D 7.1 - First draft on policy recommendation framework

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List of acronyms and abbreviations

ACRONYM	Description
ADPM	Associação de Defesa do Património de Mértola
AFDC	Association for Forests, Development and Conservation
AGIF	Agency for the Integrated Management of Rural Fires
AP	Action Point
API	Application Programming Interface
CA	Consortium Agreement
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
CCF	Continuous Cover Forestry
CFFDRS	Canadian Forest Fire Danger Rating System
CICES	Common International Classification of Ecosystem Services
CSIC	Superior Council of Scientific Research
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
EAFRD	European Agricultural Fund for Rural Development
EC	European Commission
ECAS	European Commission Authentication Service
EFFIS	European Forest Fire Information System
EFI	European Forest Institute
EGFF	Expert Group on Forest Fires
EIM	Exploitation and IP Manager
EIP-AGRI	Agricultural European Innovation Partnership
ELGA	Hellenic Agricultural Insurance Agency
ELSTAT	Hellenic Statistical Authority
EO	Earth Observation
EROS	Earth Resources Observation and Science
ESA	European Space Agency
EU	European Union
EWRA	(pan-)European Wildfire Risk Assessment

FAO	Food and Agriculture Organization of the United Nations
FBP	Fire Behavior Prediction
FCover	Fractional Vegetation Cover
FDP	Forest Development Phases
FDT	Forest Development Types
FEN	Forest Ecology Network
FIA	Forest Inventory and Analysis
FLR	Forest Landscape Restoration
FMP	Forest Management Plan
FWI	Fire Weather Index
GA	General Assembly
GBIF	Global Biodiversity Information Facility
GFW	Global Forest Watch
GHG	Greenhouse Gas
GPFLR	Global Partnership for Forest and Landscape Restoration
HSPN	Hellenic Society for the Protection of Nature
IPCC	Intergovernmental Panel on Climate Change
IPRs	Intellectual Property Rights
ITRDB	International Tree-Ring Data Bank
KoM	Kick-off Meeting
KPI	Key Performance Indicators
MEA	Millennium Ecosystem Assessment
MESMA	Multiple Endmember Spectral Mixture Analysis
NBFM	Nature Based Forest Management
NDC	Nationally Determined Contribution
NFDRS	National Fire-Danger Rating System
NGO	Non-Governmental Organization
NRM	Natural Resource Management
PAC	Project Administrative Coordinator
PES	Payments for Environmental Services
PFS	Portuguese Forest Service
PM	Project Manager
POD	Potential Operational Delineation

PQP	Project Quality Plan
RP	Reporting Period
SC	Steering Committee
SDK	Software Development Kit
SFM	Sustainable Forest Management
QAC	Quality Assurance Coordinator
QAM	Quality Assurance Manager
QAP	Quality Assurance Plan
SDGs	Sustainable Development Goals
SIC	Scientific and Innovation Coordinator
TL	Team Leader
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UCPM	Union Civil Protection Mechanism
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
VSI	Vegetation Sensitivity Index (VSI)
WFDSS	Wildland Fire Decision Support System
WP	Work Package
WPL	Work Package Leader
WRM	World Rainforest Movement
WUI	Wildland Urban Interface

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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, the EU Forest Strategy, the EU Wildfire Policy, and the recent Nature Restoration Law. The document presents sustainable forest management as a holistic approach, including traditional and multifunctional forest management, as well as the new approach of closer-to-nature forest management. 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, while 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 a major factor 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, will 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 (in 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 were burnt.

Apart from losses of millions of hectares of wood and agriculture land areas, along with native species of plants and certain animal life leading to a significant loss on biodiversity, large scales and intensive wildfires are responsible also for human losses. More than a hundred people died during the 2021 wildfire season in the Mediterranean (Eberle et. al., 2021/2022); three people died in Greece, four people died in Italy and at least eight people in Turkey (Sullivan, 2021; Gristwood, 2022). In 2017, 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). Back 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.

As depicted in Figure 1, healthy forests provide a wide range of ecosystem services, by 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 ecosystems, 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.

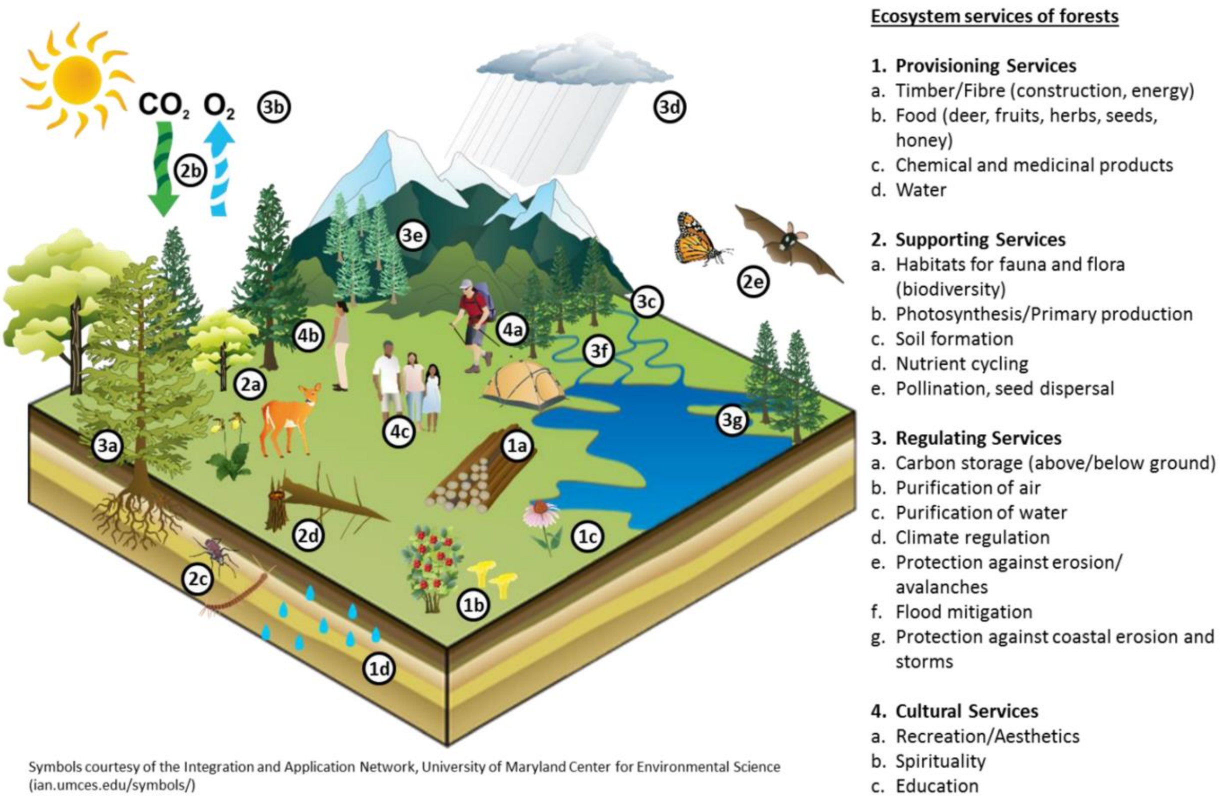

Figure 1: Ecosystem services provided by forests, divided in: provisioning, supporting, regulating and cultural services (Holzwarth et al., 2020)

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 should 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, managers have to choose the most suitable silvicultural measures, in order to achieve the set goals.

The new EU forest strategy for 2030[1] is one of the flagship initiatives of the European Green Deal and builds upon 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 (Tedim et al., 2015). 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 firefighting.

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 analyse 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 primarily involves literature reviews and also initiates the 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 is 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 analyses 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 preliminary primary research with 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). This preliminary work will serve as the basis for further discussion and elaboration during the main pilot phases of the project. 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 a literature review is to standardize the outcomes and ensure quality of the results. The use of keywords for a 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 were used in conjunction, so as to narrow down or give more focus to the results, where appropriate, such as "wildfires" or "wildfire management". The use of additional keywords could have potentially resulted in the identification of additional 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, the project team tried to approach the literature review systematically and rigorously, using multiple sources and search strategies to ensure a comprehensive coverage of the relevant literature.

Table 1: Keywords for literature review

	Identification of relevant keywords
EU policies for climate crisis	"EU climate policy", "climate change mitigation", "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", "climate resilience"
Post-fire forest restoration	"post-fire forest restoration", "ecosystem recovery", "forest rehabilitation"
Forest governance	"Forest governance", "forest policy", "forest management"

After the keyword identification, the methodology comprised the following elements:

- Use of academic databases, including Web of Science, Scopus, and Google Scholar, to identify relevant articles, reports, and policy documents.
- Review of the collected 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.
- Analysis and synthesis of the relevant 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.
- Development of 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 that was shared among the SILVANUS pilot leaders . The questionnaire was created by the domain (forest management) experts of the consortium and was initially distributed internally to WP7 participants to be reviewed and approved. After this step, it was shared among the pilot leaders of the project who catered to contact the relevant stakeholders of their countries, so as to retrieve and consolidate the responses. A period of approximately 45 days followed to allow the users to respond. Next, the task leaders of WP7 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 SILVANUS pilots and their key 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). Out of these 5 parts, for this first period, we chose to place the focus on parts 2 and 3, which are concisely presented and discussed in Section 6.7 of this deliverable. The other three parts, namely part 1, which is more generic, part 4, which is closely associated to the work of WP6, and part 5, which is pilot-specific, will be utilized as starting point and for further analysis in the next reporting period.

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

<u>If No:</u>

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

<u>If Yes:</u>

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

If Yes:

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

Please describe

If No:

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

<u>If Yes:</u>

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

The **Food and Agriculture Organization (FAO)** defines a forest as follows (FAO-FRA, 2020):

- ***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 Convention on Biological Diversity (CBD) and FAO definitions have the same numerical values for the thresholds and apply universally to 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 (Trines, 2022). Appendix 10.1 also provides the national definitions of forests in selected countries of SILVANUS, while the following section provides a more detailed comparison of the definitions and adds a discussion on the respective implications.

2.1.2 Comparison of Definitions

FAO 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. From a territory perspective, these definitions vary from international to national, state, province and local scales (Lund, 2007). As stated on national Greenhouse Gas (GHG) inventories that are reported to the United Nations Framework Convention on Climate Change (UNFCCC), the definition of forest differs 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), the major sector that benefits from this definition is the industrial tree plantation sector. The consequences led to a negative impact on local communities and their forests, as the World Rainforest Movement (WRM) 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). Out of 1150 million hectares (Mha) of forest designated primarily for production purposes in 2020, plantations accounted for 11% (131 Mha) of this area and fulfilled more than 33% of the global industrial roundwood demand (Mishra et al., 2021).

The aforementioned debates may be partially solved by establishing a dialogue among 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 evolving 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 (WRM, 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 does 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.

As depicted in Figure 2, the main forest stakeholders that can be identified are:

- The Government and traditional authorities – those who manage the forests and set 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.

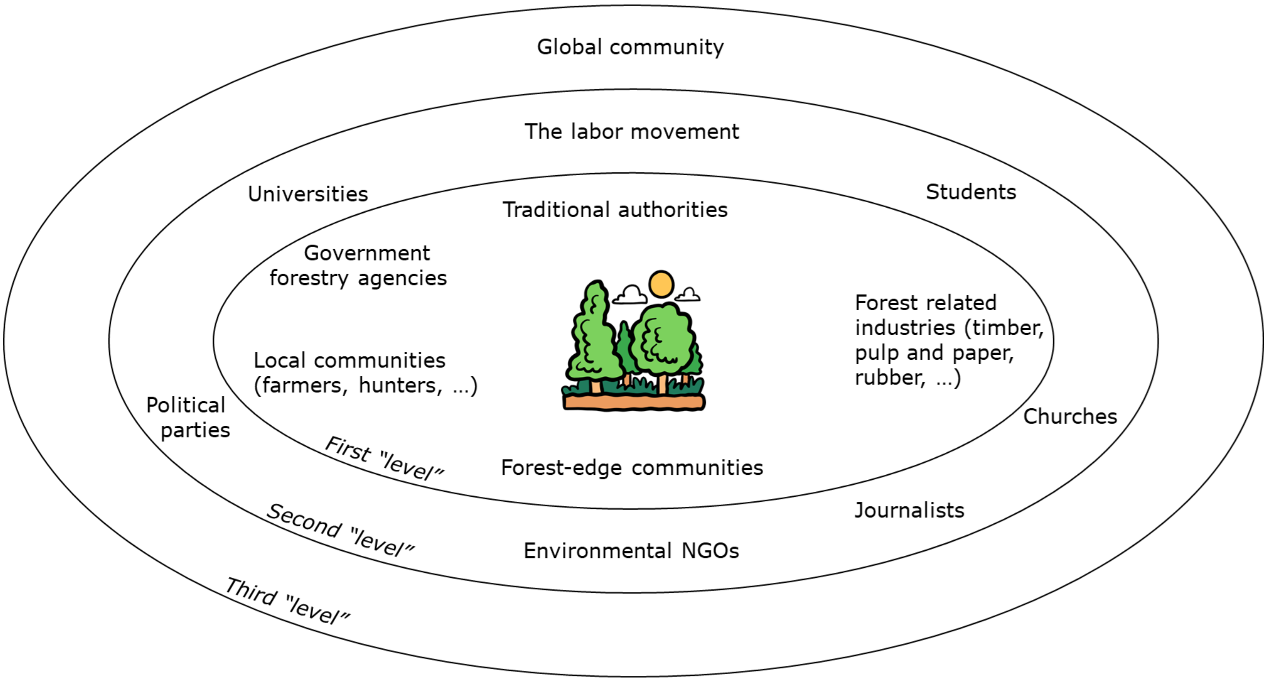

Figure 2: Levels of stakeholders (based upon Mayers et al., 2013)

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 have led to conflicts between different stakeholders, because of differing and competing interests and ideas on how these resources should be exploited (Buckles, 1999; Castro and Nielson, 2003). Conflicts represent a key and an intrinsic part of natural resource management (NRM). FAO states that conflicts over NRM “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 – manifested 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 another 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 after 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 alternatively 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, publications, 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 country, 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). As depicted in Table 3, all surveyed countries presented at least one case, with the exception of Belgium, Bulgaria, Cyprus, Luxembourg, Malta, and Portugal, where there were no reported forest conflict cases. It is also worth noting that the lack of reported conflicts only reflects the results of the specific study by Nousiainen et al. (2022), which might be missing existing (yet unreported) conflicts in the surveyed countries (as acknowledged by the authors in their publication, when they discuss the limitations of their review).

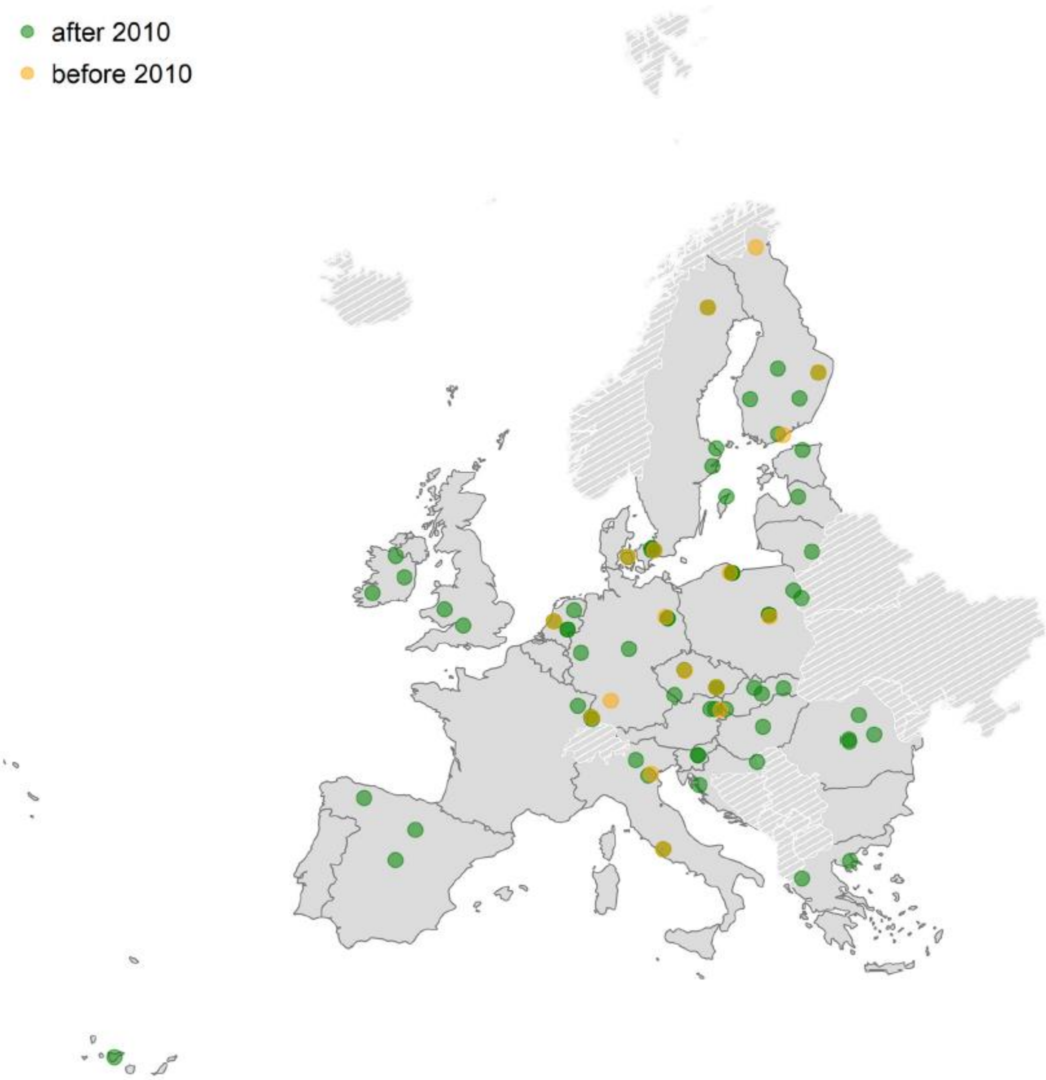

Figure 3: Forest conflicts identified (N = 84) in the period 1999–2020 in Europe (EU27 + UK), based on academic sources (Nousiainen et al., 2022)

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 et al., 2022).

Country	Forest area (x1000 ha)	Forest per capita (ha.cap^{-1})	Protected forests (×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 any case, it is crucial to have a pragmatic plan of conflict 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 conflict 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 help to reduce or solve the conflict, by acting on the ’substance’ dimension, e.g., silvicultural guidelines, forest planning at local level, 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 is 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); for instance, 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 might 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 triggers, the understanding of the main actors affected, and the identification of the factors affecting the issues, as well as the 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. maintenance of biodiversity (providing habitats as a host of other species of plants, along with numerous animals and microorganisms),
c. carbon sequestration, as well as 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. provide a host of outdoor recreational opportunities,
i. help create jobs, and
j. provide food, medicines, materials, etc.

It is globally accepted 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 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, as depicted in Figure 4. Of these, Goals 6, 12, 13 and 15 are relevant to forests. The following points summarize the SDGs and their specific targets that are relevant to forests:

- Goal 6: Ensure availability and sustainable management of water and sanitation for all.
  - Target 6.6. By 2020 protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.
- Goal 12: Ensure sustainable consumption and production patterns.
  - Target 12.2. By 2030, achieve the sustainable management and efficient use of natural resources.

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

  - It is worth noting that the aforementioned target emphasizes the sustainable management of resources, which includes not just minerals, water, and fossil fuels, but also biological resources like forests. So, while Target 12.2 does not mention forests explicitly, the sustainable management of natural resources inherently includes the sustainable management of forests.
- Goal 13: Take urgent action to combat climate change and its impacts.
  - Target 13.1. Strengthening resilience and adaptive capacity to climate-related hazards. This can involve measures related to forest conservation and sustainable management.
  - Target 13.2. Integrating climate change measures into policies and planning. This may include strategies for forest protection and reforestation.
  - Target 13.3. Improving education and awareness on climate change. This may encompass the importance of forests in climate regulation.
- 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.
  - Target 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;
  - Target 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.
  - Target 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.

Figure 4: UN Sustainable Development Goals

At the heart of the UN Strategic Plan for Forests 2017-2030, there are six Global Forest Goals and 26 associated targets to be achieved by 2030, which are voluntary and universal (UNFF, 2023). For instance, Global Forest Goal 1 calls for reversing 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).

Furthermore, FAO's report entitled "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).

In line with the above, the new EU Forest Strategy 2030 aims to overcome forest-related challenges and unlock the potential of forests for people's 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 (MEA) defined ecosystem services in 2005 as "the benefits gained by humans from ecosystems" (M.E.A., 2005), since 2005 research in this context has increased significatively (Kubiszewski et al., 2023). Ecosystem services have been divided in four (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 support people's life, 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, contributing 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 categorised as belonging both to this class and to another, e.g., erosion regulation can be considered both as a supporting and a regulating service, depending on the scale and immediacy of the impact on people. Supporting services include: soil formation, photosynthesis, primary production, nutrient cycling and water cycling (M.E.A., 2005).

Along similar lines, an alternative framework, namely the Common International Classification of Ecosystem Services (CICES) (Haines-Young & Potschin, 2018), suggests that the class of supporting ecosystem services[3] can be merged with the class of regulating ecosystem services, which also includes habitat maintenance (under the rationale that supporting services are not final services, i.e. they are not directly "used" by humans, but are instead necessary to produce the final services: provisioning, regulating and cultural).

[3] https://cices.eu/supporting-functions/

In any case, 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 products, such as fruits, nuts, berries, and seeds, as well as non-food products, such as oils (e.g., palm oil), perfumes and medical plants. 20% of all forests are managed for multiple uses, 10% mainly for conservation of biodiversity, and another 10% mainly for protection of soil and water. As depicted in Figure 5, this distribution changes widely between regions, e.g., more than 50% of forests in Europe are primarily managed for production, while only in South America around 10% of forests are primarily managed for production (FAO, 2020).

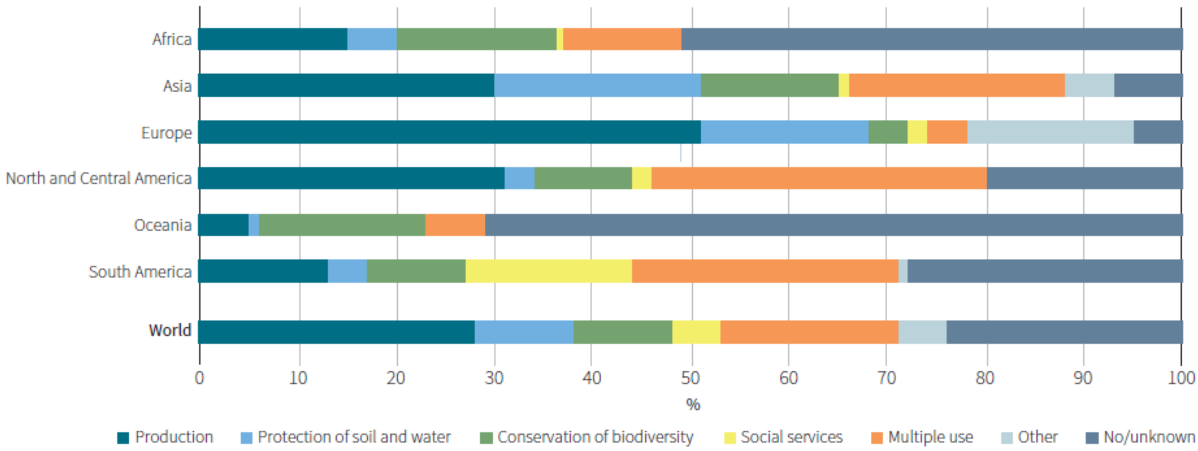

Figure 5: Proportion of total forest area designated for different primary management objectives, per region and globally, 2020. (FAO, 2020)

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 a healthy ecosystem, but also each component of the ecosystem is necessary. Regulating activities also depend on a healthy and diverse ecosystem. For instance, some vegetation is able to regulate water levels and water quality, the presence of some species of insects and climate conditions is necessary for pollination, micro-organisms are able to mobilise nutrients or can support the neutralisation of pollutants in water and soil, and more (Dirzo et al., 2014). 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 a 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 ecosystem services exist and are of different forms. In particular, they found the conflicts between timber production and other objectives to be "typical, severe and difficult to solve", while they found 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 exploit the outputs of different ecosystem services. Because of this, the conflicts between different ecosystem services translate to conflicts 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.

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. Differences between the two countries were 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)

2.3.1 Global Forest Facts

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.

The Global Forest Resources Assessment report (FAO, 2020) states that the global forest area in 2020 is estimated at 4.06 billion ha, which is 31% of the total land area. As depicted in Figure 6, 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% 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%).

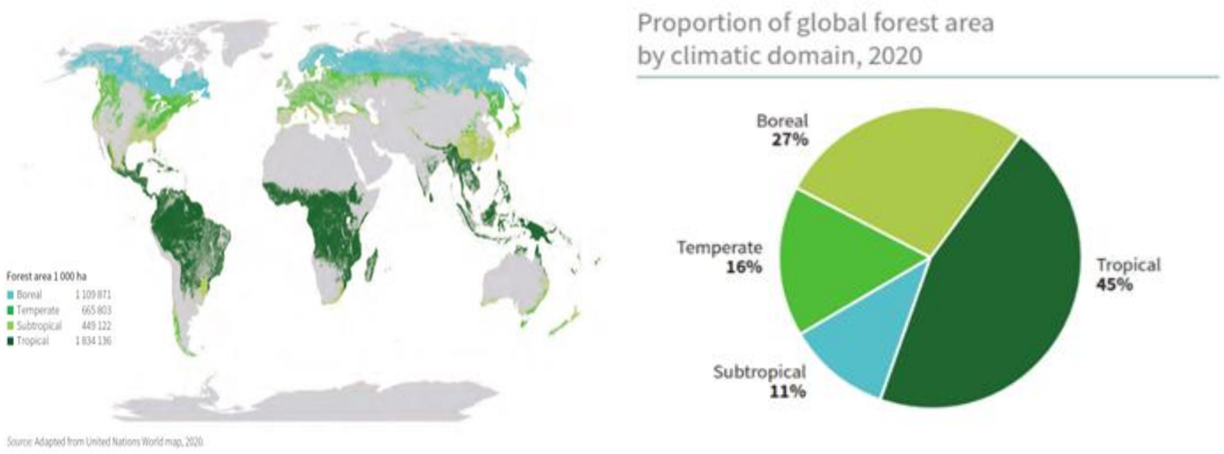

Figure 6: The global distribution of forests by climate domain (Source: Global Forest Resources Assessment report 2020)

According to the World Bank database[4], forests around the world are constantly decreasing, from approximately 31.6% of land areas in 1991 to 30.7% in the year 2020 (Figure 7). 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.

Figure 8 presents the distribution of forests per country around the globe. 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 as well, followed by Australia.

Figure 7: 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)

[4] World Bank Open Data. (2023, September 14). Retrieved from https://data.worldbank.org

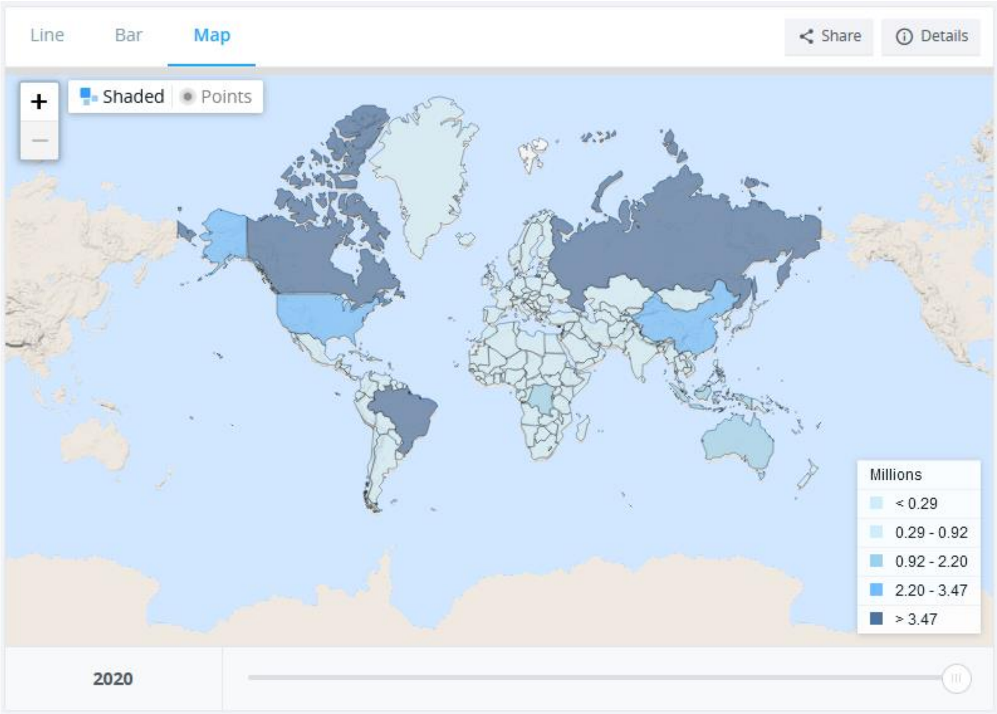

Figure 8: Forested areas in millions of sq. Km around the globe (Source: World Bank) - https://data.worldbank.org/indicator/AG.LND.FRST.K2?end=2020&start=1990&type=shaded&view=map&year=2020)

The Global Forest Resources Assessment (FRA) report (FAO, 2020) mentions 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/year in 2000–2010 and to 4.7 million ha/year in 2010–2020. However, the net change values vary per continent, as depicted in Figure 9. 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).

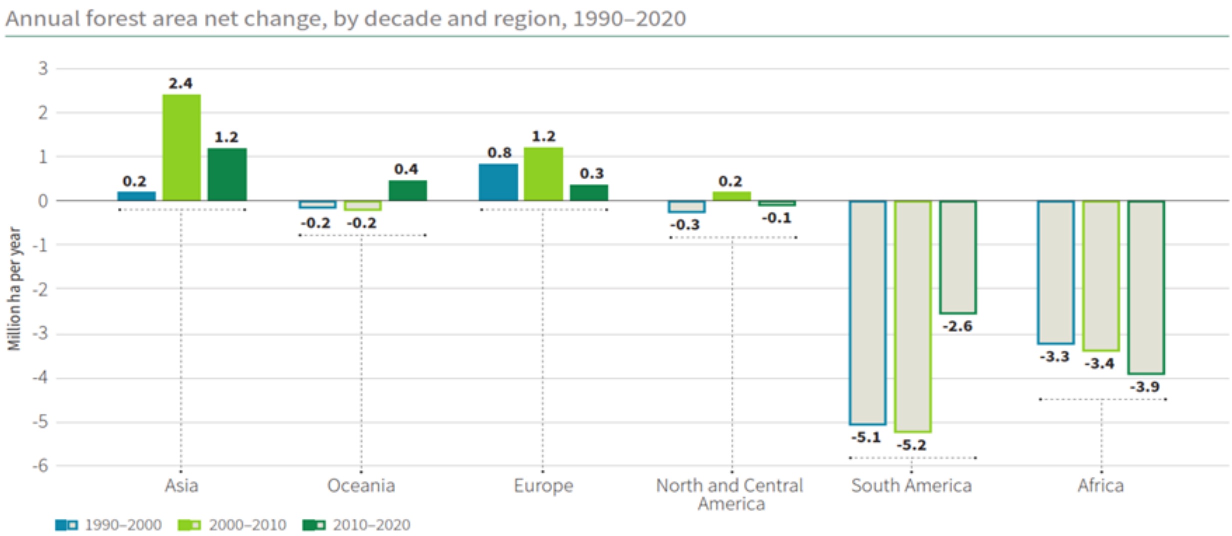

Figure 9: Annual forest area net change, by decade and region, 1990-2020 (Source: FAO, 2020)

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, while 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 three main categories (i.e., public, private, and unknown/other) from 180 countries and territories representing 97% of the world's forests, as presented in Figure 10 (FAO, 2020).

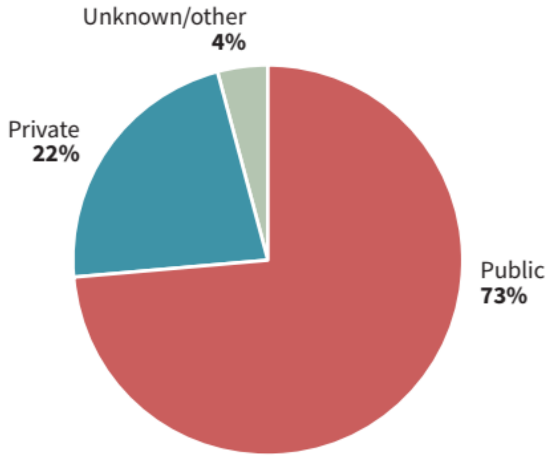

Figure 10: Proportion of total forest area, by three ownership categories, 2015 (Source: FAO, 2020)

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 (FAO, 2020).

2.3.2 Facts about Forests in Europe

According to EUROSTAT (The European Union and forests, 2023), 5% of the world forests are located in the European Union (EU), and despite the worldwide decrease in forested areas, the 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 forests to the total country area belongs to Finland, closely followed by Sweden and Slovenia, as depicted in Figure 11. Forests are approximately 30%-40% of the country total area for the majority of the EU countries.

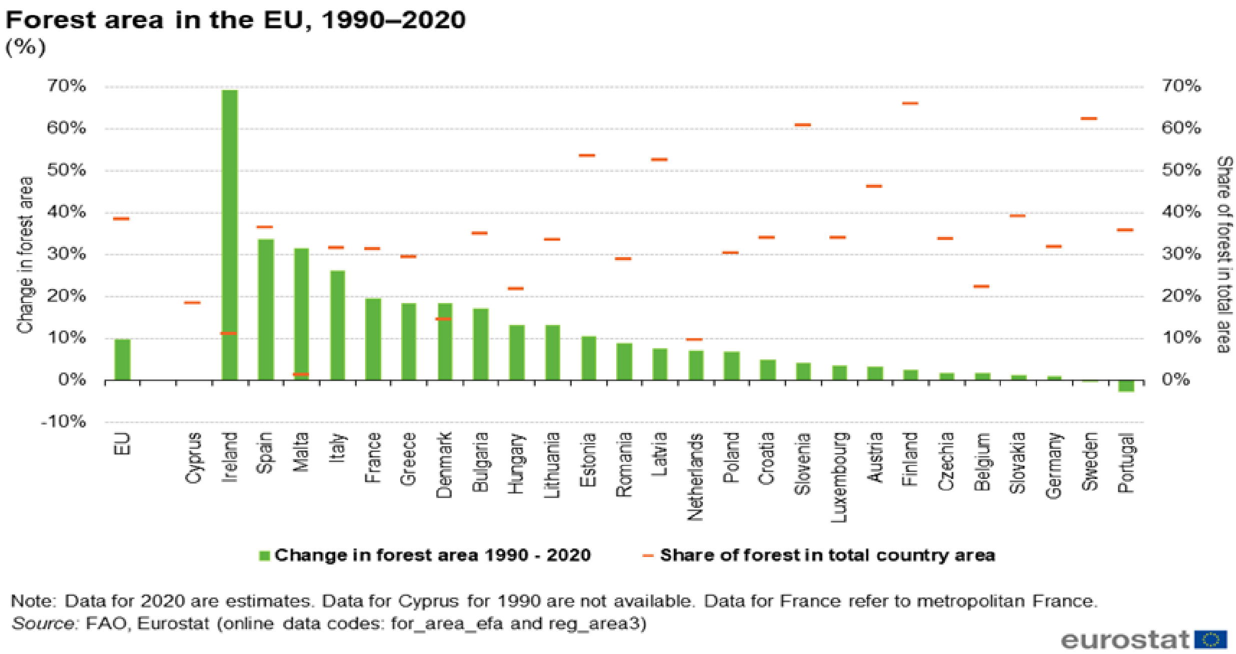

Figure 11: Forest areas in EU for the time period 1990-2020. Changes (green bar) and share of forests in total country area (red dash) (Source: EUROSTAT)

The State of Europe's Forests 2020 report (Forest Europe, 2020) presents 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).

More specifically, 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. 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 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%, and forests undisturbed by man covered 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 in about 9% (18 million ha) the main goal is the 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, Table 4 depicts 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 (Forest Europe, 2020)

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" (Pulla et al., 2013) also provides a better knowledge of the distribution of forest ownership in the 47 European countries through the following maps (Figure 12 and Figure 13). It is apparent that Western Europe has more private forests than Eastern Europe.

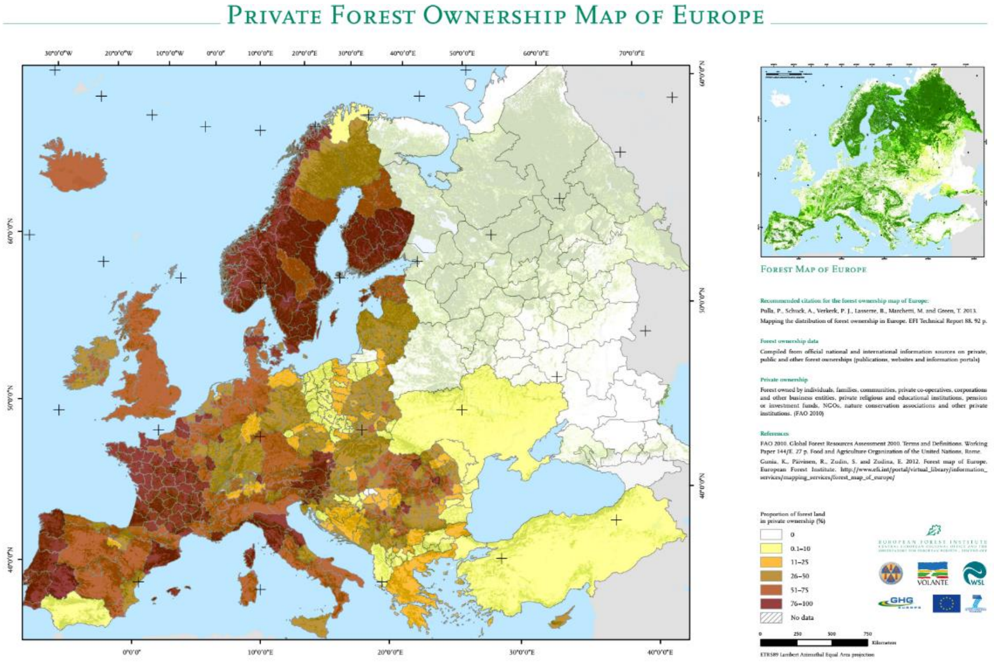

Figure 12: Private forest ownership map of Europe (Source: EFI, 2013)

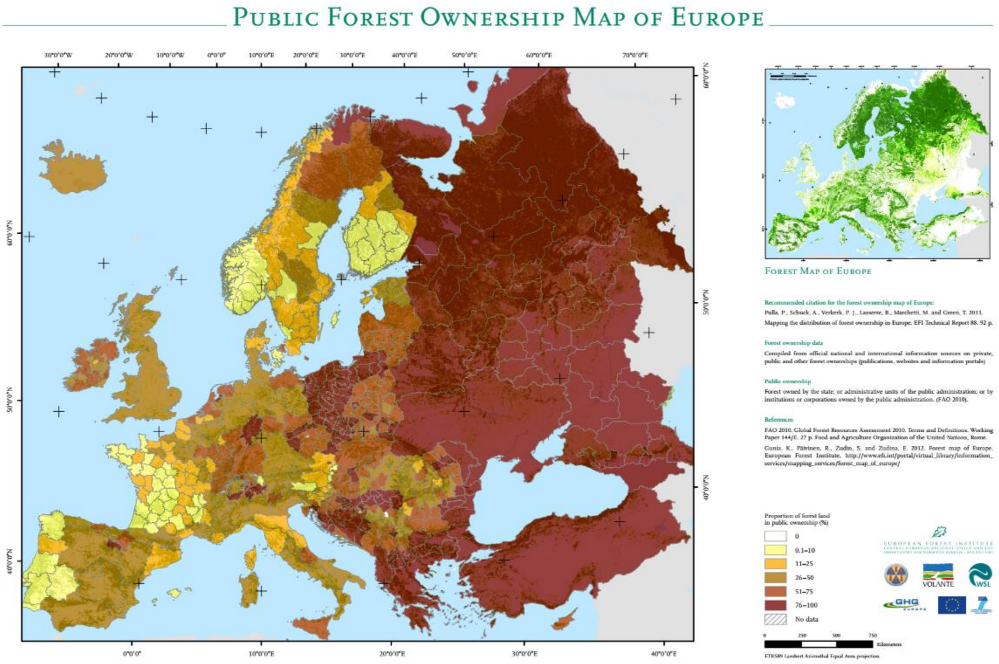

Figure 13: Public forest ownership map of Europe (Source: EFI, 2013)

3 Climate Change and Forest-related EU Policies

In 2015, the Paris Agreement was adopted by the United Nations Framework Convention on Climate Change (UNFCCC), to govern emissions' reduction from 2020 onward. According to Article 4 of the Paris Agreement, each Party shall prepare and publish the 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 emission reduction and the future steps that it will take to address and adapt to the impacts of climate change, i.e., by limiting the increase in the global average temperature to well below 2 °C above pre-industrial 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, as well as striving to achieve net zero emissions in the second half of this century.

The new EU Strategy on Adaptation to Climate Change (European Commission, 2021b) states 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 adopting 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 is also being placed on encouraging 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 (Climate ADAPT, 2023).

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 constitutes 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 enables transformation of the EU economy and society towards a sustainable Europe. The EU Green Deal works on various aspects of the economy and society, including:

- Clean energy production
- 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 is defined as 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 the Convention on Biological Diversity (CBD)[5] 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. Aligned to this, in WP6 of SILVANUS, three levels of biodiversity are considered: populations (which are defined by genetic diversity within the species population), communities (which are defined by the diversity of species present) and ecosystems. In order to make biodiversity comprehensible, the three (3) different components of Muys et al. (2022) can be seen as a triangle from three (3) separate dimensions, specifically its compositional, structural and functional diversity (Figure 14).

[5] https://www.cbd.int/convention/articles/?a=cbd-02

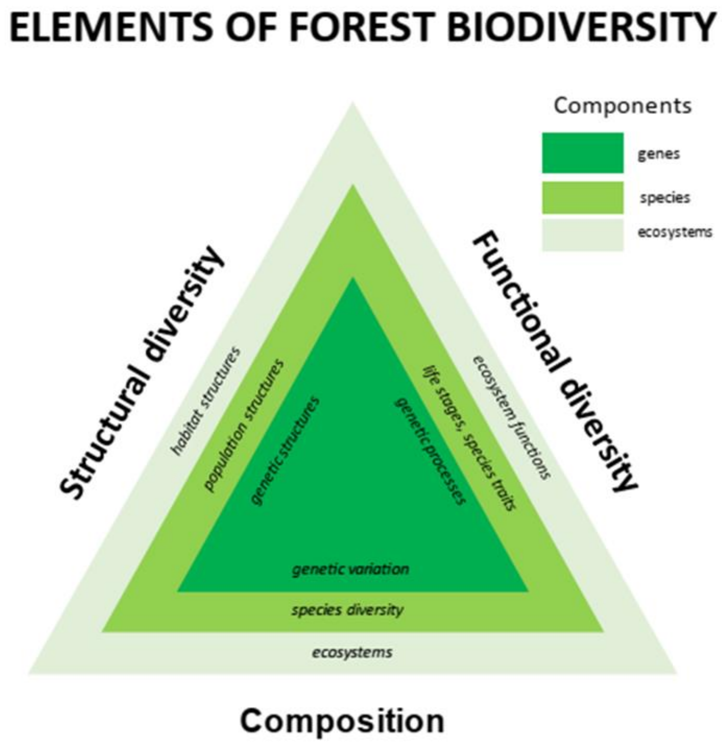

Figure 14: The main elements of forest biodiversity are represented as a triangle with three dimensions (composition, structure and function) that take account of the three hierarchical levels of components (genes, species and ecosystems) (Source: Muys et al., 2002; modified after Noss, 1990)

According to the 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 mitigating biodiversity loss at the same time.

Muys et al. (2022), with reference to Brook et al. (2008) illustrate through Figure 15 the foremost causes of biodiversity loss globally, i.e., pollution, climate change, biological invasions, land-use change and overexploitation 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".

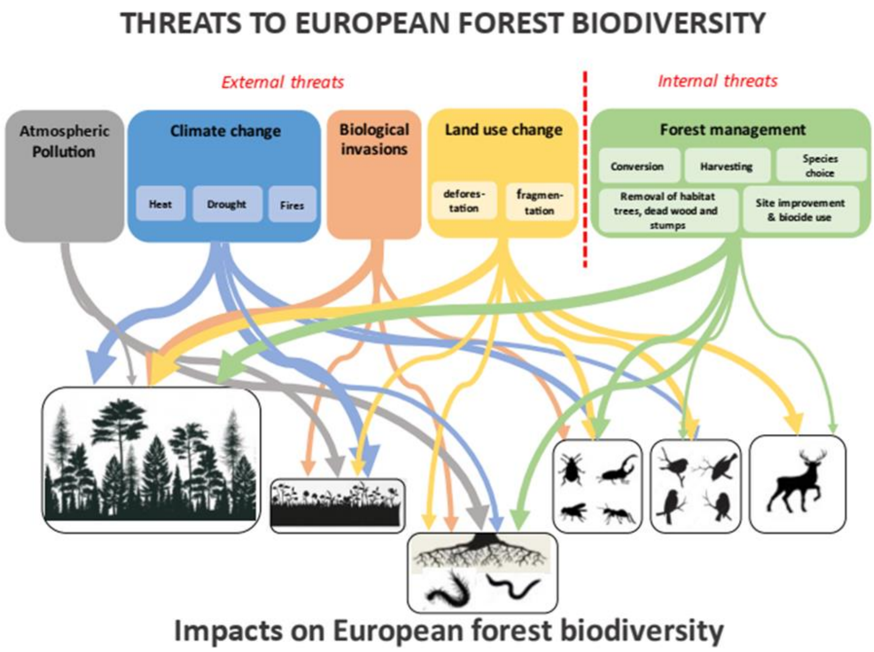

Figure 15: The relationships between major threats to biodiversity in European forests and particular groups of species (from left to right: trees, understory vegetation, soil organisms, insects, birds, mammals). The thickness of the arrows indicates the estimate (Source: Muys et al., 2022; Brook et al., 2008)

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 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
- Regulation on deforestation-free products[6], to reduce the impact of EU's consumption on global deforestation.

The EU Biodiversity Strategy for 2030 recognised forests as highly 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.

[6] https://eur-lex.europa.eu/eli/reg/2023/1115/oj

- Plant 3 billion additional trees by 2030 - to substantially increase the EU's forest area, store CO2, and provide more living space for animal and plant species.
- Create payment schemes for forest owners and managers for the provision of ecosystem services.

The EU Biodiversity Strategy also puts forward ambitious objectives for nature protection, also 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 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 (Forest Europe, 2020).

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 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 well-connected networks;
- strictly protecting 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;
- restoring degraded ecosystems in protected areas;
- 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[7] 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 that "*in order to provide increased protection for forests and in particular to step up efforts undertaken to maintain and monitor forest ecosystems and to*

[7] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992R2158

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[8]) 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.

The Joint Research Centre (JRC) of the European Commission[9] set up in 1998 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 assessment, as well. These activities led to the development of the European Forest Fire Information System (EFFIS) which became operational in 2000. 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[10].

Other tools to prevent and respond to wildfires are[11]:

- The Union Civil Protection Mechanism (UCPM), 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 mechanism was activated five times in 2019 for forest fire emergencies, namely in Greece, Israel, Lebanon, Bolivia and Guatemala.

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[8] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32003R2152
[9] https://effis.jrc.ec.europa.eu/about-effis
[10] https://ec.europa.eu/environment/forests/legislation.htm
[11] https://environment.ec.europa.eu/topics/forests/forest-fires_en

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

In 2018, after the 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 recommendations
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	Support 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). In parallel, 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.

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[12]:

- 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 which is a commitment of the EU in full respect of ecological principles.
- 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 Common Agricultural Policy (CAP) (2023-2027), in particular through the set-up of ecosystem services payment schemes.
- Provide advice and technical guidance on the development of ecosystem services payment schemes, by November 2021. Implement a 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.
- Provide 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.
- Support the 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. Also, identify and address possible hurdles to grant adequate public support to services beneficial for the public interest.

[12] https://sincereforests.eu/wp-content/uploads/2021/09/Webinar_Presentation-DGEnvironment.pdf

- In the context of the long-term vision for rural areas, promote a network of forest-dominant rural areas and municipalities, to give voice to forest rural areas.

Thus, the EU Forest Strategy for 2030 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 the following[13]:

- 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 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.

[13] https://www.europarl.europa.eu/RegData/etudes/ATAG/2022/698936/EPRS_ATA(2022)698936_EN.pdf

4 Sustainable Forest Management

4.1 Definition and Scope of Sustainable Forest Management

FAO defines Sustainable Forest Management (SFM) as "*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*" (FAO, 2020). Sabogal et al. (2013) recognizes that "*forests provide multiple uses and that different benefits accrue to different stakeholders*" (FAO, 2022).

The ITTO (1998) definition of SFM is the following: "*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 SFM, which includes voluntary principles, guidelines and indicators (refer to Appendix 10.2) 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 SFM 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 SFM, 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 (i.e., 45 in total):

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 SFM 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 be able to determine and compare different management approaches, their impacts and the condition of EU forests. SFM 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 SFM, 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 SFM, 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 for a voluntary closer-to-nature forest management certification scheme.

4.2 Main Issues in Sustainable Forest Management

As illustrated in Table 7, apart from the secondary effects of the "climate change" phenomenon, i.e. pest and diseases, insect calamities and wind-throws in Central and Northern parts of Europe, the fire risk is also 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). The Intergovernmental Panel on Climate Change (IPCC) (2021) also states that temperatures in Europe will continue to rise at a rate exceeding the global mean temperature change, regardless of the climate scenario considered (Verkerk P.J. et al., 2022).

Table 7: Main disturbances in European forests and projected changes (Source: https://ec.europa.eu/eip/agriculture/en/publications?f%5B0%5D=field_publication_date%3A2019)

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.

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 creates uncertainty or threats to (and possibly opportunities for) SFM. In other words, SFM, 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 important synergies and conflicts between forest-based mitigation and adaptation activities, as well. These are illustrated in Table 8.

Table 8: Potential conflicts and synergies between forest-based mitigation and adaptation (Source: Verkerk 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	

In addition to supporting the adaptation of (good) forest management 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", of which the three most commonly used are engineering resilience, ecological resilience and social-ecological resilience[14]. Thus, as explained by Lindner et al. (2020), there are three main concepts of resilience in forest science.

1. *Engineering resilience* is 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* 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 Holling (2016).

[14] https://efi.int/articles/how-can-we-measure-forest-resilience

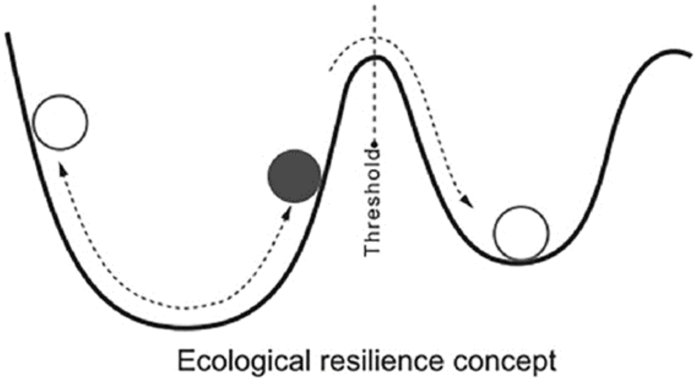

Figure 17: The theoretical ball-and-cup diagram used to depict ecological resilience as introduced by Holling (2016).

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 highlight 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.

In their final report entitled “Forest Practices & Climate Change” (2019), the agricultural European Innovation Partnership (EIP-AGRI) Focus Groups denote 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.

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. The big challenge for managers and forest owners in face of the 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 SFM concept and on 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 overlap 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.

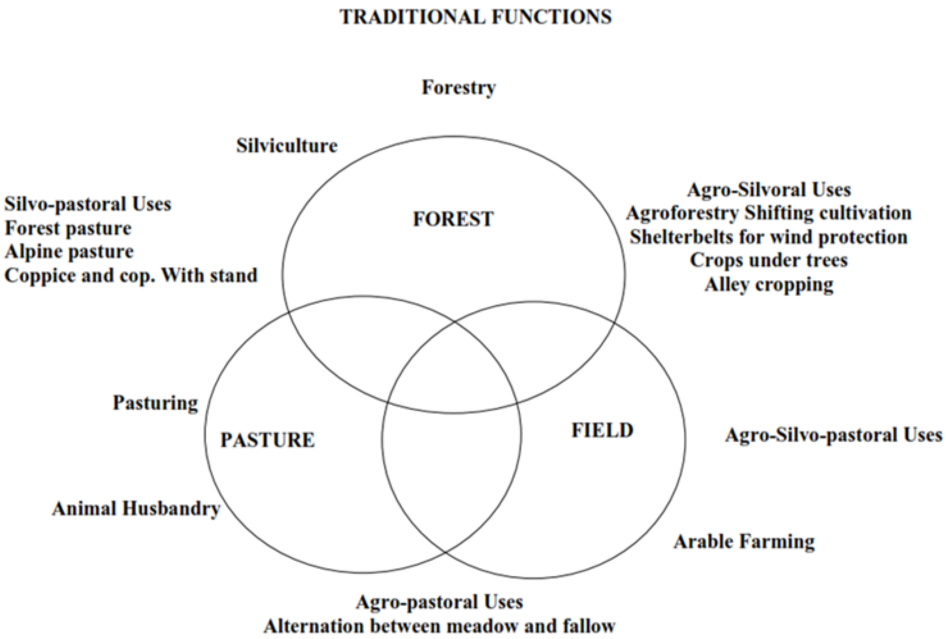

Figure 18: Overlapping of forest functions in the traditionally forestry (Adopted from Huss, 2004. Source: Kalapodis, 2010)

Around 1850, due to the desperate need for wood (timber for construction and industry), "sustainability" in the forest seemed 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, namely 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 SFM, are described below:

1. Coppice Forest – Forest stand of broadleaved species is 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 aims at meeting 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.

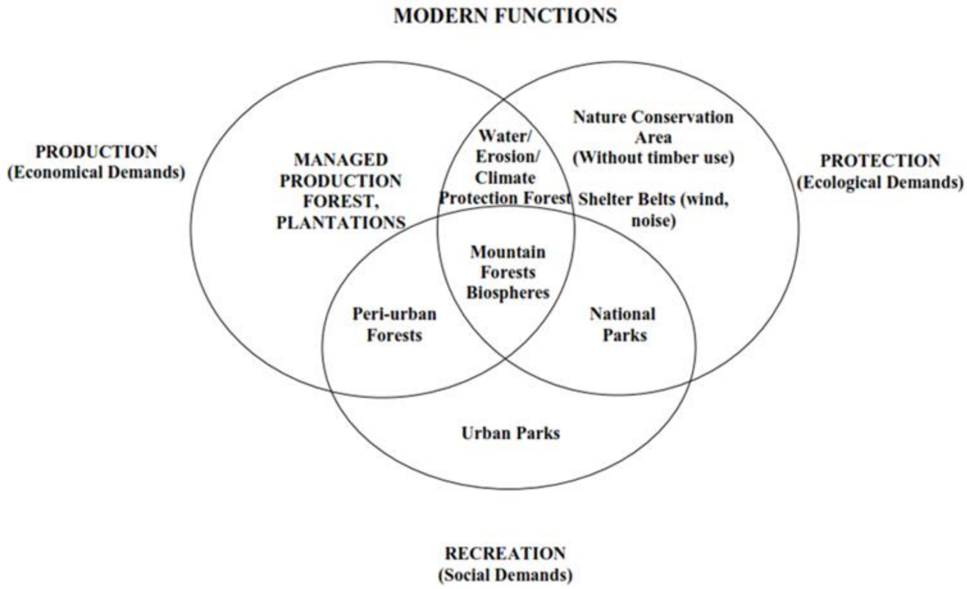

Figure 19: Forest functions in the sense of a modern multifunctional forestry (Adopted from Huss, 2004. Source: Kalapodis, 2010)

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 was beginning 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; Bengston, 1994).

The EU decided in Helsinki (1993) that all forests in the Member States that have been degraded due to over-exploitation should, in the 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 follows:

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, as well as 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 does not separate them (Figure 20).

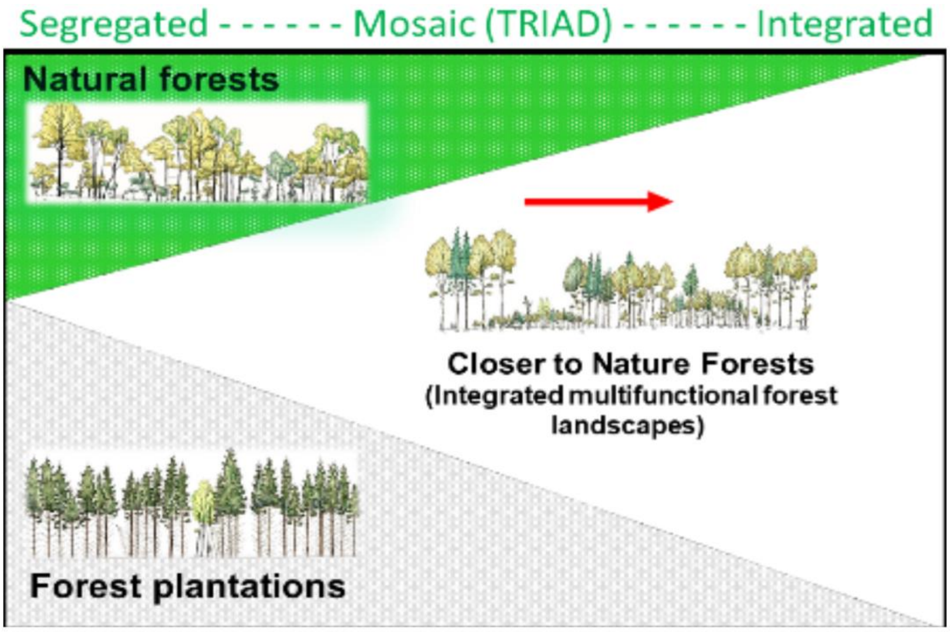

Figure 20: Landscape segregation and integration - a continuum (modified after Larsen, 2009). The term 'triad' in forestry refers to a landscape management regime composed of three parts (Himes et al., 2022): (1) intensive plantation management, (2) ecological forest reserves, and (3) a matrix of forests managed for multiple uses following the principals of ecological forestry

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, 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. The scholars point 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"[15] (Novakova et al., 2015; Thorn et al., 2017; Vacchiano et al., 2017).

As illustrated in Figure 21, in contrast to the above forest practices, 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 –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).

CTNFM 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, 2012Schütz et al., 2016). Bauhus et al. (2013) states that the main principles of CTNFM 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.

[15] https://www.eea.europa.eu/publications/forest-dynamics-in-europe-and

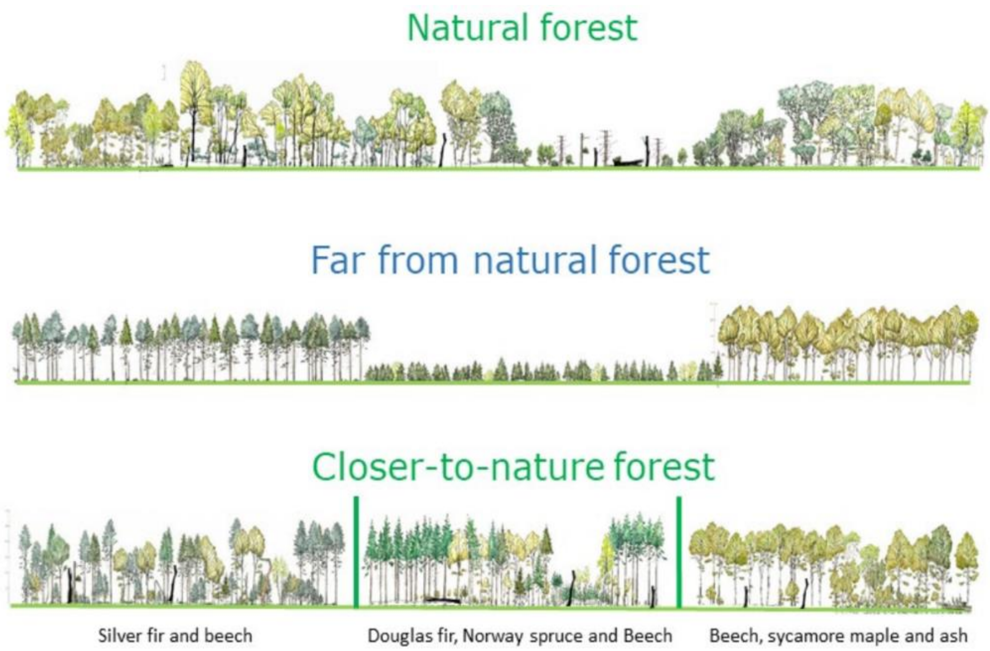

Figure 21: A natural forest (upper panel), a forest intensively managed for wood production (far from natural state) (middle panel), and a forest managed with Closer-to-Nature methods (lower panel) (Source: Larsen et al., 2022)

The representation of Figure 21 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 a natural forest. The lower panel (Closer-to-Nature forest) presents three examples of Forest Development Types (FDT) described and illustrated by Larsen (2012): Left - Silver fir and beech managed through selection cutting; Centre - Beech with Douglas fir and larch; Right - Beech with ash and sycamore maple both managed through group selection (Larsen, et al., 2022).

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

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 7 Closer-to-Nature Forest Management principles to contribute to forest resistance, resilience and adaptive capacity (Larsen et al., 2022). 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.

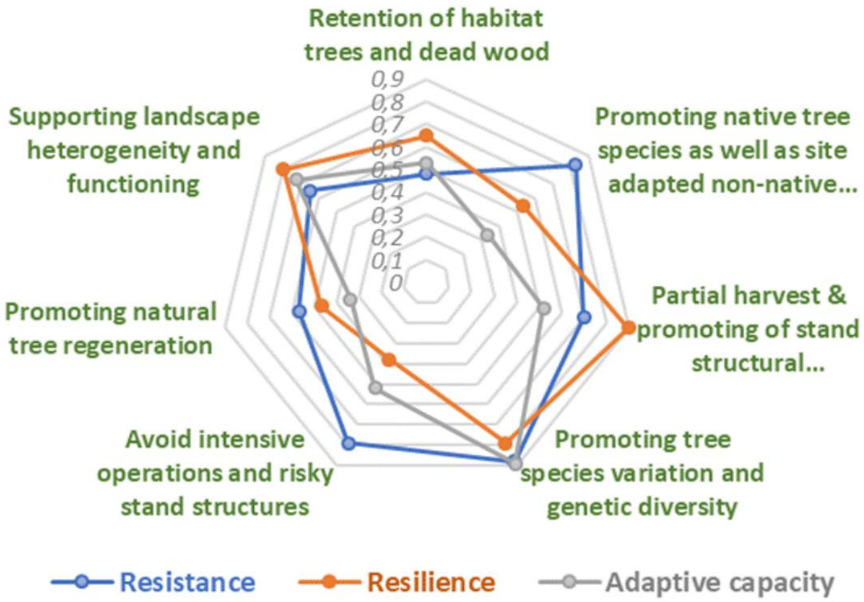

Figure 22: Visualization of the possible impact of principles of Closer-to-Nature forestry on the resistance, resilience and adaptive capacity concerning ecosystem service provisioning (Source: Larsen, J.B. et al. 2022)

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

In line with the aforementioned seven principles, Larsen et al. (2022) define CTNFM 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 SFM. CTNFM 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 et al. (2022) also 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 CTNFM principles and is mandatory in all public forests (Larsen, 2012).

NBFM is synonymous with continuous cover management in Atlantic Europe, CTNFM in Central Europe, and forest ecosystem management in the USA (Puettmann et al., 2015; Larsen et al., 2022).

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 silvicultural systems and which avoids clear cutting. Thus, Table 12 serves as an overview of the terms that have been defined in the 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 catalogue of Table 12, 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), after reviewing the literature, make it 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, which are emphasised in some of the above definitions.

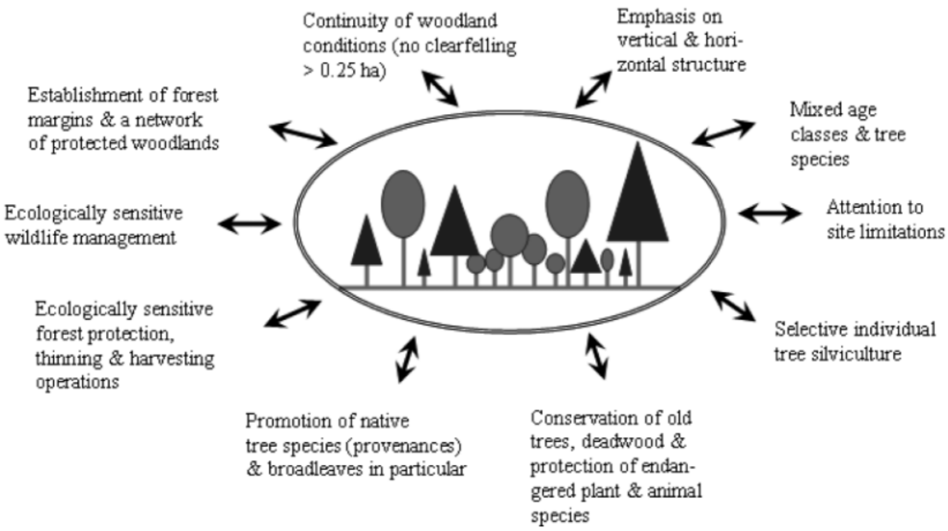

Figure 23: The main components of the contemporary international continuous cover forestry (CCF) debate (Source: Pommerening et al., 2004)

The key finding, as 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. As explained in Section 4.2, resilience can be distinguished into ecological resilience and engineering resilience or persistence (Forzieri et al., 2022), in the context of forest management. 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, namely stability and resilience. Stability attempts to detect the balancing point (equilibrium), by monitoring harvesting habits and limiting them to have as little impact as possible. On the other hand, resilience seeks persistence; and can, thus, be obtained by regulating those controllable events in the scope of narrowing down the aftermath 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 entire ecosystems to a state before an enormous tragedy is simply not possible given the predicted outcomes of human activity. For example, unsuitable temperature variance or drought significantly affect the formation of trees during the early stages (Bell et al., 2014; Dobrowski et al., 2015), and can lead, alongside local climate disturbance, to longer and drier time frames, fuelling more extreme and more frequent wildfires (Abatzoglou and Williams, 2016).

The 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 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 wildfirein Greece, a devastating wildfire that occurred in the coastal town of Mati, on July 23, 2018. The wildfire caused the death 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, which has been presented in detail in Section 3.3. Among others, 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.

5.2 Relevant Common Forest Management Treatments

The most common and cost-effective forest management treatments to increase forest resilience to fires and reduce wildfire damages, according to the literature, are the following (Kaloudis, 2008):

- Removal of logging residues, which 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, which reduces the likelihood of surface fires turning into crown fires, while improving the quality of produced timber.
- Understory thinning, which reduces the fire characteristics. In this way, in combination with the pruning of the trees, the possibility of crown fire is significantly reduced. For this treatment, grazing of light to mild intensity of domestic animals can be applied, which also provides an additional income to local communities.
- Forest thinning, which reduces fire characteristics and helps to avoid catastrophic active crown fires. 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 increases 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 case of application of the above treatments to the vegetation, it is typically considered that the cut fuel materials do not participate in a possible future fire. This assumption presupposes that the chopped biomass is properly handled, such as, for example, by burning it in the forest at an appropriate time, or through its complete removal from the forest.
- Encouraging species with high resistance to fire, which refers to the support of the native broad-leaved forest species, thus increasing 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, when mixed in coniferous forests, also increase the resistance of these forests to insects and pathogenic organisms and improve the aesthetics of the landscape. Moreover, increasing the biodiversity of a forest can help increase in parallel its ecological resilience, at least in the longer-term (Oliver et al., 2015; Thompson et al., 2009).

- Grazing of domestic animals, which reduces the fuel load (bushes and poes) and contributes to increasing farmers' income, through the production of livestock products (Bachelet, 2000; Valderrabano and Torrano, 2000; Torrano and Valderrabano, 2005; Liedloff, 2001; Balata et al., 2022; Ribeiro et al., 2023).
- Construction of firebreaks, which reduce 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 firefighters. Because the width of firebreaks should be large enough to be effective (Butler and Cohen, 1998a; Butler and Cohen, 1998b; Agee et al., 2000), the construction of composite firebreaks is suggested, consisting of zones with adapted size and cover (Kaloudis, 2008).

The application of the above treatments through forest management planning presents significant advantages, as long as they are well organized and the possible drawbacks of their application have been well considered and addressed during the planning phase. In such case, the cost of the treatments' application can be streamlined and compensated from the increased income coming from logging through logs improvement (by pruning), as well as from the livestock products of grazing animals.

5.3 Assessment of Forest Resilience

The 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 this chapter is on forest resilience from wildfires.

5.3.1 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 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 the Vegetation Sensitivity Index (VSI) (Seddon et al., 2016) and the extraction of Disturbance events for experiments conducted on the Neotropics dataset (Williams et al., 2018). 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 events 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.

5.3.2 Data Supporting Forest Resilience Assessment

Space Assets

Earth observation (EO) data can provide valuable information to support forest resilience assessment, by monitoring changes in forest health, identifying areas of risk, and informing management strategies. Some examples of EO data that can support forest resilience assessment 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**: Light Detection and Ranging (LiDAR) 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 the 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 can also overcome cloud cover and pixel contamination, but interpretation of such information can be challenging even for experts. Sampling can occur down to 5m of resolution with a coverage of up to 400km. However, 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 United States. 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 and is expected to offer around 750 (1400 in combination with the 8th generation) daily new scenes to the enormous dataset archives of the Landsat program. Data are sampled in 9 spectral bands: 8 bands at 30m spatial resolution, and 1 band at 15m. Furthermore, 2 thermal sensors provide data at 100m spatial resolution, respectively. All data produced are open through the USGS Earth Resources Observation and Science (EROS) Center, while a campaign to recalibrate all products of Landsat 9, utilizing state-of-the-art algorithms, was launched at the beginning of 2023.

Although mapping natural and artificial disasters is a core functionality of satellite data, it is not the only one. Geospatial data can be used to tackle problems from a variety of domains, including weather forecasting, observing climate change and similar phenomena, impacts of excessive agricultural land-use, timber harvesting and other factors on forest deforestation, and more. All of the previous heavily rely 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)[16] 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)[17] 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)[18] 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)[19] 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.

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16 https://www.fia.fs.usda.gov

17 https://www.globalforestwatch.org/

18 https://www.ncei.noaa.gov/products/paleoclimatology/tree-ring

19 http://www.forestecologynetwork.org/

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 through improper and exhaustive activities in the past decades, resulting in severe land degradation. This amplifies the complexity for establishing global environmental sustainability (Fu and Li, 2016). For instance, deep sea ecosystems, although being one of the most diverse types of 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 (Wenting et al., 2022). Diversity is a powerful tool that can 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, 2017).

Even though ecosystem restoration has been a practice for 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 caution; not to disturb the interactions between all the different variables of each ecosystem. Notable efforts have been made, such as, for example, the restoration programs in South China's karst landscapes (rocky terrains, rich in caves and underground tunnels) (Sijing et al., 2022), the Natural Capital project by Stanford [20], the INCASE project in Ireland[21], and others. Although policy making has been growing stronger every year, insufficient funding fails to 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, performing 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 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

[20] https://naturalcapitalproject.stanford.edu
[21] https://www.incaseproject.com/

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.

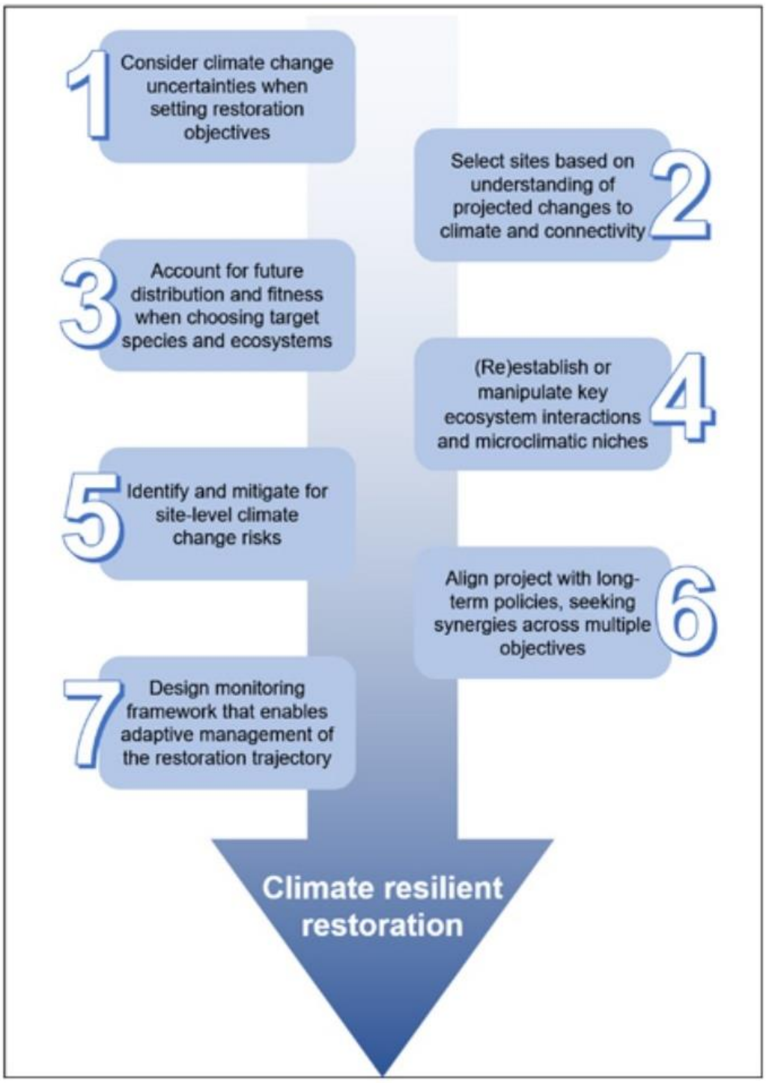

Figure 24: Seven areas that practitioners should consider when designing and implementing an ecological restoration project in order to build its climate change resilience

In the following, the remainder of this 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 that can mitigate the impacts of fires and promote 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.

Subsequently, this 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 Fire Risk and 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

Risk assessment is an essential step in pre- and ongoing fire impact assessment as well as a tool for preventive restoration. According to the European Glossary for Wildfires and Forest Fires (2012), "fire risk" is defined as the probability of a wildfire occurring and its potential impact on a particular location at a particular time.

In the effort of estimating fire risk, various studies can be found in the literature (Baetens et al., 2022). Some of them focus on the estimation of ignition probability and fire spread, thus focus on fire danger/fire hazard (Hysa et al., 2018; Martín et al., 2019). Most of these indices are designed for short-term fire hazard assessment (a few days) and usually refer to larger areas. This type of indices is useful for fire prevention, fire awareness, and firefighting preparedness. Other studies go further beyond fire danger and take into consideration the fire consequences (Kaloudis et al., 2005; Chuvieco, et al. 2023) as well, thus estimate fire risk and have been designed for long-term risk assessment (Kaloudis et al., 2005; Chuvieco et al., 2023) that are useful for forest management planning, for actions that improve forest resilience and long-term preparedness.

The most well-known indices that have been also implemented as an integrated system and are in use are the Canadian Forest Fire Danger Rating System (CFFDRS) (Van Wagner and Pickett, 1985) and the National Fire-Danger Rating System (NFDRS) (Cohen and Deeming, 1985).

Effective fire risk management requires the knowledge of fire risk for short and long periods over small and large areas. This in turn requires the establishment of a robust method for fire risk assessment. According to relevant literature (Kaloudis et al 2005; Chuvieco et al. 2023), the key dimensions for conducting a fire risk assessment, considering the incorporation of the spatial and temporal variability of fire risk, are the following: a) **Hazard**, b) **Vulnerability** and c) **Exposure**, as summarized below:

Fire danger/fire hazard: Fire danger and fire hazard assessment consider two main parameters, fire ignition and fire propagation. Ignition can be classified into natural ignition and human caused. Fire propagation is closely related to fire spread and refers to the probability that the fire will spread over an area towards a specific direction, providing information about the fire intensity and rate of spread. Specific weather data, vegetation (fuels), topography, moisture status, are necessary to estimate the fire spread (Kaloudis et al., 2005; Prestemon et al., 2005; Chuvieco et al., 2023). Nolan et al. illustrate in Figure 25 the link of forest flammability and plant vulnerability to drought, using a so-called 4-switch model with the prerequisites for a wildfire to occur and spread (fuel load, fuel dryness, fire weather, ignition). Propagation (Rothermel, 1972; Rothermel, 1983; Chuvieco et al., 2023) differs from spread, in the sense that it provides a more generic understanding of the study area and the relevant prevailing conditions.

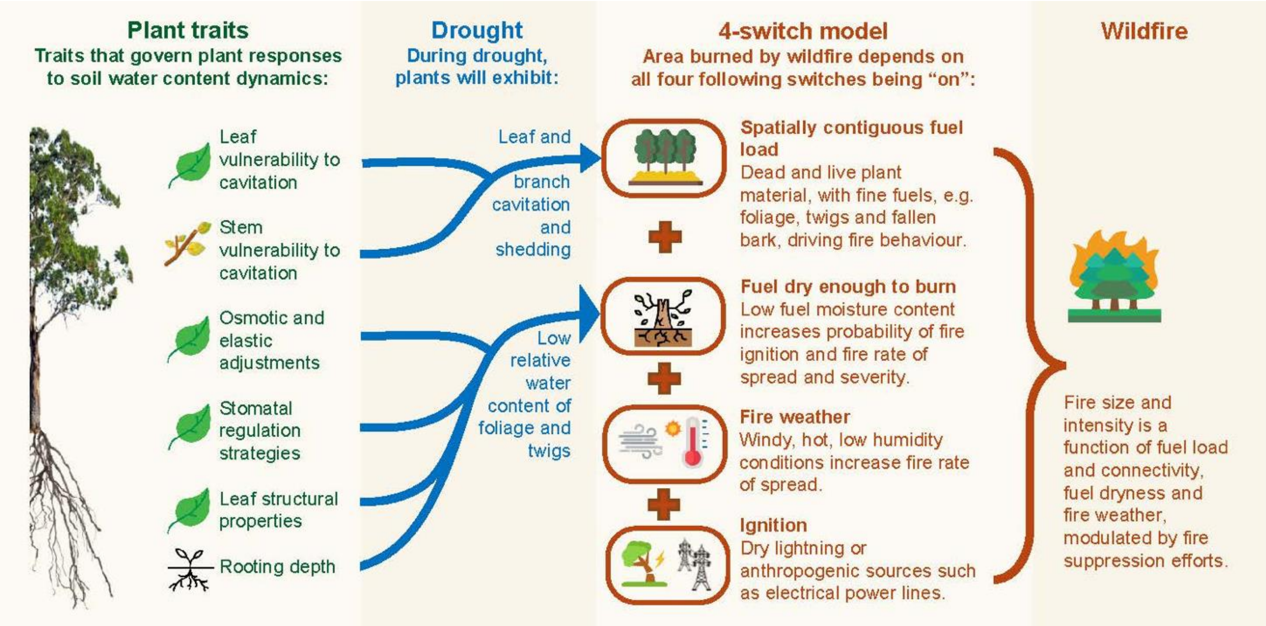

Figure 25: Linking forest flammability and plant vulnerability to drought (Source: Nolan et al., 2020)

For long-term fire risk assessment, the **fire severity** probability over long periods is essential. Fire severity refers to the fire characteristics and represents the magnitude of a fire event or a class of fires and gives a measure of the effort needed for fire extinguishing and, consequently, the size of the threat (Kaloudis et al., 2005). Fire characteristics are determined by three main environmental factors, namely fuel (vegetation), weather conditions, and topography (Rothermel, 1972). Each of these factors includes several variables, for example weather affects wildfires by air temperature and air velocity. Considering that topography does not change significantly over time (some years or decades), what is important is to estimate changes in vegetation (fuels) and weather conditions. Vegetation changes could be extracted from models, as well as vegetation monitoring systems (e.g., refer to Section 5.3), and can be regulated through vegetation management. For weather conditions, past measurements can be used for a long period to simulate future conditions (data from 50 years are needed). Moreover, climate change models can be used for future weather predictions.

The most well-known indices that have also been implemented as an integrated system and are in use, for fire danger estimations, are the Canadian Forest Fire Danger Rating System (CFFDRS) (Van Wagner and Pickett, 1985) and the National Fire-Danger Rating System (NFDRS) (Cohen and Deeming, 1985).

Exposure: This refers to people and assets that are at risk from a potential wildfire. Assets can include structures (e.g., homes, businesses), infrastructure, natural resources, and the environment. Exposure indicates the extent to which people, ecological and economic values that are sensitive to fire are threatened ("exposed"). Exposure as an element of risk assessment can be extremely valuable, especially to WUI areas (Chuvieco et al., 2023).

Vulnerability: Vulnerability refers to the potential damage caused by wildfires on a particular territory, including the losses directly caused by fires but also the ability of the threatened values to recover. It is important to note that vulnerability includes various topics/layers, such as social, economic, ecological, structural, institutional, physical, and can thus be approached from various perspectives. Vulnerability is directly related to resilience (Chuvieco et al., 2023).

Considering the above dimensions and following the suggestions of Chuvieco et al., (2023), the main variables for conducting (wild)fire risk assessment can be summarized as follows:

- Climate and weather conditions (temperature, wind speed and direction, precipitation, relative humidity, etc., both in short- and long-term)
- Topography
- Fuels (vegetation load and structure, composition, moisture content)
- Humans (both in terms of causing a fire and affected by a fire)
- Ecosystem services from which humans benefit (agriculture, water, soil, forest, fauna, timber, etc.)
- Ecological values (benefits for the environment, excluding humans, e.g. biodiversity)
- Resilience (ecological resilience, which is related to plant species and social resilience, which refers to the ability of the community/society to withstand, absorb and recover to the pre-fire status)

Hence, in a nutshell, risk assessment is the integration of the three above mentioned dimensions and should consider a variety of factors, including physical phenomena and human intervention (Chuvieco et al., 2023), as highlighted above. On this aspect, Chuvieco et al., (2023) suggest that such **integrated approach** should include two steps: i) the definition of common integration scales of measurement, and ii) a suitable method to properly weight the importance of each component.

By evaluating the potential for fires in different places (spatial) and at different times (temporal), it is possible to better plan and take specific actions to reduce the risk of those fires happening or spreading, as follows:

- **Risk Evaluation**: Based on the fire risk assessment method, short- and long- term fire risks can be calculated over small and large areas.
- **Development of mitigation measures**: Once the risk has been evaluated, mitigation measures can be developed to prevent and minimize the impact of a potential wildfire. These measures may include long-term interventions, such as fuel (forest and agricultural) management, creating firebreaks, increasing forest resilience, or targeted vegetation removal to reduce the intensity of the fire. At a short-term, the level of fire risk can be used for actions such as raising citizens' awareness, readiness of firefighting forces, and administrative actions for the prevention of fire ignition.
- **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.

Risk assessment good practices:

Chuvieco et al. (2023) illustrated how wildfire risk assessment has been approached by different operational entities. What follows is a review of those covering extensive regions with a long tradition and a wide range of risk conditions.

United States of America (USA)

The risk of wildfires in the USA is assessed using a variety of risk assessment systems and decision support tools. The Wildland Fire Decision Support System (WFDSS) is a well-known system for making decisions during an incident in real time, while the National Fire Danger Rating System (NFDRS) is widely used to evaluate fire danger. Assessing wildfire risk to towns and defining risk at the WUI are both becoming more important. For cross-boundary, cooperative strategic wildfire planning, the Potential Operational Delineation (POD) approach is employed. Additionally, efforts are being undertaken to support safer fire operations and enhance firefighter safety through fire risk assessment. Overall, the USA has a varied range of operational organizations, academic institutions, and decision-making systems that contribute to the evaluation of wildfire risk.

Canada

Significant efforts have been made in Canada related to the assessment of fire risk. The main outcomes are the Canadian Forest Fire Danger Rating System (CFFDRS), which includes the Canadian Forest Fire Weather Index (FWI) System and the Canadian Forest Fire Behavior Prediction (FBP) System. These systems provide critical information for fire management decisions. Fire simulation is being carried out with the Burn-P3 model (Parisien et al., 2005). In Canada, certain fire management organizations consider risk while making decisions, but there is no common methodology used by all organizations. Comprehensive wildfire risk evaluations are still lacking, despite the data being accessible. For the sake of future decision-making and community protection, ongoing research and projects are working on improving fire risk mapping and risk assessment tools.

Australia

Australia has been using a two fuel-specific fire danger system, but a new fuel type-specific Australian Fire Danger Rating System (AFDRS) has been implemented. The AFDRS combines fire behavior models for different vegetation types and uses fuel, weather, and climate data to derive Fire Danger Ratings (FDR) and the Fire Behavior Index (FBI). However, the system currently lacks suitable fuel availability models for certain fuel types. Future developments will include fire ignition, suppression, and impact indices to improve decision-making. Ongoing research aims to enhance the system and incorporate live fuel moisture content modelling and remote sensing data.

Europe

The development of a pan-European Wildfire Risk Assessment (EWRA) (Baetens et al., 2022) has emerged as a response to the need for a standardized approach to address EU policies related to wildfires. The European Commission invests billions of Euros each year in prevention, mitigation, management, and restoration of fire-affected areas. In 2014, the European Court of Auditors requested to establish common criteria for assessing fire risk in the EU. The development of EWRA was guided by the Expert Group on Forest Fires (EGFF) and the European Forest Fire Information System (EFFIS). EWRA assesses the structural risk by considering wildfire hazard, exposure, and vulnerability, with a focus on human lives while also considering ecological and socioeconomic aspects. It utilizes satellite remote sensing data, historical fire records, and weather conditions to generate different components and variables for the assessment. The aggregation of risk components in EWRA follows a trade-off aware approach without introducing weighting. The methodology also accounts for intrinsic uncertainties associated with risk components and integrates multiple model instances to identify high-priority areas at high risk. The next steps for EWRA involve testing, validation, and further research to enhance datasets and methods. Overall, the development of EWRA provides a unified and robust framework for assessing and prioritizing wildfire risk in Europe.

6.2.2 Impact Assessment

Conducting an impact assessment 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 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.

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 local communities. 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), all of which 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 key ways that wildfires can impact an ecosystem:

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 and frequency 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, affecting both richness and diversity, and changes in ecosystem structure and functions. The extent, severity and persistence (duration) 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 functions, including nutrient cycling, water availability, and carbon storage. For instance, 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. Such 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.

6.4 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 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. Especially with respect to 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 landslides.

In particular, 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.

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 steps are involved in the evaluation of secondary damages:

a) Identification of potential (follow-up) 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 involves 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.

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 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. As explained in Section 6.4, the immediate aftermath of a wildfire can be a period of increased risk for soil erosion, landslides, floods, and other phenomena. 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.

In order to decide the restoration efforts in terms of type and extent, dedicated risk assessments after the wildfire's occurrence are important. Hence, short-term restoration efforts involve conducting risk assessments to identify potential risks to the ecosystem and surrounding communities. Specifically, 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, as explained in Section 6.4. Such risk assessment can be based on the probability of an event, such as heavy rain, and the susceptibility of an entity to damage as it is soil erosion that depends on topography and geology. To have reliable risk assessments, specialized models for calculation of the severity of the expected events can be used. An inventory of models covering soil erosion and runoff is included in deliverables D2.4 and D6.2.

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 a potentially dangerous event.

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 types 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 wind velocity when vegetation cover is absent (Germino et al., 2015). Based on the above, the reduction of plant biomass by grazing slows down the ecosystem recovery after wildfires because of the high increase 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 natural regeneration and planting new trees, if necessary, 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. As explained in Section 7, 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 responses from experts in 9 different countries have preliminarily been collected. These represent consolidated responses from multiple experts that were contacted by the SILVANUS pilot leaders in the following countries:

1. Croatia
2. Cyprus
3. France
4. Greece
5. Indonesia
6. Italy
7. Portugal
8. Romania
9. Slovakia

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 the 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 prohibition of grazing by herds of 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

Effective forest governance is essential for mitigating the incidence of wildfires and for sustainable forest management. By implementing fire prevention strategies and creating a common vision among stakeholders, governance plays a critical role in protecting valuable forest resources. Policy-making, education and the assignment of responsibilities for wildfire protection are key aspects of governance in wildfire prevention. While sustainable forest management practices cannot eliminate all fires incidents caused by climate change or human activities, they can significantly reduce the extent of fire damage. It is important to ensure that wildfire prevention is an integral part of landscape planning and forest management, as different organisations or departments may be responsible for these tasks. By adopting a well-structured fire prevention strategy and involving all relevant entities, forest managers can improve their ability to plan for and mitigate wildfires, ultimately protecting forests and promoting resilience (European Commission, 2021; Rego et al., 2018).

7.1 Innovative Governance Models

Innovative initiatives that make a difference, mitigating wildfire risk and providing protection to communities by locally engaging with stakeholders do exist. However, ensuring that the practice of fire management and its associated governance are utilizing innovations as well as science-based findings, is a 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. Good governance practices from around the Mediterranean, highlighting how working locally is critical for efficiency, sustainability and success, are presented below.

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

  Governance aspect: In Portugal, a tool for managing forests at larger spatial scales, responding to the challenging situation of fragmented forest ownership, the Forest Intervention Zones was put in place by law in 2005. Forest Intervention Zones were integrated in the Portuguese legal and institutional framework for forest management and forest fire protection. With most of the area located in central and southern parts of Portugal[22], Forest Intervention Zones represent hundreds of thousands of hectares, potentially increasing profitability of managed forested areas and responding, at the same time, to the need of mitigating wildfire risk.

  Innovation and benefits: This approach, codenamed ZIF, 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).

[22] https://www.icnf.pt/api/file/doc/662f68cc218fc535

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

  Governance aspect: The Association for Forests, Development and Conservation (AFDC) in Lebanon, a 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.

  Innovation and benefits: 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. Forests are being seen as a natural resource that have to be protected against wildfires.

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

  Governance aspect: 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), the 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 results-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 programme. The results obtained are transferrable to other regions, for introducing livestock grazing in wildfire prevention, and offer valuable guidelines for the set up of reliable monitoring systems. 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. 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.

  Innovation and benefits: Monitoring of all RAPCA firebreaks is performed annually, from early summer to autumn, by the paying agency while pre-assessments are also common during spring. Inspectors conduct visual assessments of how much of the individual shrubs have been consumed, as well as of the overall consumption of the herbaceous layer, and evaluate the overall vegetation structure.

Regarding the observed socio-economic results, additional employment was feasible, and it is estimated that the RAPCA approach saves up an average of 63% (and a maximum of 75%) 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***

  Governance aspect: 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). Although prescribed burning is an old method for fuel management, it is still forbidden in Greece. 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.

  Innovation and benefits: 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. The Fire Service of Chios Island and the 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 the Ministry of Environment and Energy have provided all necessary permits for the implementation of the pilot 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.

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

  Governance aspect: 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).

  Innovation and benefits: 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 adopted and replicated in other areas as well.

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

  Governance aspect: 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, were 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.

  Innovation and benefits: 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***

  Governance aspect: 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. The project aimed 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).

  Innovation and benefits: Regarding wildfire risk reduction and mitigation through spatial planning, five governance-related measures were chosen for implementation, according to criteria such as social and political acceptance, and avoidance of time-consuming activities:

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

  b) Measures agreed for enhancing the self-defence 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 the assessment of their fire 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 line 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***

  This 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).

7.2 Links between Forest Landscape Restoration and Sustainable Development Goals

As already highlighted in Section 2, Europe's forests provide a wide range 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., recreational, spiritual, and educational and health benefits) services (Winkel et al., 2022; Holzwarth et al., 2020). Wildfires can threaten lives and livelihoods, affect local and/or national economies, and can cause other potentially long-lasting impacts on people. Apart from the potential loss of human life, wildfires can cause acute and chronic health problems, destruct 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 (Figure 26), as well as the 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 related to human health and well-being (Martin, 2019; Source: Kurvits et al., 2022)

The Global Partnership for Forest and Landscape Restoration (GPFLR, 2013a) outlines Forest Landscape Restoration (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" (FAO, 2022).

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*". It is also important that the Law 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 the 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*"[23].

Restoring ecosystems is also high on the international agenda. The 2050 vision under the Convention on Biological Diversity[24], the United Nations Convention to Combat Desertification (UNCCD)[25], the 2030 Agenda for Sustainable Development (Sustainable Development Goals) and the UN Decade for Restoration[26], 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[27].

In light with the above, scholars suggest that FLR is an emerging concept (Bhattarai et al., 2021) representing 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. As illustrated in Figure 27, the International Union for Conservation of Nature (IUCN) has identified the following links between FLR and specific SDGs[28]:

- 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)

[23] https://ec.europa.eu/commission/presscorner/detail/en/QANDA_22_3747
[24] https://www.cbd.int/doc/c/914a/eca3/24ad42235033f031badf61b1/wg2020-03-03-en.pdf
[25] https://www.unccd.int/sites/default/files/relevant-links/2017-01/UNCCD_Convention_ENG_0.pdf
[26] https://www.decadeonrestoration.org/about-un-decade
[27] https://unfccc.int/sites/default/files/english_paris_agreement.pdf
[28] https://unece.org/fileadmin/DAM/timber/meetings/2019/20191216/Forest_landscape_restoration_pathways_to_achieving_the_SDGs.pdf

Figure 27: Forest landscape restoration (FLR) contributions to the SDGs (Source: IUCN[29])

The EU identifies the economic costs and benefits of the Natural Restoration Law as follows[30]:

"*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".

In Figure 28, FAO and Global Mechanism of the UNCCD (Besacier et al., 2022) illustrate that investments in FLR come from a variety of private, public, and civic sources, and in diverse formats.

[29] https://unece.org/fileadmin/DAM/timber/meetings/2019/20191216/Forest_landscape_restoration_pathways_to_achieving_the_SDGs.pdf

[30] Source: https://ec.europa.eu/commission/presscorner/detail/en/qanda_22_3747

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

Additionally, as depicted in Figure 29, Besacier et al. (2022) noticed that three main types of mechanisms exist in order to restore forest and landscapes: financial, market mechanisms, and individually financed mechanisms.

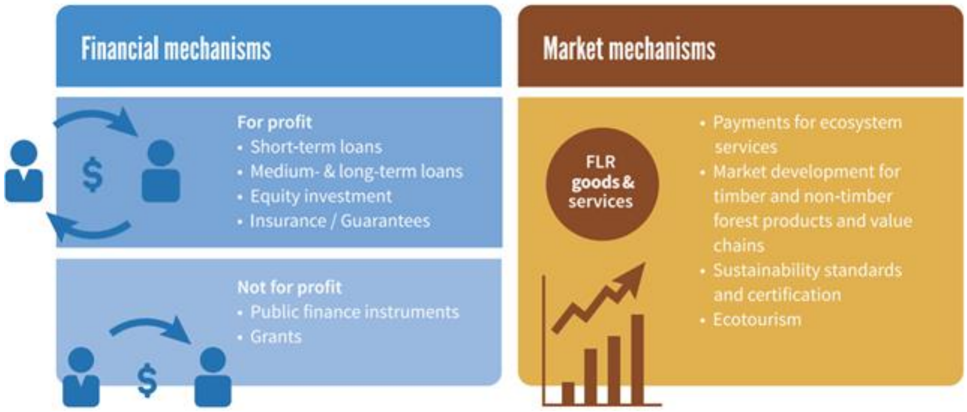

Figure 29: Financial and market mechanisms for forest and landscape restoration (Source: Besacier et al., 2022)

In conclusion, FLR plays a critical role in achieving the SDGs, by providing a wide range of ecosystem services and addressing the impacts of wildfires. FLR aims to restore the ecological, social and economic benefits of forests and landscapes, involving all stakeholders and revitalising the environment to meet the needs of people and nature. Restoration contributes to agricultural productivity, food security, climate change mitigation and adaptation, water security, gender equality and policy coherence. The economic costs of degradation are high, while the benefits of restoration far outweigh the costs. Investment in FLR may come from a variety of sources, including the private, public and civil sectors. Financial and market mechanisms are used to support and finance FLR initiatives. Some specific examples of economic incentives for wildfire prevention and FLR are provided in Section 7.3). Overall, FLR is an integrated approach that is consistent with international policy goals and promotes sustainable development.

7.3 Social Considerations and Economic Incentives for Wildfire Prevention - Strategies and Practices

As the frequency and intensity of wildfires continue to rise, there is a growing need for effective strategies to reduce wildfire risk and enhance fire management efforts. In this context, economic incentives have emerged as valuable tools to encourage landowners, managers, and communities to adopt proactive measures for wildfire prevention and risk reduction.

The policy brief of the FIRE-RES project (Wunder et al., 2023) explores various economic incentives employed in Europe, the Americas, Canada, and Australia, shedding light on their effectiveness and lessons learned. These incentives encompass subsidies, payments for environmental services, value chain labels, insurance risk premiums, liability fees, bonds, and corporate social responsibility initiatives. By examining these diverse approaches, insights can be gained into the potential of economic incentives to incentivize and support fire-resilient practices. What follows is a comprehensive overview of these incentives and their implications for promoting wildfire resilience.

I. Subsidies

Subsidies can play a crucial role in reducing wildfire risk in three ways. Firstly, they can help finance targeted mitigation efforts, such as creating fuel breaks in strategic locations. Secondly, subsidies can support rural production, preventing land abandonment and maintaining working landscapes that reduce the accumulation of flammable materials. Lastly, subsidies can be used to incentivize practices that prevent ignition risks, such as adopting no-burn agriculture. These subsidies can take the form of cost reimbursements, collective grants, or productive investments. Examples include EU programs that co-fund measures to reduce wildfire risk, grants for community-based risk management, and publicly financed infrastructure investments to promote active land management.

II. Payments for Environmental Services (PES)

Payments for Environmental Services (PES) are voluntary agreements between service users, such as municipalities concerned about increasing fire risk, and service providers, such as landowners who lack resources to take risk-reducing actions. PES incentives are more directly tied to the actual delivery of specific actions or services compared to subsidies. In addition to reducing wildfire risk, these practices can also provide other benefits, such as reducing CO_2 emissions through carbon markets, protecting watersheds, preserving biodiversity, or contributing to multi-objective agri-environmental schemes. PES schemes can also compensate non-landowners, such as pastoralists, who provide targeted grazing services. PES schemes are, for example, being tested in fire affected areas at pilot sites in Portugal (Santos et al., 2019).

III. Value Chain Labels

Value chain labels incentivize the production of agricultural or forest products that contribute to mitigating wildfire risk. These labels certify that the products are produced in a way that keeps landscapes open and prevents the growth of vegetation that could fuel wildfires. Consumers who are aware of the increasing wildfire risk may be willing to pay a premium for these certified products. The extra income generated from the premium can then be used to support producers in their ongoing risk mitigation efforts. Additionally, value chain labels can provide social recognition to producers who play a role in preventing wildfires. However, there is limited empirical evidence on the outcomes of these labels, and it is unclear if consumers are willing to pay higher prices for them. The certification standards vary as well, and it is unclear if producers are only paid for maintaining the status quo or also for actively implementing new fire-wise strategies. Overall, value chain labels are still in the early stages and have had limited impact on local markets, so their potential as standalone strategies for wildfire resilience is uncertain.

IV. Insurance Risk Premiums

Through differentiated premiums, homeowners who have implemented risk reduction measures, receive discounts, that can serve as an incentive for individuals to actively reduce their risk. However, this approach has been less commonly applied in Europe compared to California. The main reason for this is the high transaction costs associated with differentiating and monitoring compliance with risk reduction measures. Insurers may perceive these costs as too high compared to the perceived aggregate risk levels. Additionally, the public sector often steps in to cover damages in Europe, which can undermine the implementation of differentiated premiums. Despite the challenges, differentiated premiums have the potential to encourage homeowners to take proactive measures to mitigate risks, thereby reducing the overall impact of disasters.

V. Liability Fees

In some parts of the world, landowners and users may face consequences if they fail to meet their legal responsibilities in preventing wildfires. This may include fees, fines, and compensations for any damage caused by their actions. These measures are often used as disincentives and can be more easily enforced on wealthier landowners compared to smaller landholders.

VI. Bonds

Environmental Impact Bonds are a type of investment focused on environmental action. These bonds are similar to PES, but with a key difference. Instead of land managers receiving payment after the action, they receive funds upfront as debt finance. The land managers provide services such as wildfire risk reduction, and if they achieve the environmental target, investors receive their initial investment back with a return. The Forest Resilience Bond is an example of this type of bond used in the USA to finance large-scale forestry operations. The success of these bonds relies on the commitment of service beneficiaries to make future payments.

VII. Corporate Social Responsibility (CSR)

Private companies can support fire resilience through Corporate Social Responsibility (CSR) projects by providing funding to local organizations for on-the-ground activities. For example, Ryanair, an airline carrier, funded post-fire restoration in Portugal as part of their environmental commitments to reduce CO_2 emissions. Involving private companies in fire risk reduction can create new funding opportunities, as long as the focus is on making positive impacts on nature beyond simply offsetting carbon emissions.

In conclusion, the effective distribution of funds for fire management functions necessitates a comprehensive and balanced approach that considers the diverse range of economic incentives available. While subsidies, payments for environmental services, value chain labels, insurance risk premiums, liability fees, bonds, and corporate social responsibility initiatives have shown promise in incentivizing wildfire prevention and risk reduction, there is still a need for further exploration, evaluation, and adaptation of these strategies to suit specific contexts. It is recommended that policymakers, landowners, and stakeholders collaborate to identify the most suitable mix of incentives, taking into account local priorities, resources, and challenges. Additionally, ongoing research and monitoring should be conducted to assess the long-term effectiveness and socio-economic impacts of these incentives. Continuously refining and implementing economic incentives could lead to a more resilient and proactive approach to fire management that benefits both communities and ecosystems.

Moreover, a better understanding of the social aspect of fire management is needed to implement sustainable wildfire projects and effective initiatives in the long term. Educating people about forest fires through pragmatic learning approaches will ensure a better understanding of the phenomenon, increase knowledge dissemination, and contribute to forest fire prevention. Awareness-raising campaigns with emphasis on how to prevent forest fires and how to prepare their homes and themselves for such an event, help citizens to be informed, prepared and safe.

7.4 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 FLR. Chazdon et al. (2021) listed the three most common governance challenges for FLR, based on 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). They could also generate unaligned policies, as well as 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, 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 economic development can disadvantage ethnic minorities and marginalise the 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 effective management (Kowler et al., 2016).

2. Environmental and social heterogeneity

Although considered as a positive approach, multistakeholder involvement may lead to challenges for collective action in FLR, in some cases impeding progress and resulting into conflicts. Examples of stakeholders in such governance schemes include local governments, civil society organisations, private companies, rural communities, informal or traditional structures, etc. (Chokkalingham et al., 2005).

Relevant studies (Baynes et al., 2017; Chang and Andersson, 2020) confirm that the most effective and successful forest restoration programs have relied on the involvement of stakeholders from 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 key requirements to consider for the successful development of government models for FLR (Mansourian and Sgard, 2020; 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 links, a dialogue among institutional and policy bodies, at multiple levels, is fundamental for ensuring 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). The poor understanding of social networks and stakeholder relationships within landscapes (Buckingham et al., 2020), and the adaptation of bottom-up participatory approaches to 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, the role of governance for FLR is particularly important for the following reasons (Mansourian, 2023):

a. New value is 'generated' – letting the landscape return 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 the landscape (scale) 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 market orientation, that led to three governance trends, namely:

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

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

To highlight the key principles 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 governance models are discussed. This serves as an indicative and non-exhaustive list, since the challenge is that there are actions on the ground, but few reports and studies that document the results achieved.

SUPERB Project[31] 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. The SUPERB network 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 aims 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[32], Spain, will involve the plantation of climate-adapted, mixed species to create corridors to support brown bear migration. That specific land suffers from recurrent wildfires and abandonment.

SUPERB Project restoration approach in Aquitaine, France[33]

Pine plantations in Aquitaine, France, are endangered by forest fires, wind, and pest outbreaks. To increase restoration processes to one of the warmest regions in France, the SUPERB project will be planting 10km of broadleaved hedges for restoration purposes in an area of intensive maritime pine plantations, thus creating a mixed forest that provides habitat for native biodiversity and boosting natural defense mechanisms against disasters. Green barriers will prevent the expansion of climate-related disruptions, wind-induced harm, wildfires, as well as the infiltration of indigenous or non-native pests. While broadleaved hedges can still burn in wildfires, they exhibit reduced fire characteristics, such as shorter flame lengths and less energy at the frontline. This makes them suitable as pre-prepared sites for firefighting efforts. Their effectiveness in aiding fire control is enhanced when the hedges are of adequate width and are accompanied by planned access routes for firefighting teams. At the same time, the project builds a solid network of important local and regional stakeholders that agreed on supporting project activities, including nature conservation NGOs, forest owners' associations, and others, ensuring broad support for restoration from the society.

[31] SUPERB: Upscaling Forest Restoration - SUPERB. Retrieved from https://forest-restoration.eu

[32] https://forest-restoration.eu/demo-area-castille-and-leon/

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

Restoration After Fires in Mediterranean Forest Landscape, Portugal

To address the extensive and frequent forest fires that Mediterranean woodlands have faced over recent decades (Moore, 2005), WWF Portugal, a local NGO, in collaboration with Associação de Defesa do Património de Mértola (ADPM), has devised strategies for rehabilitating fire-ravaged forests. These efforts encompass a range of measures, including:

- Using Geographic Information System (GIS) based assessments to analyse soil degradation and erosion risks in different landscape parts.
- Evaluating fire frequency within forest cover and mycorrhizal soil presence across habitat types.
- Investigating the socioeconomic implications, including forecasting productivity losses, and gauging the potential for forest use abandonment and rural population displacement.
- Planning techniques for managing burnt vegetation to prevent degradation and encourage natural recovery.
- Undertaking active restoration within landscape zones vulnerable to soil erosion and showing minimal or no initial natural regeneration. Whenever feasible, a promotion of planting is recommended, combining root-sprouting species like evergreen oaks and small trees, such as strawberry trees, myrtle, and mastic trees with leguminous shrubs.

The Forestry Act[34] in Sweden

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

The Forestry Manual[35] 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 situations, such as droughts, wildfires, bark beetle crisis, etc. To address such risks, timely intervention is crucial. The basic information regarding the actions to confront and reduce risks, and restore the landscape is often unknown to forest owners, who often lack sufficient funds to use 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 to for possible recommendations, solutions, and restoration programmes, and more generally to collect all the necessary information sources in one place. Furthermore, the manual is an opportunity to share knowledge between the two sides of the border and to compare practice and legislation. To further 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 valuable information and recommendations regarding habitat, tree species, threats, property sizes, etc., in terms of prevention and forest recovery measures, including the financial and economic aspects of individual measures.

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

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

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, has proposed a major investment in the restoration of forests, grasslands, and watershed, to protect the American West. The Protect the West Act[36], 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[37]:

- establish an Outdoor Restoration & Watershed Fund as a support tool 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 money for landowners and local governments by investing in wildfire prevention and natural hazard mitigation on the front end.

PNDFCI approach in Portugal

The forest and wildland surface of Portugal is the most affected area by wildfires in Europe, with a mean annual incidence of 3% (Moreira et al., 2011; Fernandes, 2013). In addition to the usual economic, social, and environmental damages, the problem of wildfires 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, which has worsened 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, from frequent changes in 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[38]. 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, objectives, priorities and activities. The strategy considers five strategic axes of intervention (Mateus et al., 2014):

[36]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

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

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

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 respective laws and policies;
3. Increased fire suppression effectiveness, through 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 assess the potential of the burned areas to recover;
5. Adoption of an effective organic structure, to enhance agency organization and improve responsiveness actions, carrying out management at regional and national levels.

This comprehensive approach will serve as a baseline (and will be properly adapted) for the case studies of SILVANUS.

8 Discussion and Conclusions

Healthy forests provide a wide range of ecosystem services to society. These range from provisioning (e.g., timber) and regulating services (e.g., climate change mitigation and biodiversity) to cultural (e.g., recreation) and supporting (e.g., soil formation) services. The paradox of fires recognizes that, while wildfires are destructive forces, forest fires can also occur naturally. Fires provide important ecological benefits (Tedim et al., 2016) by promoting ecosystem regeneration, maintaining biodiversity, creating new habitats, and controlling invasive species. They clear out dead vegetation, stimulate seed germination, and support the growth of fire-adapted species, contributing to the overall health and diversity of ecosystems. On the social front, controlled burns and firebreaks help reduce the risk of uncontrollable wildfires, protecting human lives, property, and infrastructure. Additionally, fires can preserve cultural practices, provide recreational opportunities, and generate economic benefits through job creation and property value protection. The use of fire can range from traditional burning practices to highly specialized techniques. However, it is essential to consider local conditions and employ responsible fire management practices to maximize these benefits while minimizing risks.

On the other hand, (uncontrolled) wildfires can cause ecosystem degradation and damage large amounts of wood, potentially turning forests from sinks to net sources of carbon. In particular, 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 tons of carbon, degradation of soil and downstream water quality, disruption of wildlife habitats, environmental pollution, impact on 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 (impact on recreational and educational activities, loss of aesthetic values, psychological impacts, etc.).

Wildfires devastate forests, including agricultural land and human settlements, leading to significant destruction and loss of biodiversity. 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, while 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.

Regarding wildfire policy, the EU, in 2018, after the devastating fires that occurred in Europe, published a set of policy challenges and recommendations specifically driven from and dedicated to wildfires. Continuing its work on measures to mitigate the impacts of forest fires, it published the EU Strategy on Adaptation to Climate Change in March 2021, underlining the need to make adaptation faster, smarter and more systemic. In addition, on July 2021, the LULUCF Regulation set a binding commitment for emissions reduction, for the period of 2021-2030, for the first time in an EU law. In parallel, the European Green Deal includes an ambitious agenda on sustainable adaptation to climate change. The EU Forestry Strategy for

2030, published in July 2021, also layed the groundwork for increased fire prevention and climate resilience of forests, among other topics, building on the forest fire prevention guidelines. The Nature Restoration Law, passed through European Parliament in July 2023[39], is a key tool for adaptation and mitigation, further supporting biodiversity, as nature mitigates the impact of natural disasters, such as floods, landslides, droughts, and heatwaves.

As analysed in Section 7.2, the Nature Restoration Law of the EU 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 that target 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 source (e.g., Winkel, 2013; De Koning et al., 2014; Winkel et al., 2022) suggests that it 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 2.1.3-2.1.4, 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 governments.*

[39] New Nature Restoration Law boosts biodiversity and climate action across Europe. (12 July 2023). Retrieved from https://cinea.ec.europa.eu/news-events/news/new-nature-restoration-law-boosts-biodiversity-and-climate-action-across-europe-2023-07-12_en

- *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 terms of power, wealth, access to resources, and channels of influence. Addressing these issues means building an equal space that promotes dialogue and equal access to 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, 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 interests, and to negotiate on their own behalf.*

Wildfire prevention strategies play a key role in effective, efficient and, thus, 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 risks 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; Tedim et al., 2016). 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:

- the Macro-regional Strategy for the Alpine Region, in the context of which “Action Group 8” published the White Paper “Forest Fires in the Alps” (EUSALP, 2020), containing best practices and recommendations for integrated forest fire management,
- tools and guidelines for improving efficiency in wildfire risk governance, developed in the framework of the European project FIREfficient[40],
- guidelines for Sustainable Forest Management in Catalonia (Bonet et al., 2012), in the framework of the LIFE+ DEmORGEST project[41],
- the LIFE TAIGA project[42], in which prescribed burnings were carried out aiming to increase and conserve biodiversity in the most common habitat type across much of Sweden,

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[40] FIREfficient Project | Lessons on Fire. https://lessonsonfire.eu/en/community/firefficient-project

[41] Life+Demorgest (2013-2017). https://cpf.gencat.cat/en/cpf_03_linies_actuacio/cpf_transferencia_coneixement/cpf_projectes_europeus/cpf_life_demorgest

[42] Controlled burning in woodlands - LifeTaiga. http://lifetaiga.se/controlled-burning-in-woodlands

- the GrazeLIFE project[43], implemented in 11 European countries, evaluating the effectiveness of various grazing management models with domesticated and (semi-) wild herbivores,
- promoting locally-led sustainable farming and fire management in Ireland[44],
- the FFPE LIFE project[45], aimed 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 programs, operated by the US and EU, respectively, offer detailed Earth observation data that 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.

When considering the increase in forest resilience, it is crucial to take into account the fire adaptive strategies of certain species. Many plant species in fire-prone ecosystems have evolved fire adaptive strategies to cope with and benefit from periodic wildfires (Huerta et al., 2022; Pausas et al., 1999, 2008; Fernandez-Anez et al., 2021). These strategies include serotiny, where certain tree species retain seeds in cones or fruits until exposed to fire, enabling germination in post-fire conditions (Huerta et al., 2022). Others have developed thick bark or specialized tissues that protect against fire damage (Huerta et al., 2022; Pausas et al., 1999, 2008). Additionally, some plants have the ability to resprout after a fire using underground structures like bulbs or rhizomes (Huerta et al., 2022).

These fire adaptive strategies are crucial for post-fire recovery and ecosystem regeneration, contributing to the overall resilience of forests (Huerta et al., 2022; Fernandez-Anez et al., 2021). Mediterranean ecosystems, in particular, are known for their species' adaptations to fire (Balao et al., 2018; Rundel et al.,

[43] GrazeLIFE. (2020). https://grazelife.com

[44] O'Sullivan, K. (2021). Commission publishes guidelines on land-based wildfire prevention - Agriland.ie. https://www.agriland.ie/farming-news/commission-publishes-guidelines-on-land-based-wildfire-prevention

[45] https://www.miteco.gob.es/content/dam/miteco/es/ministerio/servicios/ayudas-subvenciones/nota208_tcm30-87693.pdf

2018). However, the effectiveness of these adaptations can vary, depending on factors such as fire intensity and frequency (Keeley et al., 2011).

Changes in climate and land use have influenced fire regimes in the Mediterranean Basin, affecting the severity, frequency, and extent of fires (Moreno et al., 2014; Pereira et al., 2016). While many species possess regenerative traits like vegetative resprouting and heat-stimulated seed germination, high-frequency fire regimes can lead to species loss and hinder ecosystem recovery (Huerta et al., 2022; Oliveira et al., 2012; Quintano et al., 2015).

To enhance resilience, it is important to consider both the pre- and post- fire conditions of ecosystems (Romero, 2020). The pre-fire condition should support a diverse and resilient vegetation community (Keeley et al., 2011; Ne'eman et al., 2012). Establishing new target conditions that align with changing fire patterns and environmental conditions may be necessary (Romero, 2020). Promoting natural regeneration of forests is crucial, but, in some cases, planting and seeding techniques may be needed to enhance resilience and biodiversity, especially in locations where natural regeneration fails (Romero, 2020; Lamont et al., 2019).

Overall, understanding and supporting the fire adaptive strategies of species are essential for increasing forest resilience in fire-prone ecosystems (Huerta et al., 2022). These strategies play a vital role in post-fire recovery and ecosystem regeneration, contributing to the overall resilience of forests (Fernandez-Anez et al., 2021), but their effectiveness can be influenced fire intensity, fire frequency, and other factors (Keeley et al., 2011). By considering the pre- and post-fire conditions of ecosystems and promoting natural regeneration, resilience and biodiversity in fire-prone areas can be enhanced (Romero, 2020; Lamont et al., 2019).

After a wildfire, not all forests will regenerate in a way that is compatible with the defined 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, 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.).

In a nutshell, 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 (i.e., avoidance of mechanical pressure on forest soils, such as the use of heavy machinery, avoidance of grazing, 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 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, 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 indigenous and 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, in areas prone to secondary disturbances, such as soil erosion, flooding or landslides after heavy rainfall, or at risk due to insect pests and diseases (fungal, bacterial, viral) (Robichaud et al., 2000; Moreira et al., 2012).

Long-term restoration methods, 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, 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 5-step framework that can be used in post-fire management and restoration.

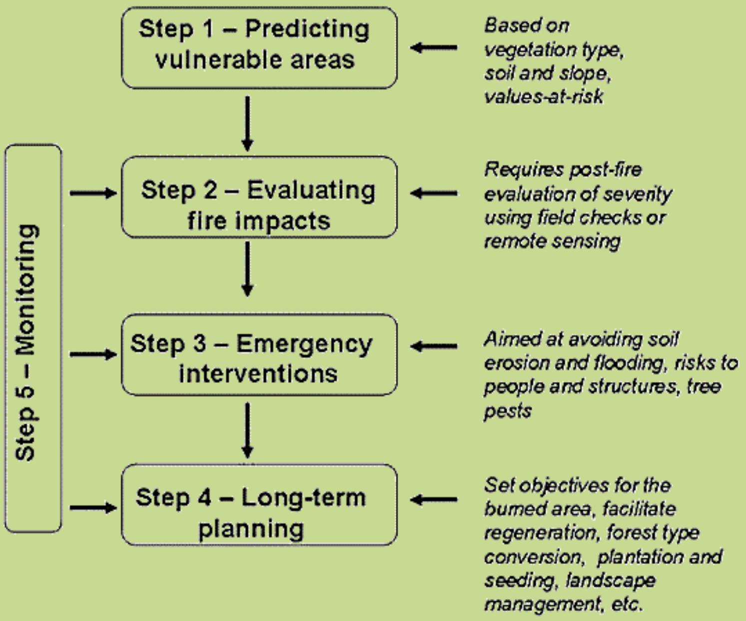

Figure 30: Framework for planning post-fire management and restoration in burned areas (Source: Moreira et al., 2012)

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.

In artificial regeneration, it is crucial to use site-adapted indigenous tree species with appropriate genetic diversity, and high phenotypic plasticity. This ensures that the trees are well-adapted to the specific site conditions and have the best chance of thriving. Additionally, forest stands should be structurally heterogeneous and uneven-aged, fostering a diverse ecosystem with a variety of tree sizes and ages, as well as 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 encouraging 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 indigenous 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; Piqué et al., 2015), the above question remains the main topic.

In contemporary forest management, creating diverse stands with a mixture of tree sizes and vertically complex groups is beneficial for wildlife habitat and forest resilience (Larson et al., 2012; O'Hara et al., 2014; Stephens et al., 2014; Ritter et al., 2023). However, concerns about fire hazards and crown base height often lead to simplified stand structures with uniform tree size distributions (Agee et al., 2005). While these structures increase crown fire resistance, Ritter et al. (2023) found that a homogeneous structure may not be necessary. Instead, they suggest that groups with various tree sizes can be made more fire-resistant by limiting the horizontal connectivity of the overstory or large tree component. By creating a discontinuous overstory layer, heated air can move between tree crowns rather than through them, reducing the risk of crown fires (Ritter et al., 2023; Tachajapong et al., 2009). This allows treatments to maintain complex vertical structures while mitigating crown fire hazards through overstory density reduction.

More specifically, according to Ritter et al. (2023), crown fire initiation is influenced by the interaction between the vertical arrangement and horizontal spacing of trees within a group. They observed that, when small- and medium- sized trees are clustered together but separated horizontally from larger canopy trees, they are unable to act as a vertical fire ladder. This emphasizes the significance of considering both vertical and horizontal tree arrangements in managing crown fire risk. Furthermore, the researchers noted that their findings generally align with established beliefs regarding the importance of structural parameters. They found that reducing horizontal continuity through a decrease in canopy bulk density at the group scale can reduce overstory tree torching and potential mortality, regardless of fuel stratum gaps (Ritter et al., 2023). This highlights the importance of actively managing horizontal continuity to mitigate the spread of crown fires. However, additional research is required to investigate the impact of reduced canopy bulk density on crown fire transition under varying wind conditions. This knowledge gap emphasizes the need for further exploration to better understand the relationship between canopy bulk density, wind speed, and crown fire behavior (Ritter et al., 2023).

These findings provide forest managers with flexibility in designing treatments to reduce fire hazards and integrate multiple management objectives. Managers can restore historical stand structures, enhance heterogeneity, and create stands resilient to various disturbances. It is important to carefully evaluate trade-offs and consult interdisciplinary research to ensure long-term sustainability (Ritter et al., 2023).

In Section 6.2.1, wildfire risk assessment approaches across the world have been highlighted. As already mentioned, the United States have a diverse range of risk assessment systems and decision support tools, such as the National Fire Danger Rating System (NFDRS) and the Wildland Fire Decision Support System (WFDSS). Emphasis is placed on assessing wildfire risk to communities and the WUI, as well as improving firefighter safety. In Canada, there is a lack of a national risk framework, but efforts have been made through the Canadian Forest Fire Danger Rating System. However, comprehensive wildfire risk assessments are still lacking, and ongoing research aims to develop better risk assessment tools. Australia has implemented the Australian Fire Danger Rating System (AFDRS), which combines fire behavior models and data to derive Fire Danger Ratings. Future developments in Australia include incorporating additional indices and improving fuel availability models.

Moreover, in Europe, the development of the pan-European Wildfire Risk Assessment (EWRA) was driven by the need for a standardized approach to address EU policies. The EWRA assesses structural risk by considering wildfire hazard, exposure, and vulnerability, with a focus on human lives, as well as ecological and socioeconomic aspects. It utilizes satellite remote sensing data, historical fire records, and weather conditions to generate different components for the assessment. The aggregation of risk components in EWRA follows a trade-off aware approach, without introducing weighting. The methodology also accounts for intrinsic uncertainties and integrates multiple model instances to identify high-priority areas at high risk. Ongoing efforts involve testing, validation, and further research to enhance datasets and methods.

Overall, the above-mentioned operational entities demonstrate various approaches to wildfire risk assessment, with each region facing unique challenges and adopting different tools and systems. The development of standardized frameworks, such as EWRA, contributes to a unified and robust approach to prioritize and manage wildfire risk. It is worth noting that scientific understanding of wildfire behavior and risk assessment is continuously evolving. Continuous research and improvement of risk assessment tools are crucial for better decision-making, community protection, and effective wildfire management strategies. Ongoing research aims to improve models, data collection methods, and understanding of the complex interactions between climate change, land management practices, and wildfire risk.

Wildfire risk assessment is a valuable tool for integrated forest management approaches. It helps identify areas at high risk of wildfires, allowing for targeted prevention and mitigation measures. By understanding and managing wildfire risks, forests can continue to provide essential ecosystem services, such as clean air, water regulation, habitat for biodiversity, and carbon sequestration. 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 of new governance guidelines may lead to conflicts, but these also present an opportunity to build sustainable forest restoration management. By involving stakeholders and finding compromises, these processes can create a balanced approach that considers both the needs of the forest ecosystem and the ecosystem services it provides. Ultimately, conflicts can drive collaboration and result in a more resilient and sustainable forest management system.

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

- EU 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 mitigating risks and building mitigation and restoration strategies.

Such approaches show how effective governance models may be integrated to traditional restoration policy measures, considering proper planning for risk mitigation, while preserving positive economic, social, and environmental impacts. The adoption of the new strategies may lead to increased forest resilience, improved management of forest services, more effective enforcement of laws and policies, and better sharing of information among heterogenous groups of stakeholders.

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10 Appendix

10.1 Indicative Forests Definitions from EU Member States

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)			