward ambitious objectives for nature protection, including by enlarging the EU's network of protected areas and through strict protection of one third of protected areas. A key commitment is that all protected areas should be effectively managed, including through clear conservation objectives and appropriate monitoring.

In line with the EU 2030 Biodiversity Strategy, the share of forest areas covered by forest management plans (FMPs) should cover all managed public forests and an increased number of private forests. Nearly 150 million ha of forests are under management plans and their equivalents as reported by 21 EU countries, accounting between them for 85% of Europe's forest area. Between 7.5% and 100% of the forest area are under management plans, nearly 100% in South-East Europe. In general, the percentage is rather high and 76% of the forest area in reporting countries is under a management plan.

To reverse biodiversity loss, the world needs to be more ambitious on nature restoration. Out of all the EU actions mentioned above, the following are some critical actions on biodiversity that should be aimed to:

- protecting more of the remaining most valuable nature, so that by 2030, 30% of land (and 30% of seas) are protected through equitably and effectively managed networks of well connected;
- strictly protect at least a third of the EU's protected areas, including all remaining EU primary and old-growth forests;
- increasing the quantity of forests and improving their health and resilience;
- protected areas restoring degraded ecosystems;
- eradicating illegal and unsustainable harvesting, trade and use of wild species of fauna and flora including by eliminating illegal, unreported and unregulated fishing and halting wildlife trafficking;
- reducing pollution from all sources, including nutrients, nitrogen deposition, use of pesticides and plastic waste;
- ensuring that all forests are sustainably managed, and an increased area of our agricultural land is under agro-ecological practices or other biodiversity-friendly practices;
- keeping human ecological footprint within Earth's carrying capacity, enhancing positive incentives and eliminating harmful incentives.

A new EU Nature Restoration Plan "*will help improve the health of existing and new protected areas and bring diverse and resilient nature back to all landscapes and ecosystems. This means reducing pressures on habitats and species and ensuring all use of ecosystems is sustainable. It also means supporting the recovery of nature, limiting soil sealing and urban sprawl, and tackling pollution and invasive alien species. The plan will create jobs, reconcile economic activities with nature growth and help ensure the long-term productivity and value of our natural capital*" (EU Biodiversity Strategy for 2030).

3.2 EU Wildfire Policy

Regulation 2158/92/EEC of 23 July 1992 set up at community level a scheme for the protection of forests against fires, providing the legal framework for specific measures devoted to forest fire (wildfire) prevention for a 10-year period, from 1992 to 2002. Art. 1 states "*in order to provide increased protection for forests and in particular to step up efforts undertaken to maintain and monitor forest ecosystems and to safeguard the various functions which forests fulfil for the benefit of rural areas, a Community scheme for the protection of forests against fire, hereinafter referred to as 'the scheme', is hereby instituted*". The purpose of the scheme was:

- to reduce the number of forest fire outbreaks,
- to reduce the extent of areas burnt.

Furthermore, this tool linked land-based prevention with wildfires monitoring and supported restoration efforts in national level. It helped improve knowledge about forest fires significantly. The scheme expired on 31 December 2002 and was replaced by Forest Focus.

The objective of Forest Focus (Regulation (EC) No 2152/2003 of 17 November 2003) was to protect EU forests against pollution and forest fires by establishing a new EU scheme for monitoring forests and environmental interactions. The scheme intended to provide reliable data and information on the condition of forests and possible harmful influences at the community level, to support the evaluation of ongoing measures for promoting conservation and protection of forests for the benefit of sustainable development, with particular emphasis on actions taken to reduce negative impacts to forests. In addition, among the objectives of the scheme was to create the necessary links between existing and new, national European and global monitoring mechanisms in accordance with the international agreements. From the start of the scheme in 2003 to its completion in 2006, it supported the implementation of forest fire prevention measures in Member States.

Established in 1998, the Joint Research Centre (JRC) of the European Commission (Source: https://effis.jrc.ec.europa.eu/about-effis) set up a research group to work specifically on the development and implementation of advanced methods for the evaluation of forest fire danger. The aim of this group was to provide EU level pre-fire risk assessments, promote preparedness, support firefighting and provide post-fire ecological effects evaluations, also. The objective of EFFIS was not to duplicate or substitute national databases, but to provide information with a European scope.

Although Forest Focus expired in 2006, a number of applications are still available through EFFIS. In 2006 the European Parliament called for further improvement of EFFIS in several areas not sufficiently developed. Before Forest Focus expired, the Commission created an ad hoc working group of forest fire prevention experts from interested Member States and forest sector non-governmental organizations as well. The aim of the working group was to put forward proposals to the European Commission on forest fire prevention policies after 2006. The group met in 2004 and 2005 (Source: https://ec.europa.eu/environment/forests/legislation.htm).

Other tools to prevent and respond to wildfires are (Source: https://environment.ec.europa.eu/topics/forests/forest-fires_en)

- The EU Civil Protection Mechanism which coordinates pan-European assistance in times of crisis. Between 2007 and 2019, 30% of all requests for assistance through the mechanism, were in response to wildfires. The Mechanism was upgraded with rescEU in 2019, establishing a new European reserve which includes firefighting planes and helicopters.

- The Emergency Response Coordination Centre which monitors forest fire risks and emergencies across Europe, supported by national and European monitoring services such as the European Forest Fire Information System.

In 2018, after devastating fires that occurred in Europe, the European Commission published a set of policy challenges and recommendations specifically driven from and dedicated to wildfires (European Commission, 2018). These are presented in Table 6.

Table 6: Policy challenges and recommendations on wildfires for Europe

Policy challenges	Policy recommendation
Promoting effective science-based forest fire management and risk informed decision-making	Integrate fire ecology principles into fire management strategies and policies to support sustainable forest management
Improving firefighting and the rescue capacities of first responders in crisis management	Reinforce the European Union's disaster response capacity to better protect EU citizens
Promoting resilient landscapes and communities through integrated fire management	Improve preparedness through FireSmart systems empowered by local communities
Developing synergies between EU and national policies to improve wildfire risk management	Support cross-sectoral and multilevel governance to leverage the impact of public policies on wildfire risk management
Shifting the focus from suppression to prevention and increasing the awareness and preparedness of populations at risk	Supporting proactive prevention operations adapted to local socioeconomic and environmental contexts

Furthermore, EU has committed to protecting the world's forests under several international agreements, initiatives, and policies, including UN Sustainable Development Goal 15, the New York Declaration on Forests, the UN Convention on Biological Diversity (Aichi biodiversity targets 5 and 7) and the Paris Agreement on climate change (Article 5). Whatsoever, the Commission has introduced protection mechanisms and a forest strategy for 2030. Several EU policy instruments address deforestation and forest degradation, directly and indirectly.

At EU level, the main source of funding available for forests is the European Agricultural Fund for Rural Development (EAFRD), which can provide support for forest fire prevention and restoration actions. Cohesion policy also finances investments in climate change adaptation and risk prevention and management, covering various types of risks, including forest fire prevention. In parallel, the EU funds research to improve forest fire risk management through various funding mechanisms such as LIFE+, Horizon 2020 and the EU Green Deal. When national response capacities to fight forest fires are overwhelmed, the Union Civil Protection Mechanism (UCPM) can be activated, and coordinates assistance. It was upgraded in March 2019 to establish a dedicated reserve of response capacities at EU level, the "rescEU reserve", which includes firefighting planes and helicopters. The mechanism was activated five times in 2019 for forest fire emergencies in Greece, Israel, Lebanon, Bolivia and Guatemala.

3.3 EU Forest Strategy

The new EU Forest Strategy for 2030, adopted by the European Commission in July 2021, is one of the flagship initiatives of the European Green Deal and builds on the EU biodiversity strategy for 2030. The strategy sets a vision and concrete actions to improve the quantity and quality of EU forests and strengthen their protection, restoration and resilience. It aims to adapt Europe's forests to the new conditions, weather extremes and high uncertainty brought about by climate change. This is a precondition for forests to continue delivering their socio-economic functions, and to ensure vibrant rural areas with thriving populations.

EU must increase the quantity, quality and resilience of its forests, notably against fires, droughts, pests, diseases and other threats likely to increase with climate change. To retain their function for both biodiversity and climate, all forests need to be preserved in good health. More resilient forests can support a more resilient economy. They also play an important role in providing materials, products and services, which are key for the circular bio-economy. One of the new EU Forest Strategy for 2030 overarching objectives is to protect, restore and enlarge the EU's forests to combat climate change, reverse biodiversity loss and ensure resilient and multifunctional forest ecosystems. Lelouvier (2021) describes the actions in order to achieve the above-mentioned objectives as follows (Source: https://sincereforests.eu/wp-content/uploads/2021/09/Webinar_Presentation-DGEnvironment.pdf):

- Propose a legally binding instrument for ecosystem restoration.
- Develop guidelines on the definition of primary and old-growth forests.
- Identify the additional indicators as well as thresholds or ranges for sustainable forest management concerning forest ecosystem conditions, such as health, biodiversity and climate objectives.
- Develop guidelines on biodiversity friendly afforestation and reforestation, by Q1 2022.
- Develop a definition and adopt guidelines for closer-to-nature-forestry practices, by Q2 2022, as well as voluntary closer-to-nature forest management certification scheme, by Q1 2023.
- Provide guidance and promote knowledge exchanges on good practices on climate adaptation and resilience.
- Plant 3 billion additional trees by 2030, implementation of the pledge
- Supplement the revision of the legislation on forest reproductive material by the end of 2022.
- Monitor the situation of tree health in the EU, including the impact of invasive alien species, diseases and pests such as bark beetles, and encourage the necessary preventive actions for early detection and eradication.
- Promote forest-related interventions in the future CAP (2023-2027) in particular the set-up of ecosystem services payment schemes.
- Provide advice and technical guidance on the development of ecosystem service payment scheme, by November 2021. Life preparatory action with stakeholders on how payment for ecosystem services can be incorporated in EU funding programmes.
- Promote forest-related remuneration schemes in an action plan by the end of 2021.
- Guidance and promote knowledge exchanges on good practices on climate adaptation and resilience, using inter alia the Climate-ADAPT platform.
- Strive to increase the uptake of rural development funds available for the purposes of this strategy
- Provide new means to share information on good practices to better design and implement forest relevant interventions, fostering the exchange between experts in Member States, providing demonstration tools for consistent use of funding, and supporting local and regional networking.
- Carbon farming initiative and develop a regulatory framework for certifying carbon removal.

- Carry out a study on behavioural science regarding the uptake of public funds by foresters explore how to facilitate the use of national funds for forestry measures and target them better for ecosystem services in the forthcoming revision of the State aid guidelines; Identify and address possible hurdles to grant adequate public support to services beneficial for the public interest.
- In the context of the Long-term vision for rural areas, a network of forest-dominant rural areas and municipalities will be promoted, to give voice to forest rural areas.

It calls for an adaptive sustainable forest management that increases biodiversity and makes forests more resilient to climate-related disturbances in order to provide different forest function and services required by the society.

The measures proposed in the strategy, to be reviewed in 2025, include (Source: https://www.europarl.europa.eu/RegData/etudes/ATAG/2022/698936/EPRS_ATA(2022)698936_EN.pdf):

- promoting sustainable forest management (SFM), including by encouraging the sustainable use of wood-based resources;
- providing financial incentives for forest owners and managers to adopt environmentally friendly practices, such as those linked to carbon storage and sequestration;
- improving the size and biodiversity of forests by planting 3 billion new trees by 2030;
- promoting alternative forest industries, such as ecotourism, as well as non-wood products, such as cork, honey and medicinal plants;
- encouraging the take-up of financial support under the common agricultural policy (CAP), which can help forests and forest-based industries mitigate against climate change;
- providing education and training for people working in forest-based industries and making these industries more attractive to young people;
- establishing a legally binding instrument for ecosystem restoration, and a new legislative proposal on EU forest observation, reporting and collection;
- protecting the EU's remaining primary and old-growth forests.

4 Sustainable Forest Management

4.1 Definition and scope of Sustainable Forest Management

FAO defines as Sustainable Forest Management (SFM) “*a dynamic and evolving concept, that is intended to maintain and enhance the economic, social and environmental value of all types of forests, for the benefit of present and future generations*” (FRA. 2020). Sabogal et al. (2013) recognizes that “*forests provide multiple uses and that different benefits accrue to different stakeholders*” (Source: FAO, 2022).

The ITTO (1998) definition of SFM, is, “*the process of managing a forest to achieve one or more clearly specified objective(s) of management with regard to the production of a continuous flow of desired forest products and services, without undue reduction of its inherent values and future productivity and without undue undesirable effects on the physical and social environment*”.

The Pan-European Ministerial Conference on the Protection of Forests ("Forest Europe") agreed on a common understanding of sustainable forest management, which includes voluntary principles, guidelines and indicators that signatories use to monitor the progress of their forests.

“Sustainable forest management means the “stewardship and use of forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels, and that does not cause damage to other ecosystems”. (Resolution H1 of the Helsinki Ministerial Conference on the Protection of Forests in Europe, 1993).

Since the first set of Pan-European Indicators for Sustainable Forest Management in 1998 and their improvement in 2003, experience has shown that criteria and indicators are a very important tool for European forest policy. The pan-European forerunner in the development of criteria and indicators is the FOREST EUROPE process, which is based on the concept of sustainable forest management. FOREST EUROPE encompasses a broader concept of sustainability, including ecological, economic, and social aspects. The six revised Pan-European Criteria (quantitative and qualitative) for sustainable forest management, were adopted by the FOREST EUROPE Expert Meeting on 30 June - 2 July 2015, in Madrid, Spain.

The pan-European criteria and indicators address sustainable forest management in the context of forest policy and governance, forest resources and carbon cycles, forest health and vitality, productive functions, biological diversity, and protective functions, as well as regarding socioeconomic functions. This set divides the sustainable forest management concept into six (6) criteria and includes eleven (11) qualitative indicators and thirty-four (34) quantitative (in total 45):

Criterion 1: Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles

Criterion 2: Maintenance of forest ecosystem health and vitality

Criterion 3: Maintenance and encouragement of productive functions of forest (wood and non-wood)

Criterion 4: Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems

Criterion 5: Maintenance and appropriate enhancement of protective functions in forest management (notably soil and water)

Criterion 6: Maintenance of other socio-economic functions and conditions

In order to better respond to new challenges and needs, and in view of the increasing role of forests in meeting the EU's commonly agreed climate and biodiversity objectives, the sustainable forest management framework needs to be further developed, in particular with regard to the "*ecosystem health*", "*biodiversity*" and "*climate change*" criteria, so that it can become a more detailed screening tool to determine and compare different management approaches, their impacts and the condition of EU forests. Sustainable forest management already covers several relevant indicators, such as deadwood and species diversity, but it does not yet define thresholds or ranges as benchmarks for the desirable conditions.

Therefore, building on the Forest Europe criteria for sustainable forest management, the Commission, together with the Member States and in close cooperation with different forest stakeholders, will identify additional indicators as well as thresholds or ranges for sustainable forest management related to forest ecosystem conditions, such as health, biodiversity and climate objectives.

At least and not last, the Commission will develop a definition and adopt guidelines for closer-to-nature-forestry practices, as well as voluntary closer-to-nature forest management certification scheme.

4.2 Main issues in Sustainable Forest Management

Except the secondary effects of the phenomenon 'climate change', i.e. pest and diseases, insect calamities and wind-throws in Central and Northern parts of Europe, the fire risk is likely to increase (KHABAROV et al., 2014). According to Lindner et al. (2014), climate change projections for the Mediterranean indicate that extremely dry years will become more frequent and droughts much longer in the future. As a result of these environmental changes in Mediterranean, the dieback and mortality of different forest types such as fir forests may increase in the future (Samaras et al. 2022). IPCC (2021) states also that temperatures in Europe will continue to rise at a rate exceeding the global mean temperature change, regardless of the climate scenario considered (Source: Verkerk P.J. et al., 2022).

From the above, it can be concluded that not only vulnerable but also steady state forest stands are increasingly affected by climate-related impacts such as the above-mentioned, that are already a cause for concern and are expected to become more frequent and severe with climate change, i.e. warming (Seidl et al., 2017, Gauthier et al., 2004).

The term 'vulnerability' (a widely used term to describe the effects of climate change on forest ecosystems) to climate change means 'the degree to which a system is susceptible to, or unable to cope with, adverse impacts of climate change, including climate variability and extremes' (IPCC 2001). This situation effects as uncertainty and/or threat to (and possibly opportunity) for sustainable forest management. In other words, sustainable forest management with a focus on climate change (adaptation), requires new approaches. These approaches should consider the complex interactions between climate and social, ecological and economic systems in response to the impacts of climate variability in order to minimise the threat to the supply of forest ecosystem services (Smit and Pilifosova 2002, Davidson et al. 2003, Nikinmaa et al. 2020).

Mitigation and adaptation are complementary strategies for reducing and managing the risks of climate change:

- Mitigation is an action to reduce the emissions sources or enhance the sinks of greenhouse gases.
- Adaptation is an adjustment of natural or human systems in response to actual or expected climatic stimuli or their effects, which mitigates damage or takes advantage of beneficial opportunities (IPCC 2001, 2014).

There are also some important synergies and conflicts between forest-based mitigation and adaptation activities as well. These are illustrated in the following Table 7.

Table 7: Potential conflicts and synergies between forest-based mitigation and adaptation (Source: Verkerk, P.J. et al., 2022).

Category	Activity	Type of activities	Synergies and conflicts between mitigation and adaptation
Protect	Avoiding deforestation and degradation	Reduced conversion of forests, reduced forest degradation	• Synergy as forests remain available as species, seed, and gene pools and landscape remains connected for tree species migration
	Forest conservation	Set-aside forest area	• Synergy by supporting natural adaptation • Conflict by decreasing options for anticipative planting, assisted migration and adaptive management interventions
Manage	Forest harvesting	Stand thinning as well as harvest practices and regimes	• Synergy as thinnings can foster drought tolerance of remaining trees and create open space for new species or individuals • Conflict when intensive thinnings lead to stand instability
	Active management (other than harvest)	Provenance selection	• Synergy or conflict due to possible trade-off between mitigation (e.g., high carbon storage) and adaptation (e.g., high fitness) of the selected provenance
		Nutrient management and soil preparation	• Synergy when more moisture is retained in soils, thus reducing drought stress • Conflict when nutrient additions increase drought stress
		Disturbance management	• Synergy when pre-emptive disturbance management (e.g., prescribed burning) increases resilience and avoids larger disturbances • Conflict when preventing disturbances that slow down natural adaptation
		Tree species selection, hydrology management	• Synergy or conflict due to possible trade-off between mitigation (e.g., high carbon storage) and adaptation (e.g., high fitness) of the selected species
Restore	Forest restoration		
	Afforestation / Reforestation	Afforestation of non-forest biomes	• Synergy or conflict, depending on whether reproductive material is well adapted to future climate conditions
		Afforestation of non-forest biomes	
Wood use	Shifts in wood uses (including by-products)	Shift to long-lived wood products	• Synergy when shift allows for management to focus on higher-added value products and leverage more revenues for adaptation • Synergy when shift leads to higher harvest pressure, which may facilitate adaptation (e.g., through species change) • Conflict when shift leads to higher harvest pressure, which may hamper adaptation • Conflict when narrower management objectives reduce adaptive options
		Shift to material uses	
		Shift to primary energy uses	
	Cascading (end-of-life)	Reuse, recycling	• Synergy when cascading reduces pressure on forests and allows silviculture to focus on adaptation and natural processes
		Downcycling	
		Energy recovery of discarded wood	
	Increased efficiency	Increased material efficiency	• Synergy when cascading reduces pressure on forests and allows focusing silviculture on adaptation and natural processes
		Increased energy efficiency	

As far as the EIP-AGRI focus groups (2019) are concerned, the risks of climate change can be managed, at least to some extent, through various adaptation measures.

Disturbances	Most Affected Regions	Projected Changes
Storms 	Temperate Oceanic, Southern Boreal and Temperate Continental Zones	– Northwards shift of storm tracks increases the risk in previously unaffected areas; – Higher top wind speeds result in increased storm intensities; – Increased spatial extent of storms with longer storm tracks affecting larger areas and reaching further into Eastern Central Europe.
Pests 	Temperate Continental, Southern Boreal and Mediterranean Zones	– New pests in the area; – Migration of known pests to northern or higher elevation areas, e.g. bark beetle damage zones are increasing in the mountains; – Shorter reproduction cycles; – Intense incidents of tree dieback.
Drought 	Mediterranean, Temperate Continental, Temperate Oceanic, and Boreal Zones	– Rainfall distribution more variable resulting in more frequent and extended drought periods; – Precipitation expected to decrease in Mediterranean leading to reduced water availability.
Forest fires 	Mediterranean, Temperate Continental and Boreal Zones	– Areas with forest fire risk will increase drastically, putting forests at risk across most of Europe; – Length of the fire risk season will increase; – Heat waves and strong winds will lead to more devastating extreme wildfire events.

Table 8: Main disturbances in European forests and projected changes (Source: https://ec.europa.eu/eip/agriculture/en/publications?f%5B0%5D=field_publication_date%3A2019)

In addition to supporting the adaptation of forest management (good) practices, improving the resilience of forests to future climate change should be a top priority in the development and implementation of forest policies. EFI highlighted that there are more than 160 identified definitions for resilience, the three most commonly used are engineering resilience, ecological resilience and social-ecological resilience (Source: https://efi.int/articles/how-can-we-measure-forest-resilience). Thus, as explained by Lindner et al. (2020), there are three main concepts of resilience in forest science.

1. *Engineering resilience* defined as "The time that it takes for variables to return towards their equilibrium following a disturbance" (Pimm, 1984);
2. *Ecological resilience* refers to "The system's capacity to absorb disturbance without changing as well as the ability to self-organize and build adaptive capacity" (Holling 1973); and
3. *Social-ecological resilience*, which is understood as "The capacity of a social-ecological system to absorb or withstand perturbations and other stressors such that the system remains within the same regime, essentially maintaining its structure and functions. It describes the degree to which the system is capable of self-organization, learning, and adaptation" (Resilience Alliance 2020).

While the exact definition is still debated, the resilience of a system is often depicted as a ball and cup metaphor (Figure 16), as has been done by Holing (2016).

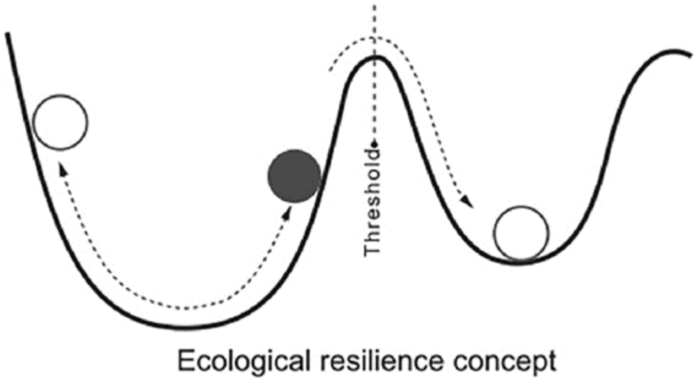

Figure 17: The theoretical ball-and-cup diagram used to depict ecological resilience as introduced by Holling (1973).

Keane, R. E. et al. (2018) very impressively explain that when an ecosystem (the ball) remains within a set of bounding conditions (sides of the cup) that represent a resilient state, the recovery trajectories converge towards the bottom of the cup when perturbed (by gravitational analogy). Perturbations - such as forest fires or extreme climate events - can act on the ecosystem with sufficient force to move the ball across a threshold (cup rim) into another resilient state (new cup).

While Nauburus et al. (2007) present four types of mitigation actions in Table 9, in terms of adaptation and mitigation linkages and vulnerability of mitigation options to climate change, Braatz (2012) on the other hand also highlighted some key strategies for increasing the resilience of forests and trees to climate change through forest management, including:

- Maintaining healthy forest ecosystems for resilience;
- Restoring degraded forests;
- Conserving, enhancing and using biodiversity.

Table 9: Adaptation and mitigation matrix (Source: Nauburus et al. 2007)

Mitigation option	*Vulnerability of the mitigation option to climate change*	*Adaptation options*	*Implications for GHG emissions due to adaptation*
A. Increasing or maintaining the forest area			
Reducing deforestation and forest degradation	Vulnerable to changes in rainfall, higher temperatures (native forest dieback, pest attack, fire and, droughts)	Fire and pest management Protected area management Linking corridors of protected areas	No or marginal implications for GHG emissions, positive if the effect of perturbations induced by climate change can be reduced
Afforestation / Reforestation	Vulnerable to changes in rainfall, and higher temperatures (increase of forest fires, pests, dieback due to drought)	Species mix at different scales Fire and pest management Increase biodiversity in plantations by multi-species plantations. Introduction of irrigation and fertilisation Soil conservation	No or marginal implications for GHG emissions, positive if the effect of perturbations induced by climate change can be reduced May lead to increase in emissions from soils or use of machinery and fertilizer
B. Changing forest management: increasing carbon density at plot and landscape level			
Forest management in plantations	Vulnerable to changes in rainfall, and higher temperatures (i.e. managed forest dieback due to pest or droughts)	Pest and forest fire management. Adjust rotation periods Species mix at different scales	Marginal implications on GHGs. May lead to increase in emissions from soils or use of machinery or fertilizer use
Forest management in native forest	Vulnerable to changes in rainfall, and higher temperatures (i.e. managed forest dieback due to pest, or droughts)	Pest and fire management Species mix at different scales	No or marginal
C. Substitution of energy intensive materials			
Increasing substitution of fossil energy intensive products by wood products	Stocks in products not vulnerable to climate change		No implications in GHGs emissions
D. Bio-energy			
Bio-energy production from forestry	An intensively managed plantation from where biomass feedstock comes is vulnerable to pests, drought and fire occurrence, but the activity of substitution is not.	Suitable selection of species to cope with changing climate Pest and fire management	No implications for GHG emissions except from fertilizer or machinery use

According to Verkehr J.P. et al (2022), the contribution of forest-based mitigation actions could be maximised in the following way:

- Adopt a holistic approach that considers all relevant carbon pools and fluxes, as well as interactions between forest-based mitigation activities and with adaptation, and which minimizes trade-offs with biodiversity and ecosystem services.
- Combine multiple forest-based mitigation activities to maximise the effect and foster synergies, interactions, co-benefits and regional applicability.
- Prioritise types of wood use that give the largest net emission reductions.
- Take note that forests across countries differ, and so do implementation actions.
- Move to policy implementation and develop appropriate support tools (e.g., through incentive systems, exchange of best practices, devising a transparent, harmonized and robust monitoring framework).
- Apply a long-term perspective beyond 2050 in climate and forestry policies that considers climate change mitigation and adaptation together to avoid future losses of forest carbon stocks and sequestration capacity.

EIP-AGRI Focus Groups in their final report with the title “Forest Practices & Climate Change” (2019) denotes that the challenges posed by climate change for sustainable forest management in Europe show strong regional differences (Table 10), ranging from increased growth and productivity mainly in the north and at higher altitudes, to increased and more frequent drought stress and mortality expected elsewhere (Lindner et al., 2014).

Table 10: Overview of regional differences in climate change impacts and selected adaptation options (Source: https://ec.europa.eu/eip/agriculture/en/publications?f%5B0%5D=field_publication_date%3A2019)

Biogeographic region	Effects of climate change	Possible adaptation measures[1]
Boreal	– Increased growth and productivity; – Difficult harvesting and reduced accessibility on non-frozen soils; – More frequent storm, fire and insect damage.	– Adapt management regimes to accelerated growth rates; – Develop harvesting technology and transport logistics with reduced soil impact; – Shorten rotation length and more stable stand structure.
Temperate Atlantic Zone	– Increased risks from storms, pests; – More frequent droughts; – Changes in productivity; – Changes in species composition.	– Diversification of both species and age composition; – Choose appropriate genetic material; – Shorten rotation length.
Temperate Continental Zone	– Drought-induced productivity decrease; – Spruce forest susceptible to pests and windthrows; – More frequent regeneration failure; – Increased fire risk.	– Proper management of old and young stands to improve regeneration; – Intensive thinning to save water.
Mediterranean	– Increased aridity with more frequent severe droughts; – Dieback of certain species leading to biodiversity loss; – Increased forest fire hazard and subsequent soil erosion risk.	– Decrease canopy density in dry areas through regular management (thinning, pruning); – Longer rotation period; – Adopt prescribed burning or other fuel management techniques.
Mountainous	– Increased productivity; – Increased run-off and soil erosion; – Shift in vegetation climax and species composition; – Increased risk of pests, forest fire, windthrow.	– More spatially diverse management that increases tree regeneration speed and protective qualities and reduces risk of bark beetles.

[1] This list is not comprehensive and some measures, such as increased landscape diversity, can be applied in all biogeographical regions.

The big challenge for managers and forest owners in the face of climate change is to identify how different forest ecosystems might interact with each other under different future regional and local site conditions. It is obvious that this will depend not only on the vulnerability of these ecosystems to climate change, but also on their resilience as well.

4.3 Traditional and Multifunctional Forest Management

Historically in Europe until up to now, depending on the different forest biomes, regions and portfolios of stakeholders and management planners, there have been several views on the concept "Sustainable Forest Management" (SFM) approach and how to implement it in practice.

In the pre-industrial period between the 16th and 18th centuries and until the middle of the 19th century, there was a shortage of wood. Nevertheless, there was an overlapping of two or more uses in Agro/Silvo/Pastoral areas. Different functions were therefore integrated. This is particularly true for grazing and wood utilisation in wooded areas. Figure 18 illustrates that there were several types of land use during this period.

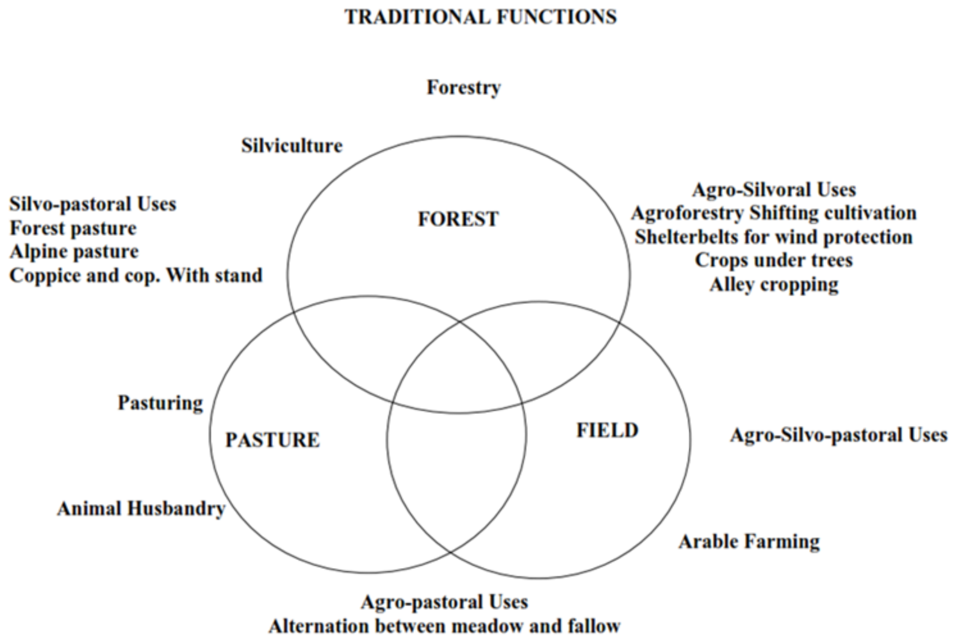

Figure 18: Overlapping of forest functions in the traditionally forestry (adopted from Huss, 2004. Source: Kalapodis, 2010)

Around 1850, due to the desperate need for wood (timber for construction and industry), "sustainability" in the forest seems to refer exclusively to the use of wood with erosion control (segregate approach).

For many decades, public forest managers have been guided by the old paradigm of traditional forestry, i.e. maximize and sustain the yield of a single resource - commercial timber. Later (~ from 1970), the silvicultural principle of sustainability gave way to a more holistic view of multiple use (social, economic and ecological). Thus, society's perception of the forest began to achieve a more multidimensional understanding of all its functions. This status put an end to the uncontrolled over-exploitation of firewood and timber, which for decades had led to significant degradation, in terms of species composition and structure, stability, forest form structure, productivity and dynamics (Table 11).

Table 11: Change of dominance of forest functions during the last 3 Centuries, especially in Central Europe (adopted from Huss, 2004. Source: Kalapodis, 2010)

FOREST FUNCTION	YIELD	PERIOD
Multifunctional	Fuel wood, timber, fruits, resin, litter, pasture	Until middle of 19th century
Monofunctional	Construction and industrial timber (erosion control)	~1850 until 1970
Multifunctional	Construction and industrial timber, landscape protection, recreation, nature protection, water protection, soil protection/erosion control	Starting ~ 1970

The main types of management according to the method of tree regeneration (traditional types of silvicultural forest use) in the context of sustainable forest management are described below:

1. Coppice Forest – Forest stand of broadleaved species are regenerated from shoots produced from the stools (cut stumps) or root suckers of the previous crop. The rotation period is generally short.
2. Coppice-with-Standards - Multi-storied forest stand consisting of a lower storey of an even-aged coppice underwood and an uneven-aged partial upper storey of standard trees grown at wide spacing which is treated as high forest
3. High Forest (even aged) – Forest stand is regenerated from seedlings, either natural or planted, or a combination of both. The rotation period is generally long.

   3.1 Single-Tree and Group Selection Cutting

   3.2 High Standard Forest with Cutting/Felling Areas – Clear Felling system, Shelterwood system, Seed tree system

The new model of multifunctional forest management is already recognised. It should meet all of the society's demands on forests in an equitable way (Figure 19). Therefore, wood should only be used to the extent that it can be sustainably reproduced, and forests should be managed in such a way that a wide range of other forest functions (services) is provided, with the aim of benefiting present and future generations and societies. Conservation (water regulation, climate regulation, erosion control, nature conservation, noise and air pollution control) and recreational functions are increasingly taken into account.

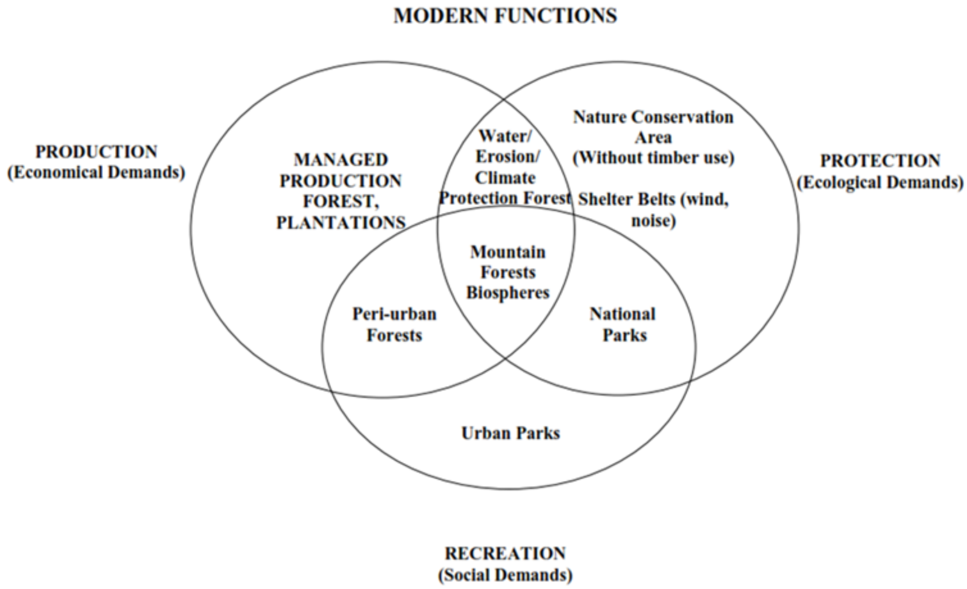

Figure 19: Forest functions in the sense of a modern multifunctional forestry (adopted from Huss, 2004. Source: Kalapodis, 2010)

Bengston (1994) notes that the introduction of sustainable yield forestry in North America in the 1890s was a major innovation in response to the destructive exploitation of forests in the 19th century, and that multiple-use forestry was discussed in the 1930s. Nevertheless, it was not until after the Second World War that it was seriously considered as the demand for recreation, wildlife, water and other non-timber forest resources began to grow. The idea of expanding the traditional focus of forestry on the production of timber to include the production of other commodities was the basic idea behind multiple-use forestry. Multiple-use forestry was legislated for national forests, beginning with the Multiple-Use Sustained-Yield Act of 1960. However, the practice of multiple-use forestry has fallen short of the ideal. The long-established doctrine of "timber priority" still governs forest management (Clary, 1986; Gliick, 1987; Hays, 1988; McQuillan, 1990; Shepard, 1990, Source: Bengston, 1994).

The European Union (EU) decided in Helsinki (1993) that all forests in the member states that have been degraded due to overexploitation should in future be restored and managed with new - more strategic -

planning, taking into account the principles of sustainability and multifunctionality. In addition to the protection of nature, the forest ecosystem should also serve the public interest for the well-being of society.

The Helsinki Criteria are defined as following:

1. Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles.
2. Maintenance of forest ecosystems' health and vitality.
3. Maintenance and encouragement of production functions of forests (wood and non-wood).
4. Maintenance, conservation, and appropriate enhancement of biodiversity in forest ecosystems.
5. Maintenance and appropriate enhancement of protective functions in forest management (notably soil and water).
6. Maintenance of other socio-economic functions and conditions.

Häusler et al. (2002) state that "*today, the concept of sustainable forest management does not represent a concrete, original management concept, but rather can be seen as a broader concept*" that incorporates other management models that have been developed that integrate conservation measures in forests managed partially or primarily for timber production. These include near-natural forestry, continuous cover forestry, retention forestry, mimicking natural disturbance, mimicking natural processes, ecosystem management, ecological forestry. (Angelstam 1996; Kuuluvainen et al. 2021; Sotirov et al. 2020; Puettmann et al. 2015; Gamborg and Larsen 2003, 2005; Pommerening and Murphy 2004).

4.4 Closer-to-Nature Forest Management

The major challenge for EU forest policy is to address and/or harmonise economic, social and environmental aspects of forest management, as defined at the Rio Conference in 1992, including the integration of nature-based forestry practices. The common denominator for such a challenge is the multiple use forest strategy, which aims at fulfilling all potential forest functions/needs in the same place at the same time (integrated multifunctional forest management) and doesn't separate them (Figure 20).

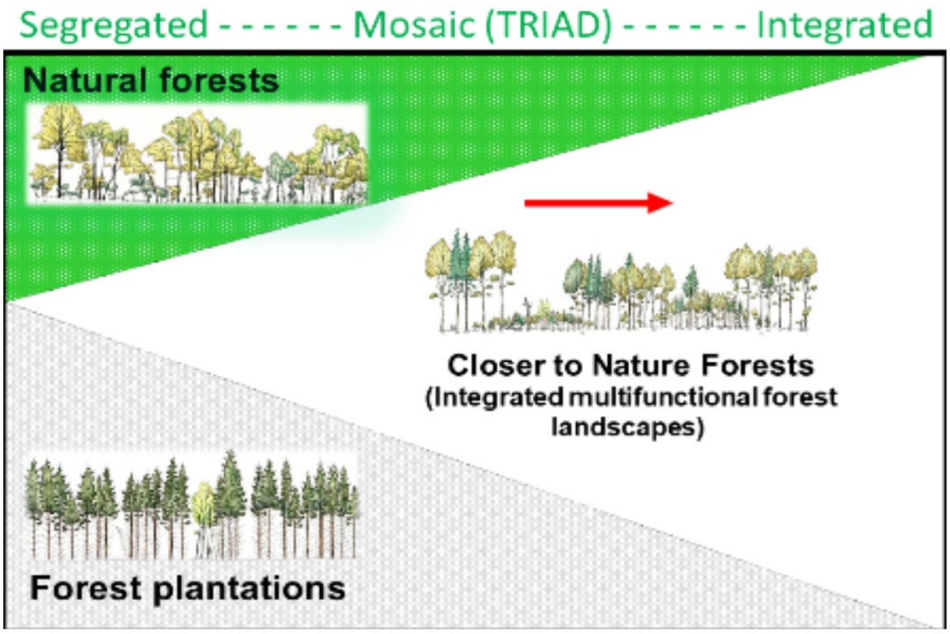

Figure 20: Landscape segregation and integration - a continuum (modified after Larsen, 2009). The term 'triad' in forestry refers to a landscape management regime composed of three parts: (1) intensive plantation management, (2) ecological forest reserves, and (3).

The situation to the left of the Figure 20 demonstrated an entirely segregated forest landscape with spatial separation of different forest management purposes: Maintenance and conservation at the top, timber utilization at the bottom. At the right side of the figure, an increasing proportion of the forested landscape is managed for multifunctional goals, mixing management for most objectives in the same forest stands including biodiversity conservation. Thus, the multiple use notion is on the mend to become the main goal for the nowadays and perhaps the upcoming forest policies.

Closer-to-Nature Forest Management (CTNFM) is a concept proposed already in the EU Forest Strategy for 2030 (EUFS 2021), which aims to improve the conservation values and climate resilience of multifunctional, managed forests in Europe.

Schütz et al. (2016) ingeniously underline that the term near-natural silviculture already contains a certain ambiguity, as (silviculture) implies the act of forest use. This term was coined a long time ago by well-known silviculturists (Gayer 1885; Engler 1905; Leibundgut 1943 and others) to characterise a new form of forest management that differed from plantation forestry and the clear-cut system.

Schütz et al. (2016) quotes Leibundgut (1943, p. 152): 'The main task of silviculture is to maximise and maintain the value produced by the forest' and emphasises that such a formulation is still quite relevant today, if the term "value" is understood in a broader sense. He points out that it would be more appropriate to use the term "utility" (original term "utilite") in the sense of Biolley (1901).

"Forest practices vary substantially across Europe ranging from no management due to abandonment, through management for nature protection, to intensive short-rotation monoculture forestry managed for producing energy-related biomass. The ecological functions of forests are resilient to certain rates and degrees of disturbance, as forests evolve under the influence of natural disturbances. The current composition and structure of Europe's forests reflects a variety of novel anthropogenic disturbances" (Novakova et al., 2015; Thorn et al., 2017; Vacchiano et al., 2017, Source: https://www.eea.europa.eu/publications/forest-dynamics-in-europe-and).

In contrast to the above forest practices (Figure 21) the management attitudes of the main proponents of CTNFM lead to an emphasis on stability, productivity, diversity and continuity of forest conditions, resulting in attempts to integrate multiple forest management objectives at small spatial scales, ideally within individual forest stands (Bauhus et al. 2013).

According to the EU Biodiversity Strategy 2030, biodiversity-friendly practices – such as closer-to-nature-forestry – efforts to conserve forest biodiversity rely on two overlapping approaches; 1) setting aside forests specifically for nature conservation in areas excluded from wood production (*functional segregation*) and 2) incorporating conservation measures within production-oriented forests (*functional integration*). These two approaches are mutually reinforcing: the more biodiversity is conserved through management that produces timber and other ecosystem services, the fewer areas need to be set aside for biodiversity conservation alone (Lindenmayer and Franklin 2002; Larsen 2009; Boncina 2011a; Bollmann and Braunisch 2013; Kraus and Krumm 2013).

Closer-to-nature management should be considered more as a set of guiding principles that are concerned with the whole ecosystem and with ensuring small-scale heterogeneity and stability, and uneven-aged silviculture systems are used as a means of implementing these principles (Helliwell and Wilson, 2012, Source: Schütz et al., 2016). Bauhus et al. (2013) states that the main principles of close-to-nature forest management comprise the use of site adapted tree species, development of mixed and uneven aged structurally diverse forests, avoidance of clear felling, focus on stand stability, reliance on natural processes and a focus on individual tree development.

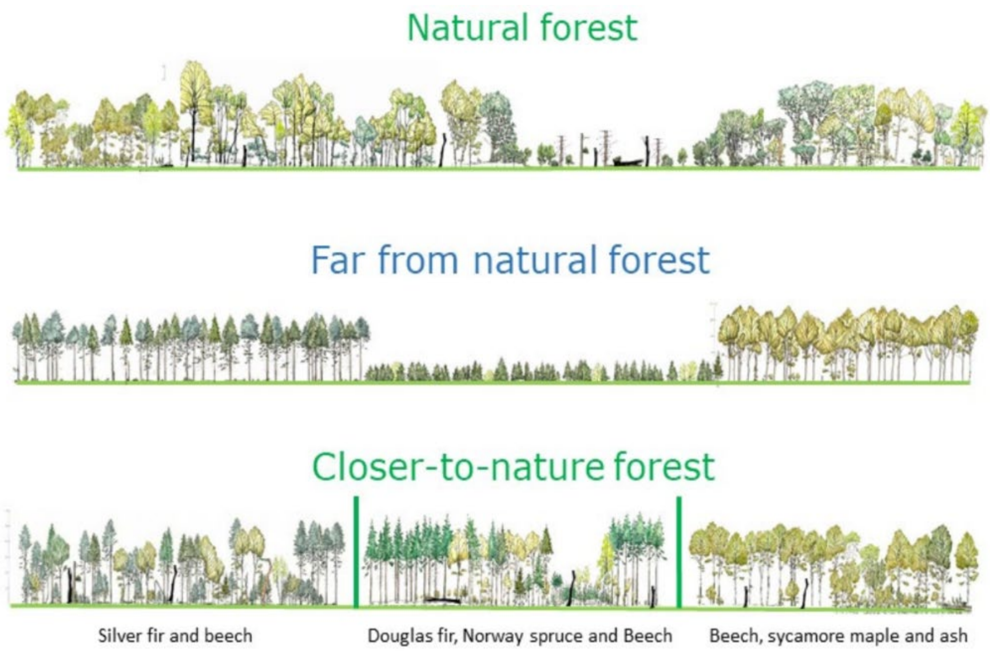

Figure 21: A natural forest (upper panel), a forest intensively managed for wood production (far from natural state) (middle panel) and a forest managed with Closer-to-Nature methods (lower panel).

This representation is highly generalized and does not capture the large variation in forest zones and landscape types of Europe. There are many types of forest management approaches in Europe leading to forest states with more or less strong similarity to natural forest. The lower panel (Closer-to-Nature forest) presents three examples of Forest Development Types (FDT) described and illustrated in Larsen (2012). Left - Silver fir and beech managed through selection cutting; centre - Beech with Douglas fir and larch, and right - Beech with ash and sycamore maple both managed through group selection (Source: Larsen, J.B. et al. 2022).

The Report of EFI (Larsen, J.B. et al. 2022) refers to 7 principles of Closer-to-Nature Forest Management as follow:

1. Retention of habitat trees, special habitats, and dead wood
2. Promoting native tree species as well as site adapted non-native species
3. Promoting natural tree regeneration
4. Partial harvests and promotion of stand structural heterogeneity
5. Promoting tree species mixtures and genetic diversity
6. Avoidance of intensive management operations
7. Supporting landscape heterogeneity and functioning

Figure 22 provides a qualitative attempt to compare the ability of the seven Closer-to-Nature Forest Management principles to contribute to forest resistance, resilience and adaptive capacity (Larsen, J.B. et al., 2022).

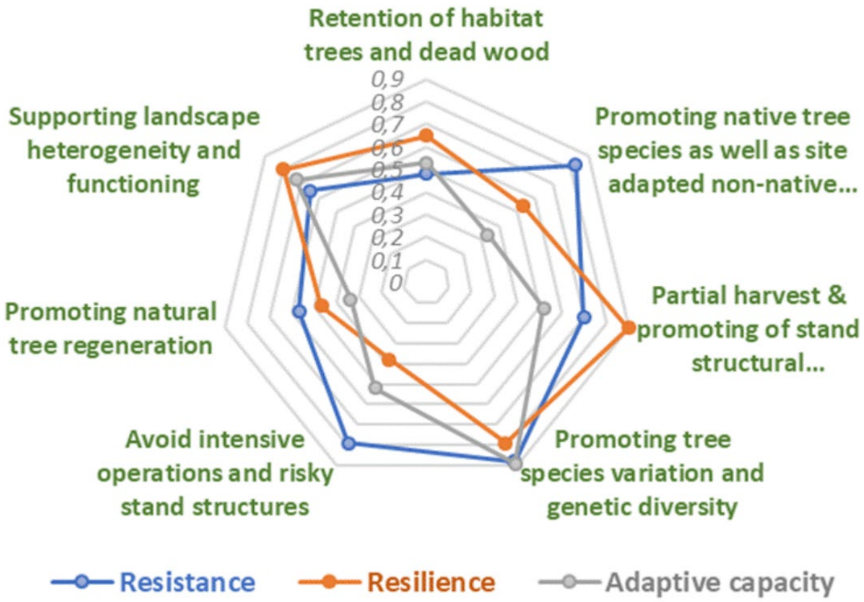

Figure 22: Visualization of the possible impact of principles of Closer-to-Nature forestry on the resistance, resilience and adaptive capacity concerning ecosystem service provisioning

(Resistance comprises the ability of an ecosystem to resist external stress; resilience comprises correspondingly the ability, when changed due to a disturbance agent, to return to its former dynamic state; adaptive capacity relates to global change, including climate change) (Source: Larsen, J.B. et al. 2022).

In general, Figure 22 demonstrates that there is a decent compliance between management options supporting biodiversity and those promoting forest health, resilience and adaptability.

In line with all of the above seven principles, Larsen, J.B. et al. (2022) define Closer-to-Nature Forest Management as an overarching 'umbrella' encompassing all approaches and terminologies that support biodiversity, resilience and climate adaptation in managed forests and forested landscapes under the auspices of Sustainable Forest Management (SFM). Closer-to-Nature Forest Management promotes components, structures and processes characteristic of natural forests and managed woodlands, thereby enhancing diversity of tree species and structures, variation in tree size and stage of development, and a range of habitats including habitat trees and deadwood. The aphorism of the British philosopher Francis Bacon that "Nature, to be commanded, must be obeyed" remains relevant, perhaps more so than ever.

Larsen, J.B. et al. (2022) states that at present Nature Based Forest Management (NBFM) is practiced on 22-30% of the forest area in Europe, however, this area is gradually but steadily increasing due to environmental, economic and social factors (Mason et al. 2021). The proportion of forests where NBFM is practiced ranges from a few percent in Portugal, Finland and Sweden to almost 100% in Switzerland, Slovenia and some German states where this approach is required by forest law. In Denmark NBFM is based on Close-to-Nature Forest management principles and is mandatory in all public forests (Larsen 2012).

NBFM is synonymous with continuous cover management in Atlantic Europe, close-to-nature management in Central Europe, and forest ecosystem management in the USA (Puettmann et al. 2015, Source: Larsen et al, 2022).

The following table (Table 12) contains a long catalogue of synonyms or semi-synonyms associated with the idea of Continuous Cover Forestry (CCF), which promotes species and structural diversity through the use of irregular silviculural systems and which avoid clear cutting, and include the terms defined above.

Table 12: The range of semi-synonyms used in connection with CCF (Source: Pommerening et al. 2004)

Synonym or semi-synonym	Source
Continuity of forest cover	
Dauerwald	Möller, 1922; Troup, 1928; Helliwell, 1997
Permanent forest	Anderson, 1953; Häusler and Scherer-Lorenzen, 2001
Alternatives to clearfelling, alternative silvicultural systems to clear cutting	Penistan, 1952; Hart, 1995
Low impact silviculture	UKWAS Steering Group, 2000; Mason *et al.*, 1999
Continuous forest	Troup, 1928; Hart, 1995
Continuous cover silviculture	Yorke, 1998
Ecosystem management	
Nature-orientated silviculture	Koch and Skovsgaard, 1999
Ecological silviculture	Lähde *et al.*, 1999
Close-to-nature silviculture	Schütz, 2001; Kenk and Guehne, 2001
Naturalistic silvicultural systems	Mitchell and Beese, 2002
Close-to-nature forestry/forest management	Mlinšek, 1996; Mason *et al.*, 1999
Ecological forestry	Mason *et al.*, 1999
Near-natural forestry/forest management	Benecke, 1996; Gadow *et al.*, 2002
Forest management based on natural processes	Pro Silva Europe, 1989
Structural diversity	
Uneven-aged/multi-aged/multi-cohort management/silviculture/forestry	Anderson, 1953; O'Hara, 1996; Oliver and Larson, 1996
Diversity-orientated silviculture	Benecke, 1996; Lähde *et al.*, 1999
Irregular structure forestry/silviculture	Johnston, 1978; Bradford, 1981; Pryor, 1990
Retention	
Variable retention	Mitchell and Beese, 2002
Managed retention	Forest Enterprise, 2000
Green-tree retention (GTR)	Franklin, 1989; North *et al.*, 1996; Vanha-Majamaa and Jalonen, 2001
Thinning/harvesting methods	
GTR harvest	North *et al.*, 1996
Selective cutting/selective timber management	Curtis, 1998
Philosophically driven semi-synonyms	
Holistic forestry	Mason *et al.*, 1999
New Forestry	Franklin, 1989

It should be emphasised that in the above catalogue semi-synonyms are often only an indication of a particular aspect of CCF rather than a broad definition of it as a whole.

Last but not least, regarding the CCF concept, Pommerening et al. (2004) reviewing the literature make clear that the debate is broader than just avoiding clearcutting on large areas (Lähde et al., 1999; Kenk and Guehne, 2001; Nabuurs, 2001; Vanha-Majamaa and Jalonen, 2001). Figure 23 presents other important elements such as selective harvesting, allowable gap size, appropriate silvicultural systems and vertical structure are emphasised in some of the above definitions.

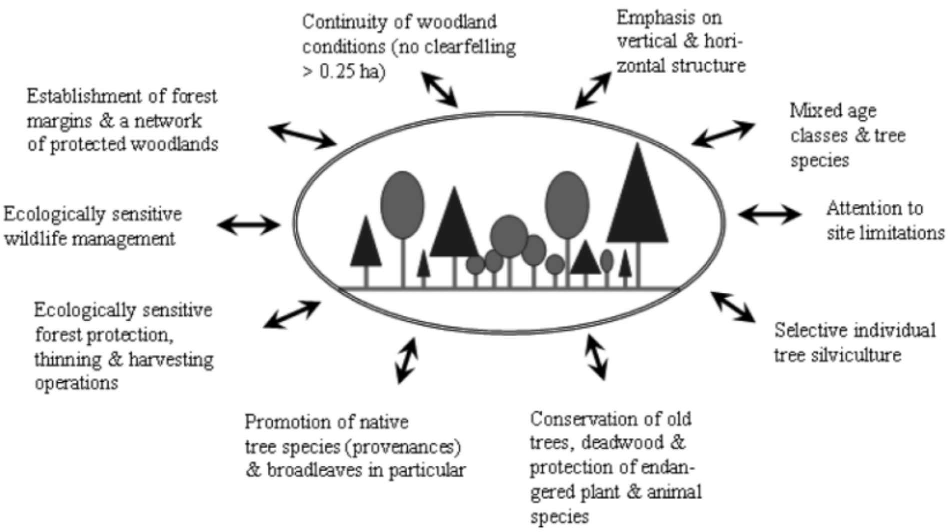

Figure 23: The main components of the contemporary international continuous cover forestry debate (Source: Pommerening et al., 2004)

The key finding presented in Figure 23 is that CCF is considered compatible with a holistic approach to forestry with multiple-use management objectives (Lower Saxony State Government, 1991; Thuringian State Institute of Forestry, 2000; Häusler and Scherer-Lorenzen, 2001).

5 Forest Resilience

5.1 Overview

Forest resilience refers to the ability of a forest ecosystem to withstand and recover from disturbances, such as wildfires, insect outbreaks, and severe weather events, while maintaining its overall structure, function, and biodiversity. Resilient forests are able to adapt to changing environmental conditions and recover from disturbances without undergoing significant changes in their fundamental ecological characteristics. The concept of forest resilience recognizes that forests are complex, dynamic systems that are influenced by a wide range of biological, physical, and social factors, and that these factors interact in complex ways to determine the ability of a forest ecosystem to resist and recover from disturbances (Falk et al, 2022; Forzieri et al, 2022; European Forest Institute, 2023).

Resource management in various ecosystems can be branched out as two individual categories; stability and resilience. Stability attempts to detect the balancing point (equilibrium), which results by monitoring harvesting habits and limiting them to have as little impact as possible. Resilience seeks persistence; and thus, can be obtained by regulating those controllable events in the scope of narrowing down the aftermaths of the random ones (Holling, 1973).

Climate warming can lead to improper function of ecosystem mechanisms (Millar et al, 2015; Turner, 2010), which can contribute to natural disasters such as wildfires and floods, as well as to the degradation of ecosystems due to unethical land use practices such as agricultural expansion and timber harvesting (Hagmann et al, 2022). These factors together form the basis for ecosystem resilience responses. Reverting whole ecosystems to a state before an enormous tragedy is simply not possible given the predicted outcomes of human activity. For example, unsuitable temperature variance and/or drought significantly affect the formation of trees during the early stages (Bell et al, 2014; Dobrowski et al, 2015), they, alongside local climate disturbance, lead to longer and drier time frames fuelling more extreme and more frequent wildfires (Abatzoglou, Williams, 2016).

Development of residential buildings near forest areas introduces individuals to potentially dangerous emissions caused by large forest fires (Radeloff et al, 2018; Bowman et al, 20187). This development has led to the so-called Wildland Urban Interface (WUI) areas and fires. This is an important issue, as these fires are more frequent and more dangerous, not only for the emissions but also for the lives lost. The WUI refers to the zone where human development meets and intermingles with undeveloped wildland vegetation (US Fire Administration, 2022). In this interface, buildings and other human-made structures are in close proximity to forested or other vegetated areas. As human development continues to expand into these areas, the risk of wildfires increases.

The WUI has become a critical issue in many parts of the world, including the United States, where it is estimated that over 44 million homes are located in WUI areas. These areas are particularly vulnerable to wildfires due to the high fuel loads of vegetation, limited access for firefighting equipment, and the presence of structures that can act as ignition sources. The risk to life and property from wildfires in the WUI has increased in recent years due to climate change and other factors, making it an important area of research and management focus.

The Wildland Urban Interface (WUI) is also a significant issue in the EU, particularly in southern Europe where there are many areas with a high risk of wildfires. In fact, wildfires in the EU have been increasing in frequency and intensity in recent years, with many of them occurring in the WUI. This is due to factors such as urban sprawl, the abandonment of traditional land management practices, and climate change. A relevant example is the Mati wildfire. It was a devastating wildfire that occurred in the coastal town of Mati, Greece, on July 23, 2018. The wildfire claimed the lives of 102 people and destroyed numerous homes and buildings in the area. It is considered one of the deadliest wildfires in Greece's history.

The European Commission has recognized the importance of addressing the WUI issue and has included it as a priority in its Forest Strategy for 2030. The strategy aims to improve the resilience of forests and promote sustainable forest management, including in the WUI. It also includes measures to support the development of new housing in areas that are less at risk from wildfires, and to encourage the use of fire-resistant building materials in high-risk areas.

The most common and cost-effective forest managements treatments to increase forest resilience to fires are considered the followings (Kaloudis 2008):

- Removal of logging residues, that reduces surface fuel load and therefore fire characteristics. However, it is noted that its intensive application causes a lack of nutrients in the forest ecosystem (Kalabokidis and Omi, 1998; Gibbons et al. 2000; Scherer et al. 2000; Smith et al. 2000; Zabowski et al. 2000; Baeza et al. 2002; Baeza et al. 2003; Fernandes and Botelho, 2003; Carter and Foster, 2004)
- Tree pruning, that reduces the likelihood of surface fires turning into crown fires while improving the quality of produced timber.
- Understory thinning that reduces the fire characteristics. In this way, in combination with the pruning of the trees, the possibility of crown fire is significantly reduced.
- Forest Thinning, that reduces fire characteristics and helps to avoid catastrophic active crown determine. In addition, it works positively on forest production by improving the quality of timber and facilitating the regeneration of the Forest. It is noted that excessive thinning reduces the amount of timber produced and the productivity of the Forest, allows the development of an undesirable rich understory, can minimize the aesthetic value of the forest, and increase the risk of soil erosion, as well as the ladder fuels that transmit surface fire to the crown (Graham et al. 1999; Baldwin et al. 2000).
- In any case of application of the above treatments of the vegetation, it is considered that the cut fuel materials do not participate in a possible future fire. This assumption presupposes that the felled biomass is properly handled, such as for example, burning it in the forest, at an appropriate time or their total removal from the forest.
- Encouraging species with high resistance to fire, that refers to the support of the native broad-leaved forest species, which increase the resistance of the forest to fires, due to the high moisture content of their foliage (Dimitrakopoulos and Panov, 2001; Dimitrakopoulos, 2001a; Dimitrakopoulos, 2001b; Dimitrakopoulos and Papaioannou 2001; Dimitrakopoulos, 2002; Dimitrakopoulos and Dritsa 2003; Liodakis, et al 2003). The broad-leaved species also, when mixed in coniferous forests, increase also the resistance of these forests to insects and pathogenic organisms and improve the aesthetics of the landscape.
- Grazing of domestic animals, that reduces the fuel load (bushes and poes) and contributes to increasing farm income, through the production of livestock products (Bachelet, 2000; Valderrabano and Torrano 2000; Torrano and Valderrabano, 2005; Liedloff 2001;).

Construction of firebreaks, that reduces the spread of fires (Omi 1996; Butler and Cohen, 1998). In general, the purpose of firebreaks is to prevent the further spread of fire and to provide protection to fire fighters. Because of the width of a firebreaks should be big in order to be effective (Butler and Cohen 1998a, Butler and Cohen 1998b; Agee et al, 2000) it is suggested the construction of composite firebreaks consisted off zones with adapted size and cover (Kaloudis, 2008).

5.2 Assessment of Forest Resilience

Assessment of forest resilience is an important tool for understanding how forest ecosystems respond to disturbances such as wildfires, insect outbreaks, and climate change. Here the focus of the document is the forest resilience from wildfires.

5.2.1 Methodologies for quantitative and qualitative aspects of forest resilience

Assessing forest resilience to wildfires involves both quantitative and qualitative methodologies. Quantitative methods focus on measuring specific ecosystem parameters that affect a forest's ability to recover from a wildfire, while qualitative methods aim to understand the social and ecological factors that contribute to a forest's resilience.

Quantitative methodologies (Schmidt et al, 2022) for assessing forest resilience to wildfires include:

- **Vegetation monitoring**: Monitoring changes in vegetation, such as plant cover and species composition, can provide insights into the recovery of the ecosystem after a wildfire. The vegetation monitoring can be addressed with different mediums depending on the specific objectives of the action (drones, ground observations, satellite imaging). In situ observations with measurements on the site by a human is also a form of quantitative vegetation monitoring. This type of monitoring can provide important information on plant density, height, and other quantitative measurements that can help assess changes in vegetation after a wildfire. In fact, ground observations are often considered a more accurate and detailed form of vegetation monitoring than remote sensing methods such as drones or satellite imaging, although they may be less efficient for covering large areas.
- **Soil sampling**: Sampling soil after a wildfire can help to assess changes in soil fertility, organic matter content, and nutrient cycling, which can affect the ability of vegetation to regrow.
- **Hydrological monitoring**: Monitoring changes in water availability and quality can help to understand the impacts of a wildfire on the water cycle and the potential for erosion and landslides.

Vegetation monitoring and soil sampling can be considered as specific techniques or methods that are often used as part of a broader methodology for assessing forest resilience to wildfires. These methods are used to collect quantitative data that can provide insights into the condition of the ecosystem and its ability to recover after a wildfire.

For example, vegetation monitoring may involve collecting data on plant cover, species diversity, and biomass to assess changes in vegetation over time. Similarly, soil sampling may involve collecting soil samples to analyze changes in soil fertility, nutrient cycling, and organic matter content after a wildfire. These techniques are typically used in conjunction with other methods, such as hydrological monitoring and remote sensing, to provide a more comprehensive understanding of the impacts of a wildfire on the ecosystem and the potential for restoration.

Qualitative methodologies for assessing forest resilience to wildfires may include:

- **Social and ecological surveys**: Surveys of local communities and stakeholders can provide insights into the social impacts of a wildfire and the factors that contribute to a forest's resilience.
- **Stakeholder engagement**: Engaging with stakeholders, such as local communities, indigenous peoples, and forest managers, can help to understand the social and ecological factors that contribute to a forest's resilience.

- **Participatory mapping**: Participatory mapping exercises can help to identify areas of high ecological and cultural value, which can inform restoration and management strategies.
- **Expert elicitation**: Expert elicitation techniques, such as workshops and interviews with forest managers and researchers, can provide insights into the ecological and social factors that contribute to a forest's resilience and inform management and restoration strategies.

In addition to these traditional approaches, modern and innovative monitoring techniques and methodologies can also be used to assess forest resilience. These may include remote sensing technologies, such as satellite imagery and LiDAR data, as well as ground-based monitoring techniques, such as plot-level assessments and ecological surveys. By combining expert elicitation with modern monitoring techniques, managers and researchers can gain a more comprehensive understanding of the ecological and social factors that contribute to a forest's resilience and develop more effective management and restoration strategies.

Aquilué et al (2020) studied current forest resilience and "multi-species plantations" in Canada by planting specific species to increase biodiversity and then observing the ecosystem's response to drought, pest-outbreak and timbering. Their results clearly show that increasing biodiversity promotes faster functional response, while improving drought effects. Planting pest-resilient species led to a fuller, better connected ecosystem.

Adolf et al (2020) utilized Vegetation Sensitivity Index (VSI) (Seddon et al, 2016) and extraction of Disturbance events for experiments conducted on Neotropics (Williams et al., 2018) dataset. Their findings also support that biodiversity plays a crucial role to an ecosystem's better response after an event, however they fail to associate past recoveries to present ones; thus, resilience might not be region specific.

A study of pre and post wildfire event in the Iberian Peninsula using Sentinel 2 images concluded that regions heavily occupied by resprouter species tend to better resist aftermaths of wildfires than those occupied by facultative seeder species. Their methodology estimated the Fractional Vegetation Cover (FCover) from the PROSAIL-D model (Féret et al, 2017) and Multiple Endmember Spectral Mixture Analysis (MESMA).

Forzieri et al (2022) utilized satellite imagery and machine learning models to indicate that there is an increment in boreal forest resilience in the last years, however tropical and temperate forests tend to lose their robustness. This conclusion was consistent to both managed and intact ecosystems, which further promotes evidence leading to climate factors.

5.2.2 Data supporting forest resilience

Space Assets

Earth observation (EO) data can provide valuable information to support forest resilience by monitoring changes in forest health, identifying areas of risk, and informing management strategies. Some examples of EO data that can support forest resilience include:

- **Optical imagery**: Optical satellite imagery can be used to monitor changes in forest cover, including the extent of deforestation, forest fragmentation, and the impacts of natural disturbances such as wildfires and insect outbreaks. High-resolution satellite imagery can also be used to monitor forest health, including changes in tree canopy cover and the presence of diseases or pests.

- **LiDAR data**: LiDAR (Light Detection and Ranging) is a remote sensing technology that can be used to measure forest structure and biomass. LiDAR data can be used to create detailed 3D models of forest ecosystems, which can provide valuable information on forest health and productivity.
- **Radar data**: Radar data can be used to monitor changes in forest cover and structure, including the detection of forest disturbance and the mapping of forest biomass. Radar data can also be used to monitor changes in soil moisture levels, which can affect forest health and resilience.
- **Climate data**: Climate data can be used to assess the potential impacts of climate change on forest ecosystems, including changes in temperature, precipitation, and extreme weather events. Climate data can also be used to model future forest growth and productivity under different climate scenarios.
- **Topographic data**: Topographic data can be used to identify areas of risk for natural hazards such as landslides, floods, and avalanches. Topographic data can also be used to identify areas of high biodiversity value and to inform conservation planning.

One of the most robust data sources that can be exploited is Copernicus data through Copernicus Open Access Hub, specifically missions Sentinel-1 and Sentinel-2 launched by the European Space Agency (ESA).

The Sentinel 1 mission deployed a constellation of two satellites (Sentinel-1A and Sentinel-1B), with the inclusion of C-SAR instrument, these satellites can sample parts of the Earth despite being day or night. They also can overcome cloud cover and pixel contamination, however interpretation of such information can be trivial even for experts. Sampling can occur down to 5m of resolution with a coverage of up to 400km. Although, the nominal spatial resolution of Sentinel-1 is 20 meters.

Sentinel 2 mission is equipped with an optical sensor that can sample at 13 different resolution bands; 3 bands at 60m, 6 bands at 20m and 4 bands at 10m. Two identical satellites obtain these multispectral images of the Earth, with a revisit interval of 5 days at the Equator. Coverage width is 290km.

Table 13: Sentinel 2A and 2B radiometric and spatial resolution (ESA)

Band number	S2A		S2B		Resolution [m]
	Central Wavelength [nm]	Bandwidth [nm]	Central Wavelength [nm]	Bandwidth [nm]	
1	442.7	20	442.2	20	60
2	492.7	65	492.3	65	10
3	559.8	35	558.9	35	10
4	664.6	30	664.9	31	10
5	704.1	14	703.8	15	20
6	740.5	14	739.1	13	20
7	782.8	19	779.7	19	20
8	832.8	105	832.9	104	10
8a	864.7	21	864.0	21	20
9	945.1	19	943.2	20	60

10	1373.5	29	1376.9	29	60
11	1613.7	90	1610.4	94	20
12	2202.4	174	2185.7	184	20

Another valuable source of information is the Landsat program operated by the US. Landsat is set to observe the Earth's surface constantly and is currently at its 9th generation. The latest version of satellites enhances quality of service just like the previous generation and is expected to offer around 750 (1400 in combination with 8th gen) daily new scenes to the enormous dataset archives of Landsat program. Data are sampled in 9 spectral bands; 8 bands at 30m spatial resolution, 1 band at 15m. Furthermore, 2 thermal sensors are provided at 100m spatial resolution, respectively. All data produced is open through the USGS Earth Resources Observation and Science (EROS) Center, a campaign to recalibrate all products of Landsat 9 utilizing state of the art algorithms is expected to take off at the beginning of 2023.

Mapping natural and artificial disasters is a core functionality of satellite data, but it is not the only one. Geospatial data can be used to tackle problems from a variety of domains. For instance, weather forecasting; observing climate change and/or similar phenomenona; impacts of excessive agricultural land-use, timber harvesting, etc… on forest deforestation heavily depend on metrics from sensors or by-products obtained directly from space.

Ground Truth

The Global Biodiversity Information Facility (GBIF) (GBIF.org, 2022), is an international organization that provides a platform for publishing, sharing, and accessing biodiversity data from around the world. GBIF works with organizations and institutions to digitize and publish primary biodiversity data, making it freely available through the internet. The organization provides the infrastructure and standards necessary for sharing data across borders and across disciplines, helping to promote collaboration and data sharing in the field of biodiversity research. GBIF also provides tools for data analysis and visualization, and supports the development of best practices for data management and data sharing in the biodiversity community.

NeotomaDB (Williams et al., 2018) is a database of paleoecological data that aims to provide a centralized repository for data on past ecosystems and biodiversity. The database is community-driven, meaning that researchers can contribute their own data to the database and access data contributed by others. NeotomaDB also provides a software development kit (SDK) and web API, which allow users to access and work with the data programmatically, making it easier for researchers to analyze and explore the data. The goal of NeotomaDB is to make it easier for researchers to access and analyze paleoecological data, ultimately improving our understanding of past ecosystems and informing conservation and management efforts.

The Forest Inventory and Analysis (FIA) (https://www.fia.fs.usda.gov) program is run by the US Forest Service and collects data on the status and trends of forests in the United States. The FIA program provides a wealth of data on forest composition, structure, and health, as well as information on forest disturbances such as wildfires, insect outbreaks, and disease.

Global Forest Watch (GFW) (https://www.globalforestwatch.org/) is an online platform that provides access to satellite imagery and other data on global forests. GFW provides a range of tools for analyzing forest change, including monitoring of deforestation, forest fires, and other disturbances.

International Tree-Ring Data Bank (ITRDB) (https://www.ncei.noaa.gov/products/paleoclimatology/tree-ring) is a global database of tree-ring data that provides information on past climate and forest growth.

Tree-ring data can be used to reconstruct historical forest disturbances, such as wildfires and insect outbreaks.

Forest Ecology Network (FEN) (http://www.forestecologynetwork.org/) is a network of researchers and practitioners that provides access to long-term ecological data on forest ecosystems. FEN provides data on forest composition, structure, and function, as well as information on forest disturbances and management practices.

6 Post-fire Forest Restoration

6.1 Overview

The interval between 2021 and 2031 has been declared as the "Decade of Ecosystem Restoration" by the United Nations (Souza-Alonso, et al, 2022). Today's state of economy heavily relies on the exploitation of natural resources, which has been conducted on improper and exhaustive measurements for decades now; resulting in boundless land degradation. This amplifies the complexity for establishing global environmental sustainability (Fu and Li 2016). Deep sea ecosystems, although being one of the most diverse ecosystems (Thurber et al, 2014), still face extreme threats to their wellbeing. Many of these threats were introduced as an aftermath to climate change, but for the most part humans are to blame; since their actions have been catastrophic to these ancient ecosystems (Wenting et al, 2022). Diversity is a powerful tool that will both prevent and tackle climate change, while effectively increasing resilience. Thriving ecosystems promote better quality of life and wealth to local communities. Additionally, nature-based solutions and restoration is a top priority of the European Green Deal (European Commission Guide to cost-benefit analysis of major projects: in the context of EC regional policy, 2017). Even though ecosystem restoration has been a practice for a little bit over forty years and has been characterized by many as the go-to scientific field for the preservation of human kind, its boundaries remain still relatively inadequate as the impact of large projects is still questionable (Aronson and Alexander, 2013). Reversing these trends requires heavy planning with proper carefulness; not to disturb the interactions between all the different variables of each ecosystem. Notable efforts have been made, i.e., restoration programs in South China's karst (rocky terrains, rich in caves and underground tunnels) landscapes (Sijing et al, 2022) Natural Capital project (https://naturalcapitalproject.stanford.edu), INCASE project in Ireland (https://www.incaseproject.com/), etc. Although policy making has been growing stronger every year, insufficient funding does not bridge the gap between concepts and practice; accumulating data on costs and benefits of restoration might be what is missing (Bodin, et al, 2022).

Pre- and ongoing wildfire impact assessment is a crucial process for effective wildfire management. It involves evaluating the potential impact of a wildfire on an ecosystem and its components, including vegetation, wildlife, soil, water, and air, as well as monitoring the effects of the fire as it progresses and after it has been contained. The process includes several steps, such as identifying the area of interest, conducting a risk assessment, performing an impact assessment, developing mitigation measures, ongoing impact monitoring, and adapting management strategies. The risk assessment involves identifying hazards, elements at risk, and evaluating the likelihood and potential consequences of a wildfire. The impact assessment includes identifying ecosystem components and their susceptibility to fire, evaluating potential effects on vegetation, wildlife, soil, water, and air quality, synthesizing the results, and developing mitigation measures. The impact assessment should be reviewed and updated regularly based on new data or information.

William et al (2021) discuss how ecological restoration, which is a tool for climate change mitigation and adaptation, is also vulnerable to the impacts of climate change. The authors present a framework that identifies seven areas of restoration design and implementation where climate change should be considered, including setting objectives, selecting sites, managing ecosystems and micro-climates, identifying site-level risks, aligning with long-term policies, and designing a monitoring framework. A scan of restoration projects in Brazil and ASEAN countries showed that few projects addressed these considerations. The authors then highlight two projects that incorporated good practices for climate-resilient restoration, including planning for climate change in connectivity and species selection, and using careful monitoring and species provenance to ensure restoration success in the long term. The article concludes by calling for more climate-resilient restoration to support global restoration targets and the UN Decade on Ecosystem Restoration.

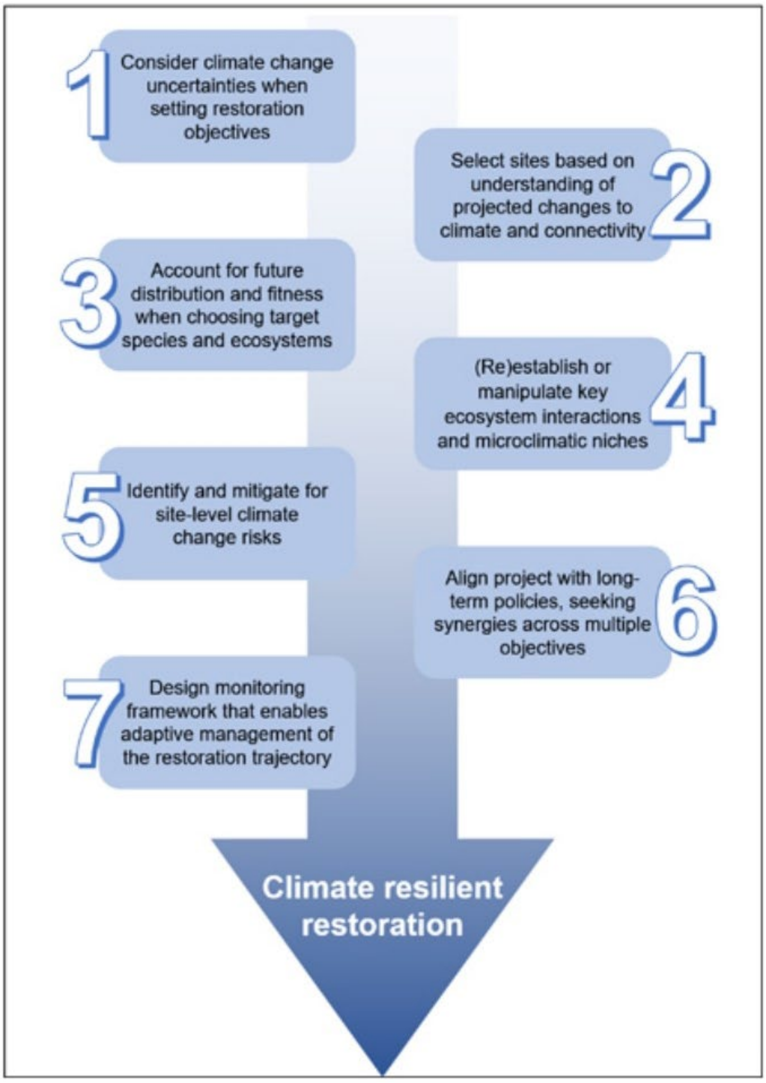

Figure 24: Seven areas that practitioners should consider when designing and implementing an ecological restoration project in order to build its climate change resilience

Following, the chapter presents how wildfires can impact ecosystem biodiversity and function. Wildfires can have both short-term and long-term consequences for an area, with the extent and severity of the impacts varying depending on factors such as the intensity and duration of the fire, the sensitivity of the ecosystem components, and the resilience of the ecosystem. The impacts of wildfires on ecosystem biodiversity can include changes in vegetation, wildlife populations, soil quality, biodiversity, and ecosystem function. Understanding these impacts is essential for developing effective strategies for mitigating the impacts of fires and promoting ecosystem recovery. Biodiversity loss caused by a wildfire can lead to the loss of habitat and food sources for wildlife, while alterations in nutrient cycling processes and the water cycle can have long-lasting effects on ecosystem productivity and resilience.

Then the chapter discusses post-fire damage quantification and secondary damages resulting from wildfires. The first step in post-fire damage quantification is to identify the damages caused by the wildfire, which may include loss of vegetation, damage to infrastructure, and impacts on wildlife and aquatic ecosystems. Earth observation (EO) technologies, such as satellite imagery and LiDAR data, can provide valuable insights into the extent and severity of damages caused by the wildfire. In addition to primary damages, wildfires can cause secondary damages such as erosion, landslides, and flooding, which can have long-lasting impacts on the ecosystem and surrounding communities. The evaluation of secondary damages is an important component of post-fire damage quantification and involves identifying potential hazards, assessing the potential for secondary damages to occur, and monitoring post-fire conditions.

Long-term forest resources performance is critical for the sustainability of forest ecosystems and the provision of goods and services such as timber, water, recreation, and biodiversity. To ensure long-term performance, forest managers must adopt sustainable forest management practices, promote watershed management, manage invasive species, restore habitats, and manage recreation. Sustainable forest management practices aim to balance the ecological, economic, and social aspects of forest management to enhance long-term forest resources performance, while watershed management can enhance water conservation, improve water quality, and reduce the risk of erosion and landslides. Invasive species can have negative impacts on forest resources performance, and effective management strategies can help promote the recovery of native vegetation and enhance biodiversity. Habitat restoration can promote the recovery of ecosystem function, support biodiversity, and enhance forest resources performance, and effective recreation management strategies can enhance the visitor experience while promoting sustainable use and reducing visitor impacts. By adopting these strategies, forest managers can enhance the recovery and sustainability of forest ecosystems and the provision of goods and services for current and future generations.

6.2 Pre- and Ongoing Fire Impact Assessment

Pre- and ongoing wildfire impact assessment is an essential part of effective and productive wildfire management. This assessment is a systematic process of evaluating the potential impact of a wildfire on an ecosystem and its components, including vegetation, wildlife, soil, water, and air. It also involves monitoring the effects of the wildfire as it progresses and after it has been contained or extinguished. The following list are part of the steps involved in pre- and ongoing fire impact assessment:

- **Identification the area of interest (AOI):** The first step is to identify the area that could be affected by the fire. This part involves mapping the extent of the fire, vegetation types and any sensitive areas such as watercourses or areas of high biodiversity.
- **Risk assessment**: A risk assessment should be carried out to assess the likelihood of a fire occurring in the designated area and the potential consequences of a fire. This assessment should take into account factors such as weather conditions, fuel types, topography and human activities.
- **Impact assessment**: An impact assessment can be conducted to evaluate the potential effects of the wildfire on the ecosystem and its components. The assessment step needs to consider factors such as the intensity and duration of the wildfire, the sensitivity of the ecosystem components, and the resilience of the ecosystem to the effects of the fire.
- **Mitigation measures development**: Based on the results of the impact assessment step, mitigation measures can be developed to minimise the effects of the wildfire. These measures include measures such as fuel management, firebreaks or targeted vegetation removal to reduce fire intensity.
- **Impact monitoring**: During and after the fire, ongoing monitoring should be conducted to evaluate the actual impact of the fire on the ecosystem and its components. This monitoring may involve collecting data on soil, water, vegetation, and wildlife, as well as measuring air quality and other environmental parameters.
- **Management strategies**: Based on the results of ongoing monitoring, management strategies may need to be adapted to mitigate the impact of the wildfire and promote ecosystem recovery. This

may include measures such as replanting vegetation, restoring wildlife habitat, or promoting the regeneration of soil.

6.2.1 *Risk assessment*

Conducting a risk assessment is an essential step in pre- and ongoing fire impact assessment, as it helps to evaluate the likelihood of a wildfire occurring in a specific area and the potential consequences of the fire. The following are some of the key steps involved in conducting a risk assessment:

- **Hazard Identification**: The first step in conducting a risk assessment is to identify the hazards that could contribute to the occurrence of a wildfire. These hazards may include factors such as high temperatures, low humidity, strong winds, and dry vegetation.
- **Elements at risk**: The next step is to identify the items that are at risk from a potential wildfire. This can include structures (e.g. homes, businesses), infrastructure, natural resources and the environment.
- **Wildfire occurrence likelihood**: Once the hazards and elements at risk have been identified, the likelihood of a wildfire occurring can be determined. This may involve analysing data such as historical fire patterns, weather forecasts, and fuel moisture levels to estimate the probability of a wildfire occurring.
- **Exposure**: If a wildfire were to occur, the next step is to determine the potential consequences, i.e. exposure of the wildfire. This may involve assessing the potential impact on human life, property, and the environment, as well as the potential economic, social, and cultural impacts.
- **Evaluate the risk**: Based on the likelihood of a wildfire occurring and the potential exposure of the fire, the risk can be evaluated. This may involve categorizing the risk as low, medium, or high and identifying the areas of greatest concern.
- **Mitigation measures development**: Once the risk has been evaluated, mitigation measures can be developed to minimize the impact of a potential wildfire. These measures may include measures such as fuel management, creating firebreaks, or targeted vegetation removal to reduce the intensity of the fire.
- **Review and update the risk assessment**: The risk assessment should be reviewed and updated on a regular basis to ensure that it remains relevant and up-to-date. This may involve revising the risk categorization, modifying the mitigation measures, or incorporating new data or information.

6.2.2 *Impact assessment*

Conducting an impact assessment is a critical component of pre- and ongoing fire impact assessment, as it helps to evaluate the potential effects of a wildfire (Pausas, and Keeley, 2021; Abrahamson, 2021) on an ecosystem and its components, including vegetation, wildlife, soil, water, and air. The following are some of the key steps involved in conducting an impact assessment:

a) **Identify the ecosystem components**: The first step in conducting an impact assessment is to identify the components of the ecosystem that could be affected by a wildfire. This may include vegetation, wildlife, soil, water, and air quality.
b) **Determine the susceptibility of the components**: Once the components have been identified, the next step is to determine the susceptibility of each component to the effects of a wildfire. This may involve evaluating factors such as the component's resilience, resistance, and sensitivity to fire.

c) **Evaluate the potential effects**: Based on the susceptibility of the ecosystem components, the potential effects of a wildfire can be evaluated. This may involve assessing the impact on vegetation, such as the loss of habitat and changes in plant species composition, as well as the impact on wildlife, such as the direct mortality of animals and the loss of habitat.

d) **Assess the impact on soil**: Wildfires can also have significant impacts on soil properties, including soil organic matter content, nutrient availability, and water-holding capacity. Assessing the impact of a wildfire on soil is critical, as it can have long-term effects on the ecosystem's productivity and ability to support plant and animal life.

e) **Assess the impact on water and air quality**: Wildfires can also affect the quality of water and air in the surrounding area. For example, wildfires can increase sedimentation in waterways, reduce water quality, and affect aquatic life. Additionally, wildfires can release pollutants into the air, such as particulate matter and greenhouse gases, which can have negative impacts on human health and the environment.

f) **Synthesize the results**: Once the impact assessment has been completed, the results should be synthesized to develop an overall understanding of the potential effects of a wildfire on the ecosystem and its components.

g) **Develop mitigation measures**: Based on the results of the impact assessment, mitigation measures can be developed to minimize the impact of a wildfire. These measures may include measures such as fuel management, creating firebreaks, or targeted vegetation removal to reduce the intensity of the fire.

h) **Review and update the impact assessment**: The impact assessment should be reviewed and updated on a regular basis to ensure that it remains relevant and up-to-date. This may involve revising the assessment based on new data or information or modifying the mitigation measures based on the potential impact of a wildfire.

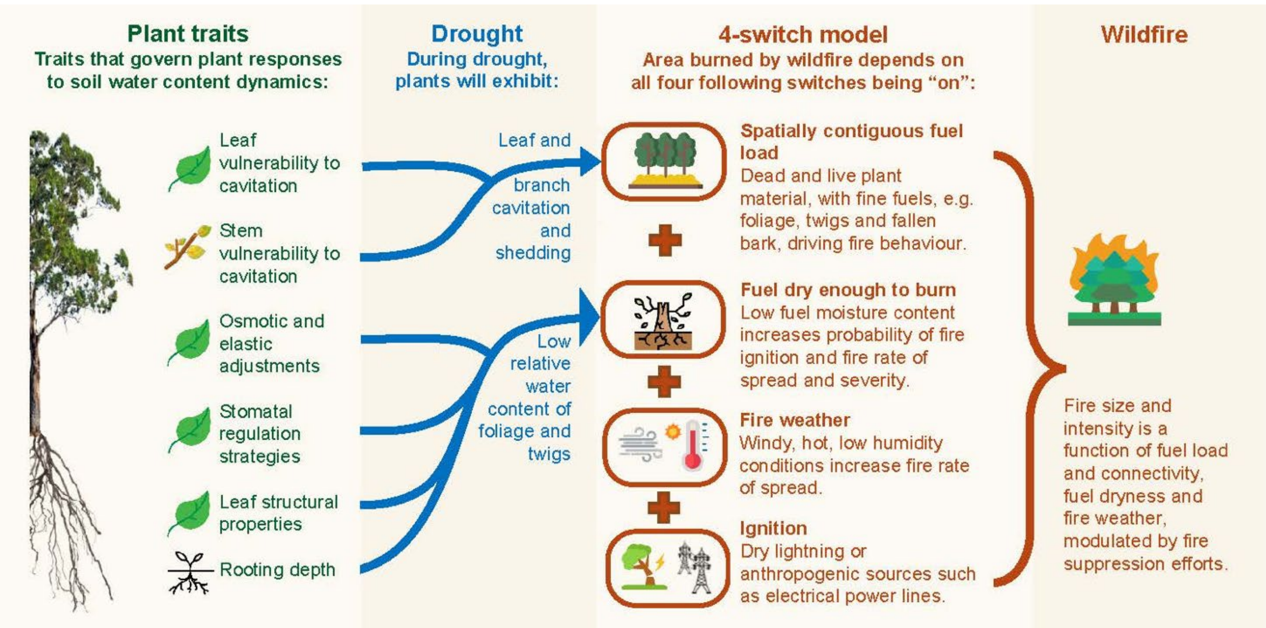

Figure 25: Linking forest flammability and plant vulnerability to drought

6.3 Impact of Wildfires – Ecosystem biodiversity

Globalism has made possible the acquisition of various exotic plants, trees and bushes that were previously unknown to each local community. Unfortunately, there is a strong correlation between extensive planting of non-native grasses and frequency and intensity of wildfires (Balch, et al, 2013; Úbeda, 2016). Wildfires size heavily relies on the topography, soil type and fire history (Pereira, et al, 2018), they tend to have both short- and long-term consequences for the area (Pereira, et al, 2021).

Wildfires can have significant impacts on ecosystem biodiversity, including changes in vegetation, wildlife populations, and soil quality. The severity and extent of these impacts can vary depending on a range of factors, including the intensity and duration of the fire, the sensitivity of the ecosystem components, and the resilience of the ecosystem to the effects of the fire. The following are some of the key ways that wildfires can impact ecosystem biodiversity:

a) **Vegetation**: Wildfires can have a significant impact on vegetation, including the loss of plant cover and changes in plant species composition. Depending on the intensity of the fire, the destruction of vegetation can be extensive, which can have cascading effects on other ecosystem components such as wildlife populations and soil quality.
b) **Wildlife**: Wildfires can also have a significant impact on wildlife populations. Some animals may be killed directly by the fire, while others may lose their habitat or food sources as a result of the fire. Additionally, post-fire vegetation recovery can take years, which can further impact wildlife populations that depend on specific types of vegetation for food and shelter.
c) **Soil quality**: Wildfires can have a significant impact on soil quality, including changes in soil organic matter content, nutrient availability, and water-holding capacity. These changes can have long-term effects on the ecosystem's productivity and ability to support plant and animal life.
d) **Biodiversity**: Wildfires can impact biodiversity at multiple levels, including changes in species composition, richness, and diversity. The extent and severity of these impacts can vary depending on the type of ecosystem and the specific characteristics of the fire.
e) **Ecosystem function**: Wildfires can also impact ecosystem function, including nutrient cycling, water availability, and carbon storage. These changes can have far-reaching effects on the overall health and resilience of the ecosystem.

Overall, wildfires can have significant and long-lasting impacts on ecosystem biodiversity. By understanding the potential impacts of wildfires on ecosystems, managers can develop effective strategies for mitigating the impacts of fires and promoting ecosystem recovery.

6.3.1 Biodiversity Impact

Biodiversity refers to the variety of living organisms and ecosystems on Earth. It encompasses the diversity of species, genetic diversity within species, and the diversity of ecosystems and habitats that support these organisms. Biodiversity is essential for the functioning of ecosystems and provides a range of ecosystem services that support human well-being, including the provision of food, fuel, and other resources, regulation of climate and water, and cultural and recreational values.

Wildfires can impact biodiversity in several ways. The loss of vegetation caused by a wildfire can lead to the loss of habitat and food sources for wildlife. Additionally, the destruction of vegetation can alter the composition and structure of ecosystems, leading to changes in species composition and diversity. The severity and extent of these impacts can vary depending on the type of ecosystem and the specific characteristics of the fire.

6.3.2 Ecosystem function Impact

Ecosystem function refers to the processes and interactions that occur within ecosystems, including nutrient cycling, energy flow, and the regulation of environmental conditions such as climate and water quality. Ecosystems provide a range of ecosystem services that support human well-being, including the provision of food, fuel, and other resources, regulation of climate and water, and cultural and recreational values.

Wildfires can impact ecosystem function in several ways. The destruction of vegetation caused by a wildfire can alter the nutrient cycling processes that occur within ecosystems, which can have long-lasting effects on the productivity and resilience of the ecosystem. Additionally, the loss of vegetation can impact the water cycle, leading to changes in water availability and quality. The severity and extent of these impacts can vary depending on the type of ecosystem and the specific characteristics of the fire.

6.4 Post-fire Damage Quantification and Secondary Damages

Post-fire damage quantification is an important component of post-fire assessment, as it helps to evaluate the extent and severity of the damages caused by a wildfire. The following are some of the key steps involved in post-fire damage quantification:

a) **Identification of damages**: The first step in post-fire damage quantification is to identify the damages caused by the wildfire. This may include the loss of vegetation, damage to infrastructure, and impacts on wildlife and aquatic ecosystems.
b) **Assessment of damages**: Once the damages have been identified, the next step is to assess their extent and severity. This may involve evaluating the area and intensity of vegetation loss, as well as the damage to infrastructure and other assets. Assessing the impacts on wildlife and aquatic ecosystems can also be critical, as these components of the ecosystem are often less visible but can be equally important for the overall health and resilience of the ecosystem.
c) **Evaluation of secondary damages**: Wildfires can also cause secondary damages, which can include erosion, landslides, and flooding. These secondary damages can have long-term impacts on the ecosystem and the surrounding communities. Evaluating the potential for secondary damages is therefore critical in post-fire damage quantification.

6.4.1 Identification and assessment of damages

Identification and assessment of damages after a wildfire can be a challenging and time-consuming process, especially in areas that are remote or difficult to access. Earth observation (EO) technologies can provide valuable insights into the extent and severity of damages caused by the wildfire.

EO technologies include remote sensing techniques such as satellite imagery, aerial photography, and LiDAR data. These techniques can be used to identify changes in vegetation cover and detect areas of high heat damage caused by the fire. EO data can also be used to map the location of infrastructure and other assets that may have been impacted by the wildfire, such as roads, power lines, and buildings.

In addition to providing valuable data for identifying damages, EO technologies can also be used to track changes in the ecosystem over time. For example, repeated satellite imagery can be used to monitor the recovery of vegetation in the years following the fire, providing insights into the effectiveness of restoration and recovery efforts.

EO data can be particularly valuable for post-fire damage quantification in areas that are difficult to access or that have limited ground-based data. By providing a bird's eye view of the wildfire impacts, EO technologies can help to identify damages and develop effective strategies for restoration and recovery.

However, it is important to note that EO data is not a substitute for on-the-ground assessments. Ground-based data is often required to validate the results of EO analysis and provide detailed information on the impacts of the wildfire. A combination of ground-based and EO data can provide a more comprehensive understanding of the extent and severity of damages caused by the wildfire, and can help to inform effective restoration and recovery strategies.

6.4.2 *Evaluation of secondary damages*

In addition to the primary damages caused by a wildfire, such as vegetation loss and damage to infrastructure, wildfires can also lead to secondary damages that can have long-lasting impacts on the ecosystem and surrounding communities. These secondary damages can include erosion, landslides, and flooding, and can be particularly severe in areas where the vegetation has been severely impacted by the fire.

The evaluation of secondary damages is an important component of post-fire damage quantification and is critical in developing effective restoration and recovery strategies. The following are some of the key steps involved in the evaluation of secondary damages:

a) Identification of potential hazards: The first step in evaluating secondary damages is to identify the potential hazards that may be present in the area affected by the wildfire. This may include areas of high slope, unstable soils, or areas that are prone to flooding.
b) Assessment of the potential for secondary damages: Once the potential hazards have been identified, the next step is to assess the potential for secondary damages to occur. This may involve evaluating the soil stability and the potential for erosion, as well as assessing the risk of flooding or other water-related hazards.
c) Monitoring of post-fire conditions: After the wildfire, it is important to monitor the post-fire conditions to identify any changes that may be occurring in the ecosystem. This may include monitoring changes in soil moisture levels, vegetation regrowth, and erosion potential.

Soil erosion: Wildfires can remove vegetation cover and organic matter from the soil, making it more susceptible to erosion. In areas with steep slopes or areas that are prone to heavy rainfall, this can lead to soil erosion and landslides.

The follow-up hazards that can occur after a forest wildfire are (WHO, 2019; US Forest Service, 2023):

- **Flooding**: Wildfires can increase the risk of flooding by reducing the ability of the soil to absorb water and increasing the likelihood of heavy runoff. This can result in flash floods, which can be particularly dangerous in areas with steep slopes or narrow canyons.
- **Debris flows**: Wildfires can increase the risk of debris flows, which are fast-moving mixtures of water, rock, and other debris. Debris flows can occur in areas with steep slopes or in canyons and can be particularly dangerous in areas downstream from the burn area.
- **Water quality impacts**: Wildfires can impact water quality by increasing the levels of sediment and other pollutants in streams and rivers. This can have impacts on aquatic ecosystems and can also affect the availability of clean water for human consumption.
- **Hazardous materials**: Wildfires can release hazardous materials such as chemicals and heavy metals that may be present in burned infrastructure, such as homes and other buildings.
- **Soil nutrient loss**: Wildfires can remove nutrients from the soil, making it more difficult for vegetation to regrow. This can result in reduced soil fertility and can make it more difficult for the ecosystem to recover after a fire.
- **Habitat fragmentation**: Wildfires can create patches of vegetation that are isolated from each other, leading to habitat fragmentation. This can impact the movement and distribution of wildlife and can make it more difficult for the ecosystem to recover.

6.5 Long-term Forest Resources Performance

Long-term forest resources performance is critical for ensuring the sustainability of forest ecosystems and the provision of goods and services such as timber, water, recreation, and biodiversity. Effective long-term restoration strategies must consider the diverse forest functions and the complex interactions between management practices and ecosystem performance. The following are some of the key methods used for promoting long-term forest resources performance:

a) **Sustainable forest management** practices aim to balance the ecological, economic, and social aspects of forest management to enhance long-term forest resources performance. Sustainable forest management may involve measures such as promoting the growth of diverse tree species, protecting critical wildlife habitat, managing forest fires, and harvesting timber in a sustainable and responsible manner.
b) **Watershed management** is a critical component of long-term forest resources performance as it can enhance water conservation, improve water quality, and reduce the risk of erosion and landslides. Effective watershed management strategies should consider the interactions between forest management practices and water quality, such as the effects of logging on water quality.
c) **Invasive species** can have negative impacts on forest resources performance by competing with native vegetation and disrupting ecosystem function. Effective management strategies for invasive species can help to promote the recovery of native vegetation, enhance biodiversity, and support timber production and water conservation.
d) **Habitat restoration** can promote the recovery of ecosystem function, support biodiversity, and enhance forest resources performance. Restoration efforts may involve creating habitats for threatened or endangered species, restoring natural hydrological processes, and promoting the recovery of wetlands and riparian ecosystems.
e) **Recreation** is an important forest function that provides social and economic benefits to local communities. Effective recreation management strategies can enhance long-term forest resources performance by promoting sustainable use, reducing visitor impacts, and enhancing the visitor experience.

Overall, effective long-term restoration and management strategies for forest resources performance must consider the diverse functions that forests provide and the complex interactions between management practices and ecosystem performance. By adopting sustainable forest management practices, promoting watershed management, managing invasive species, restoring habitats, and managing recreation, managers can enhance the recovery and sustainability of forest ecosystems and the provision of goods and services for current and future generations.

6.6 Post-fire Short-term and Long-term Restoration

Post-fire restoration is a critical process for promoting the recovery of ecosystems and communities after a wildfire. Effective restoration efforts must take into account both short-term and long-term restoration needs to support the long-term recovery of the ecosystem. The following are some of the key considerations for post-fire short-term and long-term restoration:

a) **Short-term restoration**: Short-term restoration efforts typically focus on addressing immediate needs in the aftermath of a wildfire. These efforts may include emergency stabilization of the burnt area to prevent erosion and landslides, as well as measures to protect critical infrastructure and water resources.
b) **Long-term restoration**: It refers to the efforts focus on promoting ecosystem recovery over a period of several years. This includes measures such as revegetation, invasive species management, and habitat restoration to promote the recovery of native vegetation and wildlife. Long-term restoration efforts may also include measures to support the restoration of ecosystem services such as water conservation and carbon sequestration.
c) **Community involvement**: Engaging local communities in post-fire restoration efforts is a critical component of both short-term and long-term restoration. Residents can provide valuable input on restoration priorities and can be important partners in monitoring and evaluation efforts. Community involvement can also help to build support for restoration efforts and promote the long-term sustainability of the ecosystem.
d) **Monitoring and evaluation**: Monitoring and evaluation efforts are essential for assessing the effectiveness of post-fire restoration strategies and identifying areas where additional intervention may be needed. Monitoring efforts may include tracking changes in vegetation cover, soil stability, and water quality, as well as assessing the recovery of wildlife populations and ecosystem services.
e) **Adaptive management**: Effective post-fire restoration requires a flexible and adaptive approach that can respond to changing ecological, social, and economic conditions over time. Adaptive management involves monitoring and evaluating restoration efforts and making adjustments as needed to promote the long-term recovery of the ecosystem.

Overall, post-fire restoration requires a comprehensive and integrated approach that takes into account both short-term and long-term restoration needs. By engaging local communities, monitoring and evaluating restoration efforts, and adopting an adaptive management approach, managers can promote ecosystem resilience and support the long-term recovery of the ecosystem and surrounding communities.

6.6.1 Short-term restoration

Short-term restoration efforts are typically focused on addressing immediate needs in the aftermath of a wildfire. These efforts are aimed at stabilizing the burned area and preventing further damage to the ecosystem and surrounding communities.

A first step to the short-term restoration is the **emergency stabilization**. The immediate aftermath of a wildfire can be a period of increased risk for soil erosion, landslides, and other hazards. Short-term restoration efforts may involve emergency stabilization measures to prevent further damage to the ecosystem and surrounding infrastructure. This may include the installation of erosion control structures, such as check dams and silt fences, as well as the use of re-vegetation and other erosion control techniques.

Continuing the short-term restoration efforts, is the **hazard assessment** step. Short-term restoration efforts involve conducting hazard assessments to identify potential risks to the ecosystem and surrounding communities. This involves assessing the risk of landslides, debris flows, and other hazards, as well as identifying potential risks to water quality and other ecosystem services.

Short-term restoration efforts include measures to protect critical infrastructure, such as homes, roads, and water treatment facilities. This may include the installation of barriers to prevent erosion or the use of fire-retardant materials to protect structures from future wildfires. In addition, the protection of water resources is part of the process. This involves the installation of sediment control structures to prevent erosion and the implementation of water quality monitoring programs to assess the impact of the wildfire on water resources.

Finally short-term restoration efforts involve measures to ensure public safety in the aftermath of a wildfire. This may include the closure of trails or other public areas in the burn area, as well as the installation of warning signs and other safety measures to alert the public to potential hazards.

Overall, short-term restoration efforts are aimed at stabilizing the burned area and preventing further damage to the ecosystem and surrounding communities. By addressing immediate needs and identifying potential risks, short-term restoration efforts can help to lay the foundation for long-term restoration and recovery of the ecosystem.

During rainstorms, the decrease in aboveground biomass due to fires allows detaches of mineral material that later are available for transportation and increase water runoff (Lu et al. 2016). Moreover, the reduction of soil cover biomass increases water runoff and water erosivity (Tongway et al. 2013). In hillslopes with complete absence of vegetation cover after the fire, the runoff rate and soil erosion are much greater than those in hillslopes with vegetation patches that saved from fire. The measurements provide evidence that the largest loss of soil happens during the first raining season after the wildfire (Hubbert et al. 2012).

Other type of soil loss from hillslope mostly due to the absence of vegetation are a) the gravitational movement of soil particles downhill due to gravity, without water force (Gabet et al. 2003) and b) the wind erosion due to the increased of wind velocity when vegetation cover is absent (Germino et al. 2015).

Based on the above, the reduced of plant biomass by grazing slow down the ecosystem recovery after wildfires because of the high increased of soil erosion rates due to water and/or wind action. To prevent land degradation livestock grazing on burnt areas should be restricted after the fire (Stavi et al. 2016).

6.6.2 Long-term restoration

Long-term restoration efforts are focused on promoting the recovery of the ecosystem over a period of several years or more after a wildfire. These efforts are aimed at restoring the natural ecological processes and functions of the ecosystem, as well as supporting the recovery of the surrounding communities.

Reforestation is a common strategy for promoting the recovery of the ecosystem after a wildfire. This involves planting new trees and vegetation to replace those that were lost in the fire. Reforestation can help to restore ecosystem functions, including carbon sequestration, water conservation, and habitat restoration. Invasive plant species can colonize the burnt area after a wildfire, competing with native vegetation and disrupting ecosystem function. Long-term restoration efforts may involve the removal or control of invasive species to promote the recovery of native vegetation.

Habitat restoration involves the restoration of natural habitat for wildlife in the burned area. Within this process the creation of habitat for threatened or endangered species is included. Also, the restoration of natural hydrological processes to support the recovery of wetland and riparian ecosystems. Wildfires can have significant impacts on watersheds, disrupting water quality and reducing the capacity of the ecosystem to provide water-related ecosystem services. Long-term restoration efforts may involve measures to restore watersheds, such as the restoration of stream channels and the implementation of erosion control measures.

Long-term restoration efforts include the adoption of sustainable forest management practices to promote the long-term health and productivity of the ecosystem. This encompasses measures to promote the growth of diverse tree species, as well as the protection of critical wildlife habitat.

Engaging local communities in restoration efforts is an important component of long-term restoration. Local residents can provide valuable input on restoration priorities, as well as play a key role in monitoring and evaluating restoration efforts. Community involvement can also help to build support for restoration efforts and promote the long-term sustainability of the ecosystem.

6.7 Preliminary results from the stakeholders' survey

Through the questionnaire-based survey that has been designed (as presented in Section 1.2.2), a set of 10 responses from experts in 9 different countries were initially collected. These responses were from:

1. Croatia: Šapjane, Primorsko-goranska Region
2. Greece
3. Cyprus
4. France: La Jonchère St Maurice
5. Indonesia, Sebangau National Park
6. Italy - Sardinia region: PNRT–Tepilora Natural Regional Park
7. Italy – Gargano park
8. Portugal: Cova da Beira – Quinta da França (QF) farm
9. Romania: Romania – Rodnei Mountains National Park
10. Slovakia, Podpolanie

The responses were preliminarily analyzed from the perspective of forest restoration (Parts 2 and 3 of the Questionnaire, i.e. decision procedures and actual practices applied for the restoration) and a synthesis of the results is presented in following. Although interesting results have been reached even at this initial stage, additional responses will be collected, and a further comparative analysis will be conducted in the next phases of the project, so that evidence regarding policy recommendations is further strengthened.

Synthesis of results from Parts 2 and 3 of the Forest Management questionnaire (Section 1.2.2) circulated among experts:

2. DECISION PROCEDURES FOR FOREST RESTORATION

2.1 Is there any official methodology on the basis of which the decision of the restoration (holistic or partial) is taken?

70% YES, 30% No

If Yes:

2.1.1 What is this *official methodology*? Please describe the methodology and provide the relevant literature references if available.

In most of the cases, the forest regenerates by itself without human intervention. In few cases, human intervention for the restoration is the first choice.

In these cases, or when natural regeneration fails, the decision is taken through the general forest management planning process or forest owner.

In one case, there is a minimum of diagnosis to determine, e.g., what has been burned, with what intensity in order to subsequently select the techniques for restoration. This land analysis is supplemented by damage analysis to determine the owners affected by the disaster.

If No:

2.1.2 Please describe the *empirical process* that guides the decision about the objectives of the restoration and their prioritization.

In general, the decision to restore the burned area does not follow a specific methodology and the decision is taken from the entity in charge or the owner, based on various environmental and/or social criteria that are not clearly established in some regulation.

2.2 Which Entity/ies (actor) is in charge of taking the decision for the objectives of the restoration?

The decision is usually taken by the forest administration or local authorities. Also, the forest manager could decide who could be the owner (i.e., individual or company) of the forest but strictly based on forest management plan.

2.3 Is there a participatory process that is followed between various administration services and local stakeholders to guide the decision for these objectives?

In most of the cases, there is no participatory process for the decision of performing the restoration or not. However, in some cases of burned parks and protected areas, such a process has been followed.

If Yes:

2.3.1 Please describe the participatory process.

The parties responsible for the area themselves are consulted in accordance with national regulations and regional agreements. In one of the participating countries, local stakeholders and municipal authorities may occasionally be involved, as well as private citizens, NGOs and informal groups.

2.4 Is there a strategy that is followed to engage with the local stakeholders that will be involved in any part of the restoration (from planification to execution)?

In more than half of the cases, there is no strategy to engage local stakeholders in the restoration process. However, in some of the cases, there is this type of strategy.

If Yes:

2.4.1 Please describe this strategy.

Even if there are some plans, there is no integrated plan for the engagement of stakeholders. In public forests, in one case, some local (forestry level), regional (subsidiary), and national (Directorate of the company for forests) interact, but not private entities.

2.4.2 How are the interests of the (local) stakeholders considered?

In general, the decisions consider first the general scope and then the local necessities.

2.5 What are the main factors that trigger the restoration process?

In cases of no legal obligation for restoration, the usual factors that affect the decision for the restoration are the size of the burned area, the possibility of spontaneous reconstitution, the type of vegetation, the soil status, the type of damage, the adaptive characteristics of the tree species that make up the stands, land preservation, landscape conservation, local economic interests, chemical analysis of soil, air or water implemented in the burned area.

2.6 Is chemical analysis of soil, air or water implemented in the burned area?

In general, for the restoration process, no chemical analysis is applied. In some cases, water chemical analysis is applied. Otherwise, chemical analysis of forest soils is implemented, but in the general framework of forest soil studies.

2.7 What are the most common objectives of the restoration process?

The usual objectives of forest restoration are: Forest restoration according to Forest Management Plan; Soil protection, native vegetation restoration and enhancing ecosystem's fire resilience; Protection of particular environmental values and ecosystems; Landscape conservation; Local economic interests; Restoration of biodiversity and hydrological conditions; Restoring the forest land by afforestation with forest species adapted to the climatic conditions of the affected areas (respecting the fundamental natural type of forest).

2.8 Which Entity/ies is responsible for implementing the restoration?

The Entities responsible for implementing the restoration differs across the countries. Usually, the responsibility belongs to Local Forest Authorities; Ministry of Environment and Forestry; Qualified Forest Managers; Land owner; Forests' associations; and Municipalities or Regions.

2.9 Please describe Is there any follow-up or recurrent action if the restoration process fails?

In most of the cases, completion (replanting) and maintenance works are carried out until the forest stage is reached. In cases of failure, the reforestation effort is repeated. But, in some cases, there is no follow up for reestablishment of the forest.

3. FOREST RESTORATION PROCESS

3.1 What are the most common actions for the restoration of burned areas (e.g., artificial regeneration, natural regeneration, works for reduction of soil erosion and flood risk, etc.)?

In almost all countries that replied to the questionnaire, the burned area is left to recover by natural regeneration. Very rarely, the artificial regeneration is the first option. Artificial regeneration is applied where the natural regeneration either fails or, in specific cases, where the prediction for the successful natural regeneration is poor.

To assist natural regeneration, some actions are taken after the fire, most usual of which is the removal of the dead trees. If extraction of trees is not possible, only the demolition (cutting) of the remaining damaged trees is done.

Also, in some cases, works are applied for emergency stabilization of slopes and protection of underlying infrastructures of landslides, especially due to the possible rolling or detachment of stones, very frequently caused after the passage of fire. Actions, in some cases, are also applied for the reduction of flood risks, by construction barriers across the most dangerous torrents or on the hilly slopes, typically using barriers with cut logs.
After the start of the regeneration, some precaution actions are applied, such as protection against game and nomadic flocks of grazing animals, and cultivation treatments may be applied to the new stand as coppicing and thinning.

3.2 What is the usual sequence (order) of actions and the time extent of each one (e.g., dead tree removal, flood protection works, artificial or natural regeneration)?

There is no common method or sequence of actions applied for the burned areas' recovery throughout the surveyed countries. The most comprehensive approach includes an inventory of the burned area and an estimation of the damage and, subsequently, the preparation of a study about the afforestation plan.
In general, the order of actions for the recovery of the forest could be arranged as follows: Firstly, an estimation of the damage is made, followed (not always) by the removal of dead trees and, usually, the construction of protective works from landslides, floods, and soil erosion. The first option, in most of the cases, is to wait for natural regeneration to take place. Only in few cases artificial regeneration is the first option. In case of failure of natural regeneration, artificial regeneration could be applied. Some actions are taken to protect the regeneration from risks, such as game on domestic animals.

3.3 Are precaution works or other activities to control soil erosion usually implemented?

Yes, in some countries, when it is necessary.

3.4 Is there any provision during the restoration process on increasing long-term forest resilience? What are the typical measures taken in this direction?

Usually, the afforestation is made by the same species as the ones that covered the area before the fire. Few cases refer that species more resistant to fire could be used for replanting if artificial planting is applied. Also, some silvicultural treatments, capable to increase forest resilience to fire, are incorporated in forest management practices in one case.
In some cases, stricter legal regulations are also applied, in addition to the punishment of arson, to minimize the motivation to burn the forest. Such regulations involve the prohibition of constructing buildings for some years or generally the intervention in the burned area.

3.5 In what time depth are the restoration actions applied (i.e., how many years)?

The minimum time is 2 years for the regeneration, but this time may expand to 10 or 15 years, depending on the country and case, and may even extend to 25 years.

3.6 Do the forest restoration processes involve any (strategic) planning that is related to a future resilient forest model? Please describe, for example, whether the goals is simply to return to a pre-fire ecological status or to an improved one that can mitigate damage/impacts of a potential future event.

In general, yes. However, in practice, there are no measures applied for increasing gores resilience to fire.

7 Forest Governance

7.1 Innovative governance models

Governance plays a key role in wildfire prevention by supporting a common vision and awareness of the risks amongst the entities involved and defining who is responsible for wildfire protection (European Commission 2021). Wildfire prevention includes policymaking for forging sustainable and resilient forest management services, forest management, and education of citizens (Rego et al. 2018). Governance is defining who as well is responsible for landscape planning and forest management. Both responsibilities often lie within different organisations or in different parts of the same organisation. *"It is thus important to ensure that wildfire prevention is also part of the priorities of those working on the planning and management of the landscape"* (European Commission 2021). There are innovative initiatives that make a difference, mitigating wildfire risk and providing protection to communities by locally engaging with stakeholders. However, ensuring that the practice of fire management and its associated governance are utilizing innovations as well as science-based findings, is one major challenge. The integration of science into operations can be facilitated by adequate and transparent governance mechanisms which in turn can increase citizens' participation and politicians' accountability, occasionally integrating traditional and local knowledge.

Cases from around the Mediterranean, highlighting how working locally is critical for efficiency, sustainability and success, are presented below:

- ***The ZIF (Forest Intervention Zones) approach in Portugal***

  Forest Intervention Zones are a tool for managing forests at larger spatial scales, responding to the challenging situation of fragmented forest ownership, in Portugal. The approach, defined by law in 2005 and integrated in the Portuguese legal and institutional framework for forest management and forest fire protection, brings together small-scale forest owners to identify and implement a joint forest management and protection system. ZIF may include both private, common, and public lands and aims to overcome intervention constraints caused by land structure and size, help integrate local and central management efforts, increase sustainable management of forests, and protect them against fires through structural measures (Valente et al. 2013, Benali et al. 2021). Mainly in central and southern parts of Portugal, Forest Intervention Zones represent hundreds of thousands of hectares, potentially increasing profitability of managed areas and responding to the need for mitigating wildfire risk.

- ***Fire resilient communities in Lebanon***

  The Association for Forests, Development and Conservation (AFDC), a Lebanese non-profit and non-governmental organization, has identified villages with high forest fire risk (Mitri et al. 2015) and collaborates with two Unions of Municipalities, Qaraoun Lake and Al Sahel, helping vulnerable communities to build resilience against wildfires. The project objective is to develop a local fire management plan compatible with the national strategy, provide local communities with the knowledge and resources to implement the plan and increase durability of the project results (Chedid et al. 2018), through the local and participatory approach. The organization works all over the country, involves many volunteers and runs programs that promote among others environmental education, forest fire management, rural development, emergency response and relief work, eco-tourism, rehabilitation of degraded natural landscapes, reforestation and sustainable use of primary natural resources.

- ***The RAPCA (Red de Áreas Pasto-Cortafuegos de Andalucía) programme in Andalusia, Spain***

Directed by the General Directorate of Management of the Natural Environment and executed through the Environment and Water Agency, as a continuation of the collaboration and scientific advice of the Group of Pastures and Mediterranean Silvopastoral Systems of the Superior Council of Scientific Research (CSIC), RAPCA programme is a payment scheme that rewards shepherds for services of biomass control and fuel break maintenance on public forest land providing sheep and goat farmers with additional income, depending on the size of the area, success, and difficulty of the effort (Herrera 2014, Lovreglio et al. 2014, Ruiz-Mirazo et al. 2011, Varela et al 2018). CSIC Granada carried out the first pilot tests, conducted detailed research, provided capacity building and technical support, and developed a result-based payment system and monitoring methodology. Additional local experiments were developed by the Department of Environment in pilot areas of Malaga province.

Identifying which livestock characteristics were relevant for effective grazing management in Andalucía and determining which field parameters best indicated the accomplishment of grazing objectives, was the subject of this research. The results obtained are transferrable to other regions as for introducing livestock grazing in wildfire prevention and offer valuable guidelines for the setting up of reliable monitoring systems.

In terms of grazing objectives and biomass reduction on firebreaks, the required consumption is 90% of annual herbaceous growth and 75% of growth of shrubs. Monitoring of all RAPCA firebreaks is performed annually, from early summer to autumn, by the Paying Agency while pre-assessments are also common during the spring. Inspectors conduct visual assessments of how much of the individual shrubs have been consumed, of overall consumption of herbaceous layer and evaluate the overall vegetation structure. Shepherds are selected to participate based on their capacity and availability to graze specifically targeted firebreaks and they are being advised by RAPCA staff on carrying out grazing work and assessing the results.

Regarding observed socio-economic results, additional employment was feasible, and it is estimated that the RAPCA approach saves up an average of 63% (75% maximum) of the costs of managing firebreaks through mechanical clearance with brush cutters without considering the costs of administration and monitoring of the different approaches.

- ***Prescribed burning pilot project in Chios island, Greece***

Since 2021, a two-year pilot project on prescribed burning on the island of Chios, aims to introduce prescribed burning as a tool for forest fuel management in Greece and change policy (Athanasiou et al. 2022a). Researchers and practitioners from WWF Greece, the Institute of Mediterranean Forest Ecosystems of ELGO DIMITRA, the Forest Directorate of Chios Island, and the Voluntary Action Team OMIKRON, conduct planned field prescribed burning experiments, matching fire behaviour with the fire impact on soil properties, the effects on trees and the plant biodiversity. A series of parameters is monitored, measured, and recorded before, during and after the implementation of prescribed burning. Fire Service of Chios Island and Municipality of Chios support the pilot project by supplying water trucks and personnel during the burns. The project is sponsored by Procter & Gamble. The General Directorate for Forests and Forest Environment of Ministry of Environment and Energy have provided all necessary permits for the implementation of pilot application of prescribed burning in Chios. The project is expected to be the starting point for the application of prescribed burning in Greece (Athanasiou et al. 2022b). Prescribed burning improves social-ecological fire resilience over a particular landscape, reduces the probability of fire ignition, affects fire behaviour, making firefighting easier and safer, mitigates fire severity and reduces fire damages, contributing to a climate-resilient future.

Prescribed burning is expected to be institutionalized in Greece, and assimilated by services and local communities, as a tool for fuel management and consequently forest fire prevention through documented policy proposals that will be based on the results of this pilot implementation. The pilot project aims to introduce prescribed burning as a tool for forest fuel management, increase social– ecological resilience to wildfire and contribute to a climate – resilient future.

- ***Reducing vulnerability of high-risk Wildland Urban Interface (WUI) areas in Catalonia, Spain***

  In Catalonia, it is obligatory for communities to establish and maintain a security buffer zone of vegetation, treating unbuilt interior areas and adopting a self-protection plan. The Provincial Deputation of Barcelona has established a programme to support local authorities and communities to establish and maintain these protective zones in high-risk areas and encourage residents in maintenance of the WUI (Alcasena et al. 2019, Bento-Gonçalves and Vieira 2020, Galiana-Martín 2011, Pastor et al 2020). Since 2004, the programme has provided technical assistance and financial aid to hundreds of residential areas and towns, increasing wildfire resilience of the communities living in the WUI. The approach can be easily be replicated elsewhere.

- ***PREVAIL - PREVention Action Increases Large fire response preparedness***

  Within the European project PREVAIL (PREVention Action Increases Large fire response preparedness), collaborative processes in the Mediterranean Basin between private and public actors that developed "smart solutions" were analysed and their key elements for wildfire risk prevention in Southern EU namely sustainability, cost-benefit ratio, synergies between sources of financing, inter-sectoral cooperation and integration between strategic prevention planning and multiple land governance objectives, innovation and knowledge transfer, and adaptive approach, are presented. To reach the distribution and the quantity of treated surface necessary to modify the fire regime and its impacts and reduce forest stand and landscape flammability, initiatives that catalyse the interests of multiple stakeholders towards common goals are needed along with improving the cost-efficiency ratio of prevention.

  Fire smart solutions are a concrete example of implementing the Green Deal locally in fire risk management (Ascoli et al 2022) while their fundamental criteria derive from a direct exchange with local realities and define the most important aspects to create functional networks for fuel management. The implementation of their objectives at a local level and replication at a European scale is only possible through close communication between initiatives and institutions involved in fire risk and land management, including communities in a mutual exchange of good practices.

- ***INCA Project - Linking civil protection and planning by agreement on objectives***

Institute of Mediterranean Forest Ecosystems and Forest Products Technology, Harokopio University of Athens and Region of Attica (Greece), Regional Civil Protection Department and Associazione Nationale Comuni Italiani of Lazio, T6 Ecosystems (Italy), Dortmund University of Technology and City of Dortmund (Germany), coordinated by the, Institute of Research on Population and Social Policies of National Research Council (Italy), worked on an innovative project called INCA aiming to address wildfire prevention weaknesses and make significant improvements, leading to more efficient regional governance and flexibility in local risk prevention and response actions (Xanthopoulos 2010).

Regarding wildfire risk reduction and mitigation through spatial planning, five measures have been chosen for implementation according to criteria such as social and political acceptance, and avoidance of time- consuming actions:

a) Information- Awareness- Education and Training of the public on wildfire prevention, through the training seminars with guidelines and information concerning forest fires, their causes and their prevention.

b) Measures agreed for enhancing the self-defense of residences versus fires in WUI areas. Volunteers with the collaboration of the mayors and personnel of the municipalities, selected and registered the residences in WUI areas, aiming to facilitate assessment of their fire risk and vulnerability levels. The volunteers were also responsible for contacting homeowners in their area and inform them about the findings and evaluation results.

c) Coordination of the Regional Services' and local authorities' staff involved in forest fire mitigation through correction of ambiguities and contradictions regarding delineation of competences.

d) Coordination of the local authorities and the Forest Service regarding forest fuels management.

e) Proposals for changes in the legal framework regarding the central administration in concern with the influence of City and Regional Planning and wider environmental policies on forest fire risk.

- ***Mobilising local citizens for fire prevention in Kythera island, Greece***

The novel project, coordinated by the Hellenic Society for the Protection of Nature (HSPN) and the Institute of Mediterranean and Forest Ecosystems, focused on mobilising local citizens for fire prevention through volunteer work and awareness raising on fire safety with talks and workshops. Emphasis was placed on understanding fire risk in Kythira, which involved analysis of the island's fire statistics, preparation of a forest fuels map, fire modelling and volunteer-led vulnerability assessment of 610 structures (Xanthopoulos et al. 2022).

Defining the distribution of funding between the various fire management functions, such as prevention, suppression activities and post-fire rehabilitation needs, to include many contrasting priorities, related with policy aspects, technical issues, social considerations, and economic balances. The development of innovative methodologies for fuel management planning guided by rules and criteria about location of fuel treatments, not only results in maximizing management effectiveness and efficiency but creates income for the local communities. However, achieving an optimum result is not always straightforward and decisions may vary depending on the cost of carrying out fuel management, but also on the examination of potential economic benefits.

Moreover, a better understanding of the social aspect of fire management is needed to implement wildfire sustainability projects and efficient initiatives in the long term. Educating people about wildfires through pragmatic learning approaches ensures a better understanding of the phenomenon, increases knowledge dissemination, and helps wildfire prevention. Awareness raising campaigns with emphasis on how to prevent forest fires, prepare their homes and themselves for such an event, help citizens be informed, prepared and be safe. Moreover, mobilizing them to carry out fuel management and forest rehabilitation work helps them support forest protection activities.

7.2 Economic Investment Models

As mentioned previously, Europe's forest provide a wide range (multiple) of ecosystem services to society, ranging from provisioning (e.g. timber/fibre, food, chemical and medicinal products, water), supporting (biodiversity, photosynthesis, soil formation, nutrient cycling, pollination) and regulating (e.g. carbon storage, local and global climate mitigation, hydrological regulation and soil protection, purification of air and water) to cultural (e.g. e.g., recreational, spiritual, and educational and health benefits) services (Winkel et al., 2022, Holzwarth et al., 2020).

Furthermore, as noted above, (wild)fires can threaten lives and livelihoods, affect local and/or national economies, and causes have other potentially long-lasting impacts on people. In addition to the potential loss of human life, wildfires can cause acute and chronic health problems, devastate infrastructure, and degrade ecosystem services (Eberle et al., 2021/2022, Gristwood, 2022, Kurvits et al., 2022, Sullivan, 2021).

In developing countries, an increase in damaging (wild)fires could reverse or delay progress towards the United Nations Sustainable Development Goals (SDGs,Figure 26), Paris Agreement and Sendai targets (Kurvits et al., 2022).

Figure 26: Impacts of wildfire on the United Nations Sustainable Development Goals (SDGs). The changing scale and intensity of wildfires may impact achievements across several of the SDGs that impact human health and well-being (Martin 2019, Source: Kurvits et al, 2022)

The Global Partnership for Forest and Landscape Restoration (GPFLR, 2013a) outlines FLR as "an active process that brings people together to identify, negotiate and implement practices that restore an agreed optimal balance of the ecological, social and economic benefits of forests and trees within a broader pattern of land uses." GPFLR (2013b) explains further: "Forest and landscape restoration turns barren or degraded areas of land into healthy, fertile, working landscapes where local communities, ecosystems and other stakeholders can cohabit, sustainably. To be successful, it needs to involve everyone with a stake in the landscape, to design the right solutions and build lasting relationships. FLR is not just about trees. It is about revitalising the landscape so that it can sustainably meet the needs of people and the natural environment" (source: FAO, 2022).

In the proposal for a Regulation on nature restoration the Directorate-General for Environment of EU (2022) states that "*restoration means the process of actively or passively assisting the recovery of an ecosystem towards or to good condition, of a habitat type to the highest level of condition attainable and to its favourable reference area, of a habitat of a species to a sufficient quality and quantity, or of species populations to satisfactory levels, as a means of conserving or enhancing biodiversity and ecosystem resilience*". It is also very significant that the Law also defines the terms "good condition" and "favourable reference area" as follows:

- *'good condition' means a state where the key characteristics of an ecosystem, namely its physical, chemical, compositional, structural and functional state, and its landscape and seascape characteristics, reflect the high level of ecological integrity, stability and resilience necessary to ensure its long-term maintenance;*
- *'favourable reference area' means the total area of a habitat type in a given biogeographical region or marine region at national level that is considered the minimum necessary to ensure the long-term viability of the habitat type and its species, and all its significant ecological variations in its*

natural range, and which is composed of the area of the habitat type and, if that area is not sufficient, the area necessary for the re-establishment of the habitat type;

Moreover, the Directorate-General for Environment of EU (2022) underlines that "*Restoring ecosystems will help increase agricultural productivity and provide important fish spawning and nursery areas at sea, hence reducing food security risks and enhancing the food system resilience. Healthy nature boosts our life support systems - from the production of oxygen, pollination, to the delivery of fresh drinking water and healthy soils. Nature restoration plays an important role in limiting the progress of global warming by capturing and storing carbon, and in adapting to climate change, as well as in mitigating the impact of increasingly violent natural disasters such as floods, droughts, and heat waves. Natural ecosystems are equally important to our physical and mental health and are home to precious wildlife*" (https://ec.europa.eu/commission/presscorner/detail/en/QANDA_22_3747). Restoring ecosystems is also high on the international agenda. The 2050 vision under the Convention on Biological Diversity (https://www.cbd.int/doc/c/914a/eca3/24ad42235033f031badf61b1/wg2020-03-03-en.pdf), the United Nations Convention to Combat Desertification (UNCCD) (https://www.unccd.int/sites/default/files/relevant-links/2017-01/UNCCD_Convention_ENG_0.pdf.), the 2030 Agenda for Sustainable Development (the Sustainable Development Goals) (https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E) and the UN Decade for Restoration (https://www.decadeonrestoration.org/about-un-decade) all call for protecting and restoring ecosystems. Restoration will also be necessary for the EU to meet its commitments under the United Nations Framework Convention on Climate Change, and the Paris Agreement (https://unfccc.int/sites/default/files/english_paris_agreement.pdf)".

FLR is an emerging concept (Bhattarai et al., 2021) and an integrated approach that advances the SDGs and other internationally agreed policy goals. Gromko et al. (2019) highlight that FLR is a globally recognised approach to align national 'green economy' development agendas with sustainable natural resource management. Below, the International Union for Conservation of Nature (IUCN) provides an excellent example of the linkages between FLR and specific SDGs. (Source: https://unece.org/fileadmin/DAM/timber/meetings/2019/20191216/Forest_landscape_restoration_pathways_to_achieving_the_SDGs.pdf):

- Improved livelihoods, economic opportunities and jobs (SDGs 1, 8)
- Sustainable supply of forest-based products for energy, consumption and production (SDGs 7, 12)
- Food security and health benefits (SDGs 2, 3)
- Water security and healthy ecosystems (SDGs 6, 15)
- Climate change mitigation and adaptation (SDG 13)
- Gender equality and empowerment (SDG 5)
- Policy coherence and partnerships (SDG 17)

Figure 27: What are the economic costs and benefits of nature restoration Law? the answer that comes from EU is as follows (Source: https://ec.europa.eu/commission/presscorner/detail/en/qanda_22_3747)

"*Overall, the impact assessment indicates that every euro spent on restoration delivers a return on investment between €8 and €38 depending on the ecosystem in benefits from the many services healthy ecosystems provide.*

The economic cost of the degradation of nature is remarkably high. The cost of EU soil degradation, for example, now exceeds €50 billion per year. The benefits of nature restoration, by contrast, far outweigh the costs. Restoring marine ecosystems will allow fish stocks to recover, reversing the decline in pollinators will benefit agriculture, and more biodiverse forests will be more resilient to climate change.

*To take another example, the benefits for health, economic resilience, recreation of restoring peatlands, marshlands, forests, heathland and scrub, grasslands, rivers, lakes and coastal wetlands are estimated to be more than €1 800 billion, with costs of around €150 billio*n".

FAO and Global Mechanism of the UNCCD (Source: Besacier et al., 2022) illustrates through to the following picture that investments in Forest and Landscape Restoration come from a variety of private, public, and civic sources, and in diverse formats (Figure 28).

Figure 28: FLR funding sources (FAO and Global Mechanism of the UNCCD, 2015, Source: FAO, 2021)

Last but not least, Besacier et al. (2022) noticed that exists three main types of mechanismsin order to restore forest and landscapes; financial, market mechanisms, and individually financed mechanisms (Figure 29).

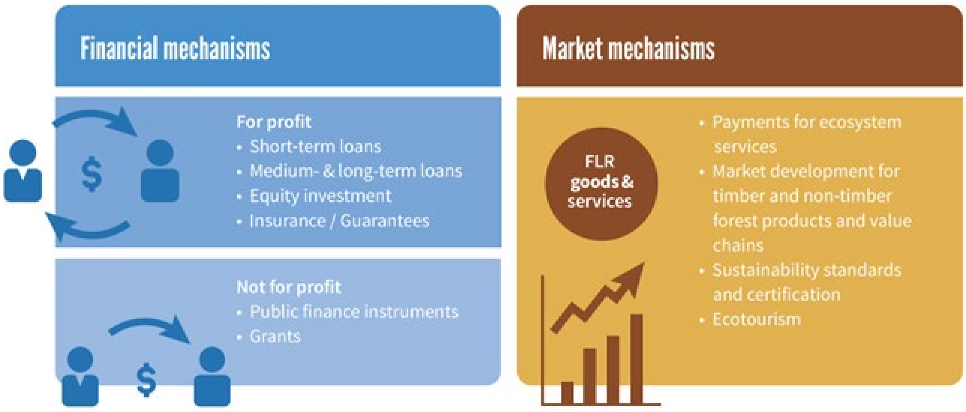

Figure 29: Financial and market mechanisms for forest and landscape restoration

7.3 Governance Models for Forest Restoration

Environmental governance refers to "regulatory processes, mechanisms, and organisations through which political actors influence environmental actions and outcomes" (Lemos and Agrawal 2006). Governance, which is related to power and decision-making, plays a critical role on the determination of the success of the environmental sector, and forest restoration specifically (Carter et al. 2009; Guariguata and Brancalion 2014).

Despite the fundamental role that governance has on forest restoration, some reglementary issues affect such processes and pose obstacles to achieving the multiple objectives and the long-term sustainability of Forest and Landscape Restoration (FLR). Robin L. et al, listed the three most common governance challenges for FLR identified in the literature. These are:

1. Poor alignment across levels and government agencies

Restoration processes may create unbalances between the government and industrial sector (e.g., forestry, agriculture, water, conservation), it could generate unaligned policies, and power and information imbalances between and within levels of government (Buckingham et al., 2020; Sapkota et al., 2020; Sayer et al., 2020; Schweizer et al., 2020; von Kleist et al., 2020). The poor alignment between parties may cause conflicts among action on the ground and contradictory government policies that on the one hand may support forest restoration, and on the other hand could undermine restoration processes by encouraging deforestation, forest degradation, or plantation (Abessa et al., 2019; Lambin et al., 2014). There is also the need to confront each group's needs at the same level because of economic development that obstacles ethnic minorities and marginalise poor (McLain et al., 2020; Welch and Coimbra Jr, 2020). Furthermore, mandates of different government agencies focusing on a given land use type are often poorly aligned (i.e., a particular body is in charge of 'land-use planning', and another one on 'land-use change', resulting in lack of dialogue and management issues), hampering a proper management (Kowler et al., 2016).

2. Environmental and social heterogeneity

The multistakeholder involvement even though it is considered a positive attribute, may conduct to challenges for collective action in FLR, in some cases impeding progress and leading to conflicts. Studies (Baynes et al., 2017; Chang and Andersson, 2020) confirm that the most performant and successful forest restoration programs met the involvement of stakeholders belonging homogenous population, which share common knowledge, needs, priorities and can negotiate more easily on rules, objectives, and norms. When it happens to merge heterogenous groups of people, different terms of land use, economic status and property rights, cultural traditions, ethnic identity and values towards the landscape must be considered (Buckingham et al., 2020; Sanches et al., 2020; Welch and Coimbra Jr, 2020). Lack of creation of a common language, clarity and/or unbalanced distribution of land and tree tenure rights (access, use, management, exclusion, and alienation) directly impede the planning and implementation of FLR (McLain et al., 2020). Strong local institution, inclusive and effective communication, prediction capacity towards climate change adaptation and flexibility over time in a developing environment are all valuable requiremeents to consider for a successful development of government models for forest landscape restoration (Mansourian and Sgard (2020) and Walters et al. (2020).

3. Lack of enabling conditions and implementation capacity

The lack of enabling conditions and implementation capacity from local to global scale is another critical aspect of FLR, leading to barriers into decision-making and adaptive management processes. To create such linkages, a dialogue among institutional and policy bodies at multiple levels are fundamental for the interactions between social agents involved in landscape governance (Brondizio et al., 2009). Another barrier is the duration of projects that may be not enough to build a solid local capacity and leadership needed to drive effective long-term implementation of restoration plans (Techel et al., 2020; Walters et al., 2020). Other crucial aspects that need to be considered and addressed, are poor understanding of social networks and stakeholder relationships within landscapes (Buckingham et al., 2020), and the adaptation of bottom-up participatory approaches that emphasize social learning and reflection on management outcomes are less commonly applied in the context of the global FLR agenda (Chang and Andersson, 2020).

When the above-mentioned conflicts are properly addressed and assessed, governance's role for landscape restoration is particularly important for the following reasons (Mansourian, 2023):

a. New value is 'generated' – letting the landscape returning to its initial state brings additional value, such as water and soil protection, micro-climate regulation, goods such as nuts and oils etc. (Light and Higgs 1996; Vieira et al. 2014).
b. Competing land use – the allocation of lands for forest restoration prevents the use of that land for other purposes, such as mining, plantation for food production, etc (Barr and Sayer 2012). Such activities might lead to the insurgence of conflicts among stakeholders interested to forest ecosystem services.
c. Tenure and rights – restoring tree cover may accelerate the processes linked to tenure and rights systems; especially where these are unclear and may generate conflicts among landowners.
d. Scaling up – the expansion of restoration to landscape and forests adds further complexity to governance, raising the need to build governance models to correctly managing them.

The development of governance models has been of central interest at international level because of forests' strategic and financial importance (Rayner et al. 2010). After the strengthening of civil society and markets, that led to three governance trends, namely:

- decentralisation,
- increased role of logging companies,
- growing importance of market-oriented schemes (such as certification),

national governments in forest sector met a gradual weakening (Agrawal et al.2008).

The governance of forests applies to multi-stakeholder involvement; examples are local governments, civil society organisations, private companies, rural communities, informal or traditional structures, etc (Chokkalingham et al. 2005).

To highlight the key principles and dimension of forest governance applied in part to forest restoration, four frameworks have been developed by major international organisations: a) the "Framework For Assessing and Monitoring Forest Governance" (FAO and Profor 2011); b) the "Roots for Good Forest Outcomes: An analytical framework for governance reforms" (World Bank 2009); c) "Assessing Forest Governance" (WRI 2009); and d) "The Pyramid: A Diagnostic And Planning Tool For Good Forest Governance" (Mayers et al. 2002).

In the following paragraphs, specific cases of FLR approaches, projects, and government models are discussed.

SUPERB Project[3] restoration approach in Castille and Leon, Spain

SUPERB (Systemic solutions for upscaling of urgent ecosystem restoration for forest related biodiversity and ecosystem services) is a project funded by the Horizon 2020 Research and Innovation Programme under the EU Green Deal. Its scope is to restore hectares of forest landscapes across Europe. The project will carry out 12 demonstrations across Europe, to test different restoration approaches with local stakeholders and increasing societal awareness and support. SUPERB project net of stakeholders includes agricultural and nature protection ministries and government agencies from over 20 European countries, landowner associations, certifiers, funders, NGOs etc. The multidisciplinary team aim to build governance models, restoration-support guidelines, recommendations, and tools to enhance forest restoration across Europe. The restoration approach carried out in Castille and Leon[4], Spain, will involve the plantation of

[3] https://forest-restoration.eu/, SUPERB Project, GA No: 101036849
[4] https://forest-restoration.eu/demo-area-castille-and-leon/

climate-adapted, mixed species to create corridors to support brown bear migration. That specific land suffers as main constraint the recurrent wildfires and abandonment.

SUPERB Project restoration approach in Aquitaine, France

Pine plantation in Aquitaine[5], France, are endangered by forest fires, wind, and pest outbreaks. To increase restoration processes to one of the warmest regions in France, SUPERB's project will be planting 10km of hedges for restoration purposes in an area of intensive Maritime pine plantations, while building a solid network of important local and regional stakeholders that agreed on supporting project activities, including nature conservation NGOs, forest owners' associations, and other.

The Forestry Act[6] in Sweden

When Sweden went through its industrialisation era, to contrast the absence of restoration measures, large areas of forest had been depleted by the end of the 19th century. This led to political actions, when in 1903 the Parliament declares a national forest policy and passed a Forestry Act, which initially had a focus on regeneration. The Swedish Forest Agency work to implement the legislation and policies related to forests. The Swedish Forestry Act regulates Swedish forest management, and states the demands that the society has towards forest owners. The law states that forests are a renewable resource that need to be managed sustainably yielding a good revenue.

The Forestry Manual[7] among Czech Republic and Austria foresters

Foresters from Czech Republic and Austria are initiating a dialogue to share information on both sides of the border. Specialists from both sides are preparing a manual (The Forestry Manual) on how to act in risky situation, such as droughts, wildfires, bark beetle crisis, etc.; to address such risks, timely intervention is crucial. The basic information regarding the actions to confront risks, reduce them, and restore the landscape is often unknown to forest owners, that most of the times happen to don't have money for specialists. This manual has been drafted to meet the forest owner's needs, especially to increase their knowledge on where to look for information about current and potential risks, to get to know who to turn for possible recommendations, solutions, restoration programmes, and to collect all the necessary information sources in one place. Furthermore, the manual is an opportunity to share knowledge among both sides of the border and to compare practice and legislation. To furtherly support forest owners, the manual provides financial support systems for forestry and forest management in Czech Republic and Austria. The Forestry Manual is not intended to overwhelm with general information, but to provide information and recommendation according to habitat, tree species, threats, property sizes, in terms of prevention, measures, forest recovery, including the financial and economic aspects of individual measures.

Protect the West Act programme in American West

The American West is currently facing extreme megadrought events, and endless wildfire seasons. Colorado U.S. Senator Michael Bennet, chair of the U.S. Senate Committee on Agriculture, Nutrition, and Forestry's Subcommittee on Conservation, Climate, Forestry, and Natural Resources, is proposing a major investment in the restoration of forests, grasslands, watershed, to protect the American West. The Protect the West

[5] https://forest-restoration.eu/demo-area-aquitaine/

[6] https://www.skogsstyrelsen.se/en/laws-and-regulations/skogsvardslagen/

[7] https://ldf.mendelu.cz/en/foresters-from-the-cr-and-austria-are-to-share-information/?psn=630

Act[8], thanks to the support of the American Legislation, collected a $60 billion fund to reduce wildfire risk, restore watersheds, and protect the communities. In detail, the Protect the West Act will[9]:

- establish an Outdoor Restoration & Watershed Fund as a support for local effort to restore forests and watersheds, reduce fire risks, enhance wildlife habitat, remove invasive species, and clean up public lands;
- empower local leaders by making $20 billion directly available to state and local governments, Tribes, special districts, and non-profits to support restoration, drought resilience, and fire mitigation projects;
- collaboration with tribes and states to invest $40 billion to tackle restoration programs, fire mitigation, and resilience projects across public, private, and tribal lands;
- support existing industries (i.e., forest products, agriculture, outdoor recreation) with the introduction or sustenance of two million good-paying jobs, primarily in rural areas;
- Save landowners and local governments money by investing in wildfire prevention and natural hazard mitigation on the front end.

PNDFCI approach in Portugal

Forest and wildland surface of Portugal are the most affected areas by wildfires in Europe, with a mean annual incidence of 3% (Moreira et al. 2011; Fernandes 2013). In addition to the usual economical, social, and environmental damages, wildfires problem has been exacerbated by frequent institutional changes, loss of the state capacity to intervene, and the absence of a strong private sector counterpart (ISA 2005). Moreover, the Portuguese Forest Service (PFS) went through frequent changes in the last 40 years, worsening the situation in terms of policy and decision making, affecting the effectiveness of fire management in Portugal (Mateus et al. 2014). The current national fire system (DFCI) and fire plan were established in 2006, following the catastrophic fire years of 2003 and 2005; this system suffers as well of endless charges un the legal and institutional framework (Silva et al. 2008). To address these management issues, the National Plan for Forest Protection (PNDFCI) against fires has been established with the Government Resolution No. 65/2006[10]. The Plan seeks to minimise the risks of fire and follow the directives of the National Forest Strategy (EFN). The PNDFCI defines the fire management strategy and goals and determines its objectives, priorities and activities. The strategy considers five strategic axis of intervention (Mateus et al. 2014):

1. Increased fire resilience with the expansion of actively managed forests and fuel treatment;
2. Decreased fire incidence, promoting environmental and forest education, improving the determination of fire causes, enforcing the laws and policies;
3. Increased fire suppression effectiveness, with tailored activities, integration of firefighting teams with agents, improving integration of planning and decision-support tools;
4. Ecosystem restoration, with recommendations to establish a post fire event recovery program, evaluate the post rehabilitation work, and evaluate the potential of the burned areas to recover;
5. Adoption of an effective organic structure, to enhance agency organization and improve responsiveness actions, and management at regional and national levels.

This approach will be used as a baseline (but will be properly adapted) for the case studies of SILVANUS.

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[8]https://www.bennet.senate.gov/public/_cache/files/6/1/61d2eed7-5dda-4c25-957f-1e64fbbc1a0f/AC16FBC510F0F5800424F7AEDE665348.2023.02.22-protect-the-west-act-bill-text.pdf

[9]https://www.vailvalleypartnership.com/2023/02/bennet-crow-introduce-protect-the-west-act-to-combat-intensifying-wildfires-and-drought-across-the-american-west/

[10] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC065317/

8 Discussion and Conclusions

Healthy forests provide a wide range of ecosystem services to society. These range from provisioning services (e.g., timber) and regulating services (e.g., climate change mitigation and biodiversity) to cultural services (e.g., recreation). However, wildfires can cause ecosystem degradation and damage large amounts of wood, potentially turning forests from sinks to net sources of carbon.

Moreover, wildfires have multiple impacts, such as:

- life and health impacts (loss of lives, injuries as well as short and long-term health effects),
- environmental (burning of thousands of hectares of forest, emission of millions of tonnes of carbon, degradation of soils and downstream water quality, disruption of wildlife habitats, environmental pollution - aquifers and biodiversity, etc.),
- economic (damage to buildings and infrastructure, significant losses of timber and non-timber products, impacts to tourism, carbon sinks, reduced protection of agricultural soils, aquifers and biodiversity costing on average millions of euros per year), and
- social and cultural (recreational activities, educational activities, loss of aesthetic values, psychological impacts, etc.).

They devastate forests, including agricultural land and human settlements, leading to significant destruction. Biodiversity can be severely affected. Restoration of burned areas should not only be a question of how to carry out reforestation. Management objectives for burned areas should be defined in the context of sustainable development in general and sustainable forest management in particular.

However, are forests conceived in a uniform manner? As described in Section 2.1.2, some definitions may ignore fundamental aspects of forests. FAO's definition does not include land that is predominantly under agricultural or urban land use, the major sector that benefits from this definition is industrial tree plantation sector.

A widely accepted definition considers forests as a whole ecosystem, including not only tree stands but also other biotic organisms, natural processes, wood and non-wood products and services.

The EU, in 2018, regarding the wildfire policy after the devastating fires that occurred in Europe, published a set of policy challenges and recommendations specifically driven from and dedicated to wildfires. Thus, EU persists to work on measures to mitigate the unavoidable impacts of forest fires and published the EU Strategy on Adaptation to Climate Change in March 2021. In addition, on July 2021, the LULUCF Regulation sets a binding commitment for emission reduction, for the period 2021-2030, for the first time in an EU law. The European Green Deal includes an ambitious agenda on sustainable adaptation to climate change, and in March 2021 the Commission adopted the EU Strategy on Adaptation to Climate Change, which underlines the need to make adaptation faster, smarter and more systemic. The EU Forestry Strategy for 2030, which published in July 2021, also lays the groundwork for increased fire prevention and climate resilience of forests, among other topics, building on the forest fire prevention guidelines. The proposal for a Nature Restoration Law is a key tool for adaptation and mitigation, as nature mitigates the impact of natural disasters such as floods, landslides, droughts and heatwaves.

As analysed in Section 7.3, in the proposal for a Regulation on nature restoration the Directorate-General for Environment of the EU (2022) states that "*restoration means the process of actively or passively assisting the recovery of an ecosystem towards or to good condition, of a habitat type to the highest level of condition attainable and to its favourable reference area, of a habitat of a species to a sufficient quality and quantity, or of species populations to satisfactory levels, as a means of conserving or enhancing biodiversity and ecosystem resilience*".

To date, the way in which adaptation and ecosystem resilience are pursued has largely depended on the ecosystem services targeted. Winkel et al. (2022) highlight two main mechanisms:

1. Mechanisms that focus primarily on wood production and/or other provisioning ecosystem services (e.g., food, water, chemical and medicinal products) emphasize a) 'healthy' forests, b) the adoption of adapted native tree species and genetic provenances, c) adapted management practices (e.g., shorter rotations, increased thinning intensity), and d) enhanced climate change mitigation through increased use of forest products, and
2. Mechanisms targeting regulating (e.g., carbon storage, climate regulation), supporting, e.g., biodiversity, soil formation, pollination) and cultural services (e.g., forest recreation, education) are more likely to aim for a) low management intensity, b) longer forest rotations, and c) increased species mixture and aged diversification.

Evidence from several literature references (e.g., Winkel, 2013; De Koning et al., 2014. Winkel et al., 2022) suggests that there is likely to be considerable tension between these two management perspectives, embedded in the general polarisation of conservation and forest use interests. However, Winkel et al. (2022) suggest that the integration of the two mechanisms may be possible at the landscape level.

A balance needs to be found between the two mechanisms on a larger scale. Supporting the adaptation of (good) forest management practices and improving the resilience of forests to future climate change, and more generally to changing and dynamic climatic situations, should be a top priority in the development and implementation of forest policies.

In this context, participatory processes are of high importance. As discussed in Sections 2.1.2 – 2.1.4, conflicts can also have constructive aspects and positive outcomes. Solved conflicts may lead to an improvement of trust and a better relationship among the conflicting actors. Thus, conflicts not only need to be prevented, but also managed to avoid potential escalations.

One action that could mitigate the insurgence of conflicts is eliminating legal inconsistencies and balancing the policy and law processes that tend to favour powerful actors while obstructing many of the livelihoods and activities of small-scale forest users and local communities.

- *Governments should learn from the successful resolution methods adopted in other countries and integrate multistakeholder dialogues among the interested parties*
- *International assistance and financial support should be promoted by the governance*
- *Governments should provide ready and affordable access to justice for all to avoid inequalities among multiple stakeholders and legal inconsistencies*
- *Alternative conflict-resolution mechanisms provided by local non-governmental organizations, and the promotion of continuous risk assessment, early warning strategies, information sharing among all the forest stakeholders should be encouraged as well.*

The wide variety of forest actors dealing with forests and ecosystem services show significant disparities in power, wealth, access to resources, and channels of influence among each group. Addressing these issues means building an equal space where reforms promote equal access among voiceless and marginalised stakeholders to represent their interests and to allow them to have an active participation in decisions that affect them. The types of actions that must be considered are (Koning, R. de, et al., 2007):

- *Involvement of multiple actors in multistakeholder forums and establishment of restricted socio-political spaces for meaningful dialogue at different levels*

- *Major support to the disenfranchised stakeholders (especially indigenous peoples, impoverished forest-dependent communities, and women), giving them the possibility to participate to discussions that concern their interest, and to negotiate on their own behalf.*

Wildfire prevention strategies play a key role in effective, efficient, and therefore sustainable forest management. Effective fuel management strategies that expand the treatment footprint to landscape scales help reduce fire severity and mitigate catastrophic wildfires while the limitations of relying on small, scattered fuel treatment units to manage long-term wildfire risk, should not be ignored.

Integrated forest fire management evaluates the potential positive and negative consequences of wildfire, promoting its beneficial use, and striving to reduce any negative impacts from unwanted fires while seeking to include communities, land managers and government agencies in this decision-making process; it combines both prevention and suppression strategies (Rego et al. 2010). To select and implement appropriate wildland fire management strategies and enable continuous improvement to reduce vulnerability and underpin resilience, application of existing and further research is required (Moore 2019). The Agency for the Integrated Management of Rural Fires (AGIF) in Portugal as the result of a new strategy, after the catastrophic 2017 fire season in the country, is a recent example. The agency is responsible for the analysis, planning, evaluation, and strategic coordination of the wildfire management, including the qualified intervention in high-risk events. Additional examples are:

- a) the Macro-regional Strategy for the Alpine Space's Action Group 8 with best practices and recommendations for an integrated forest fire management which have resulted in White Paper "Forest Fires in the Alps",
- tools and guidelines for improving efficiency in wildfire risk governance, developed in the frame of the European project FIREfficient,
- guidelines for Sustainable Forest Management in Catalonia (Bonet et al. 2012), in the frame of the LIFE+ DEmORGEST project,
- the LIFE TAIGA project in which prescribed burnings were carried out aiming to increase and conserve biodiversity in the most common habitat type across much of Sweden,
- the GrazeLIFE project, implemented in 11 European countries, which is evaluating the effectiveness of various grazing management models with domesticated and (semi-) wild herbivores,
- promoting locally-led sustainable farming and fire management in Ireland,
- FFPE LIFE project, the aim of which was to raise awareness on forest fire prevention in Estonia, provide training in the field and improve networking amongst key stakeholders.

Regarding forest resilience, various sources and programs provide valuable geospatial and ecological data that can be used to address a wide range of environmental issues. The Landsat and Copernicus program, operated by the US and EU correspondingly, offer detailed earth observation data, which are useful for mapping natural and artificial disasters, weather forecasting, climate change observation, and monitoring the impacts of land-use practices.

Complementary to Landsat and Copernicus, several organizations and databases offer crucial information on biodiversity and forest ecosystems. The Global Biodiversity Information Facility (GBIF) promotes data sharing and collaboration in biodiversity research, while NeotomaDB serves as a community-driven database for paleoecological data. The US Forest Service's Forest Inventory and Analysis (FIA) program provides essential data on the status and trends of forests in the United States.

Additionally, Global Forest Watch (GFW) offers an online platform for analyzing forest changes through satellite imagery and data, the International Tree-Ring Data Bank (ITRDB) contributes information on past climate and forest growth through tree-ring data, and the Forest Ecology Network (FEN) establishes a network of researchers and practitioners sharing long-term ecological data on forest ecosystems.

Together, these sources and programs enable researchers, policymakers, and environmentalists to analyze, monitor, and make informed decisions on various environmental challenges, ultimately contributing to the preservation and sustainable management of our planet's ecosystems.

Standard restoration principles have already been established by integrating and maximising factors to support the restoration of burned forest areas to the following aspects: ecological, societal and cultural, economic and life and health.

After a wildfire, not all forests will regenerate in a way what is compatible with the required management objectives (resilience, adaptation, mitigation); burned areas may enter degradation loops that must be avoided.

Therefore, management measures that promote stand resistance and resilience are particularly needed in fire-prone systems such as (Mediterranean) pine forests (Moreno, J., 2014). Great care should also be taken to ensure that the defined restoration measures for degraded or deforested areas are in line with national and EU strategy/legislation. In other words, an enabling environment should be in place to sustain restoration efforts (supportive legal framework, stakeholder involvement, mobilisation of additional resources, etc.).

As mentioned above, there are two common approaches to forest restoration that are being used in practice and theory for the restoration of large areas of deforested and degraded forest:

Indirect (passive) restoration, in which no measures are taken other than the cessation of environmental stressors (avoidance of any mechanical pressure on forest soils, e.g. use of heavy machinery, overgrazing, etc.) and reliance on natural regeneration (passive restoration - biological automation). Further stages of natural regeneration involve assisted restoration and may include thinning, selection of sprouts in coppices, and selection of sprouts in coppices and control of unwanted vegetation or protection from grazing animals (Lamb et al, 2003; Moreira et al. 2009; Vallejo et al. 2006; Whisenant 2005; Moreira et al. 2012; Soung-R. R. 2017).

Active restoration, which involves the implementation of more artificial management techniques such as planting seeds or seedlings (Moreira et al., 2009c; Moreira et al., 2012; Ryu, S.-R., 2017).

Natural regeneration of forests remains of paramount importance. However, where appropriate, planting or seeding is used to supplement natural regeneration and/or increase biodiversity.

It should be stressed that artificial regeneration should only be accepted in forested areas and in cases where the degradation of the station makes it impossible for the forest to regenerate naturally, i.e. where there is a need for a rapid rescue operation, e.g. to deal with soil erosion or other flooding. Ideally, the species chosen for planting should be those best adapted to current and future climatic conditions.

The restoration of burned areas can use:

Emergency (short) restoration methods (e.g., creation of a log strip terrace barrier), also called first-aid rehabilitation, can be used in areas prone to secondary disturbances such as soil erosion, flooding or landslides after heavy rainfall and the damage to trees, woods and forests by insect pests and diseases (fungal, bacterial, viral) (Robichaud et al. 2000; Moreira et al., 2012).

Long-term restoration methods can be used in order to define and maximize the economic, ecological, scenic, and environmental values of the burned area and the actions needed to achieve these values (Moreira et al., 2012; Ryu, S.-R., 2017). Long-term restoration needs to be reviewed periodically.

The following scheme (Figure 30), from Moreira et al. (2012) presents the proposed description of a framework that could be used in post-fire management and restoration. It is based on five main steps.

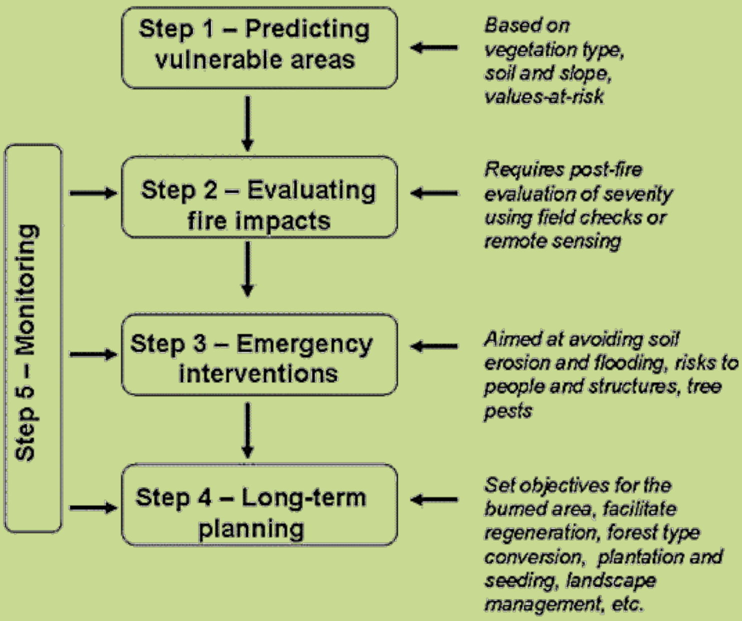

Figure 30: Framework to planning post-fire management and restoration in burned areas (Source: Moreira et al., 2012)

It is well known that forest regeneration is generally associated with several forest development phases (FDP), which make up the biological life cycle of the forest.

Degraded or deforested areas should be left to follow their natural succession (with special attention to rare and endangered species). Where necessary, artificial regeneration may be used to mimic natural processes and complement the indigenous vegetation pattern.

Where artificial regeneration is used, site-adapted tree species with appropriate genetic diversity or those derived from locally adapted provenances should be used. Forest stands should be structurally heterogeneous and uneven-aged, with a diversity of trees and other plant species.

The natural succession cycle of degraded or afforested areas is not necessarily always stable. Due to various anthropogenic or natural disturbance factors at the site, it could be interrupted and return to one of its previous development and ecological succession stages. Nevertheless, close-to-nature silvicultural measures must be adapted to each stage of the dynamics of fire-prone forests.

For example, reducing the density of pure young conifer stands and introducing resprouting broadleaved species is recommended to increase fire resilience. Mixed forests with fire-resistant, drought-tolerant and stand-adapted species, and with fire-resistant and resilient stand structures, are more likely to be the pre-

and post-fire management model for the coming decades to increase ecosystem fire resilience and tolerance to the predicted increase in drought.

A wildfire management strategy based on close-to-nature silvicultural treatments, i.e. restoring a more natural overstory and understory in several stages of succession, with a mixture of site-adapted native and non-native tree species, could allow fire to play its more natural role and minimise the severity of wildfires. However, in regions such as the Mediterranean, the weather conditions will be more conducive to fire (drier weather conditions), which is a major challenge, especially in fire-prone forest stands.
The question that needs to be asked is the following:
How could the spread of wildfires caused by the horizontal and vertical continuity of different fuel layers (surface fuels, ladder fuels, aerial fuels) in such forest stands be reduced without decreasing or eliminating the key characteristics of an ecosystem?
Apart from numerous publications that provide managers with information on silvicultural treatments and management guidelines for fuel reduction and how to create crown fire resistant forest structures, also through silvicultural treatments (Carey et al., 2003; Graham et al., 2004; Peterson et al., 2005; Johnson et al., 2007; Fernandes et al., 2007; Serrada et al., 2008; Piqué, 2011, 2012, Source: Piqué et al., 2015), the above question remains the main topic.
With respect to governance models for forest restoration, the analysis in Section 7.4 demonstrates how governance models -when applied to forest management- represent a critical factor to determine the success of forest restoration from various disturbances (natural occurrences or human influence).

The implementation processes of new governance guidelines may generate conflicts, but they can be considered as an opportunity to build solid sustainable forest restoration management and find compromises among the stakeholders and actors involved in forest management and the ecosystem services it produces.

Innovative governance models currently used for forest restoration have been tested and integrated through:

- European funded projects supporting forest management and restoration;
- Initiatives, programs, and plans from forestry bodies and services;
- Funds by the government and policy-makers;
- Co-operation and dialogue between different countries sharing the same needs of contrasting risks and building mitigation and restoration strategies.

Such approaches show how effective governance models may be integrated to traditional restoration policy measures, considering a proper plan to mitigate potential risk, while preserving positive economic, social, and environmental impact. The adoption of the new strategies may lead to increased forest resilience from risks, improved management of forest services, enforcement of laws and policies, and better sharing of information among heterogenous groups of stakeholders related to forests.

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10 Appendix

10.1 Indicative EU Member States National definitions for forests

Croatia

A forest is considered land overgrown with forest trees in an area larger than 10 ares. Forests are also considered to be: forest nurseries and seed plantations that are an integral part of the forest, forest infrastructure, fire protection paths and other smaller open areas within the forest, forests in protected areas according to a special regulation, forests of special ecological, scientific, historical or spiritual interest, windbreaks and protective zones – protective belts of trees with an area of more than 10 ares and a width of more than 20 m. (Law on forests NN 68/2018).

Cyprus

According to article 2 of the Act 25(I), "forest" means an area greater than 0.3 hectares, bearing forest trees, which have greater than five meters and a degree of land cover greater than 10% or with trees that at a mature age have the ability to satisfy these criteria and include; (a) forest roads, fire zones and other small open spaces, located within it and (b) reforested areas as well as burned forest areas or areas that have temporarily low vegetation due to human intervention or natural causes and their recovery is expected but does not include city parks and gardens.

Forested area, according to the same article, means an area larger than 0.3 hectares that cannot be characterized as a forest, with a degree of land cover by forest shrubs and forest trees greater than 10%.

Greece

According to the Greek Constitution (Article 24), "*forest or forest ecosystem means the organic set of wild plants with woody trunk on the necessary surface of the soil, which together with the coexisting flora and fauna form through mutual interdependence and their interaction, a particular biocommunity (forest biocommunity) and a particular natural environment (forest based). There is a forest area when, in the above set, the wild woody vegetation, high or bushy, is sparse*".

The term "forest" refers to:

- either the concept of an autonomous (in terms of ownership, geographically) administrative unit (forest or forest complex) independently managed on the basis of an independent management plan,
- or the concept of a forest ecosystem, indicating that forests, as a single and integrated whole, are not only composed of forest-covered areas, but also of other wooded and possibly non-wooded lands, when they form ecologically single entities with the wooded lands.

"Forests" are the natural areas described in Article 3(1-5) of Law 998/1979, as currently in force:

"1. (a) Forest or forest ecosystem means the organic set of wild plants with wood-based trunk on the necessary surface of the soil, which, together with the coexisting flora and fauna, constitute through their mutual interdependence and interaction, a special biocommunity (forest) and a special natural environment (forest based).

(b) A wooded land exists when, in the above set, the wild wood-based vegetation, high or bushy, is sparse.

2. Forests and forest areas also means uncultivated areas of any kind (scrub areas or grasslands, rocky outcrops and generally uncovered areas) that are enclosed, respectively, by forests and forest areas, as well as above forest or alpine areas or forest areas of the mountains and their steep slopes.

Presidential Decree 32/2016 provides the criteria taken into account cumulatively to determine the organic unit, the distinction between forest and forest area, and the conceptual definition of grasslands and rocky areas".

Indonesia

There are different applicable regulations from different local governments and ministries.

Forest definition based on forest ownership:

1. **State Forest** is a forest that is on land that does not have land rights. This state forest is owned by the state. All forms of control and management must be licensed by the state.
2. **Private Forest** is a forest that is on land that has land rights. Ownership of private forest can be in the hands of individuals or legal entities.
3. **Customary Forest** is a state forest located in customary territory whose management is delegated by customary law.

Forest definition based on forest function:

1. **Conservation Forest** is a forest area with certain characteristics, which have the main function of diversity preservation of plants and animals as well the ecosystem.
2. **Protection Forest** is a forest area that has the main function as protection of the life buffer system to regulate water management, prevent floods, control erosion, prevent seawater intrusion, and maintain soil fertility.
3. **Production Forest** is a forest area that has the main function of producing forest products.

Italy

Forest in Italy is defined by Legislative Decree 3 April 2018, n.34. In addition to forest definition, several other definitions of forest related matters are defined, e.g., sustainable forest management. The definition of forest is provided in Art. 3.:

3) *For matters falling within the exclusive competence of the State, forests are defined as areas covered by arboreal forest vegetation, associated or not with shrub vegetation, of natural or artificial origin, in any stage of development or evolution, with an extension not lower than 2,000 square meters, width average not less than 20 meters and with forest tree cover higher than 20 percent.*
4) *Regions, as far as they are responsible and in relation to their own territorial, ecological and socio-economic needs and characteristics, can adopt a supplementary definition of forest from the one dictated by paragraph 3, as well as supplementary definitions of areas treated as forest and of areas excluded from the definition of forest referred to, respectively, in articles 4 and 5, provided that the level of protection and conservation thus ensured to forests as fundamental safeguard of the quality of life is not decreased.*

In Art. 4 Legislative Decree 3 April 2018, n.34 the areas that are treated as forests for the matter falling within the exclusive competence of the State are indicated, these are:

a) *Plant formation of tree or shrub species in any stages of development, intercropping and evolution, including cork oaks and those characteristics of the Mediterranean maquis, recognized by current regional legislation or identified by the regional landscape plan or in the context of specific agreement of collaboration stipulated, pursuant to article 15 of the law of 7 August 1990, n. 241, by the regions and by the competent territorial bodies of the Ministry of Cultural Heritage and Activities and Tourism for the particular forest interest of their specific functions and characteristics and which are not already classified as woods;*
b) *Funds subject to the obligation of reforestation for the purposes of hydrogeological defense of the territory, improvement of air quality, protection of the water heritage, conservation of biodiversity, protection of the landscape and environment in general;*
c) *New forests created, directly or through monetization, in compliance with the compensatory intervention obligations referred to in article 8, paragraphs 3 and 4;*
d) *Forest areas temporarily without tree and shrub cover due to anthropic interventions, damage from biotic or abiotic adversities, accidental events, fires or due to transformation implemented in the absence or in discrepancy with the authorization required by current legislation*
e) *Clearings and all other surfaces of less than 2,000 square meters that interrupts the continuity of the forest, not recognized as permanent meadows or pastures or as meadows or wooded pastures;*
f) *Linear infrastructures of public utility and the respective pertinent areas, even if wider than 20 meters that interrupt the continuity of the forest, including forest roads, power lines, gas pipelines and aqueducts, located above and below ground, subject to periodic vegetation containment and ordinary and extraordinary maintenance interventions aimed at guaranteeing the efficiency of the works themselves and which do not require further authorization documents.*

Art. 4 also states that *to the cork woods referred to in the law of 18 July 1956, n. 759, the definitions referred to in paragraph 1 and in article 3, paragraph 3 do not apply, and the cultivation interventions governed by the same law and by specific regional provisions are permitted.*

In Art. 5 Legislative Decree 3 April 2018, n.34 the areas that are excluded from the definition of forest for the matter falling within the exclusive competence of the State are indicated, these are:

a) *Formations of artificial origin built on agricultural land also following adherence to agri-environmental measures or as part of the interventions envisaged by the common agricultural policy of the European Union;*
b) *Wood arboriculture, referred to in article 3, paragraph 2, letter n), artificially cultivated truffle grounds, hazelnut and chestnut groves currently under cultivation or subject to cultivation restoration, as well as coppice at rapid rotation referred to in Article 4, paragraph 1, letter k of Regulation (EU) No 1307/2013 1307/2013 of the European Parliament and of the Council, of 17 December 2013;*
c) *Urban green spaces such as public and private gardens, street trees, nurseries, including those located in non-forest areas, seed orchards not established pursuant to legislative decree 10 November 2003, n. 386, and sites in non-forest areas, crops for the production of Christmas trees, fruit-growing plants and other agricultural tree production, hedges, rows and groups of tree plants;*
d) *The areas subject to eradication measures and plans in implementation of regulation (EU) no. 1143/2014 of the European Parliament and of the Council of 22 October 2014.*

Additionally, Art. 5, states that *for matter falling within the exclusive competence of the State, expect as provided by the landscape plans referred to in article 22 and 156 of the legislative decree 22 January 2004, n.42, the following are not considered forest, exclusively for the purpose of restoring agricultural and pastoral activities or the restoration of pre-existing buildings, without increases in volumes and surfaces and without the construction of new buildings:*

a) *The formations of tree species, associated or not with shrubs, originating from natural or artificial processes and established on surfaces of any nature and destination also following abandonment of cultivation or pre-existing agro-forestry-pastoral activities, recognized as worthy of protection and restoration from the regional landscape plan or in the context of the specific collaboration agreements stipulated pursuant to article 15 of the law of 7 August 1990, n. 241, by the regional structures in charge of agro-forestry-pastoral, environmental and landscape matters and by the competent territorial bodies of the Ministry of Cultural Heritage and Activities and Tourism, in accordance with the minimum national criteria defined pursuant to article 7, paragraph 11, and without prejudice to the territories already protected for naturalistic interests;*
b) *The areas referred to in letter a) identified as rural landscapes of historical interest and included in the "National Register of rural landscapes of historical interest, agricultural practices and traditional knowledge", established at the Ministry of Agricultural, Food and Forestry Policies;*
c) *Manufactured goods and already built rural nucleuses that have been abandoned and colonized by trees or shrubs at any stage of age.*

The cases referred to in letters a) and b) of paragraph 2 continue to be considered forest until the start of the execution of the restoration and recovery interventions of agricultural and pastoral activities authorized by the competent structures.

Portugal

Because of its diversity and the nature of goods and services it provides, forest is recognised as a renewable natural resource, essential to the maintenance of all forms of life, and it is the responsibility of all citizens to conserve and protect it. (Portuguese Law nº. 33/96, 17 August, Article 2º, nº1, point a, of the Portuguese Law on Forestry Policy)

"Forest land" means land occupied by forest, brushwood and pasture or other spontaneous vegetation. (Portuguese Law nº. 16/2009, 14 January, Article 2º, point a)

Romania

The totality of forests, lands intended for afforestation, those that serve the needs of culture, production or forestry administration, ponds, streambeds, other lands for forestry purposes, including non-productive ones, included in forestry arrangements on January 1, 1990, including surface changes, according to the entry-exit operations carried out under the law, constitutes, regardless of the form of ownership, the national forest fund.

Slovakia

Forest: an ecosystem consisting of forest land and forest cover together with its atmospheric, living organisms and soil with its air and water regimes.

Forest cover: an assemblage of trees, shrubs and their mixtures at forest land.

(Act of the National Council of the Slovak Republic No. 326/2005 Coll. on forests, as amended)

10.2 Pan-European criteria and indicators for sustainable forest management (FOREST EUROPE)

	No.	Indicator
Forest policy and governance	1	National Forest Programmes or equivalent
	2	Institutional frameworks
	3	Legal/regulatory framework: national (and/or sub-national) and international commitments
	4	Financial and economic instruments
	5	Information and communication

Criteria	No.	Indicator	Full text
Criterion 1: Maintenance and Appropriate Enhancement of Forest Resources and their Contribution to Global Carbon Cycles	C.1	Policies, institutions and instruments to maintain and appropriately enhance forest resources and their contribution to global carbon cycles	
	1.1	Forest area	Area of forest and other wooded land, classified by forest type and by availability for wood supply, and share of forest and other wooded land in total land area
	1.2	Growing stock	Growing stock on forest and other wooded land, classified by forest type and availability for wood supply
	1.3	Age structure and/or diameter distribution	Age structure and/or diameter distribution of forest and other wooded land, classified by availability for wood supply
	1.4	Forest carbon	Carbon stock and carbon stock changes in forest biomass, forest soils and in harvested wood products
Criterion 2: Maintenance of Forest Ecosystem Health and Vitality	C.2	Policies, institutions and instruments to maintain forest ecosystem health and vitality	
	2.1	Deposition and concentration of air pollutants	Deposition and concentration of air pollutants on forest and other wooded land
	2.2	Soil condition	Chemical soil properties (pH, CEC, C/N, organic C, base saturation) on forest and other wooded land related to soil acidity and eutrophication, classified by main soil types
	2.3	Defoliation	Defoliation of one or more main tree species on forest and other wooded land in each of the defoliation classes
	2.4	Forest damage	Forest and other wooded land with damage, classified by primary damaging agent (abiotic, biotic and human induced)
	2.5	Forest land degradation	Trends in forest land degradation

Criteria	No.	Indicator	Full text
Criterion 3: Maintenance and Encouragement of Productive Functions of Forests (Wood and Non-Wood)	C.3	Policies, institutions and instruments to maintain and encourage the productive functions of forests	
	3.1	Increment and fellings	Balance between net annual increment and annual fellings of wood on forest available for wood supply
	3.2	Roundwood	Quantity and market value of roundwood
	3.3	Non-wood goods	Quantity and market value of non-wood goods from forest and other wooded land
	3.4	Services	Value of marketed services on forest and other wooded land

Criteria	No.	Indicator	Full text
Criterion 4: Maintenance, Conservation and Appropriate Enhancement of Biological Diversity in Forest Ecosystems	C.4	Policies, institutions and instruments to maintain, conserve and appropriately enhance the biological diversity in forest ecosystem	
	4.1	Diversity of tree species	Area of forest and other wooded land, classified by number of tree species occurring
	4.2	Regeneration	Total forest area by stand origin and area of annual forest regeneration and expansion
	4.3	Naturalness	Area of forest and other wooded land by class of naturalness
	4.4	Introduced tree species	Area of forest and other wooded land dominated by introduced tree species
	4.5	Deadwood	Volume of standing deadwood and of lying deadwood on forest and other wooded land
	4.6	Genetic resources	Area managed for conservation and utilisation of forest tree genetic resources (in situ and ex situ genetic conservation) and area managed for seed production
	4.7	Forest fragmentation	Area of continuous forest and of patches of forest separated by non-forest lands
	4.8	Threatened forest species	Number of threatened forest species, classified according to IUCN Red List categories in relation to total number of forest species
	4.9	Protected forests	Area of forest and other wooded land protected to conserve biodiversity, landscapes and specific natural elements, according to MCPFE categories
	4.10	Common forest bird species	Occurrence of common breeding bird species related to forest ecosystems
Criterion 5: Main-tenance and Ap-propriate Enhan-cement of Protec-tive Functions in Forest Management	C.5	Policies, institutions and instruments to maintain and appropriately enhance of the protective functions in forest management	
	5.1	Protective forests – soil, water and other ecosystem functions - infrastructure and managed natural resources	Area of forest and other wooded land designated to prevent soil erosion, preserve water resources, maintain other protective functions, protect infrastructure and managed natural resources against natural hazards
Criterion 6: Maintenance of other socio-economic functions and conditions	C.6	Policies, institutions and instruments to maintain other socio-economic functions and conditions	
	6.1	Forest holdings	Number of forest holdings, classified by ownership categories and size classes
	6.2	Contribution of forest sector to GDP	Contribution of forestry and manufacturing of wood and paper products to gross domestic product
	6.3	Net revenue	Net revenue of forest enterprises
	6.4	Investments in forests and forestry	Total public and private investments in forests and forestry
	6.5	Forest sector workforce	Number of persons employed and labour input in the forest sector, classified by gender and age group, education and job characteristics

Criteria	No.	Indicator	Full text
Criterion 6: Maintenance of other socio-economic functions and conditions	6.6	Occupational safety and health	Frequency of occupational accidents and occupational diseases in forestry
	6.7	Wood consumption	Consumption per head of wood and products derived from wood
	6.8	Trade in wood	Imports and exports of wood and products derived from wood
	6.9	Wood energy	Share of wood energy in total primary energy supply, classified by origin of wood
	6.10	Recreation in forests	The use of forests and other wooded land for recreation in terms of right of access, provision of facilities and intensity of use
= 34 quantitative indicators + 11 qualitative indicators (total 45 indicators)			