A Holistic Fire Management Ecosystem for Prevention, Detection and Restoration of Environmental Disasters

# TREEADS D.6.1 SOCIOTECHNOLOGICAL Solution for Restoration and Adaptation V1

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|---|---|
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# Revision and history chart

| Version | Date | Main author | Summary of changes |
|---|---|---|---|
| **0.1** | 25/11/2022 | SQD<br>Charemis Athanasios | Draft for review of the structure, Table of Contents preparation |
| **1.0** | 27/02/2023 | SQD<br>Charemis Athanasios | Deliverable v1.0 finalized |
| **2.0** | 23/11/2023 | SQD, ACCELI, GBD, LAMMC, UdG | Deliverable v2.0 with corrections based on Review comments |

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## LIST OF ABBREVIATIONS AND ACRONYMS

| Abbreviation | Meaning |
|---|---|
| **A/R** | Afforestation and Reforestation |
| **API** | Application Programming Interface |
| **BSI** | Bare Soil Index |
| **C2** | Command and Control |
| **CaCO3** | Calcium Carbonate |
| **CCS** | Command and Control System |
| **CEC** | Cation Exchange Capacity |
| **CNNs** | Convolutional Neural Networks |
| **CORDIS** | Community Research and Development Information Service |
| **D&C** | Communication & Dissemination |
| **DL** | Deep Learning |
| **dNBR** | Delta Normalized Burn Ratio |
| **DoA** | Description of Action |
| **DSS** | Decision Support System |
| **DSS-APM** | Decision Support System (DSS) for Adaptive Post-fire Management |
| **DX.X** | Deliverable X.X |
| **EC** | European Commission |
| **EU** | European Union |
| **FIRMS** | Fire Information for Resource Management System |
| **GA** | Grant Agreement |
| **GDPR** | General Data Protection Regulation |

| | |
|---|---|
| **H2020** | EU Horizon 2020 research and innovation framework programme (2014-2020) |
| **HTTP** | Hypertext Transfer Protocol |
| **ML** | Machine Learning |
| **MODIS** | Moderate Resolution Imaging Spectroradiometer |
| **NBR** | Normalized Burn Ratio |
| **NDVI** | Normalized Difference Vegetation Index |
| **NIR** | Near-infrared |
| **PLA** | Polyactic acid |
| **S-2** | Sentinel 2 |
| **SCC** | Seed Container Capsules |
| **SOC** | Soil Organic Carbon |
| **UAV** | Unmanned Aerial Vehicle |
| **UAVsSS** | Unmanned Aerial Vehicle – Supported Seed Sowing |
| **VIIRS** | Visible Infrared Imaging Radiometer Suite |
| **WP** | Work Package |

# EXECUTIVE SUMMARY

The main purpose of the first version of the present deliverable (D6.1, V1) is to propose a holistic framework for TREEADS SOCIO-TECHNOLOGICAL solution for Restoration and Adaptation, based on the technologies and innovations involved, the technical meetings with TREEADS WP6 partners and the D2.7 and the D3.5 for the Restoration and Adaptation Framework of TREEADS.

The deliverable emphasizes on the restoration and adaptation tools and solutions that will be developed within the context of WP6. The set of tools are designed focusing on the implementation of more effective approaches and innovative tools for targeted ecological restoration interventions in burned areas that have specific needs. All tools have been designed based on the state-of-the-art technological advancements with the ultimate goal to support the decision-making processes of the stakeholders/end-users involved, for empowering them to undertake value-added actions in the pilot cases.

The starting point is the great variety of the fire regimes and the impact of climate change in wildfire incidences. These complex effects generate alternate impact on and interactions within the forests or other natural ecosystems, along with several other disturbances, including environmental, ecological, human-interventions and several other stressors. All these factors generate direct and indirect threats on the environmental and ecological integrity.

Building on this basis, the TREEADS Sociotechnological Solutions Framework for Restoration and Adaptation provides not only the core guidelines and principles for effective environmental and ecological restoration, using advanced methodological and technological tools and means, but also includes a holistic view. The framework leverages emerging technologies and state-of-the-art innovations to describe the innovative processes and prototype tools, with the ambition to improve the decision-making process of the stakeholders, facilitate the planning, and provide insights for successful restoration actions.

The postfire restoration framework is rooted in six science-based guiding principles:

- Consider landscape context
- Restore key ecological processes
- Promote regional native biodiversity
- Sustain diverse ecosystem services
- Establish a prioritization approach for management interventions
- Incorporate adaptation to agents of change

# 1 INTRODUCTION - BACKGROUND

## 1.1 PURPOSE AND SCOPE OF THE DOCUMENT

The present deliverable aims to holistically and comprehensively describe the framework approach and the results achieved in the four main tasks that compose the TREEADS WP6. In this sense, deliverable D6.1 has a clear scope of establishing a unified vision of the framework modules for all related Tasks and the developments in progress. The modules for the restoration and adaption after a wildfire event within the context of the TREEADS project form a general conceptual framework. At the same time the progress achieved on the development of the proposed solutions is also described.

Furthermore, the deliverable in hand establishes the roadmap for showcasing TREEADS's innovative technological solutions for restoration and adaptation support of decision-making. The deliverable is the first iteration released of the vivid series of the WP6 deliverables, which will be provided in three versions (v1 up to v3). The second version (v2) will be accompanied by the demonstrator (demo version) which will include the stand-alone tools developed in the context of the WP6. Another important aspect described in the deliverable is the integration of the restoration and adaptation modules and tools within the TREEADS platform.

All, the deliverables of the WP are a live document focusing on the socio-technological solutions of TREEADS for restoration and adaption after a fire occurrence. As a result, all four Tasks involved in the context of WP6 do contribute to the 1st version dually, meaning both scientifically and technologically. In the second iteration of deliverable D6.1, during the evolution of WP6 five monthly WP-level meetings have already taken place virtually for the managerial and technological progress and the 6th has been scheduled. Since the beginning of 2023, the WP-level meetings will turn bi-weekly. Bi-weekly development-focused meetings among the collaborating partners are considered to facilitate the achievement of better alignment on the technological developments and accomplish more solutions that are robust and better integrated. All tasks, which are described in the next sub-sections, will lead to the initial Deliverable 6.1 and its updates D6.2 and 6.3 (See Table 1). Moreover, these deliverables focus on 2 Milestones of TREEADS (See Table 2).

Table 1. List of linked deliverables with D6.1.

| Deliverable | Lead partner | PU/CO | Due Date |
|---|---|---|---|
| **TREEADS SOCIO-TECHNOLOGICAL Solution for Restoration and Adaptation V1** | SQD | Public | M15 |
| **TREEADS SOCIO-TECHNOLOGICAL Solution for Restoration and Adaptation V2** | SQD | Public | M23 |
| **TREEADS SOCIO-TECHNOLOGICAL Solution for Restoration and Adaptation V3** | SQD | Public | M33 |

The progress of all tasks is based on the inputs from the deliverables that have been finalized and submitted so far, especially the platform architecture and the requirements analysed in D2.7 which were delivered in M6, and focuses on the restoration. Furthermore, several pieces of information have been shared and descriptions of data availability and models were discussed in ad hoc meetings and based on the contribution of the partners involved in each task.

Table 2. List of linked milestones with D6.1.

| Deliverable | Lead partner | PU/CO | Due Date |
|---|---|---|---|
| **MS5 First version of TREEADS risk management, services & modules prototype completed** | SIMAVI | WP5, WP6, WP7 | M14 |
| **MS7 The first set of TREEADS Holist fire management Ecosystem prototypes completed** | SIMAVI | WP5, WP6, WP7 | M15 |
| **MS13 The final version of TREEADS Holist fire management Ecosystem prototypes completed** | SQD | WP6 | M40 |

The core purpose of the present deliverable (D6.1, v1) is to focus on developing the overall theoretical and conceptual framework and the methodological approaches for the implementation of the four complimentary tasks involved within the after-wildfire management framework of WP6.

In this document, all tasks of WP6 detail their development process and the next steps in four individual chapters from Chapter 3 to Chapter 6. So, each individual chapter presents the frameworks and the modules for the solutions. Upon these and the requirements, the developments of a demonstrator to showcase the TREEADS Technology Solutions for Restoration and Adaptation has already begun, after a systematic research of the state-of-the art innovations and technologies. Before the beginning of the solutions development, the research part which included a vast number of related articles and the data collection, provides the scientific and technical playground for the development, testing and validation of the final solutions.

The deliverable contains the following information based on the Structure:

- Executive summary.
- Section 1 – Introduction - Background: provides the purpose and scope of the deliverable, as well as a short overview of its objectives and its relationship with other deliverables.
- Section 2 – TREEADS Socio-Technological Solutions for Restoration and Adaptation: establishes a brief literature review of the concept and the general state-of-the-art of the framework, emphasizing the severity and vulnerability of the strategy for

restoration. In addition, it includes a short brief of the risk analysis and planning for the integration of the solutions.
- Section 3 – TREEADS Solution for Assessment, Agroforestry and Soil Enhancements and automation.
- Section 4 – TREEADS Seedpods and soil microbiota enhancement, along with the state-of-the-art solutions and their innovation in restoration processes.
- Section 5 – TREEADS Involvement, coordination, and cooperation of different actors and sectors, where the development of the DSS Methodological Framework is explained.
- Section 6 – TREEADS Pre-fire status model and post-fire automation, where the methodology of Task 6.4 is explained and the development of a state-of-the-art solution using Deep Learning.
- Section 7 - Conclusions of the deliverable and brief presentation of the following steps towards the development of the demonstrator (D6.2, V2).

## 1.2 DELIVERABLE OBJECTIVES

The objectives of the present deliverable are multiple and are fully aligned with those of the WP6, as included in the GA. Each objective is linked with one of the four tasks in total, that structure the present deliverable. More specifically, the defined objectives are summarized as follows:

- The use of Soil quality assessments for evaluating the effects of Wildfires on the health of the soil.
- The utilisation of agroforestry techniques for restoring land back to health by using methods from agroforestry including rotational grazing of livestock and recycling forest waste into biochar.
- The enablement of animal evacuation plan, in the pre-forest phase, as well as the grazing of livestock in general churns up the soil, and spreads manure and seeds.
- The development of a hardware technology for seed container capsules (SCC) using state-of-the-art bio-polymers and mass production technology, as well as the extension of Bioclip technology that enables soil microbiota enhancement.
- The framework for facilitation and handling of the tactical, strategic and operational activities in the event of an alarm and the activation of the restoration processes after the end of a wildfire.
- The description of the framework and a software infrastructure for the expansion of geospatial data infrastructure for the integration, visualization and assessment of all the data involved in the mission, specially developed for data acquired from the ground.
- The development of solutions that include multi-temporal processing methods for improving visualization to complex behaviour processing methods that are taking into account all related communities' attribution and reasoning.

- The ability for comparison of alternate models developed using 1) post-fire imagery and 2) differenced imagery (pre-fire minus post-fire imagery).
- The functionalities for the enablement of public-private cooperation to optimise and accelerate the process of post-fire imagery and differenced imagery and the utilization of the outputs for the support of insurance models for the PRE/POST fires.

## 1.3 RELATIONSHIP WITH OTHER TREEADS TASKS AND DELIVERABLES

This present deliverable is unique for all Tasks included in WP6 and is related to the following WPs, tasks, and deliverables based on the Grant Agreement. The relationships between D6.1 and all interlinked WPs and deliverables are represented in Figure 1. More specifically, the present deliverable is linked with the following work packages and deliverables:

- **WP2 Deliverables 2.7 and 2.8:** WP2 focuses on the concept of understanding the lifecycle of wildfires. The present deliverable in strongly linked with deliverable D2.7 and its updated version D2.8. These deliverables deal with the definition and recording of the specific functional and not functional Requirements in the Restoration and Adaptation phases of wildfires that were applied as an initial input to the current deliverable.
- **WP3 Deliverables D3.1 and D3.2:** Report on Ecological and environmental Models of Wildfires. In general, Task 3.1. compiles and details the necessary studies about ecological and environmental models, thus providing a clear roadmap about the definition and implementation of the TREEADS models and services during the lifecycle of the project. D3.1 entails a comprehensive literature review conducted.
- **WP3 Deliverable D3.5:** The deliverable under Task 3.6 establishes the description of the TREEADS solutions and the overall architecture of the TREEADS platform. More specifically, it includes the initiation of some of the specific back-end modules related to restoration and adaptation and their role in the overall platform solution.
- **WP7 Deliverable 7.1**: Task 7.2 establishes an incremental deployment strategy that follows a step-by-step procedure adapted in this case to different demands in prevention and preparedness provided by end-users.

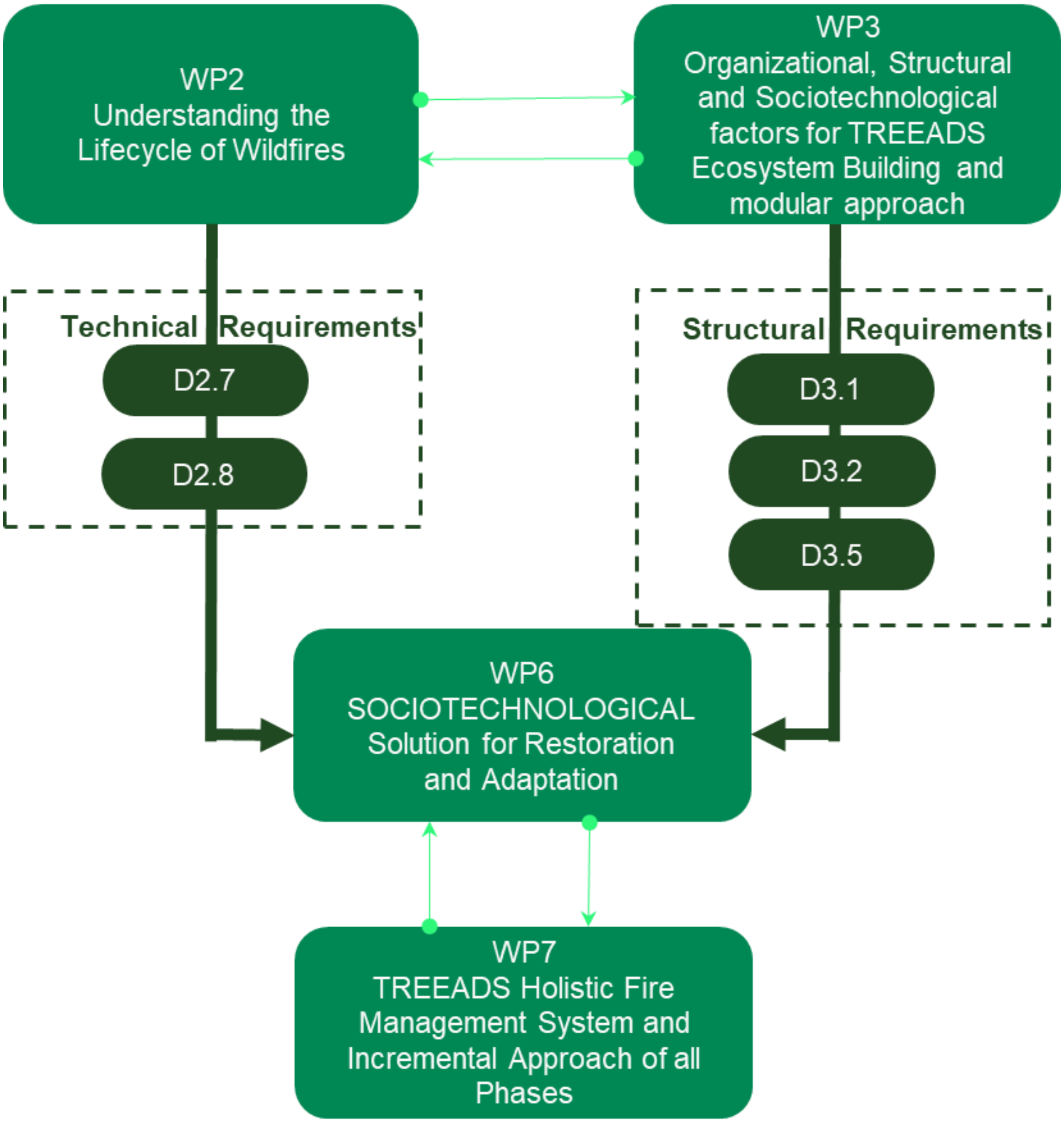

Figure 1: Relationship of WP6 with other deliverables.

# 2 TREEADS SOCIO-TECHNOLOGICAL SOLUTIONS FOR RESTORATION AND ADAPTATION

## 2.1 GENERAL OVERVIEW

The content of the present document is based on the scientific and technological basis of wildfire restoration, aiming to capture the socio-technological features, for the development of the post-wildfire environmental and ecological restoration framework. This framework is holistic and targets the needs received from the eight (8) pilots of TREEADS. The framework has been designed based on core restoration and adaption principles focusing on the recovery and enhancement of environmental and societal integrity.

To this point, there is the need to emphasize the contribution of the pilots' feedback and ideation on the concept and the interaction on issues concerning the national legislation and policies implied by the agencies, as well as their fundamental needs. The feedback has been provided through the WP8 implementations and the national workshops that took place, especially at the end of 2022.

Restoration actions and managerial decision-making in this direction, for burned areas, are subject to multiple factors, which need to be undertaken into consideration, including the ecological impact, social and economic impact, including also possible hazards [1].

To this extend, available information entails a vital role to facilitate decision-makers Managers need to have as much information as possible in the shortest possible time on the environment affected and the characteristics of the fire. The most suitable management alternatives must emerge from the analysis and interpretation of this information. Timely restoration actions, therefore, need to be planned, when a risk of environmental degradation is detected.

The formulation and selection of alternatives for the management of burned areas can emulate an adaptive management process. This allows the system to learn, as new information enters the pipeline, especially coming from the assessment of management actions being performed, is available. This process focusses on the successive time phases, until achieving a global recovery of the affected area. The procedures or techniques to be implemented will consist of a diagnosis of the affected ecosystem, the selection of action alternatives in accordance with the diagnosis, quality control, and the monitoring and evaluation of actions.

Given the critical role of information in decision-making, the following sections will explore distinct processes and phases crucial for efficient ecosystem management. These may include the fire impact assessment, environmental assessment, the emergency stabilization measures, and subsequent phases involving restoration and adaptation.

The main objective of a fire impact assessment is to estimate the extent of damage caused by a fire. This assessment aims to determine two key aspects: the extent of the fire, usually measured as the perimeter of the fire, and the degree of severity of the fire, which encompasses the extent of organic matter consumption by the fire, involving both soil and vegetation [3].

To assess the ecological vulnerability of an ecosystem following a fire, it's essential to determine the specific impact of the fire on that ecosystem. Two primary factors play a pivotal role in this assessment [91]. First, vegetation characteristics and environmental conditions significantly influence both short-term and long-term vegetation recovery rates. The recovery capacity of burned vegetation is primarily shaped by key characteristics of the vegetation, including its reproductive strategy, individual maturity, and overall structural integrity [92]. Second, abiotic factors, particularly those related to post-fire soil susceptibility, play a crucial role. Soil susceptibility to erosion is predominantly influenced by factors such as erodibility, terrain slope, and the severity of the fire's impact on both the ground and vegetation cover [91].

Emergency stabilization phase begins right after the fire is contained and aims to address the most urgent post-fire issues. The primary objective is to prevent or mitigate the immediate consequences, such as soil erosion, landslides, and the loss of topsoil. During this phase, measures are taken to stabilize the burned area [93]. This can involve the installation of erosion control structures like silt fences, straw barriers, and mulching [94]. Hazard assessments are also conducted to identify and address risks to public safety, infrastructure, and water quality.

The restoration and adaptation phase, which can extend over several years, focuses on complete ecosystem recovery, enhancing its resilience to future disturbances (Martin 2017). Restoration is a more comprehensive and long-term process aimed at returning an ecosystem to a condition that closely resembles its pre-disturbance state in terms of structure, function, and biodiversity [96]. Restoration may involve extensive native species planting, ongoing ecosystem health monitoring, and long-term management to support natural processes [94]. It often includes community engagement and partnerships to achieve broader conservation and restoration goals.

In order to improve the structure and functionality of ecosystems that have been affected by wildfires  it is property to carry out rehabilitation measures. The goal of rehabilitation is often to enhance ecosystem services and increase resilience, even though they may not be entirely identical to the pre-fire state. Rehabilitation efforts may have a shorter time horizon, and the emphasis is on mitigating the impacts of degradation rather than achieving a return to the ecosystem's pristine condition. Rehabilitation efforts include reseeding native plant species, restoring riparian zones, removing invasive species, and replanting trees and shrubs as needed [95]. Habitat restoration, the enhancement of wildlife corridors, and water quality improvement measures are examples of rehabilitation. It aims to promote the resilience of ecosystems, reduce the risk of secondary environmental impacts, and support the long-term recovery of natural systems after a wildfire [92] as part of a restoration and adaptation phase.

Adaptation in ecosystem management enhances resilience for effective function in changing conditions. Enhancing resilience in ecosystem management involves multifaceted strategies. It begins with comprehensive research and ongoing monitoring to understand the ecosystem's response to changing conditions.

Implementing adaptive management approaches allows for flexibility in decision-making, ensuring timely adjustments based on evolving circumstances. Alongside this, fostering community engagement and education fosters a shared understanding of the importance of ecosystem resilience [97]. Sustainable management of natural resources, coupled with climate-smart planning in infrastructure development, further fortifies ecosystems against future challenges. Collectively, these actions support the adaptability and sustainability of ecosystems, enabling them to function effectively amidst dynamic environmental conditions [98].

Finally, within ecosystem management, adaptation becomes a fundamental tool for strengthening resilience, especially under increasing climate change impacts. The path to greater ecosystem resilience requires a multi-faceted strategy. It begins with thorough research and continuous monitoring, essential to understand how ecosystems respond to rapidly changing climate dynamics and stressors. This understanding forms the basis for developing accurate and effective adaptation strategies aimed at strengthening ecosystems in the face of increasing challenges posed by a changing climate.

## 2.2 LITERATURE OVERVIEW

The section presents a summary of the current technological innovations (state-of-the-art) for each task of WP6 in the restoration and adaptation phase as well as the expected technological innovations that will be developed in TREEADS.

### Short Overview of Post-Fire Management

In this direction, Scheper et al. (2021) provide a holistic approach for mitigating a holistic post-fire management strategy [2]. Post-fire management strategies, to be successful, need to focus on building up an overview of the identifying current gaps in knowledge needed for effective stabilization, rehabilitation and restoration after fire, hereby taking into account the environmental and socio-economic context in which these fires occur. Figure 2 represents a virtual synopsis of the existing interactions and the milestones that rise in the related literature review.

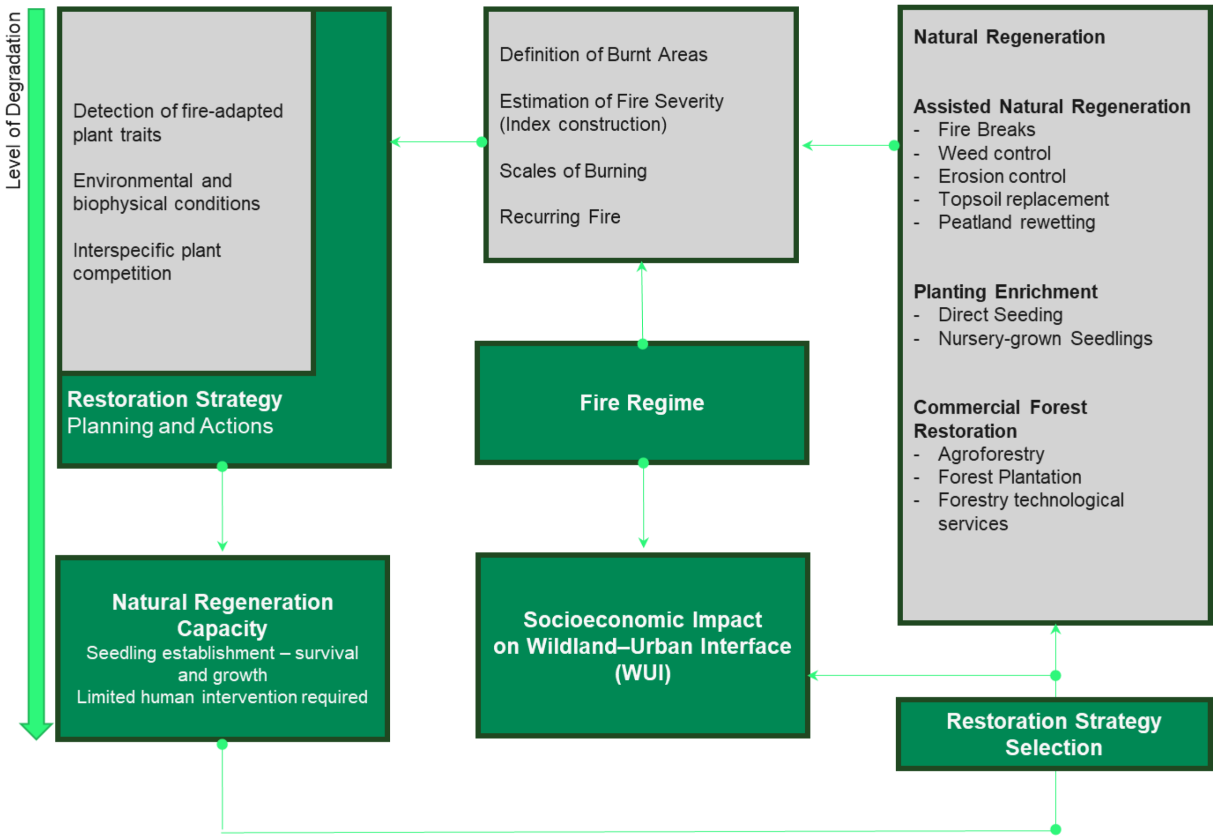

Figure 2: Post-fire forest restoration, created based on the illustration originally published in Scheper et al. (2021).

The above framework provides and documents the necessity of post-fire management strategies, in a post-fire ecosystem dynamics era, to set the scene not only for a successful adaption but also for effective prevention in the WUI ecosystem. In addition, this framework provides insights into a major challenge arise in any post-fire management policy or strategy implementation, the dealing of existing gaps in knowledge and awareness of the local societies. The gaps in which these fires occur are not only of technological nature, but also environmental and socioeconomic1 (see Figure 2 for a visual representation of the interactions). As such, this work can inform post-fire management practice and provides directions for further research in the field of humid tropical forest restoration after a fire.

The European Union has set goals for mitigating the effects of climate change, and in order to achieve these goals, the development of a sustainable bioeconomy is of paramount importance. The development of an innovative bioeconomy is a key strategy towards

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[1] For more information on the socioeconomic factors related with the wildfires in WIU areas and the life-cycle of fires, the reader can revisit the TREEADS deliverable D3.1 for a detailed analysis.

decoupling human progress from environmental decline, with European forestry playing a major part in providing feedstock and services in sustainable bioeconomy paths *(Hetemäki et al., 2017)*.

There is a big body of research that is currently also growing on the potential contribution of European forestry to a bioeconomy in a way that is sustainable. Based on the information from the World Economic Forum, the conservation, restoration and sustainable management of forests could generate EUR 190 billion in business opportunities and 16 million jobs worldwide by 2030[100].

There are multiple projects that are ongoing concurrently with TREEADS with similar goals in mind but at the same time with differentiating factors that set them and the TREEADS project apart. Although small parts of the technologies or the services and functionalities created in this WP6 and the TREEADS project are available, such as the Fire Severity calculated by EFFIS [101], they get new meaning and purpose in combination with the rest of the information, technologies, and services, creating new tools that serve the end-user of the reforestation and adaptation phase.

Based on the pilots, there is a clear demand for the technologies created under WP6 of the TREEADS project. The new technologies developed, the streamlined processes that are created with eventually new tools, provide the end-users and related stakeholders with powerful tools to assist them in the reforestation actions. Their successful adoption will depend on a plethora of factors, such as perceived effectiveness, accuracy, ease of use, compatibility, alignment with policies and others.

To maximize the adoption of WP6 technologies, tools and services, the end-user has been part of the requirements and development process, taking into account the different policies. The tools and applications are being developed with the end-user in mind, both for the hardware solutions as well as the software ones, e.g., providing web solutions that would increase the compatibility with friendly and intuitive UI that enable the ease of use.

The present deliverable focuses on the post-fire restoration phase of ecosystems, but in a holistic view that recognizes the importance of information and the channels of the whole ecosystem. In this context, it targets a larger landscape-scale for biological, ecological and environmental processes and the delivery of a series of innovative services to the ecosystem. This framework is focused on medium- and long-term postfire management, a topic that differentiates it from WP4 and WP5, which focus more on real-time decision-making, for the cases of precaution and effective fire management.

Despite the long-term character and focus of the tasks, the immediate response with the frame of a restoration and adaptation strategy, especially to severely burned landscapes, on pilots and national forests in general, is crucial. Delays might have a negative direct or indirect impact on the ecosystem. This general framework does perpetuate and counteract new social and environmental mindsets, with the involvement of technology for effective restoration and adaption for agencies, communities and the overall ecosystem.

As exposed in the Theoretical framework's section, wildfires are natural and essential forces that drive the composition, structure, function and geographic distribution of ecosystems [3]. Many plants and animals have strategies to naturally avoid or recover after a wildfire, showing a high resilience to fire disturbance. This can be an environmentally friendly and cost-free strategy, especially important when prioritizing possible interventions in a burned area. In those areas where a danger of ecosystem degradation is detected (e.g., soil erosion or lack of regeneration), restoration measures must be taken.

## Severity and Vulnerability as Starting Points

The overall framework has the measurement of fire severity in a burned area as a core component, along with vulnerability. Fire severity represents the degree of fire-induced environmental changes, as measured by the quantity of fuel and organic matter consumed aboveground (vegetation) and belowground (soil) during a fire. Fire severity is about physical and chemical changes to the soil, conversion of vegetation and fuels to inorganic carbon, and structural or composition transformation that bring about new microclimates and species assemblages. So, fire intensity mainly describes the physical combustion process of energy release from organic matter. It is accepted to use burn severity as a synonym for fire severity, but burn severity also includes the effects of fire on the environment [3].

Fire, as a complex disturbance, affects a large list of natural processes (erosion, vegetation regeneration, fauna recolonization, etc.) but not all of them have been directly related to fire severity. The ecological effects of fire are often considered a combination of the fire regime and the ecosystem's vulnerability.

There is no specific consensus on the metrics used to evaluate fire severity, which may vary depending on management needs and objectives. Despite this, general indicators and qualitative variables are most used to establish a quantification of fire severity. They are based on the total quantity of fuel consumed in different strata: tree canopies, understory vegetation and soil's organic matter [3]. Generally, the assessment requires ground observations, inspections and measurements, but for large wildfires (hundreds of hectares) this task can be simplified by using remote sensing. Remote sensing, however, has practical limitations, including the difficulty to measure strata concealed by the canopy and the inability of working at fine spatial resolution.

The evaluation and assessment of fire severity is a critical stage for the posterior application of restoration techniques. From a practical point of view, it is easier to separate severity assessment into two main components, soil and vegetation, as both react differently to fire severity. Fire severity effects on the soil depend on fire behaviour, fire intensity at the soil, combustion duration, and soil and vegetation characteristics.

In addition, fire severity on vegetation is mainly assessed by quantifying the degree of consumption or/and suffocation of foliage and wood. Considering its direct relationship with biomass consumed, the evaluation and assessing of severity is a fundamental variable that provides essential information for prioritising restoration measures and techniques.

Two main techniques are used to assess fire severity on vegetation: field assessment and/or remote sensing. The first one uses specific ground measures that combine different metrics to estimate fire effects on each vegetation strata. Remote sensing is based on the optical spectrum and relies on reflectivity changes of the cover. Both techniques could be combined depending on the robustness willed to acquire and the availability of economic and physical means. No automated procedure currently exists for this task.

Vulnerability is the compound outcome of exposure, impacts on ecosystem services, and adaptability of natural and human systems [4]. The analysis of an ecosystem's vulnerability provides information on its weaknesses as well as on its capacity to recover after suffering an impact. The effect of fire on soil and vegetation increases the risk of water erosion and soil degradation, therefore, during the years immediately after the fire, processes of degradation can be triggered in the most vulnerable zones. The vulnerability will depend on the assessment of a combination of factors relating to both soil and vegetation levels, such as the soil's susceptibility, the slope, the vegetation's protection capacity, the vegetation's recovery speed, or the meteorological conditions after the fire.

## 2.3 DEVELOPING STATE-OF-THE-ART SOLUTIONS FOR RESTORATION

Traditionally, the evolution of modern forestry walks hand-by-hand with innovations in related sciences and technological developments, as well as the general socioeconomic context that facilitates technology diffusion and affects the restoration processes. In the general concept, the impact of evolutionary technologies seems to work as a catalyst in a Schumpeterian "creative destruction" approach that facilitates the restoration and adaption transformation, both operational and digital, in forest ecosystems. This dynamic process generates new more advanced, sustainable and viable structures.

In this section, we will illustrate the core technological and disruptive innovation techniques that work as catalysts and the new opportunities they provide, while at the same time meeting the experience and the real needs of the agencies involved for each pilot, as discussed and formed the requirements for the restoration and adaption. The scope of the state-of-the-art section is to examine and record the existing opportunities based on the best practices already tested with a glimpse into the future and thinking to create new structures, which are more robust. The purpose of the following comprehensive analysis is to identify the current state of research on the concepts of restoration and adaption, and build-up a robust basis for the core knowledge of WP6. In addition, this works as the standardized basis and the development of the tools2. build a secure incident management toolset that will consider all socio-technical factors.

At the core of this process, we can find the existence of information and the availability of data. In parallel, the development of advanced technological solutions enhances an essential role in the better understanding of the knowledge and research advances that are taking place in areas such as biology, biotechnology and precision forestry.

State-of-the-art solutions for restoration require a better understanding of the nature of both the needs in terms of forestry and the technological developments that take place.

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[2] Note that the nature of the present section is to describe the overview of the WP6 areas of focus, while the related scientific and technical literature was included with the Chapters 4-7 for the tools that will be developed for each task.

The technology generates a great impact, both in the present and the future on the forests' sustainability and resilience. The restoration phase after a wildfire is the preparedness phase of the future, not limited to wildfires. Restoration extends the viewpoints not only to fire but also to a range of natural disasters and catastrophes that might occur in the future, for example, floods and rock-falls in urban areas.

As a result, at the core of a restoration process stands the environmental and vulnerability element. So within this context, it is important to stress that technological solutions across all the restoration process, are as important as is the technology itself, and so are the social needs, policies, and institutional settings that drive and define technology development. A solution to be characterized as state-of-the-art in terms of innovations and technologies shall be holistic to create a high impact on the forest ecosystem and all the stakeholders. This requires insights into both the scientific and tech fields' trends and their likely impacts on the forest sector. In addition, tech and innovative prototype developments need to correspond to general environmental and socio-economic development (pulled by demand). So there is a need for the end-users and stakeholders, who have awareness of the local societies and ecosystem participants, to define the needs and a general vision. The needs and strategy will define the technological advancements that need to be involved.

The use of technologies runs nearly for three decades, though there is no convergence even among countries. This is subject to the differentiation in policies implied and the different levels of technologies and innovations uses (mainly awareness). In the context of TREEADS, the major challenge is the alignment of available data, due to the heterogeneity of data availability among the different pilots. The related literature, along with the theoretical background on restoration has been also analysed in D2.7 and partially in D3.5. Specific emphasis is given by the existing research not only on the need for innovative tools, but mostly on new policies, institutional interventions, and deep-minded strategies for the socio-technological transformation of the operations and the societies. Well-informed decisions, based on a complete set of information, could be more effective, as long as they are accompanied by structural intervensions that guarantee the sustainability and resilience of the ecosystems. The three software tools and the seedpods/seedballs solutions proposed within the context of TREEADS generate a new holistic approach and motivation for these necessary and innovative structural interventions taking place in the forest in the pilot countries.

As a result, the role of emerging digital technologies and sustainability practices have an increasingly important role in the restoration and adaption practices worldwide, setting the scene for a new forest landscape. In the current section, we will investigate in a coherent but in-depth way the involvement of digital platforms and modern advanced technological tools that mainly involve Deep Learning and Artificial Intelligence modelling to reconfigure restoration practices and improve the decision-making of agencies dealing with environmental resources concerning forestry, and policy makers across all scales.

The present analysis is based on a coherent analysis of digital restoration platform solutions, mainly focusing on five complimentary needs in the reforestation context:

- Involve state-of-the-art scientific expertise for optimal decision-making

- Developing new channels for information flow for effective supervision and management
- Leveraging digital and tech capacity for efficiency
- Facilitating agents and community participation for co-creation and
- Creating a digital forestry ecosystem

Current developments in digital and socio-technological solutions aim to transform restoration processes and operational models. The strategy in this direction deals with the development of new innovative practices, techniques, and methodologies, establishing new networks and ecosystem pillars and facilitating the data and information flow. The big picture and core of the philosophy of TREEADS place these socio-technological solutions and the tools under development not only as stand-alone solutions that work as neutral solutions for restoration and adaption but most importantly to become catalysts for the developments of dynamic processes within the forest reforestation framework.

# 3 ASSESSMENT, AGROFORESTRY AND SOIL ENHANCEMENTS AND AUTOMATION

## 3.1 INTRODUCTION

This part covers the work that is in developed within the scope of Task 6.1. This includes the scientific research and the steps being taken to produce a first implementation of the methodology to extract soil related indicators for physical or chemical soil related characteristics. These indicators will be utilized for the adapted agroforestry solutions, and will aid the soil enhancement development and automation.

The Technical University of Crete is collecting all related datasets and is working on the development of the methodology and the main architecture for the assessment of soil characteristics using aerial means. In close collaboration with the University of Girona, there is on-going scientific research to determine the variables and the parameters that will be evaluated and will be used as an output for the assessment of the most suitable Agroforestry techniques. SQD coordinates the work package, and as work package leader they have provided support with the data acquisition from other TREEADS tasks (Task 6.4). For the outcome of the soil characteristics, it will be useful also for Task 6.2, and for that reason, LAMMC and GBD have provided the parameters that will be taken under consideration for their task developments.

The soil indicators that will be extracted will be trained by datasets coming from aerial means provisioned in Task 6.4. Nonetheless, there is a developing discussion for the possibility to use datasets coming from the Spanish Pilot. Due to the unavailability of aerial means datasets within TREEADS project (will be available in the first semester of 2023), a demonstration using satellite datasets is under development supporting the research and the investigation in the first steps of the task.

## 3.2 SOIL MONITORING AND MANAGEMENT

### Soil Management in Burned Areas

In burned areas, soil management is essential for the ecosystem's recovery and rebuilding. Wildfires can have a negative effect on the soil, causing erosion, nutrient loss, and structural problems.

Stabilizing the soil after a wildfire is essential for avoiding erosion and sediment discharge. Installing erosion control techniques like biodegradable erosion control blankets, hydromulch, or straw mulch can accomplish this. These steps support soil preservation, moisture retention, and vegetation growth.

Long-term soil management techniques can be used to enhance the health and fertility of the soil once it has settled. These techniques include replenishing the soil with native plants and organic materials, such as compost or manure, and using conservation tillage techniques. Conservation tillage can enhance soil structure, lessen erosion, and boost water infiltration.

Monitoring the soil's pH and nutrient levels can also be used to evaluate whether or not further additions, such as lime or fertilizer, are required for the growth of vegetation.

In general, efficient soil management in burned regions is crucial for the ecosystem's recovery and regeneration. It aids in stopping additional harm, enhancing the condition of the soil, and encouraging the growth of vegetation.

## Soil Characteristics Monitoring

By giving pertinent information about the terrain, vegetation, and soil conditions, remote sensing can be useful for soil restoration. Remote sensing has been used to measure soil moisture, identify changes in soil erosion, evaluate vegetation regeneration, determine the area and intensity of a fire, and keep an eye on possible invasive species. With the help of this information, restoration actions can be planned and put into action, management techniques may be evaluated for effectiveness and changed as needed, and overall soil restoration results can be improved.

As a remote sensing product, precise maps of the impacted area can be produced. These maps can be used to pinpoint important restoration locations, such as those with significant erosion risk or high potential for vegetation recovery. Topographic and soil parameters can be tracked over time via remote sensing. It is possible to identify changes in soil erosion patterns and modify management strategies by monitoring changes in elevation, slope, and soil parameters.

Additionally, it is widely observed that Mediterranean environments are prone to wildfires thus may be particularly sensitive to disturbance. It is possible to take extra precautions to safeguard these locations during the repair process by identifying them.

In conclusion, remote sensing is a potent instrument that may deliver useful data about the state of the land, vegetation, and soil, which can be used to direct restoration efforts and enhance the efficacy of soil management approaches. Remote sensing can help to identify important regions for restoration, prioritize activities, and more efficiently distribute resources by providing precise information about the impacted area.

The focus of this task is the development of an artificial intelligence methodology that aims to identify physical and chemical indicators of soil. As stated above, remote sensing is already in use for the understanding and identification of soil properties. Remote sensing and machine learning are effective techniques that can be utilized to analyse soil properties and enhance land management procedures. Combining the two technologies allows for the analysis of massive volumes of data and the accurate prediction of soil attributes, which are useful to increase soil health, enhance crop yields, and overall safeguard the environment.

This task develops an Artificial Neural Network first using satellite datasets to investigate the effectiveness of the methodologies proposed by the literature. Then, with the knowledge acquired, and when the data from aerial means are available this task aims to produce thematic maps of soil characteristics of higher spatial resolution.

Once trained, the Artificial Neural Network aims to produce thematic images for specified burned areas to aid the implementation of specific adapted agroforestry solutions. The resulting images will be available as a service, through HTTP APIs, which will be developed as part of Task 6.1. Further details of this service will be provided in a later version of this updated document.

For a better understanding of the requirements of this task but more importantly, to provide a robust methodology using State-of-the-art research outcomes, a literature review is being conducted.

Correlated to the subject of the task using specific queries in Web of Science (WoS) and Google Scholar, the keywords attached bellow were used for the first implementation of this review. As can be derived from the keywords, the focus was on the soil properties under investigation and how remote sensing methodologies can extract them. To further enrich the review, publications regarding machine learning approaches for the extraction of soil-related information and related publications to post-fire assessment were added. In total, 52 scientific publications were extracted and these are included in the analysis for the development of the methodological framework of Task 6.1.

Table 3: Task 6.1 Keywords Listing for Literature Research.

| Keyword | Logical Expression | Keyword |
|---|---|---|
| “Remote Sensing” | **AND** | “Soil Properties” |
| | | “Artificial Intelligence” |
| | | “Machine Learning” |
| | | “Artificial Neural Network” |
| | | “Digital Soil Mapping” |
| | | “Soil pH” |
| | | “Soil Erosion” |
| | | “Soil Moisture” |
| | | “Soil Monitoring” |
| | | “Soil Organic Carbon” |

## 3.3 ARTIFICIAL INTELLIGENCE FOR SOIL CHARACTERISTICS MONITORING

### POST-FIRE soil properties assessment

There are multiple approaches to evaluating different soil characteristics used in the Digital Soil Mapping domain. Because of the nature of remote sensing, as we are investigating mostly topsoil properties, it is common to perform indirect measurements (used as proxies) to evaluate different soil properties. Most case studies focus on the identification and the correlation of a soil characteristic, most of the time inferring information from said indices.

Numerous studies have shown that it is possible to identify soil characteristics from satellite remote sensing, and from open-source datasets available such as ESA's Sentinel 2 satellites. Sentinel 2 data are a valuable input for digital soil mapping. E. Vaudour et al. have successfully predicted 8 soil properties (clay, SOC, iron, $CaCO3$, pH, and CEC levels) in representative temperate and Mediterranean agroecosystems [5].

Soil Organic Carbon is also considered an important soil characteristic for the need of soil characterisation and to propose effective restoration properties. For its identification there are multiple studies, suggesting multiple methodologies [6], [7]. It is suggested that remote sensing products are capable of identifying soil pH [7], [8]. This identification is difficult by directly relating the spectral reflectance derived from the satellite images, so it is necessary to use proxies, in the form of spectral variables, combining spectral bands and spectral indices.

Soil moisture is a crucial parameter that can help determine soil characteristics. Studies have suggested that satellite remote sensing can provide an insight into the soil surface moisture [9], [10], [11], even in the form of specific Soil Moisture indices, such as NSDSI [12]. This study also aims to investigate the ability of remote sensing to predict soil salinity. Previous studies have managed to identify soil salinity [13], [14], [15], [16] and produce respective Soil Salinity Indices, such as NDSI [16].

For the first iteration, several indices were collected from multiples studies that appeared to have the most correlation to soil characteristics assessment. Additionally, after discussions with the partners involved in this task the output that is most useful for them is the identification of soil pH, for the optimisation of the seed capsules and their container (Task 6.2).

Thus, from the research contact, the suggested soil characteristics under investigation are the following:

- Soil Organic Carbon (SoC).
- Moisture.
- Salinity.
- Fire Severity.
- pH.
- Iron (Hematite) content.

- Physical Soil Reflectance.

The indices of the characteristics are analytically described in Table 4, along with their formulation and the satellite source that are available. Some of these characteristics can be calculated directly but, in most cases, a proxy or an index correlated to the characteristic has to be evaluated.

Table 4: Task 6.1 Indices under investigation

| Acronym | Name | Formula | Satellite Product |
|---|---|---|---|
| **NDVI** [17] | Normalized Difference Vegetation Index | $NDVI = \frac{NIR - Red}{NIR + Red}$ | **Sentinel 2** |
| **MSAVI** [18] | Modified Soil Adjusted Vegetation Index | $MSAVI2 = \frac{2 * NIR + 1 - (\sqrt{(2 * NIR + 1)^2 - 8 * (NIR - Red)})}{2}$ | |
| **RDVI** [19] | Renormalized Difference Vegetation Index | $RDVI = \frac{NIR - Red}{\sqrt{(NIR + Red)}}$ | |
| **MNLI** [20] | Modified Non-Linear Index | $MNLI = \frac{(NIR^2 - Red) - (1 + L)}{NIR^2 + Red + L}$ | |
| **BI** [21] | Brightness Index | $BI = \frac{(Red^2 + Green^2 + Blue^2)}{3} * 0.5$ | |
| **SI (SCI)** [21] | Saturation Index/(Soil Color Index) | $SI = \frac{(Red - Blue)}{(Red + Blue)}$ | |
| **RI** [21] | Redness Index | $RI = \frac{Red^2}{(Blue * Green^3)}$ | |
| **HI** [21] | Hue Index | $HI = \frac{2 * Red - Green - Blue}{(Green - Blue)}$ | |
| **CI** [21] | Coloration Index | $CI = \frac{(Red - Green)}{(Red + Green)}$ | |
| **BSI** [22] | Bare Soil Index | $BSI = \frac{(SWIR + Red) - (NIR + Blue)}{(SWIR + Red) + (NIR + Blue)}$ | |
| **NDSI** [23] | Normalized Difference Salinity Index | $NDSI = \frac{R + NIR}{R - NIR}$ | |

| | | | |
|---|---|---|---|
| **NSDSI** [24] | Normalized Difference Salinity Index | $NSDSI1 = \frac{SWIR1 - SWIR2}{SWIR1}$ | |
| **BAI2** [24] | Burned Area Index for Sentinel 2 | $BIAS2 = \left(1 - \sqrt{\frac{B6 * B7 * B8A}{B4}}\right) * \left(\frac{B12 - B8A}{\sqrt{B12 + B8A}} + 1\right)$ | |
| **NBR** [3] | Normalized Burn Ratio | $NBR = \frac{NIR - SWIR}{NIR + SWIR}$ | |
| **DSM** | Digital Surface Model | | **JAXA/ALOS** |
| **Slope** | Slope | | |

## POST-FIRE Soil Assessment Methodology

Studies conducted so far, have proposed multiple approaches combining remote sensing datasets and machine learning algorithms to extract soil characteristics. There are two large groups regarding the types of datasets and their classifications.

**Supervised learning:** This type of algorithm uses labelled training data to classify different types of soil based on their physical and chemical properties. Decision trees, random forests, and support vector machines are all examples of supervised classification algorithms. Regarding supervised machine learning approaches, several studies achieved the extraction of soil characteristics [25], [26], [27].

**Unsupervised learning:** This type employs unlabelled data to categorize various soil types according to their characteristics. K-means clustering and self-organizing maps are two popular unsupervised classification techniques. Unsupervised neural networks are popular approaches used to identify patterns of features in data when there are no labels on datasets.

To meet the needs of this study TUC developed the suggested methodology as shown in Figure 3. Two fire events in Greece were selected (a burned area greater than 1000 He) as study areas. For this first phase of the project, open-access satellite products (Sentinel 2 & JAXA/ALOS), have been selected. To extract and perform this preliminary analysis, Google Earth Engine API and TensorFlow Machine Learning library are being used. This framework is developed with a combination of JavaScript and Python programming languages.

Figure 3: Framework for methodology development

As there are no labelled datasets, an unsupervised machine-learning approach will be implemented. In the second stage, supervised approaches (Convolutional Neural Networks - CNN) will be investigated with the addition of the aerial datasets that will be obtained as part of Task 6.4. Deconvolutional networks (DeconvNets),i.e. CNNs that work in a reverse process will be used to identify patterns in soil characteristics.

The full proposed methodology is presented in Figure 4 for the soil characteristics extraction. The methodology describes the process for the data formation and the processes for the raining and testing for the estimation of the final outputs. For the preparation of the input, the 15 aforementioned soil-related indices and products are calculated (Figure 5). The dataset is normalized to values from 0 to 1, featuring 30 m spatial resolution, stacked to a final input of 21 combined bands per image. This sample of 40 sub-regions from each fire event was extracted using a 480 x 480 pixel window. The ratio selected for the splitting of the dataset into testing and training subsets is 75 – 25 per cent. The output will be a single image with the predicted soil characteristic.

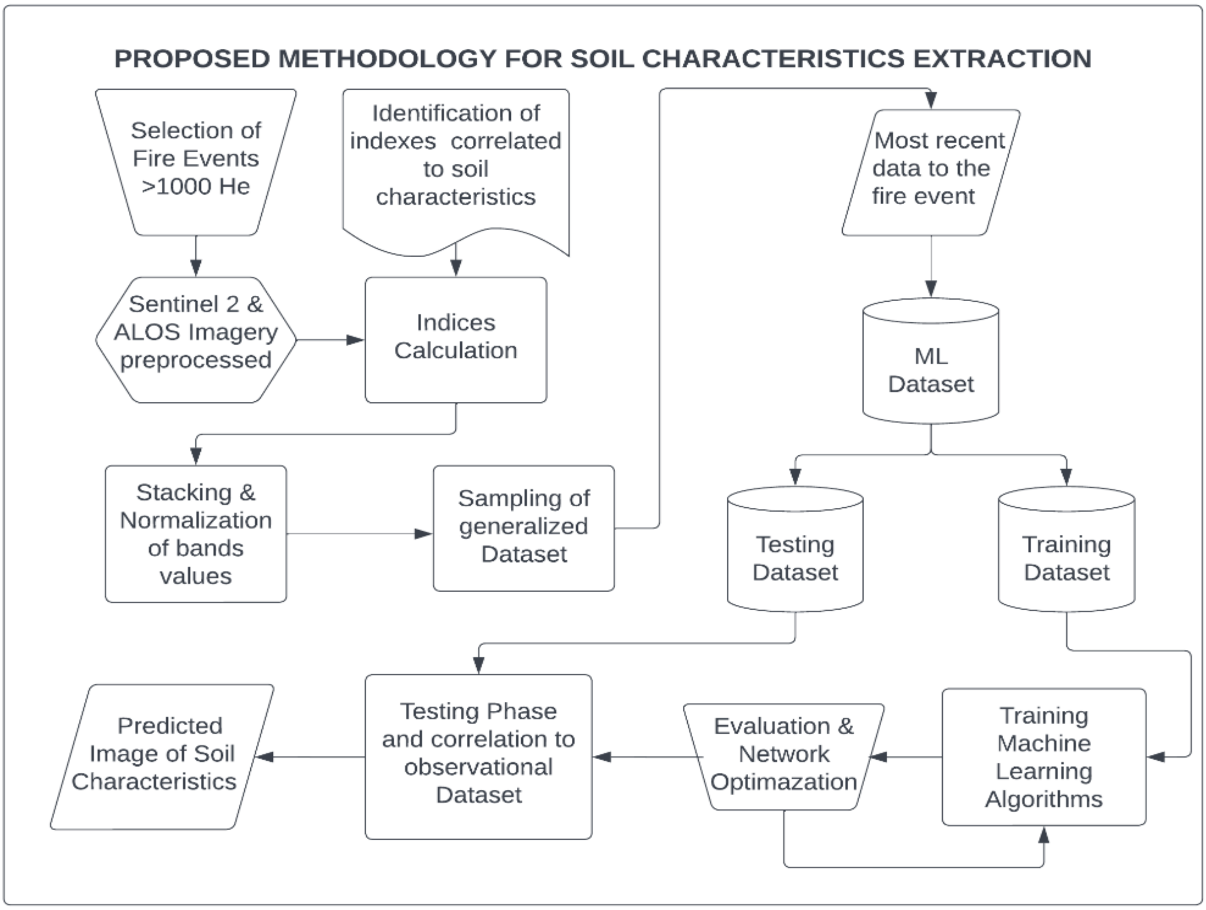

Figure 4: A suggested methodology for soil characteristics extraction.

Source: TUC

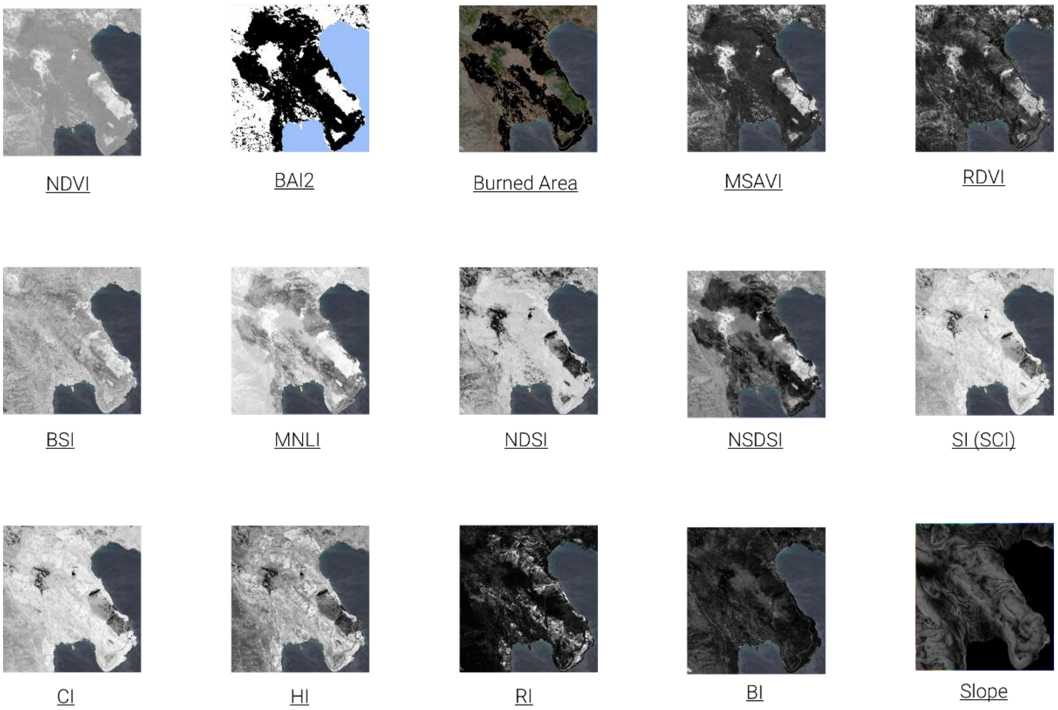

Figure 5: Indices and satellite products used in the proposed methodology.

The dataset is being split into training and testing datasets to feed the select neural network.

At the time this report is being written, TUC is examining the preliminary results and is re-evaluating the proposed Deconvolutional Neural Network (Figure 6).

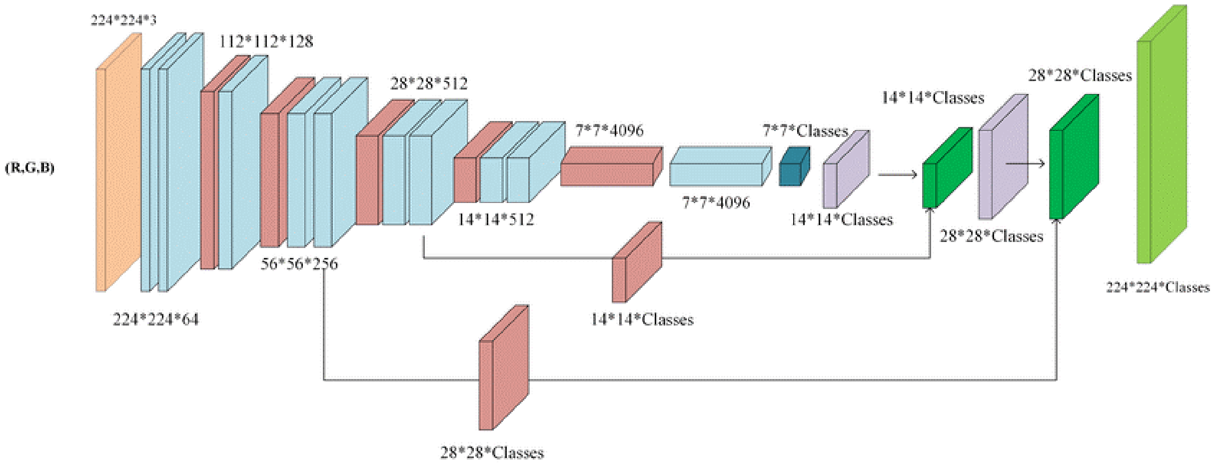

Figure 6: Example of Deconvolution Neural Network (adopted by Piramanayagam et al., 2018).

The evaluation being implemented at this stage is focused on achieving optimal accuracy:

- Optimize Training dataset (e.g., Remove outliers (faulty images)).
- Investigate different maximum pooling (e.g., 480x480 compared to 300x300).
- Investigate different learning rates.
- Change Batch size (e.g. from 8 images to 16).
- Change Network size (add/remove layers).

The focus of this study is to facilitate the methodology and assess the feasibility of remote sensing datasets to extract soil characteristics. This will enhance the model and the methodology with the addition of the provisioned aerial datasets, in the context of Task 6.4.

## 3.4 NEXT STEPS

As described above, if the availability of datasets allows, data from multiple sources will be combined. By integrating data from different remote sensing platforms, such as satellite, aerial, and ground-based sensors, it is possible to collect detailed information on soil properties from a wide range of spatial and temporal scales. Integrating data from other sources, such as weather and/or climate data, can also provide valuable information about the interrelations between soil properties and environmental factors.

For example, by analysing data on precipitation and temperature, it is possible to understand how these factors affect soil moisture and nutrient levels.

Also, it is under investigation the implementation of additional data augmentation techniques that can be used to generate new images by applying different transformations to the existing ones. This might help the model generalize better and improve its performance on new images.

# 4 SEEDPODS AND SOIL MICROBIOTA ENHANCEMENT

## 4.1 INTRODUCTION

The Seed Container Capsule (SCC) is an innovative solution to enable successful reforestation with a higher seedling survival rate compared to state of the art solutions while diminishing the total system costs. These improvements are a result of the innovations in the technical and functional aspects of its clever design described in the following sections.

Task 6.2 is strongly linked with the previous Task 6.1 in many aspects. In addition, faces a number of serious challenges of modern forest restoration management. In many cases after the occurrence of a wildfire, the restoration processes are difficult to be implemented, while at the same time, serious challenges arise for agencies. The reasons for such a case are numerous, such as the effects of urbanization and urban sprawl, land abandonment, the rise of the number of unmanaged forests, and changing climate conditions. All these factors not only contribute to the emerging and growing risks of wildfires, but also to the uncontrolled spreading and burning with greater intensity which makes successful restoration more difficult as this process takes a long time.

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### State-of-the-art for Seedpod and Soil Biodata Enhancement

“Rapid upscaling of afforestation and reforestation (A/R) activities are required in many areas worldwide, especially in the most biodiverse biomes, such as tropical moist forests and other regions affected by climate-type forest disturbances (e.g., extreme wildfires), given the ongoing global changes that are partially caused by unsustainable anthropogenic activities, such as fossil fuel consumption and land-use land-cover change” [28].

As it is very important to choose the right reforestation approach for specific scenarios a vast variety of different technologies has evolved. These technologies should be understood as both complementary but also competitive to each other (depending on the scenario). With each new problem that arose, new technologies were introduced to provide better reforestation results. Still “current tree planting strategies are not cost-effective over large landscapes, and suffer from constraints associated with time, energy, manpower, and nursery-based seedling production” [28].

One of the broadest used solutions is the planting of young tree nurseries either by hand or a machine. Even though this technology can be considered rather effective it is very time and cost-consuming. Especially in hard-to-reach areas, this kind of approach is limited due to its need for manual labour [29]. Therefore, technologies that rely on the usage of an unmanned aerial vehicle – supported seed sowing (UAVsSS) became popular. They promote rapid, cost-effective, fast, and environmentally friendly reforestation by just dropping seed balls in the area of interest. Recently, studies observed the true success of this kind of UAVsSS by analysing the germination rate of the released seeds. They concluded that ”[t]he establishment of seedlings was found to be limited by numerous factors (such as humidity, solar exposure, [winds, heavy rains] and predation) that affected the efficiency of the seed dispersal, germination, and growth" [28]. True germination rates are to be considered as low as 4 %. That is why most companies promoting their UAVsSS commonly emphasize their efforts on the number of released seeds rather than the true result of established trees [30].

Given this situation, there is a significant gap between tough and hard-to-reach areas especially as to be expected in post-wildfire areas. Typically, a burned area is large compared to commercial forest reforestation and the conditions are to be considered disadvantageous for the establishment of new trees. For these reasons, planting young trees or the application of seed balls is not to be considered promising. That is why TREEADS is promoting a technology specially designed to comply with these challenges.

## Innovation and Competitive advantage of the SCC

As described in the previous chapter, there are no effective and efficient solutions existing to comply with the expected conditions of post-wildfire areas. That is why Global Biodesign (GBD) developed in alignment with Lithuanian Research Centre for Agriculture and Forestry (LAMMC) requirements, the adaptations needed for a seed container capsule (SCC) for aerial release and post-fire conditions. The SCC is specifically designed to tackle all the above-mentioned challenges and hence provide the most cost-efficient and reliable reforestation. To accomplish this performance, the SCC is divided into three sections, each designed precisely to serve the overall goal of providing the most secure reforestation technology available.

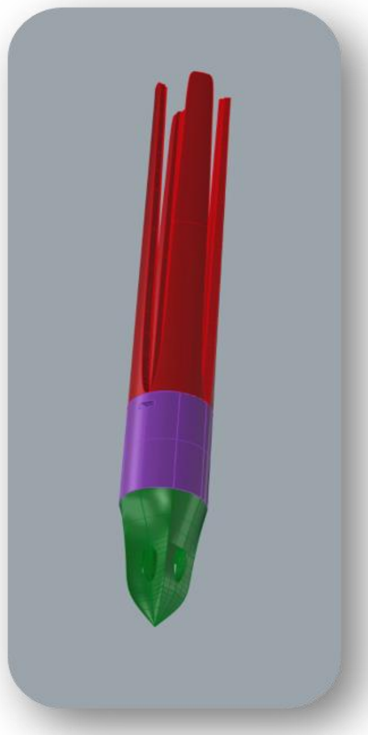


Figure 7: SCC design with its three sections

In Figure 7, the 3 sections with different functionalities are shown. The combination of these functionalities in this particular order and shape is the key element that enables the SCC to achieve top efficiency while diminishing the system costs.

For more simple comprehension, the SCC sections are differentiated by colours. For each section, the functionalities and advantages are going to be explained below. It is worth mentioning that most of these features are the ones to be claimed in the patent application and therefore confidential.

**Section 3:** Spike animal protection + shadow and heat dissipation.

**Section 2:** Soil enhancer & seedling container + cap holder.

**Section 1:** Fixing + rooting tunnels + hydrogel cap.

Section 1: The aerodynamic tip enables deeper penetration into the humid lower layers of the soil. The angular shape of the tip with columns (by the side of the rooting tunnels) helps fixing the SCC in the pre-selected position (hotspot). This functionality is highly desired because the installation of these devices is done in the rainy season, and each device must stay in the desired hotspot (preventing it from being washed out) so that the designated tree species grow in the programmed location. Therefore, the SCC technology enables biodiverse reforestation where it can be ensured that complementary species will be next to each other in a precise location and specially selected according to their needs (next to a river, on a slope, etc). Also, this system aims to help the reforestation in difficult access areas such as slopes, where seeds can be easily washed away unless a special device such as the SCC is used. The rooting tunnels are side holes in the tip which makes it possible for the roots, seeds and microbiota to access the humid underlayer of the soil. These tunnels can be open or slightly covered by a thin wall of biopolymer (which degrades faster than the thick walls and also could break open at the impact of the SCC into the soil). Also, the inner shape of Section 1 is designed to hold a hydrogel ball that works as a cap for the whole seed + soil content, preventing the falling of the content throughout the rooting tunnel holes. The hydrogel can provide extra humidity to the soil enhancement composition and works as a buffer for the dry periods in between the rainy days.

Section 2: This part refers to the container. It is specifically designed to work with the launching mechanism and to provide a strong shape to the SCC. Furthermore, the container can hold up to twice the minimum specified amount required by LAMMC. This amount is precisely adjusted so that there is a maximum probability of successful germination from each SCC. This is to be considered one of the main aspects of reforestation, as the forest pattern is precisely planned, and a failure of growth could decrease the overall reforestation activity. Depending on the final consistency of that preparation, section 2 of the SCC is to be designed to provide a fixation for an upper cap to prevent content from falling from the SCC while being launched.

The SCC content is composed of three main components (developed by LAMMC), that may be adjusted based on the requirement of the specific site/location. Firstly, tree seeds are selected based on the specific requirement of the reforestation site. A certain number of seeds will be placed in each SCC depending on the species' average germination rate to ensure that each SCC bares at least one seedling. The SCC could be filled with single-species seeds, or seeds of multiple species or the percentage of SCCs with each species could be based on the percentage of different trees in the area. That would allow for the most biodiverse option. Tree seeds would be selected from the local seed orchards or similar entities to ensure that no non-local species or genotypes are introduced and to ensure the best possible adaptation to local conditions. Secondly, the SCC will contain a small amount of soil that will create a favourable environment for seed germination by regulating temperature and humidity. The soil also acts as a binding agent to all of the components in this mixture. Potentially local soil can be used to further ensure no outside intervention. Furthermore, the soil contains all the necessary micronutrients and organic matter for both the seedling in the initial stages of growth before it reaches the soil through the root holes of the SCC and the third component, which is the microbiota. Soil microorganisms are a key aspect necessary for plant growth, as they make the nutrients and microelements in the soil bioavailable to plants [31] [32]. The addition of microorganisms known to promote tree growth and health is the innovation that can potentially make reforestation in this manner more effective than simple direct seeding, but more cost and labour effective than using nursery-grown seedling planting [33] [34]. Without them, reforestation may take significantly longer and be significantly less successful [35] [36]. One of the negative effects of wildfires may be the damage done to the soil microorganisms [37] [38]. Thus, to ensure the survival and wellbeing of the new trees we will add selected microorganism blends (that are commercially available for ease of access) at certain concentrations. The effectiveness of this microbiota enhancement will be tested before under greenhouse conditions and determined based on the effect they have on selected model tree species [39] [40] [41]. Tree growth parameters and biochemical parameters associated with adaptability in disadvantageous situations will be measured [42].

Section 3: Finally, section 3 provides two main performance advantages. First, the spike and feather design serve as a design feature to enhance a straight flight while being launched. Secondly, the design promotes different safety & protective features, that can be described with the following:

The spikes work as “parasol”: They provide sun insulation protection as they project shadow onto the surface of section 2. Explanation: To keep the preparation as humid as possible, is highly desired for the safe development of both the SCC and the soil-microbiota–seed mixture (which needs to stay humid to optimize tree growth).

The spikes work as “radiators”: They make it possible to irradiate the heat received in sections 2 and 3 by the sun. Explanation: The thin and beneficial ratio of surface to volume, makes it possible for section 3 to disperse that received energy by radiation.

The spikes work as “braking arms”. They prevent soil (of the surroundings where the SCC is inserted) from getting into the section 2 main container. This is useful to ensure the correct development of the seeds by keeping them at the desired/ideal burial depth.

The spikes work as “protection”: They will prevent predation from larger animals such as birds. They make it difficult for predators to access the main container with the seeds, keeping them sheltered.

The spikes may also work as a “deterrent”: The spikes can be embedded in deterrent substances such as pepper solutions, which will ward off bigger animals (such as squirrels, mice, or wild pigs). This can be considered as an additional principle of protection to the physical barrier described before.

For these reasons, it is fair to state, that the SCC will provide an innovative solution to the market of reforestation solutions. Its clever design aims to combine and erase all the current issues when trying to reforest burned areas. It has a combination of solutions to ensure healthy seedling development, and also ensures it will be protected until the tree grows big enough to withstand by itself.

Regarding the price and the positioning: It can be stated that it competes with the most efficient and effective solutions which are manual seedling planting and waterboxx® (the top efficient device currently used in the market, that enables high germination in harsh conditions). Furthermore, the SCC design is ready to be used and released together with UAV deployment technologies (such as the ones used by Dendra, DroneSeed and AirSeed) to enhance the release efficiency even more. Therefore, it can be concluded that the SCC will potentially enable fast, reliable, economic, and safe reforestation.

## Present effort and plan of execution

Since the official start of WP6 in month 7 of the project, the main goal was the design adaption of the SCC to the needs and inputs from the project forest experts (UDG, FAFCYLE, LAMMC) as well as the end users and stakeholders. Therefore, the initial capsule design underwent the necessary modifications to accomplish the mission of summing up all the requirements for the particular scenarios of the TREEADS project. For this design adaptation process development, the methodology of Design Thinking was applied (Figure 8).

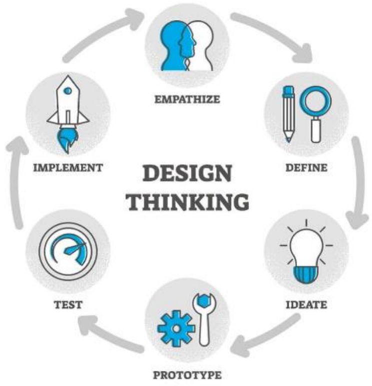


Figure 8: Design Thinking methodology

Following the spirit of the project, the SCC design adaptations respect the input from the end users' desires, State-of-the-art launching mechanisms (pneumatic systems), safety regulations (consulted by the Spanish fire brigade and expert partners), as well as environmental conditions to ensure that no wild animals or humans are present during the installation of the SCC and therefore the risk of harming any living organism is zero. By following all these TREEADS-related expertise, the SCC design was finalized by M13. For the next period, which will be summarized for D6.2 the main objective is the production with the prototyping injection moulding process in final material as well as continuing with the patenting process of the SCC technology.

In terms of SCC content/biomaterial for reforestation, data on potential test sites was gathered and research pertaining to the most suitable tree species for a given location as well as their average germination rates were determined. Local reforestation practises were researched as well. Microbial products commercially available in the EU were researched and based on their microbial composition the most promising according to scientific literature reviews and expert opinion were selected for further testing.

Model trees for greenhouse trials were selected based on germination rates and overall data available for a particular species, i.e., pine for coniferous trees and aspen for deciduous trees. In total 8 products were selected for further testing. A methodology for determining which products are the most effective and which concentrations are the most optimal to enhance tree growth and induce resistance to pathogens and other disadvantageous factors were created. Experiments are ongoing and data is being analysed for them (Figure 9). Different soils were tested to determine which are most effective as a binding agent for the SCC content, but at the same time doesn't hinder tree germination or delay growth too much. Results showed that peat-based substrate was the most effective for growth and didn't hinder germination.

Figure 9: Pine (Pinus sylvestris) seedlings grown in a greenhouse with different microbial products.

## 4.2 BIOCLIP ADAPTATION

The Bioclip is a patented device that protects and releases beneficial insects into the environment to restore natural balance. It is made out of a biodegradable biopolymer and no need to collect it back from the field is needed, saving logistic costs and CO2 emissions.

### State-of-the-art of the release of beneficial insects

The state-of-the-art devices used for the release of insects (such as paper or cardboard envelopes) are mainly used in closed crops, given that they are designed to be applied in controlled environments because they are not resistant to adverse weather conditions during prolonged periods. If used outdoors (i.e., forestry field), the efficacy of the release strategy can be seriously diminished.

Figure 10: State-of-the-art devices for the release of beneficial insects

Furthermore, hanging devices uses a hook/rope and can have stability problems when suspended outdoors (Figure 10). Due to a pendulum effect, they can cause the eggs of beneficial insects to become stuck to their food (honey deposited inside the device) before the insects can hatch and go outside.

It is also known that state-of-the-art devices have efficacy problems given their water permeability and flood-ability when it is raining in a lateral direction due to strong winds.

None of the current release devices are as effective as the Bioclip to withstand heavy weather conditions such as inclined rain (a mix of rain + wind) or direct sun insulation which heats the inside of the containers, drying out the beneficial insect inside its cocoon/eggs before they are able to be born.

## The competitive advantage of the Bioclip

To deal with all these issues, that current State-of-the-art solutions face, the Bioclip was developed. The advantages and features of the Bioclip can be found in the patent description as well as in the following Figure 11 [43].

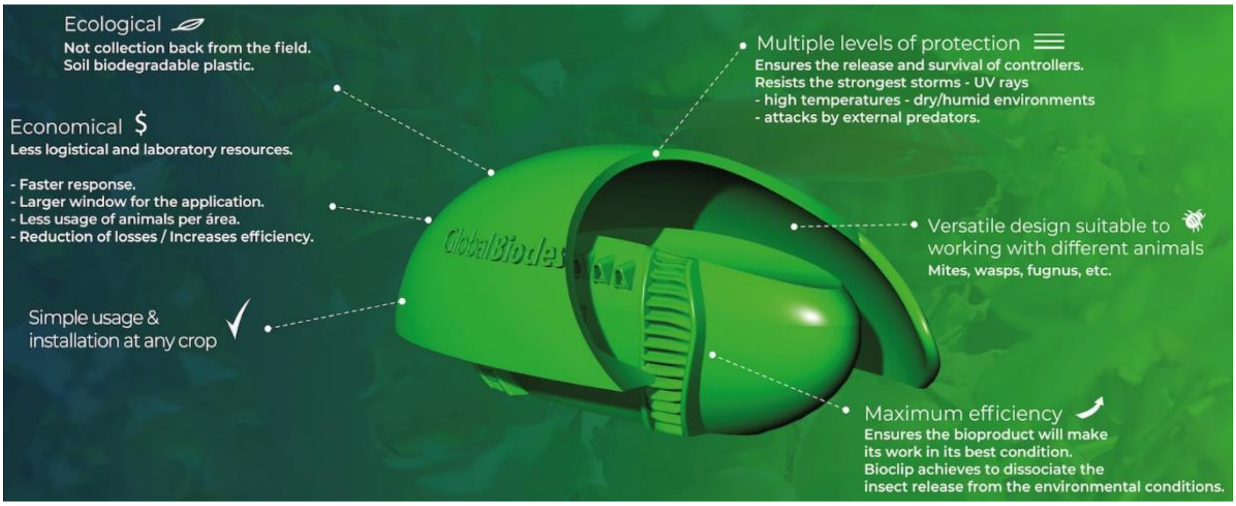


Figure 11: 3D-model of Bioclip and a short description of design features and patented innovations.

These features have been tested by independent top investigation institutes and organizations. It was concluded that the Bioclip is capable of reducing the overall release costs and securing the egg safety by more than 3x in comparison with the other studied devices. The Bioclip has been proven as the best release device for beneficial insects in harsh environmental conditions such as the forestry open fields. In particular, the recent publication from the Wageningen, proves the Bioclip device to be preferred over the natural excitant shelters, by a certain species that uses it as a refugee, nursery and to lay their eggs [44], [45].

To understand graphically all the constrains that face the beneficial insects (the ones that combat the seedling pests), the following graphic (Figure 12) shows a typical scenario. On the horizontal axis, the different problems are presented and on the vertical axis, a qualitative population rate is displaced. Also, the qualitative comparison between other commonly used technologies and the Bioclip technology is shown.

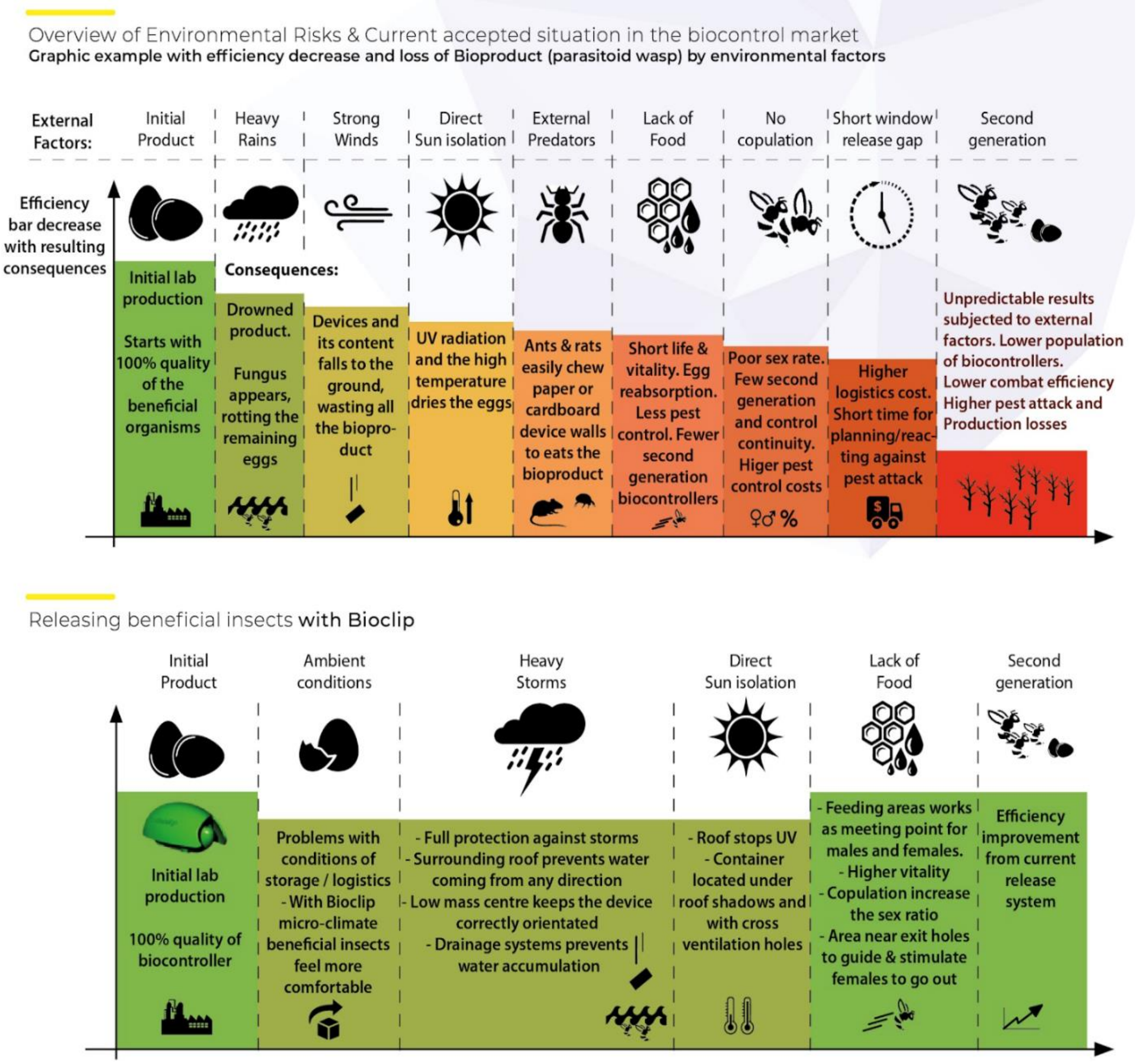


Figure 12: Bioclip performance comparison to state-of-the-art solutions.

Source: Global Biodesign

For the TREEADS project, the Bioclip application will be studied especially as the burned forests may lack beneficial insects. To enhance the re-establishment of the gone populations, the Bioclip can serve as a key technology as it provides the needed protection for vulnerable beneficial organisms. Furthermore, as the burned areas have very specific characteristics, it will be observed, whether a different installation system has to be established. For this, two main concepts will be followed. One could be the usage of a fixing attachment specifically designed for the Bioclip and the specific post-fire soil conditions. The second alternative could be the usage of any wiring application to work with the remaining burned trees. In both cases, the Bioclip is fixed to the applicable location and raised from the ground to avoid flooding.

Summarizing it can be said, that the Bioclip incorporated many patented protective features to ensure the release of beneficial insects. For the restoration in the TREEADS, the technology will be adjusted to work best with the post-wildfire conditions and enhance the success of restoration of beneficial organisms to the damaged areas.

## Present effort and plan of execution

As the Bioclip technology is already patented, produced, and commercialized, the main focus for the past month for T6.2 was on the design adaptations for the SCC. As the final design of the SCC was frozen in M13 and the next steps as outlined are the realization of the prototyping mould and the drafting of the patents, the SCC will be ready for a demonstration soon. In parallel, the investigation of the need for a Bioclip adaptation will be emphasized as outlined in the Gantt and priority planning. Also here, the design process for the adaptations (in case they are needed) will follow the Bernard Bürdeks methodology process [46]. Figure 14 shows how that methodology suggest an iterative approach to design new applications by following six consecutive and connected phases.

Figure 13: GBD-team Pilot site investigations

It has to be emphasized, that in the site visit of the post-fire areas, it could be observed that an adaptation for the installation of the Bioclip would be beneficial, especially for the areas where natural supports (i.e. branches) are non-existent or too fragile because they were affected by the fire. Based on the different conditions and variables, the type and biodegradable characteristics of the material to be used for the external application support will be adapted accordingly. After the prototyping phase (using 3d printing & polyactic acid (PLA) based filament, or wires), the following steps will be executed: testing of the solutions, iteration and improvements on the design, and later producing one final adaptation prototype.

In parallel, the needs for the evaluation of the protective behaviour of the Bioclip in the specific conditions of post-wildfire areas are under discussion with the experts from USAL. For this reason, the burned areas of the Spanish pilot were investigated to contemplate the possibility of making a study about the protective and insulation capabilities of the Bioclip in this environment, or if another adaptation of the features (different from the ones applied in the current version) is needed.

Summarizing, initial activities have been accomplished and will be followed to outline the two main field of interest which is 1st to study the possible alternatives for suitable installation of the Bioclip in burned areas and 2nd to generate a clear picture of how to study its protective features (especially for these post-wildfire conditions) together with USAL and discussing the needs with UdG.

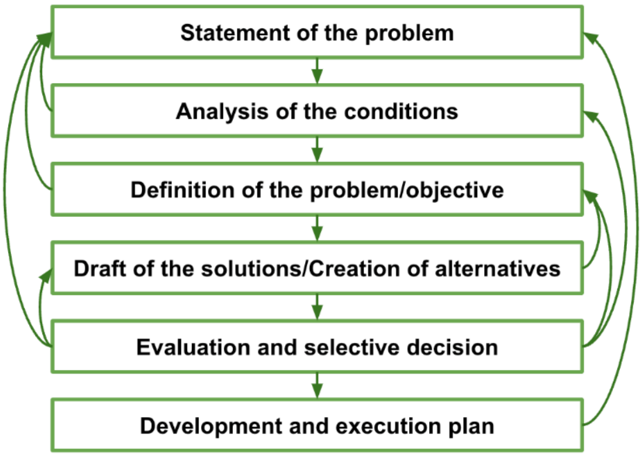


Figure 14: Bernhard Bürdek design process methodology.

## Timescale for effective field and market testing of the SCC and the Bioclip

Even though D6.2 already describes a detailed outlook for field tests and market tests, a detailed plan is presented here again to give a better understanding of the progress.

In addition to the technical progress, which deals with the concept and design freeze of the two technologies, the Bioclip adaptation and the SCC, as well as their production ramp-up, it is important to test the technologies in relevant markets, especially with the background of Treeads being an IA project. For this purpose, we have divided the test approach into 2 stages.

The first stage dealt with the confirmation of the developed adaptations of the designs, which were incorporated into the final product application through the input of relevant TREEADS partners. To this end, we carried out penetration tests of the SCC in M10 in Germany and checked whether the SCC and launching mechanism system harmonized. The successful test results confirmed the concept freeze of the adaptation, which is the reason the technology could be tested in a relevant environment in a further field test in Spain. This first field test in Pedro Bernardo, a location of the Spanish pilot, was carried out in M12 and was particularly interesting as both the Biolip adaptation and the Seed Container Capsule were applied in real post-fire conditions for the first time. Based on these helpful findings, a further field test was planned for M19 in Pedro Bernardo. In this field test, in addition to the already positively confirmed penetration of the SCC using a pneumatic launcher, the first long-term test in the field was planned. The aim was to investigate the unique protective features of the SCC against predators. After 3 months of field testing, the protective features were confirmed, which confirms an enormous advantage over comparable non-protective solutions that involve seed dispersion, such as the ones deployed by UAVs. During this test trial, FAFCYLE also invited relevant stakeholders such as forest owners, forest managers and other interested parties to present the two technologies and introduce them to the relevant market. The aim was to demonstrate the success and added value of the two solutions but also to obtain feedback from potential users.

As this first stage was a complete success as a combination of technical confirmation and market tests, the second stage will focus on a dedicated demonstration of SCC and Bioclip adaptation integrated to the pilot demonstrations. In addition to the dissemination presented in WP10, two further field/market tests are planned for this purpose. In the next step, the two technologies will be presented in the Austrian pilot in M28. We will also bring together relevant stakeholders and potential users, like the Spanish pilot, to experience the technologies live. It is planned to spread the SCCs on a test area of approximately 200 hundred square meters and to evaluate the germination and long-term success of the reforestation.

At the same time, a further demonstration/test site in Spain is planned for M33 in order to install a final application within the framework of Treeads, similar to Austria, and to demonstrate/evaluate what findings can be obtained from an open field long-term observation (at least until the end of Treeads). Since the stakeholders under FAFCLE in Pedro Bernardo had to deal with the consequences of forest fire hazards and forest fires in recent years, it is expected that the demonstration shows a significant USP (unique selling proposition) and can generate relevant information/data for the go-to-market phase. The detailed preparations for the individual tests are shown in the corresponding deliverables under WP8.

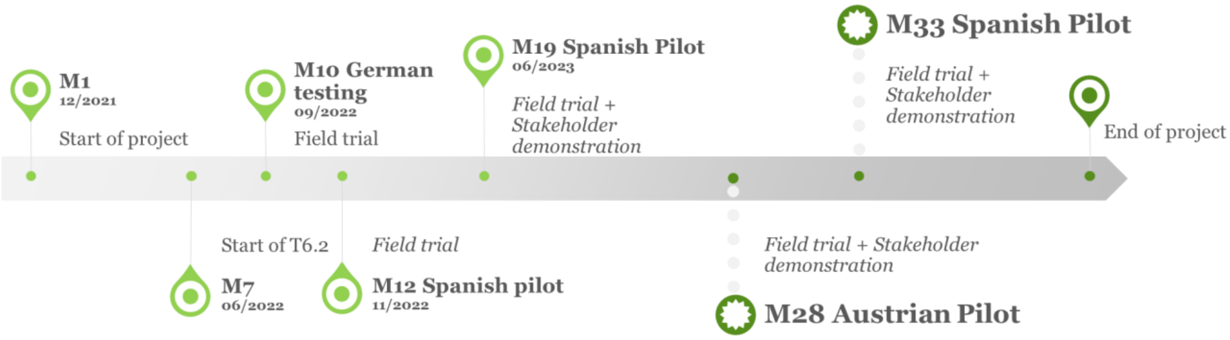


**Figure 15: Timescale for effective field and market testing for SCC and Bioclip adaption**

In summary, it can be said that various iterations of market and field tests are planned, while some have already successfully taken place, in order to ensure the development success and integration of the two technologies on the one hand and to prepare for the successful marketing of the two innovations on the other. A schematic representation of this planning is shown in Figure 15.

## 4.3 SEEDBALL SOLUTION

### Seedball/seedpods description and specifications

Seedballs for reforestation will be composed of four main parts, that may be adjusted based on the requirement of the specific site/location. Firstly, tree seeds are selected based on the specific requirement of the reforestation site. A certain number of seeds will be placed in each seedball depending on the species' average germination rate to ensure that each seedball bares at least one seedling. The seedball could be filled with seeds from a single species, or seeds of multiple species or alternatively, a percentage of seedballs with each species could correspond to the percentage of different trees in the area. That would allow for the most biodiverse option. Tree seeds would be selected from the local seed orchards or similar entities to ensure that no non-local species or genotypes are introduced and to ensure the best possible adaptation to local conditions.

Secondly, the seedballs will contain a certain amount of soil that will create a favourable environment for seed germination by regulating temperature and humidity. Potentially local soil can be used to further ensure no outside intervention. Furthermore, the soil contains all the necessary micronutrients and organic matter for both the seedling in the initial stages of growth before it reaches the soil beneath the seedball and the third component, which is the microbiota. Soil microorganisms are a key aspect necessary for plant growth, as they make the nutrients and microelements in the soil bioavailable to plants [31] [32]. The addition of microorganisms known to promote tree growth and health is the innovation that can potentially make the reforestation in this manner more effective than simple direct seeding or even seedballs/seed pelleting, but more cost and labour effective than using nursery-grown seedling planting [33] [34]. Without microorganisms, reforestation may take significantly longer and be significantly less successful [35] [36].

One of the negative effects of wildfires may be the damage done to the soil microorganisms [37] [38]. Thus, to ensure the survival and wellbeing of the new trees we will add selected microorganism blends (that are commercially available for ease of access) at certain concentrations. The effectiveness of this microbiota enhancement will be tested prior to under greenhouse conditions and determined based on the effect they have on selected model tree species [39] [40] [41]. Tree growth parameters and biochemical parameters associated with adaptability in disadvantageous situations be measured [42]. The fourth component of the seedball is the binding agent, which alongside the soil creates and allows to hold the seedball shape but doesn’t hinder tree growth.

Progress so far: Data on potential test sites was gathered and research pertaining to the most suitable tree species for a given location as well as their average germination rates were determined. Local reforestation practices were researched as well. Microbial products commercially available in the EU were researched and based on their microbial composition, the most promising according to scientific literature reviews and expert opinion were selected for further testing. Model trees for greenhouse trials were selected based on germination rates and overall data available for a particular species, i.e., pine (Pinus sylvestris) for coniferous trees and aspen (Populus tremula) for deciduous trees.

In total eight products were selected for further testing. A methodology for determining which products are the most effective and which concentrations are the most optimal to enhance tree growth and induce resistance to pathogens and other disadvantageous factors were created. Different soils and binding agents were tested to determine which are the most effective, but at the same time don’t hinder tree germination or delay growth. Results showed that peat-based substrate was the most effective for growth and didn’t hinder germination. A 1:1 v/v ratio of soil and a gelling agent was selected to create the seedball shape. This was also shown to not hinder germination and held its shape when released from ~12 meters. The optimal size of the seedball was determined based on the necessary soil for the seedling's survival and seed size, i.e. 2.0cm in diameter with a weight of ~7g (that maybe affected by the humidity) (Figure 16).

Figure 16: Seedball prototypes.

Currently, research focusing on the most convenient and effective ways to produce, such seedballs on a larger scale is ongoing. Experiments that involve the trees' growth, with the enhancement of microbial products are ongoing (greenhouse trials may take from several months to a year; however most likely several shorter trials will be implemented), as well as specialized data is still in the analysis phase (Figure 17). Further field trials will take anywhere from a year up to the end of the project. It's important to note, that overall, based on expert opinion and available reforestation data, true forest establishment should be evaluated only after several years post reforestation (3-10 years). Field plots will likely be observed by LAMMC and local partners even after the end of the TREEADS project.

Figure 17: Greenhouse experiments using different microbial products with pine seedlings.

## Drone-integrated seed-pod releaser mechanism for Reforestation seeding by use of seedballs

ACCELI's prototype CERBERUS UAV (Figure 18) will be equipped with a customized seed release mechanism (developed by ACCELI) to optimize and speed up the reforestation process, especially in places with difficult access (landslides, steep slopes, etc.).

The Seedpods generated by the LAMCC will be loaded into the seed pod releaser, which will release them in a way that maintains the landing distance between each seed pod release, so that the growing trees have enough space and access to sunlight.

Figure 18: Seedpod releaser attached on CERBERUS UaV.

Main seedpod releaser Input Specifications:

- The drone to be used has a maximum payload capacity of 5 kg (Accelligence - Cerberus model).
- The seedballs have a diameter of 20mm and their weight is 7g (LAMMC).
- The seedballs shall be released sequentially so that each one shall be landed approximately 2m away from the previous (LAMMC).

Secondary specifications:

- The design should aim to the minimize of the device weight, in order to maximize the number of seedballs per flight.
- The device needs to be properly suspended below the drone, so as to be able to release the seedballs to the ground. Easy mounting and dismounting the device on the drone is a plus.
- Easy loading of the seedballs in the device canister should be ensured.

The following figure (Figure 19) represents the design of the seedball releaser prototype, in its first version.

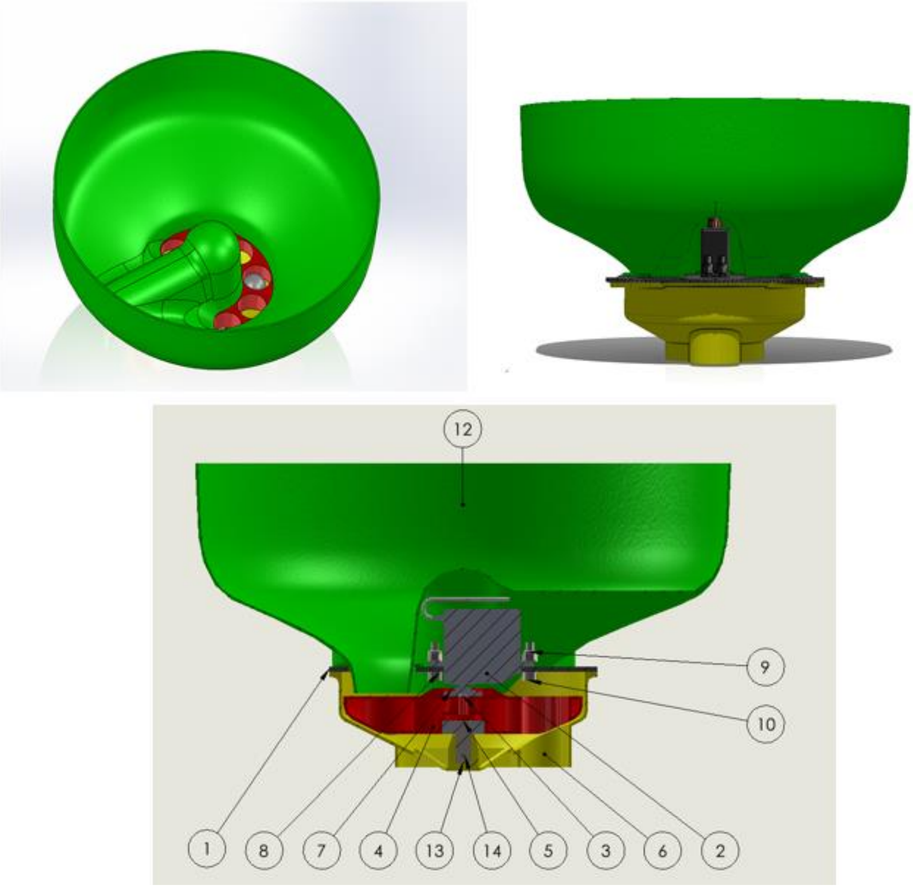


Figure 19: Seedpod releaser prototype.

The main parts of the device consists of:

a. A canister (12) to contain the seedpods during flight. The canister shape also ensures that by gravity, all seedballs shall be led to the revolver mechanism, so that the drone shall empty its load after each flight.
b. A revolver (4) that shall collect each individual seedball as it rotates.
c. A lower case (6) with a release hole, that prevents all but one of the collected seedpods to fall, as the revolver rotates.
d. A servomotor (2) that receives the input signal from the drone computer and drives the revolver rotation to release the seedballs at the correct rate.
e. Several other secondary parts (1, 3, 5, 7, 8, 9, 10, 11 and 13) are required to enable this assembly to be integrated and work properly.

Our main progress until now (M14):

- At this phase, the device is manufactured – assembled to test its function(s).
- The first tests shall be conducted in the lab (the device shall be tested with the seedballs without suspending it under the drone. Modifications/additions may be required depending on the test results.
- Flight tests shall follow to verify the correct operation of the whole system.

## UaV path planning for optimal reforestation results and sustainability of the proposed method.

As mentioned earlier, seeds must be released in a way that maintains an optimal distance between trees as well as the possibility of successful planting for each seed. This requires specific path and flight conditions of the UAV during the planting procedure. Based on best practices the distance between trees, i.e., a seedball should be released every 2 meters with 2 meters on the sides as well, thus creating a 2-meter clear radius on all sides. This equals about 2500 trees per ha. Based on experts' opinion, the flight plan may follow a spiral design in a flat area and a contour-line flight plan on a slope or in a flat area.

# 5 TREEADS INVOLVEMENT, COORDINATION, AND COOPERATION OF DIFFERENT ACTORS AND SECTORS

## 5.1 INTRODUCTION

Traditionally, the monitoring and management of restoration and adaption were subject to several dependencies on traditional methodologies based on detailed information obtained from field plots. The rise of the platform economy initiated a new paradigm extended to achieve effective and successful restoration, based on the accessibility to crucial information and scientific advancements. With the use of modern technologies restoration has become a more agnostic process that can be successfully implied both at small-scale and large-scale, with the specific needs of a burnt area at the epicentre. Moreover, since restoration is composed of long-lasting procedures, in contrast to the preparedness and fire management operation phases, modern transformations use dynamic databases, updated automatically to improve decision-making. Fortunately, recent advancements in technologies related to forestry and restoration provide space for unprecedented shifts in the way restoration planning in executed, monitored and reported.

In this section, the planning and the conceptual framework of an advanced Decision Support System (DSS) platform, are described. In addition, the development progress is recorded, leveraging the latest scientific advancements and innovative technologies for the establishment of the new generation of holistic solutions for restoration. The inputs and the modules were provided by the scientific partners, in collaboration with the technology partners, based on the requirements recorded in D2.7. The solution aims to provide a holistic approach for the use in the future in ambitious restoration programs planned for the coming decades. At the core of the software application the partners have positioned information and the framework relies on effective monitoring.

The DSS is an essential component of adaptive management and accountability in the restoration phase, after the occurrence of a wildfire. The development of this innovative new app which involves new remote sensing approaches for data collection and their application to a restoration context has the ambition to open new avenues for expanding our capacity to assess restoration performance over unprecedented spatial and temporal scales.

As far as the developments are concerned, the progress of the task focuses on the TREEADS System Architecture analytically described in deliverable D3.5. More analytically, the platform architecture and the description of a command and control (C2) system is a component that is expected to facilitate the coordination between the involved stakeholders that simulates a command-and-control system (CCS), among the authorized users in the platform. The purpose is better monitoring and to coordinate the stakeholders (authorized representatives from local fire agencies, local police etc).

To this extend, several discussions are in progress on the request of multispectral images (EO/IR), and the image processing with involved partners, so that the final requirements to be defined. From the discussions that have taken place until now, this web application is expected to use telemetry to collect system information such as operational status, while recording socio-technological services history.

## 5.2 DECISION SUPPORT SYSTEM DESCRIPTION

At first, Task 6.3 focuses on developing a uniform cooperation framework for enabling end-user agencies to co-ordinate the resources and efficient handle the tactical, strategic and operational activities in the event of an alarm. Based on this framework, within the context of Task 6.3, a Web App solution, is in the development phase, in the form of a stand-alone tool which will be integrated on the TREEADS platform. The purpose of the app is to vitalize the post fire management framework proposed, support the decision-making process of the stakeholders involved, and facilitate communication among all respective stakeholders. The tool will also be enhanced with a communication solution for the interactive communication of the stakeholders. The final architecture of the DSS will include the definition of specifications, the overall design, as well as the integration and testing steps. In the end, the tool will represent a complete geospatial data infrastructure for the integration, visualization and assessment of all the data involved in the restoration and adaption phase.

While several intelligent mechanisms and solutions have been analysed for restoration, several user-friendly interfaces have also been researched for parametrization in the algorithms and settings for a more accurate adaptation. In this framework, several multi-temporal processing methods for improving visualization to complex behaviour processing methods are considered from the existing literature which is under several discussions among the partners.

Considering scalability issues such as the effective handling of a large amount of information, the core decision support engine will be encompassed with intelligent mechanisms for analysing the monitoring data stemming from the control & management and data planes used in TREEADS. To this end, several detection algorithms for events and activity monitoring will be integrated with the platform, and data from alternate sources will be integrated for model testing.

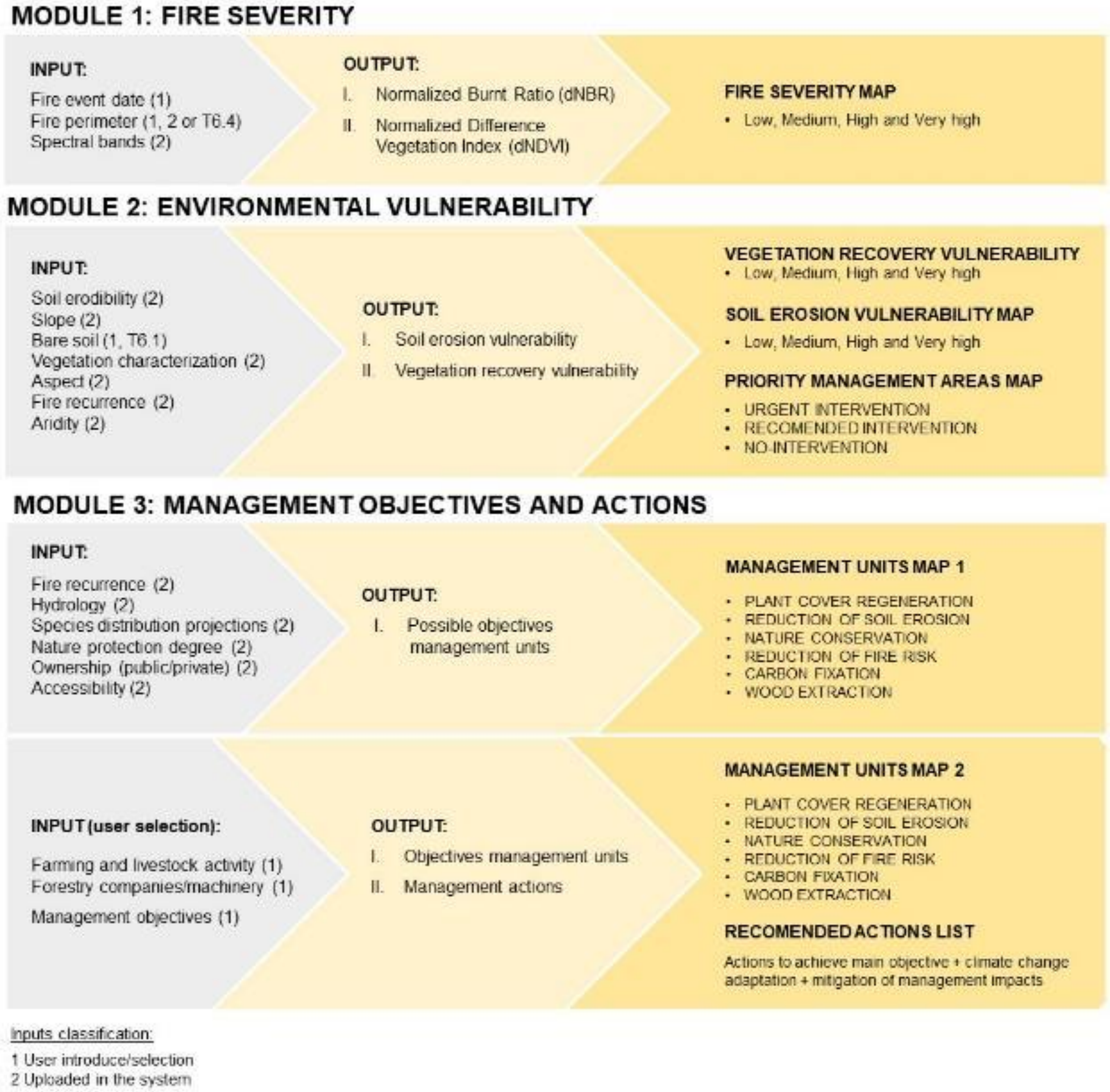


Figure 20: Technical aspects of the Decision Support System module.

Source: University of Girona

The overall goal of Task 6.3 is to develop a holistic and user-friendly Post-fire Decision Support System to support the effort of related public and private agencies for the successful post-fire management and restoration process. Under this scope, this stand-alone tool is organized into three main research modules as developed with the contribution of UdG, augmented with one additional technical module that involves the integration part of the final API. The proposed modules set the framework in action and comprise the APIs developed by the rest of the Tasks involved and analysed in the next section 5.3.

## 5.3 DSS METHODOLOGICAL FRAMEWORK

The Post-Fire Decision Support System (DSS) is a tool that integrates the phases of the environmental assessment and management process of burned areas to assist managers in making necessary decisions for the emergency stabilization, restoration and adaptation of fire-affected ecosystems. The purpose of this task is to incorporate technological solutions into the current system and provide new techniques with the goal to assess, monitor, manage and restore burned wildland areas. The DSS is integrated into the TREEADS platform, allowing for an agile environmental assessment of burned areas based on remote sensing and mapping available in the system. It provides fire severity maps, management priority zoning maps and management zoning maps with objectives and recommended actions.

- **Module 1 (Fire Severity Mapping):** the present module will focus on two main and complimentary topics. The first one is related to the development of the Task 6.4 tool which will use satellite data provided by Sentinel2 and MODIS in order to define the map of the burnt area, using advanced deep-learning models.
- **Module 2 (Associated wildfire impact evaluation due to climate and other socioeconomic factors):** the module aims to capture changes in future fire risk due to climate and other socioeconomic changes, and to evaluate future expected impacts on the vegetation, landscapes and, ultimately, on fire regime. To this extend, field studies and modelling for a range of scenarios and means and, in particular, extreme climate will be examined.
- **Module 3 (Adapting to change)**: the module introduces new approaches and procedures to manage risks and landscapes under climate and social change to reduce vulnerability to fire). In addition, it analyses the capacity to adapt to future conditions by developing restoration strategies, and reviewing current protocols and procedures for fire prevention, fire-fighting and the management of fire-prone areas under more extreme conditions. This analysis is complemented by an assessment of economic costs and policy implications of the expected changes.

More analytically, each module focuses on specific outputs that will be useful for all stakeholders in their decision-making process, as described in Figure 19 and described analytically below.

More specifically, Module 1 aims to provide innovative and serious advancements in the existing fire severity mapping outputs. The module is dedicated on generating a highly sophisticated methodology in the field of severity map creation and also to developing a stand-alone software tool for the creation of the TREEADS fire severity map. The tool will provide the degrees of a wildfire impact on vegetation, on a scale ranging from LOW categorization to VERY HIGH. The final output will be the map which will contribute as a starting point in the process of restoration and adaptation. To achieve this, two crucial inputs will be provided for the construction of the tool, the high-precision burnt map and the severity index.

Fire severity represents the degree of fire-induced environmental changes. It can be defined as the quantity of fuel and organic matter consumed aboveground (vegetation) and belowground (soil) during a fire. The general indicators and qualitative variables are based on the total amount of fuel consumed in different strata: tree canopy, understory vegetation and soil organic matter [3]. In addition, historical wildfires show differentiations in size and in fire severity and worldwide the fire seasons are lengthening, A fire's severity is crucial to be measured in the adaptation process, since specific fire regimes correspond to historical conditions and shifts, with serious impact on the environmental ecosystem.

The inputs for Module 1, will require the users involvement and some simple initial inputs. A user of the tool will need to enter/choose the date of the fire event (day, month and year) of his interest, so that the system can find the satellite images immediately before and after the fire event occurence. From the date introduced by the user in the previous step, the system will show a list and/or a map with the fire perimeters detected around that date (± 15 days). The user will select the wildfire polygon geometry of its interest shown by the map/list.

Using remote sensing to establish fire severity is much less time-consuming than assessments entirely based on field sampling. The wide range of available sensors, from multi-spectral to hyperspectral, with different spatial and temporal resolutions, can provide an essential source of data to map and assess burned areas.

Each spectral band responds differently due to the superficial characteristics of the earth and when they are combined in mathematical equations, information about targeted features can be enhanced, isolated, and analysed [47].

Fire severity will be calculated through different indices using satellite imagery, as described analytically in Table 5, in which the formulation and description of the indices selected for tool are presented. Regardless of the index used, satellite images must consider the following requirements:

- Pre/post-image as close to wildfire date as possible (post-fire image should be smoke-free).
- Recommended cloud coverage: less than 10%.
- Idealy the images need to be atmospherically corrected.

Last but not least, Figure **21** shows the combination of informational outputs within Module 1 and the final output of the module. The map with the detection of the burnt area will be enhanced with the severity index and the final output will be the map with the higher-precision burnt area along with the information of the severity index.

Table 5: Indices selected to study fire severity, formula, and description

| Index | Equation | Description |
|---|---|---|
| **Normalized Difference Vegetation Index (NDVI)** as described in [48] | $NDVI = \frac{R_{NIR} - R_R}{R_{NIR} + R_R}$<br>$dNDVI = NDVI_{pre} - NDVI_{post}$ | Detects photosynthetically active biomass. Chlorophyll absorbs red and reflects near-infrared (NIR) plateau. |
| **Delta Normalized Burn Ratio (dNBR)**<br>as described in [47] and [49] | $NBR = \frac{R_{NIR} - R_{SWIR}}{R_{NIR} + R_{SWIR}}$<br>$dNBR = NBR_{pre} - NBR_{post}$ | Like NDVI, NBR implies two bands that respond most, but in opposite ways to burning. SWIR detects changes in moisture content, where reflectance is low in healthy vegetation. dNBR measures the change caused by fire, as it relates fire effects on previously existing vegetative communities. |

+

**Fire Severity Map (M1.1):**

| **Categories** | O1.1/O1.2 values | Description |
|---|---|---|
| **Unburned** | <0.099 | No changes on vegetation detected. |
| **Low** | 0.100 to 0.269 | Fire has caused minimal impact on the ecosystem, possibly only burning surface litter and some understory |
| **Medium** | 0.270 to 0.439 | Fire has caused a moderate impact on the ecosystem, possibly burning small shrubs and trees, but leaves most of the vegetation unscathed. |
| **High** | 0.440 to 0.659 | Fire has caused significant changes to the ecosystem, possibly burning large numbers of trees and shrubs. |
| **Very High** | >0.660 | Fire has caused an extreme impact on the ecosystem, consuming almost all the vegetation in one area, and potentially damaging the soil and rocks. |

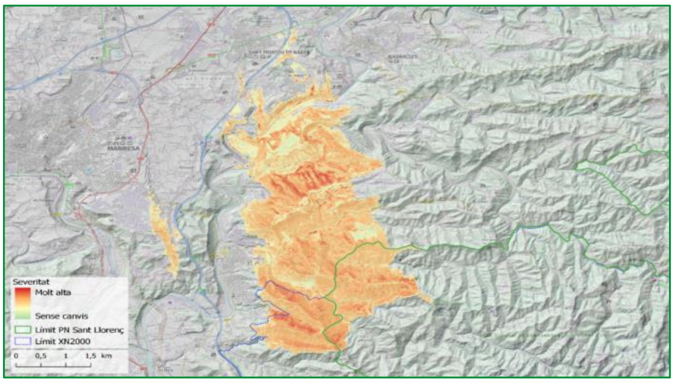


Figure 21: Conceptual structure of Modules 1.

Additionally, Module 2 endeavors to assess the environmental vulnerability within the burned area, encompassing soil and vegetation, with the aim of identifying priority management zones. These areas will be targeted for immediate intervention to prevent future degradation and mid-long term actions to help recovery. This includes urgent stabilization actions to safeguard against soil degradation and restorative measures to ensure ecosystem recovery.

So that the **short-term ecological vulnerability** of an ecosystem following a fire could be assessed, the extent of the damage caused by the fire must be evaluated and the specific effect on the affected ecosystem must be determined. For any ecosystem, two main factors are considered [50]:

- Vegetation characteristics and environmental conditions crucially influence the short-term and long-term **vegetation recovery rate**.

- Abiotic factors relating to post-fire **soil susceptibility to erosion**. In addition, post-fire vegetation re-establishment is also important for rapidly protecting bare soil from post-fire erosion.

Both soil erosion vulnerability and the vegetation recovery rate are integrated into the short-term ecological vulnerability to determine the priority areas to be managed (Figure 22):

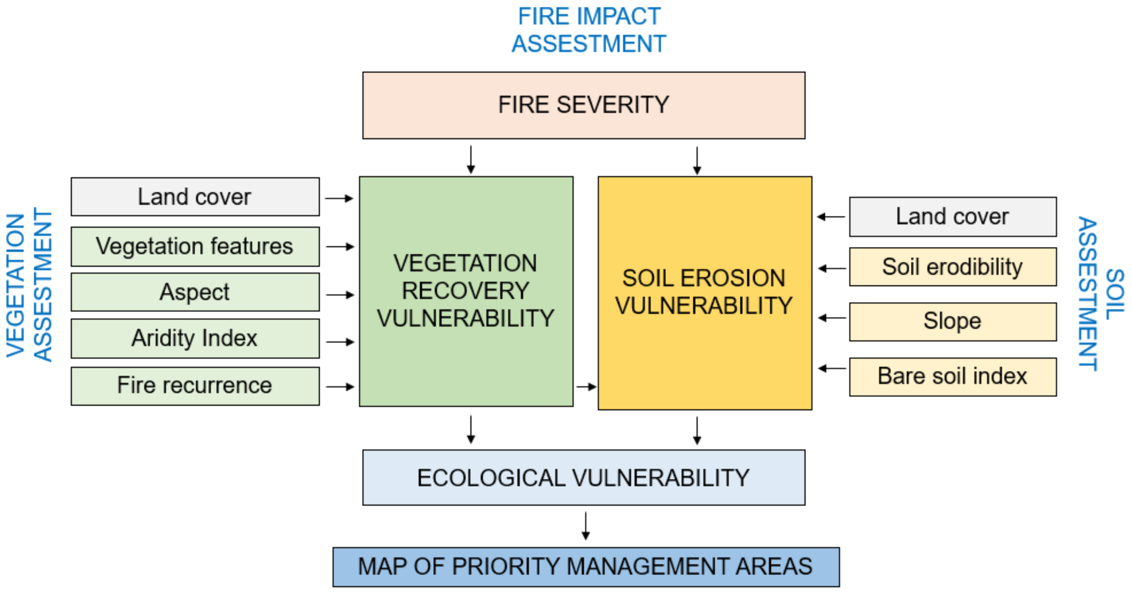


Figure 22: Conceptual map of the short-term post-fire ecological vulnerability for the post-fire DSS.

Source: University of Girona

This task outlines a method for evaluating the vulnerability of vegetation recovery and soil erosion in the aftermath of a fire. The TREEADS Post-fire DSS model is being proposed as a superior tool for environmental assessment and post-fire management decision making compared to the commonly used First Order Fire Effects Model (FOFEM). The TREEADS model integrates creativity, expertise, and up-to-date information to provide a more accurate representation of the impact of fire. This model provides a larger scale view of the landscape, reducing the potential for biases that can result from extrapolating point measurements to a larger area. Furthermore, the TREEADS model uses high-resolution and constantly updated cartographic and satellite data sources, reducing the need for extensive field sampling and making the evaluation process more efficient.

One of the key differences between the TREEADS model and FOFEM is the way in which they approach the impact of fire. FOFEM relies on user-defined conditions to simulate the potential impact of fire, whereas TREEADS combines expertise and up-to-date information from the area before and after the fire to determine the actual impact. Additionally, FOFEM only predicts first-order fire effects, such as tree mortality, fuel consumption, emissions production, and soil heating, whereas TREEADS considers secondary effects such as tree regeneration and soil erosion in its analysis, providing a more comprehensive understanding of the vulnerability of the burned ecosystem.

The TREEADS Post-fire DSS tool takes into account various environmental factors, including the existing vegetation structure and composition, the topography, lithology, and climate, in order to estimate the vulnerability of the ecosystem in the short and medium term. This makes it a more robust tool for environmental assessment and post-fire management decision making, as it provides a deeper understanding of the impacts of fire on the ecosystem.

In conclusion, the TREEADS Post-fire DSS model provides a more comprehensive and efficient approach to evaluating ecological vulnerability in the aftermath of a fire. By integrating expertise, up-to-date information, and advanced data sources, this model offers a more accurate representation of the impact of fire and provides a more robust tool for environmental assessment and post-fire management decision making.

The integration of information from modules 1 and 2 will make it possible to classify the burned area according to the three sub-modules that follow:

- **Soil erosion vulnerability (Module 2.1):** Classification of the area's vulnerability to soil erosion, water runoff and flood risk.
- **Vegetation recovery vulnerability (Module 2.2):** Classification of the vulnerability of the area based on the natural recovery potential of the vegetation.
- **Priority management areas (Module 2.3):** Classification of areas according to the need for management measures to prevent environmental degradation: emergency stabilization needed, restoration needed and no-intervention needed.

Finally, Module 3 aims to develop the TREEADS Decision Support tool for adaptive post-fire.

The Decision Support System for Adaptive Post-fire Management (DSS-APM) will be a core component of our proposed ecosystem. The main operational characteristics of this module will include the extraction of maps for early post-fire management with recommended interventions. Initially, maps will illustrate three types of management areas: non-intervention areas, areas with sustainable salvage logging and natural generation, and areas with sustainable salvage logging and assisted seed sowing by drones. Moreover, it will include the adaptation of the corresponding management model, providing managerial recommendations that could be modified according to the new information obtained over time and feeding the DSS-APM model. The main sources of information inputs, throughout the communication channel of the platform and in the mid-term will be soil properties, vegetation regeneration and socioeconomic variables, related to the decision-making process (Figure 23).

In addition, a conceptual "Module 4" will be involved in order to achieve the integration to the overall TREEADS platform solution and the knowledge transfer to the end-users and stakeholders of the project. To this extend the SQD will develop an API of the stand-alone tool that will be introduced using the knowledge transfer from the scientific partners and the feedback from the stakeholder experts. The tool will be fully functional to provide the restoration management information needed to end-users and will contribute to the achievement of the overall objectives of WP6. In addition, the data inputs and outputs are planned to establish a prototype common database, a network of study sites for model testing and validation, and promotes knowledge transfer through training actions with users, among other.

The DSS application only covers the province of Avila. This area is the most data-rich among the pilots and could imply all features. Although the tool will be available for other partners who wish to test it. This Spanish pilot allows the DSS to work and be tested in full functionality, in terms of models used. The software developed of course will be available and implementable also in other pilots, though the results and the outputs will be subject to the data availability for the predictions and insights provided. In areas where information and inputs are limited, the software, might not be able to provide the same value, due to the data dependencies and availability for each pilot.

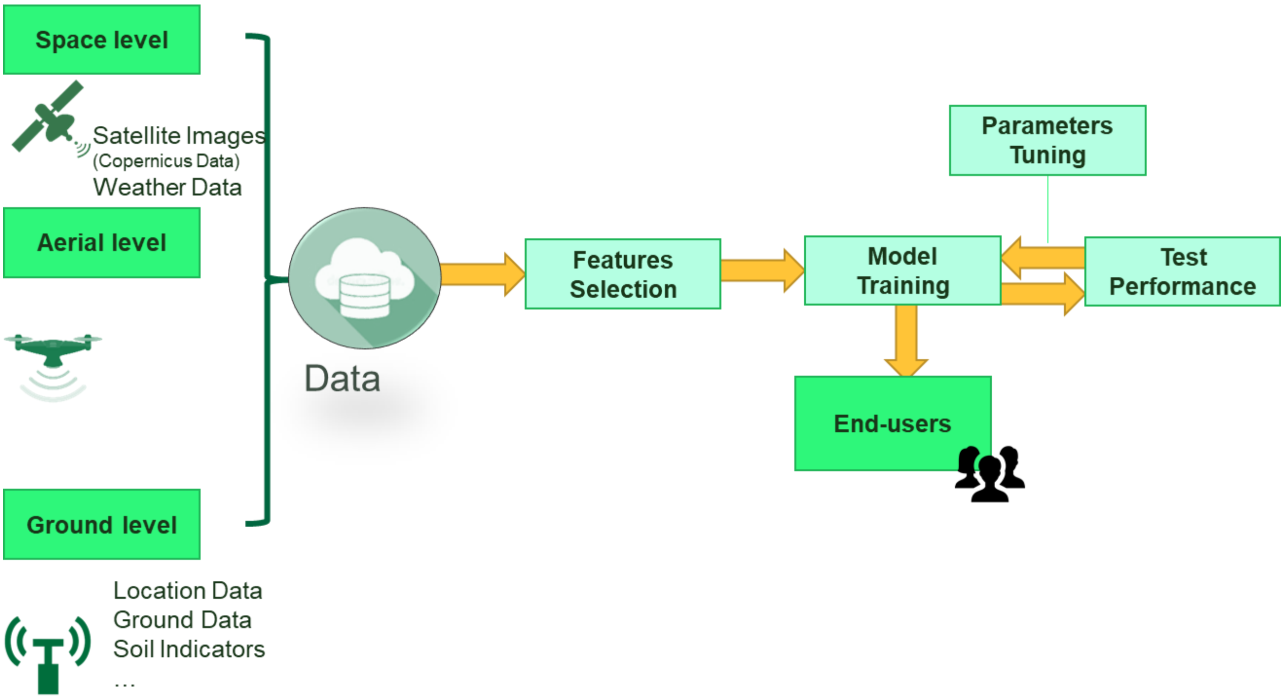
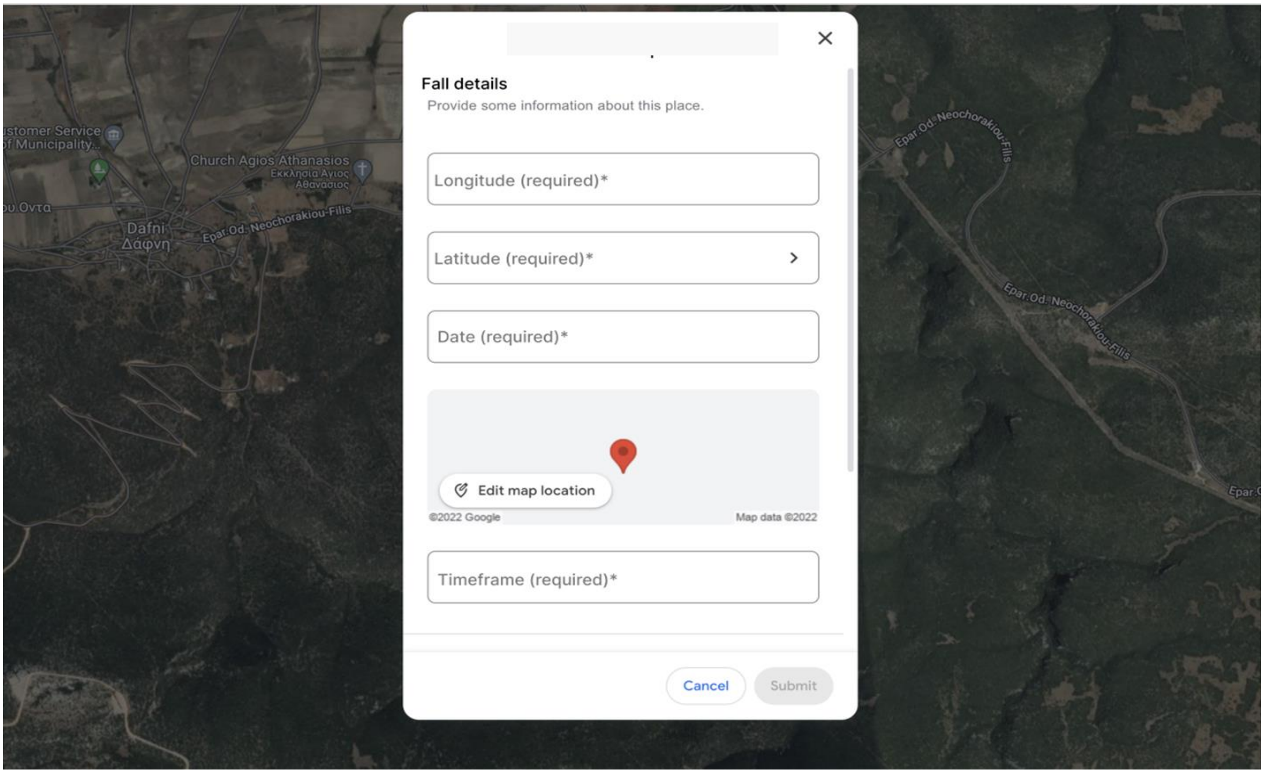


Figure 23: Conceptual illustration of the DSS model and the process.

Source: Squaredev BV.

Last but not least, the DSS system will be augmented with a communication function, that will work as a channel of communications and exchange information for the development of a uniform cooperation framework, which will enable end-user agencies to co-ordinate the resources and efficient handle the tactical, strategic and operational activities at the event of a fire. The progress of the task focuses on D3.5 which develops the platform architecture and he description of the command and control (C2) system is a component that is expected to facilitate a command-and-control system (CCS) and monitoring. The app will be simple in terms of architecture, so that the end-users could use it, instantly, without any complexities and the information communicated will be able to come in the form of text to the recipients (Figure 24 presents the mock-up of the messaging functionality of the DSS). In addition, several discussions are in progress on the request of multispectral images (EO/IR), and the image processing with involved partners, so that the final requirements to be defined. From the discussions that have taken place until now, this API is expected to collect system information such as operational status, location, orientation, and restoration service. The final architecture of the CSS is expected to specify, design, integrate and test all on-board and ground communication hardware, software and protocol components for a consistent and versatile airship connectivity and communication infrastructure.



Fall details

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Longitude (required)*

Latitude (required)*

Date (required)*

Timeframe (required)*

Figure 24: Mock-up of the messaging functionality of the DSS platform.

## 5.4 NEXT STEPS

In the progress of Task 6.3, in the upcoming period the partners involved will develop the framework and complete architecture of the Module 3, for decision-making support. This will involve determining plausible management objectives in burned areas, based on environmental and technical information available on the tool. The DSS platform will be developed in the context of T6.3 by SQD, so that the demo will be available for the second version of this live deliverable. In addition, an API will be developed so that the tool could be integrated in the TREEADS platform.

The suitability, accuracy and functionality of the DSS (modules 1, 2 and 3) will be tested to integrate the necessary corrections in the next versions of the DSS. In addition, Module 3, as designed will include the associated to each priority management area defined after running modules 1 and 2 and additionally, will provide capabilities in providing propositions and strategic recommendations for proposed managerial actions, so that these objectives could be achieved.

In the coming months, we will develop the architecture of Module 3. This will involve determining plausible management objectives in burned areas based on environmental and technical information associated with each priority management area defined after running modules 1 and 2. Module 3 will also propose detailed recommendations and management actions to achieve these objectives. Once the first version of the DSS demo is created, the suitability, accuracy and functionality of the DSS (Modules 1, 2 and 3) will be tested to integrate the necessary corrections in the next versions of the DSS. In addition, on the communications functions for the support of the restoration operations, several discussions take place between SQD and the pilots for the user capabilities and information.

# 6 TREEADS PRE-FIRE STATUS MODEL AND POST-FIRE AUTOMATION

## 6.1 INTRODUCTION

Due to the intensification of wildfires caused by global warming and climate change, the timely and accurate mapping of the inflicted damage is becoming an increasingly important task [51]. Detailed and consistent information on burnt land at a fine spatial scale can greatly assist forest scientists, government agencies and local authorities to assess the damage, formulating effective response and recovery strategies as well as determining major fire drivers and implement effective fire mitigation and prevention measures where possible. In this regard, remote sensing can greatly contribute to a more reliable and systematic mapping of the burn scar boundary, due to the availability of numerous satellite sensors with varying spatial, spectral and temporal characteristics. Spatial resolution (or ground sample distance) represents the size of a single satellite image pixel on the ground and corresponds to the level of spatial detail one can acquire with this particular sensor. Spectral resolution represents the range of the electromagnetic spectrum (wavebands) that the sensor can acquire observations in, while temporal resolution (or revisit time) represents the time interval between two consecutive image acquisitions of the same location. As can be seen in Table 6 there is usually a trade-off between these factors and no available sensor can capture information in the highest spatial and temporal resolution across all wavebands. For that matter, one of the hottest topics in remote sensing research is the fusion of multi-source data to combine their strengths and improve the performance of the subsequent processing and analysis steps.

## 6.2 DEEP LEARNING FOR BURNT AREA MAPPING

Traditionally, the automatic extraction of burnt area mappings has been based on satellite data with a low spatial but high temporal resolution, e.g., MODIS/VIIRS, which allows for a quick, albeit coarse, assessment of the affected region. An additional downside of this approach is the fact that smaller-scale fires usually cannot be mapped effectively or are missed altogether. Subsequently, and for selected wildfire events, further enhancement of the coarse mappings takes place. This is achieved by trained analysts who manually refine the fire boundaries through visual interpretation of higher-resolution satellite imagery, e.g., Sentinel-2/Landsat. However, this approach is time-consuming, subject to human error and not scalable to large affected areas or multiple concurrent events. In recent years, there has been a growing interest in the use of Machine Learning (ML) and Deep Learning (DL) techniques for the automatic extraction of burnt areas in the highest spatial and temporal resolution possible. These techniques have the potential to significantly improve the speed, accuracy and scalability of the whole process in a cost-effective way.

Various traditional ML algorithms have been proposed in the literature, with Random Forest, Support Vector Machines and Multilayer Perceptron being the most popular and best-performing methods [52], [53]. Although the aforementioned techniques provide a way to automatically assess burnt areas without a need for human intervention, they require heavy feature engineering processes, and the final predictions are usually noisy and not as accurate. On the other hand, Deep Learning is one of the most rapidly growing and highly promising fields of Artificial Intelligence, which includes a family of algorithms that have long been proven to outperform traditional ML approaches and deliver state-of-the-art results in a multitude of tasks.

The governing principle of DL is the construction of artificial neural networks with a big number of layers (indicated by the adjective "deep" in the term) which mostly comprise convolutional, pooling and fully connected units. Although several architectures with these building blocks have been proposed, some of which have been carefully handcrafted for a specific task, the main idea is the construction of a hierarchy of features extracted from raw input data. This hierarchy is computed through representation learning approaches that can be supervised, semi-supervised or unsupervised. Overall, the strongest advantage of DL is its ability to process raw data, thus mitigating the need for manual feature extraction, and unravelling complex non-linear dependencies in the input.

However, despite the advantages of deep neural networks, there are only a handful of DL techniques in the literature for tackling the task of burn scar mapping through multispectral satellite data. In particular, a number of methods take as input only post-event imagery and perform semantic segmentation where the goal is to classify each pixel in the image into one of the predefined classes (i.e., burnt, unburnt) [54] - [58]. The most common models in this category employ the U-Net [59] and U-Net++ [60] architectures. Another approach is change detection, where the goal is to identify the changes in the landscape between two or more images taken at different times (i.e., before and after the event) [61]-[65]. The most common architectures for this task are the U-Net and simple multi-layer CNNs. Finally, a single work has tackled the task through an anomaly detection approach with a CNN trained in a self-supervised way to classify a whole image patch as burnt/unburnt [66].

Table 6: Related work on DL methods for burnt area mapping.

| Method | Input data | Input type | Bands | Output resolution |
|---|---|---|---|---|
| Double-Step U-Net [67] | Post | S-2 (L2A) | R, NIR | 10m |
| Knopp et al. [54] | Post | S-2 (L1C) | R, G, B, NIR, SWIR | 10m |
| Tran et al. [55] | Post | UAV | R, G, B | ? |
| Florath et al. [56] | Post | S-2 (L2A), Land cover | All | 10m |
| Hu et al. [57] | Post | S-2 (L1C), L-8 | NIR, SWIR | 20m |
| Coca et al. [66] | Post | S-2 | All | 10m |
| Burnt-Net [53] | Post | S-2 (L2A) | 10m + 20m | 10m |
| BA-Net [61] | Pre, Post | VIIRS, FIRMS | R, NIR, MIR | 500m |
| Pinto et al. [62] | Pre, Post | VIIRS, FIRMS, S-2 (L1C) | R, NIR, SWIR | 10m |
| Martins et al. [64] | Pre, Post | L-8, PlanetScope | G, R, NIR | 3m |
| Kashtan et al. [65] | Pre, Post | S-2, spectral indices | All | 10m |

Notes: Input data in the table are categorized in “pre” standing for pre-fire data and “post” for post-fire data. The input types represent the satellite data source with S-2 concern data received from Sentinel-2, with L2A, L1C, L-8, VIIRS, FRIMS, PlanetScope and spectral represent the type of images used (Table 7).

Nevertheless, all of these methods suffer from one or more of the following shortcomings:

- **Evaluation of single events**: the progression and behaviour of a wildfire are highly correlated with the underlying forest type (boreal, tropical, etc.), the terrain formation and the local weather conditions [53]. Most models are evaluated on specific fire events, so their generalization ability is under question.
- **Inference time**: after a wildfire is extinguished, authorities must be informed of the scale and severity of the damage as soon as possible to develop a relief plan. So any automatic system for the estimation of the burnt area must be temporally constrained and provide results shortly after a fire incident is deemed complete.
- **Manual setting of hyperparameters**: some studies heavily rely on the manual tuning of thresholds and other hyperparameters which hinders the usability and flexibility of the proposed method.
- **Feature engineering**: several studies also define an elaborate feature extraction pipeline which somehow contradicts DL’s ability to extract useful information from raw input data.

Table 7: The characteristics of various satellite sensors.

| Satellite | Sensor type | Number of bands | Spatial resolution (expressed in meters) | Temporal resolution (expressed in days) |
|---|---|---|---|---|
| Sentinel-2 (A-B) | optical | 13 | 10m, 20m, 60m | 5 days |
| Sentinel-3 (A-B) | optical (SLSTR) | 11 | 500m | 1 day |
|  | optical (OLCI) | 21 | 300m | 1-2 days |
| MODIS (Terra-Aqua) | optical, thermal | 36 | 250m, 500m, 1000m | <1 day |
| VIIRS (JPSS) | optical, thermal | 22 | 375m, 750m | <1 day |
| Landsat-7 | thermal | 1 | 60m | 16 days |
|  | panchromatic | 1 | 15m | 16 days |
| SPOT 6-7 | optical | 4 | 6m | 26 days |
|  | panchromatic | 1 | 1.5m | 26 days |

## 6.3 PURPOSE AND SCOPE

The focus of this task is the development of an artificial intelligence pipeline for the accurate and timely mapping of the burnt area. In particular, an end-to-end DL model will be designed which will take as input a high-resolution pre-event satellite image and a low-resolution post-event satellite image of the impacted area and will predict the binary map of the burn scar in the highest spatial resolution possible. This choice of input ensures that a damage assessment can be conducted a day or two after the wildfire. The resulting model will be available for integration into the holistic TREEADS platform as well as into a dedicated platform developed by SQD for task 6.4.

### Dataset Curation

Nevertheless, an extended dataset of high-resolution polygons and the respective satellite imagery is required to train our DL model. Ideally, such a dataset should:

- be representative of the European climate and biome, esp. the Mediterranean area where the developed algorithm will be tested (Spanish pilot),
- include a great number of events because DL models require large volumes of training data,
- include multi-resolution satellite imagery both before and after each event, and
- contain burnt area mappings in the highest possible spatial resolution.

Similar datasets are provided by several organizations as dedicated data products, most of which are relying on sensors that provide high temporal but low spatial resolution. Examples of such products are provided in Table 8. However, there is currently no available product under public access offering mappings with high spatial resolution, i.e., in tens of meters.

To fill this gap, different researchers have assembled public datasets comprising the burn scar polygons of several historical events. Table 9 offers an overview of these datasets. It is evident that the spatial resolution is highly improved, reaching up to 10m in most cases, however, none of the available datasets fulfils all our needs for this particular application.

For that reason, the first contribution of NOA to task 6.4 is the development of a training dataset which contains polygons for ~331 historical wildfire events in Greece over the period 2017-2021. These polygons were obtained through manual effort conducted by the Hellenic Fire Service. Each event is accompanied by MODIS (MOD09GA) and Sentinel-2 (L2A) satellite images both before the ignition date and after the extinguishment date. Auxiliary data, such as cloud masks for each image, are also included. Both small and large-scale events were selected, with the smallest corresponding to ~0.25 km$^2$ of burnt land and the largest to ~4,474 km$^2$.

Table 8:Public and operational BAM products.

| Product | Provider | Satellite | Spatial resolution | Temporal compositing | Time span | Ref. |
|---|---|---|---|---|---|---|
| BA 300 | Copernicus | PROBA-V | 300m | 10 days | 2014-present | [68] |
| MCD64A1 | USGS | MODIS | 500m | 1 month | 2000-present | [69] |
| FireCCI51 | ESA CCI | MODIS | 250m | 1 month | 2001-2019 | [70] |
| GFed4 | ORNL DAAC | ATSR, MODIS | 0.25° | 1 month, 1 day | 1995-present | [71] |
| GFed4s | ORNL DAAC | ATSR, MODIS | 0.25° | 1 month, 1 day | 1997-present | [72] |
| VNP64A1 | USGS | VIIRS | 500m | 1 month | 2014-2019 | [73] |
| Burnt area | EFFIS | MODIS, VIIRS | 250m, 375m | 1 day | 2007-present | [74] |

Table 9: Public BAM datasets.

| Product | Spatial resolution | No. events | Spatial coverage | Time span | Satellite imagery included? | Ref. |
|---|---|---|---|---|---|---|
| NIFC GeoMAC Historic Perimeters | - | - | USA | 2000-2019 | No | [75], [76] |
| Satellite Burnt Area Dataset | up to 10m | 73 | Europe | 2017-9 | Yes | [77] |
| BARD | up to 10m | 2661 | Global | 1988-2018 | No | [78] |

More specifically, in Fgure 24 a single sample from the NOA's dataset is presented, on the process. The satellite images used, are shown as NIR-Red-Green composites. Graphs (i) Pre-event Sentinel-2 image at 20m and (ii) Pre-event MODIS image at 500m, provide the maps before the ignition date. Moreover, the graphs (iii) Post-event Sentinel-2 image at 20m and (iv) Post-event MODIS image at 500m present the maps after the extinguishment date. Finally, the burnt area marked in blue. Furthermore, Figure **26** presents the distribution of recorded events over Greece, for the period, while Figure **27** and Figure **28** show the number of fires per month for the years 2017-2021 and the distribution of positive and negative pixels in the NOA's historical dataset.

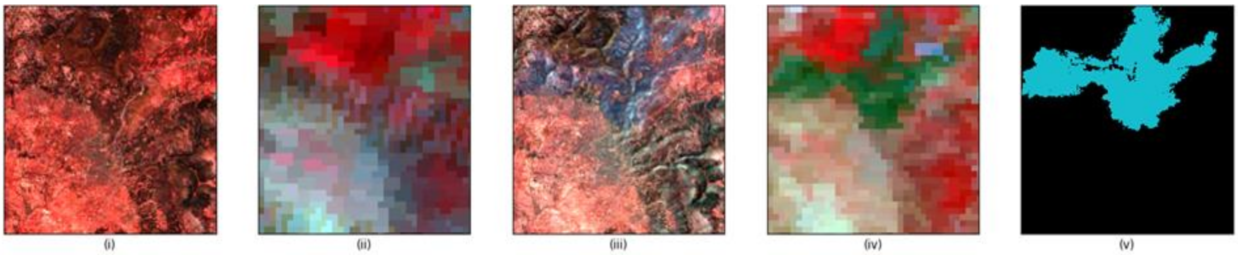

Figure 25: A single sample from our dataset. (i) Pre-event Sentinel-2 image at 20m, (ii) Pre-event MODIS image at 500m, (iii) Post-event Sentinel-2 image at 20m, (iv) Post-event MODIS image at 500m, (v) The burnt area marked in blue. Satellite images are shown as NIR-Red-Green composites.

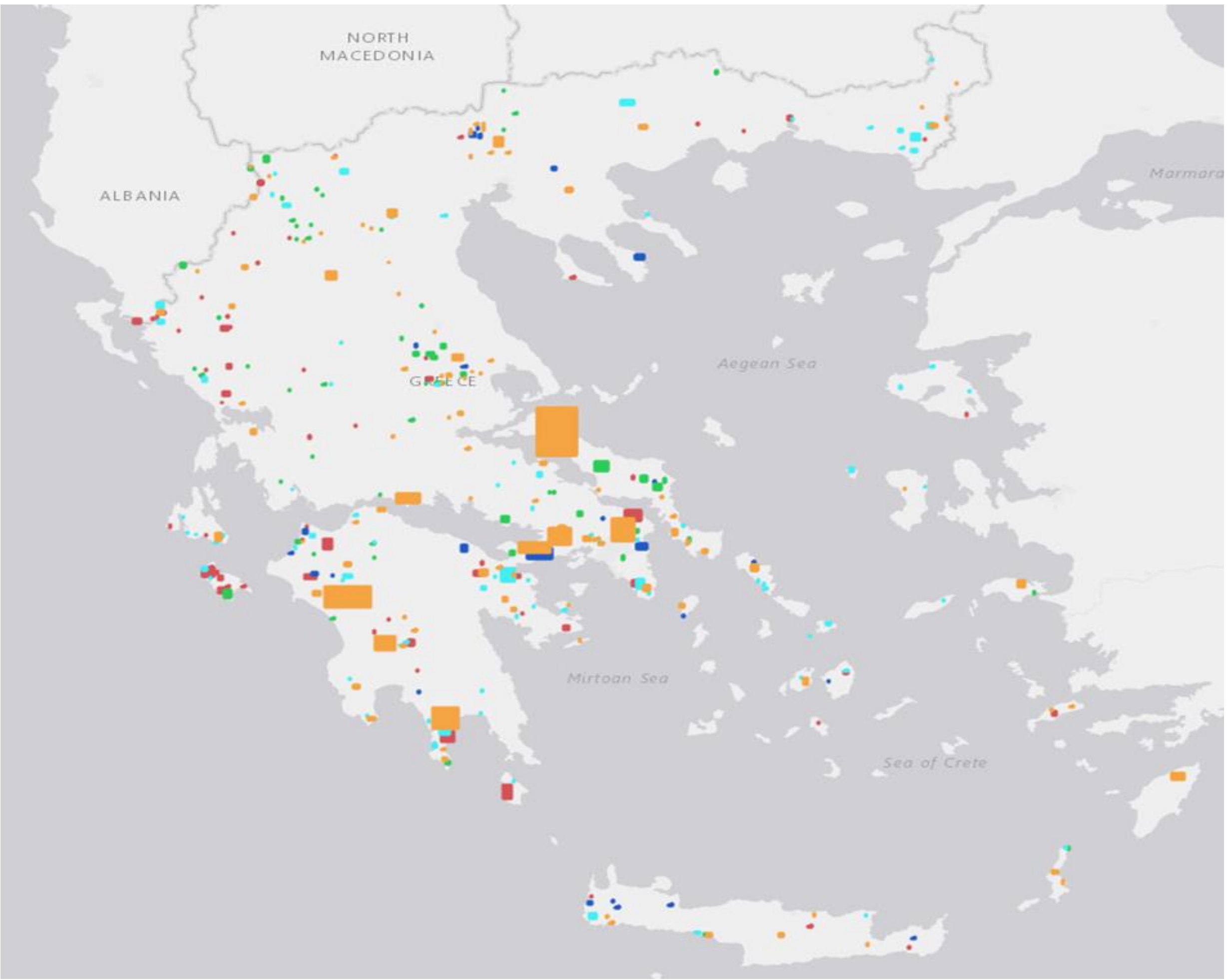

Figure 26: The distribution of recorded events over Greece. Red for 2017, blue for 2018, green for 2019, cyan for 2020 and orange for 2021. Only the bounding boxes of the burnt areas are shown for clarity.

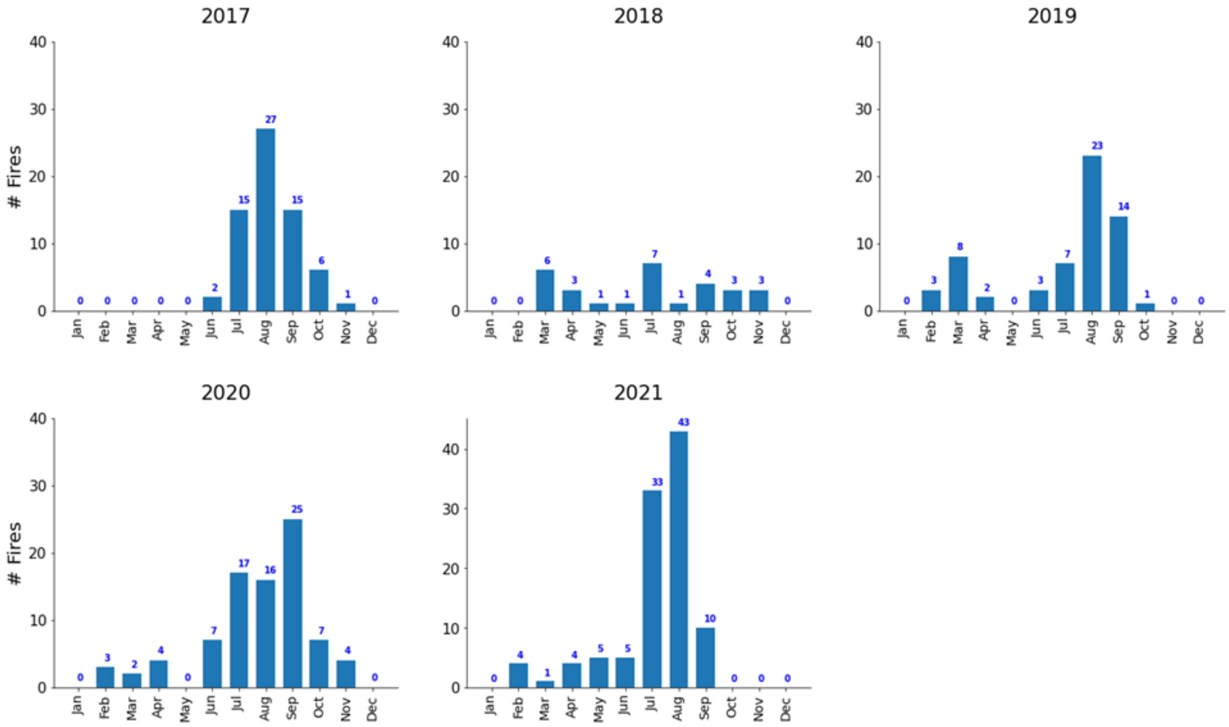

Figure 27: The number of recorded fire events per year.

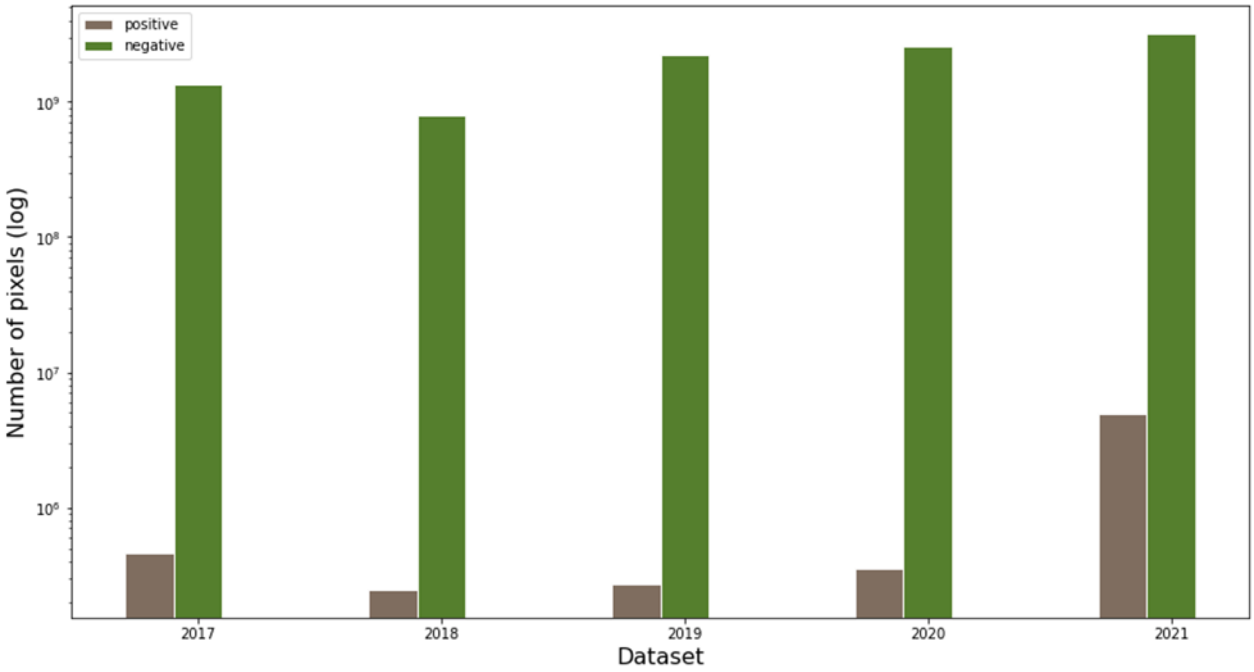

Figure 28: The distribution of positive and negative pixels in our dataset.

## Methodology

As seen from the above literature review, two main approaches are usually adopted for the task at hand: semantic segmentation of the post-event data vs. change detection between pre- and post-event data. We opt for the latter in order to ensure that no past burnt areas are mistakenly identified and also to reduce the risk of confusion with spectrally similar surfaces (e.g., water bodies, dark soil, agricultural harvesting, etc.) [79], [80]. In addition, spatial downscaling techniques will be integrated to align the input imagery to a common high-resolution scale. A thorough investigation of such methods proposed in the literature for remote sensing tasks can be found in [81]. An overview of our approach is shown in Figure **29** for the training phase and Figure **30** for the inference.

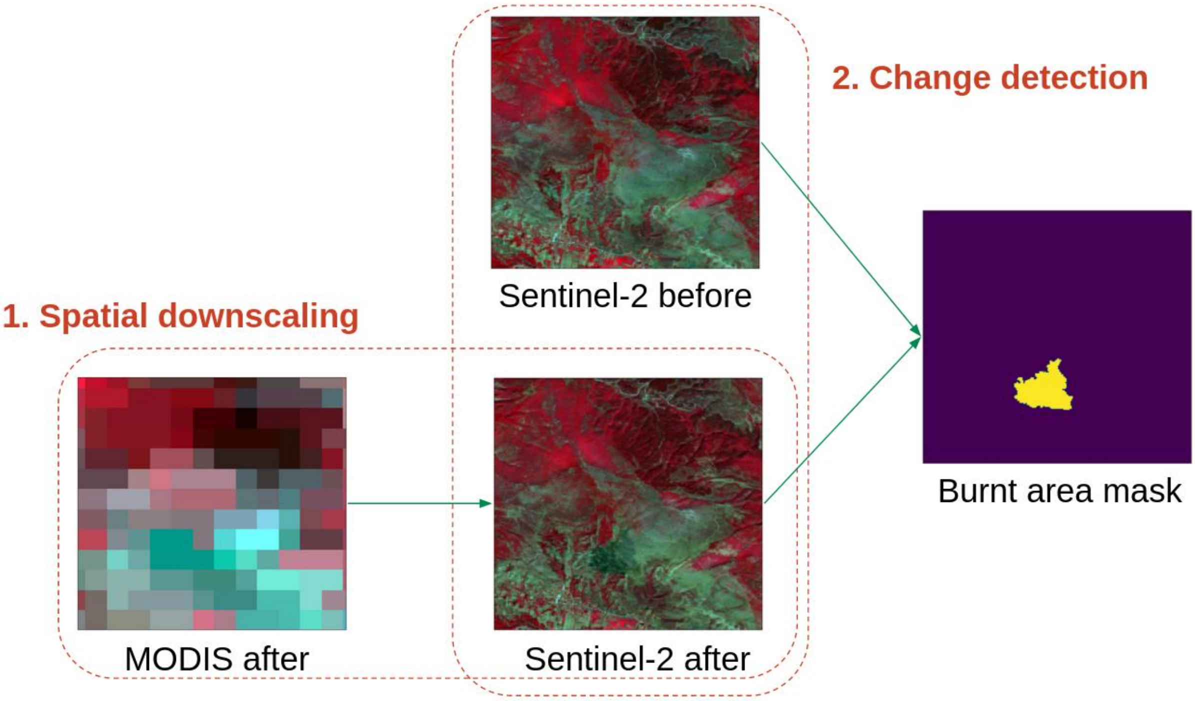

Figure 29: Training phase of the developed DL pipeline.

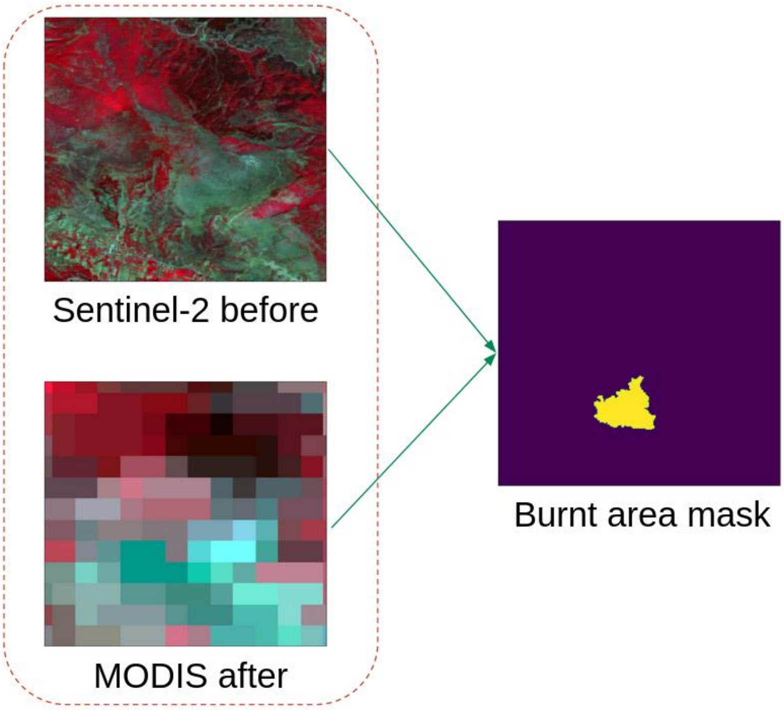

Figure 30: Inference phase of the developed DL pipeline.

## Deep Learning Modelling

Only a limited number of similar approaches which perform spatial enhancement along with change detection can be found in the literature. Namely, SRCDNet proposed in [82] employs a Generative Adversarial Network (GAN) for downscaling and a siamese network with attention modules for change detection. Both models are trained end-to-end using a hybrid loss and contrastive learning. Furthermore, MM-Trans [83] utilizes a pseudo-siamese feature extractor to produce features from the bitemporal images of varying resolutions. Then, a cascade of transformer modules aligns the feature maps to the same resolution and finally a prediction head exports the final binary change map. The last approach is RACDNet [84] where an enhanced WDSR [85] model downscales the low-resolution input and then a siamese U-Net with deformable convolutions and attention units compares the images and predicts the change. We must note here that none of the aforementioned approaches was applied to the burn scar mapping task.

In order to assess and evaluate our method we initially have to set up a number of baseline models to compare with. To that end, we initiated a series of experiments with basic as well as state-of-the-art models designed for change detection in general computer vision. Our input data come solely from Sentinel-2 and our goal is to determine the outcome when the highest-resolution possible data are available. These models include U-Net [59], FC-EF [86], FC-EF-Diff [86], FC-EF-Conc [86], STANet [87], HFA-Net [88] and BIT-CD [89]. The final results of our experiments are still pending.

## 6.4 NEXT STEPS

After the evaluation of the baseline models has been completed, the next step is the design and implementation of our proposed DL approach. Architectural details as well as formulation of the particular loss function have yet to be decided. Several different techniques will be examined, whereas our focus will be on diffusion models [90] since they are easier to train and attain more realistic results than other generative methods. In addition, when applied to the task of downscaling (or super-resolution) they achieve higher magnification factors via cascading, which will enable us to produce an even sharper burnt area mapping. Furthermore, in case our model needs a larger volume of training data than what we have available, we will experiment with data augmentation techniques and/or different learning schemes, such as semi-supervised learning, to leverage more unlabeled data. Finally, great care must be taken to handle the prevalent class imbalance in our data (see Figure **28**) so as not to let the samples of the negative/unburnt class dominate the training of the model.

# 7 CONCLUSIONS

Wildfires nowadays represent a common disturbance in the life of Europeans. It is known that wildfire occurrence trends are increasing worldwide due to a combination of different factors: elevated human-natural areas interaction, an increase of fuel in forests and higher temperatures, changes in precipitation patterns and longer drought periods as a consequence of global climate change, among others.

Society must adapt to this new scenario, and this goes by smartly managing burned areas and their restoration in the post-fire context. The restoration should include the results and data collected after an initial post-fire assessment, different perspectives of post-fire techniques and processes and adapting the objectives and intervention actions to each particular burned area.

In the end, the main objective is to help generate more resilient ecosystems to cope with wildfires and increasing global warming and to reduce, to a sustainable point, the negative impacts of fire. This vision can be changed to a completely different perspective: once an area has been burned -the inevitable-, it could be managed in a specific way considering that someday it will become the pre-fire territory. Environmental assessment and the application of different post-fire techniques have a crucial role in setting up future fire risks.

The proposed framework aims to provide services that may be used for fire risk planning, by combining diachronic burnt area patterns with LC and geomorphology maps, thus identifying the most vulnerable areas that need continuous supervision and immediate intervention for the protection of environmental and social sustainability. The literature review of the optimal solutions has been completed, as well as the major research part for the developments and the data involved in the development of the solutions. The initial dataset for modules 1 and 2 is in the collection process and nearly finalized to build-up a common database of reference for the developments of the TREEADS WP6 tools and solutions.

To this end, the TREEADS solution for restoration and adaptation will provide a holistic framework and an integrated system composed of interdependent components outcomes and innovations provided as presented in Chapters 3 to 6 for each of the Tasks that structure WP6. All the system's components as well as the testing of the seedpods and the seedball will be tested and validated. The holistic methodological approach aims to provide the tools and to-the-field solutions and components, which aim to create real value for the end users.

With this mind-set, WP6 provides a simple, user-friendly and practical strategy to produce simple solutions that lead to a value or at least an integral part. More specifically, the technological and operational solutions for restoration and adaptation from all Tasks will act as independent components and will be integrated into TREEADS Platform developed within WP7. Regarding the tools, the different Deep Learning and Artificial Intelligence models will be integrated within the tools of each Task allowing a comparison among models and predictors. In addition, the tool of T6.3 will include those variables of interest to be mapped and their origin as data sources and geospatial information, providing this information to the end-users for the restoration strategies and processes. In this tool, the communication capabilities for restoration and information sharing among the end-users will be also included. The design will include different layers and geo-information will be provided, so we can perfectly know the territory, the environment characteristics, the burned area, the severity index, as well as the resources (provided by the end-users) for restoration and action for adaptation.

# 8 REFERENCES

1. Moreira, F., Catry, F., Lopes, T., Bugalho, M. N., & Rego, F. (2009). Comparing survival and size of resprouts and planted trees for post-fire forest restoration in central Portugal. Ecological Engineering, 35(5), 870-873.;
2. Scheper, A. C., Verweij, P. A., & van Kuijk, M. (2021). Post-fire forest restoration in the humid tropics: A synthesis of available strategies and knowledge gaps for effective restoration. Science of the Total Environment, 771, 144647.
3. Keeley, J. E. (2009). Fire intensity, fire severity and burn severity: a brief review and suggested usage. International journal of wildland fire, 18(1), 116-126.
4. Turner, M. G., Romme, W. H., & Tinker, D. B. (2003). Surprises and lessons from the 1988 Yellowstone fires. Frontiers in Ecology and the Environment, 1(7), 351-358.
5. Vaudour, E., Gomez, C., Fouad, Y., & Lagacherie, P. (2019). Sentinel-2 image capacities to predict common topsoil properties of temperate and Mediterranean agroecosystems. Remote Sensing of Environment, 223, 21-33.
6. Angelopoulou, T., Tziolas, N., Balafoutis, A., Zalidis, G., Bochtis, D., 2019. Remote Sensing Techniques for Soil Organic Carbon Estimation: A Review. Remote Sens. 11, 676. https://doi.org/10.3390/rs11060676
7. Qi, J., Chehbouni, A., Huete, A.R., Kerr, Y.H., Sorooshian, S., 1994. A modified soil adjusted vegetation index. Remote Sens. Environ. 48, 119–126. https://doi.org/10.1016/0034-4257(94)90134-1
8. Xia, C., & Zhang, Y. (2022). Comparison of the use of Landsat 8, Sentinel-2, and Gaofen-2 images for mapping soil pH in Dehui, northeastern China. Ecological Informatics, 70, 101705.
9. Adab, H., Morbidelli, R., Saltalippi, C., Moradian, M., Ghalhari, G.A.F., 2020. Machine Learning to Estimate Surface Soil Moisture from Remote Sensing Data. Water 12, 3223. https://doi.org/10.3390/w12113223
10. Ali, I., Greifeneder, F., Stamenkovic, J., Neumann, M., Notarnicola, C., 2015. Review of Machine Learning Approaches for Biomass and Soil Moisture Retrievals from Remote Sensing Data. Remote Sens. 7, 16398–16421. https://doi.org/10.3390/rs71215841
11. Zhang, D., Zhou, G., 2016. Estimation of Soil Moisture from Optical and Thermal Remote Sensing: A Review. Sensors 16, 1308. https://doi.org/10.3390/s16081308
12. Yue, J., Tian, J., Tian, Q., Xu, K., Xu, N., 2019. Development of soil moisture indices from differences in water absorption between shortwave-infrared bands. ISPRS J. Photogramm. Remote Sens. 154, 216–230. https://doi.org/10.1016/j.isprsjprs.2019.06.012
13. Alexakis, D.D., Daliakopoulos, I.N., Panagea, I.S., Tsanis, I.K., 2018. Assessing soil salinity using WorldView-2 multispectral images in Timpaki, Crete, Greece. Geocarto Int. 33, 321–338. https://doi.org/10.1080/10106049.2016.1250826
14. Erkin, N., Zhu, L., Gu, H., Tusiyiti, A., 2019. Method for predicting soil salinity concentrations in croplands based on machine learning and remote sensing techniques. J. Appl. Remote Sens. 13, 034520. https://doi.org/10.1117/1.JRS.13.034520
15. Periasamy, S., Shanmugam, R.S., 2017. Multispectral and Microwave Remote Sensing Models to Survey Soil Moisture and Salinity. Land Degrad. Dev. 28, 1412–1425. https://doi.org/10.1002/ldr.2661
16. Wang, N., Xue, J., Peng, J., Biswas, A., He, Y., Shi, Z., 2020. Integrating Remote Sensing and Landscape Characteristics to Estimate Soil Salinity Using Machine Learning Methods: A Case Study from Southern Xinjiang, China. Remote Sens. 12, 4118. https://doi.org/10.3390/rs12244118
17. Rouse, J.W., Haas, R.H., Schell, J.A., Deering, D.W., 1974. Monitoring vegetation systems in the Great Plains with ERTS.

18. Qi, J., Chehbouni, A., Huete, A.R., Kerr, Y.H., Sorooshian, S., 1994. A modified soil adjusted vegetation index. Remote Sens. Environ. 48, 119–126. https://doi.org/10.1016/0034-4257(94)90134-1
19. Roujean, J.-L., Breon, F.-M., 1995. Estimating PAR absorbed by vegetation from bidirectional reflectance measurements. Remote Sens. Environ. 51, 375–384. https://doi.org/10.1016/0034-4257(94)00114-3
20. Gong, P., Pu, R., Biging, G.S., Larrieu, M.R., 2003. Estimation of forest leaf area index using vegetation indices derived from Hyperion hyperspectral data. IEEE Trans. Geosci. Remote Sens. 41, 1355–1362. https://doi.org/10.1109/TGRS.2003.812910
21. Ray, S.S., Singh, J.P., Das, G., Panigrahy, S., 2004. USE OF HIGH RESOLUTION REMOTE SENSING DATA FOR GENERATING SITE- SPECIFIC SOIL MANGEMENT PLAN. Conf. Int Arch Photogram Rem Sens Spat. Inf. 35, 5.
22. Rikimaru, A., Roy, P.S., Miyatake, S., 2002. Tropical forest cover density mapping. Trop. Ecol. India.
23. Khan, N.M., Rastoskuev, V.V., Sato, Y., Shiozawa, S., 2005. Assessment of hydrosaline land degradation by using a simple approach of remote sensing indicators. Agric. Water Manag., Special Issue on Land and Water Use: Environmental Management Tools and Practices 77, 96–109. https://doi.org/10.1016/j.agwat.2004.09.038
24. Filipponi, F., 2018. BAIS2: Burned Area Index for Sentinel-2. Proceedings 2, 364. https://doi.org/10.3390/ecrs-2-05177
25. Chung, J., Lee, Y., Kim, J., Jung, C., Kim, S., 2022. Soil Moisture Content Estimation Based on Sentinel-1 SAR Imagery Using an Artificial Neural Network and Hydrological Components. Remote Sens. 14, 465. https://doi.org/10.3390/rs14030465
26. Li, X., Fan, P., Li, Z., Chen, G., Qiu, H., Hou, G., 2021. Soil Classification Based on Deep Learning Algorithm and Visible Near-Infrared Spectroscopy. J. Spectrosc. 2021, e1508267. https://doi.org/10.1155/2021/1508267
27. Zhang, X., Sun, Y., Zhang, J., Wu, P., Jiao, L., 2018. Hyperspectral Unmixing via Deep Convolutional Neural Networks. IEEE Geosci. Remote Sens. Lett. 15, 1755–1759. https://doi.org/10.1109/LGRS.2018.2857804
28. Mohan, et al., M. (2021). UAV-Supported Forest Regeneration: Current Trends,Challenges and Implications. Basel: MDPI. https://www.mdpi.com/2072-4292/13/13/2596
29. Stelzer, H. (2019). How to plant forest tree seedlings. University of Missouri. Abgerufen am 14. 01 2023 von https://extension.missouri.edu/publications/g5008
30. Aghani, M., & Manteuffel-Ross, T. (2020). ENHANCING DIRECT SEEDING EFFORTS WITH UNMANNED AERIAL VEHICLE (UAV) “SWARMS” AND SEED TECHNOLOGY. Tree Planters´ Notes(2). https://rngr.net/publications/tpn/63-2/enhancing-direct-seeding-efforts-with-unmanned-aerial-vehicle-uav-201cswarms201d-and-seed-technology
31. Yadav, et al., N. (2020). Plant Microbiomes for Sustainable Agriculture. https://doi.org/10.1007/978-3-030-38453-1
32. Terhonen, et al., E. (2019). Forest Tree Micriobiomes and Assosiated Fungal Endophytes: Functional Roles and Impact on Forest Health. Forests, 10(1), S. 1 - 32. https://doi.org/10.3390/f10010042
33. Grossnickle, S., & Ivetic, V. (2017). Direct Seeding in Performance Review - A Reforestation Field. Reforesta, 4, S. 94-142.
34. Ceccon, et al., E. (2016). Is Direct Seeding a Biologically Viable Strategy for Reforesting Forest Ecosystems? Evidences from a Meta-Analysis. L. Degrad. Dev., 27(3), S. 511-520. https://doi.org/10.1002/ldr.2421
35. Amaranthus, M. P., & Perry, D. A. (1987). Effect of Soil Transfer on Ectomycorrhiza Formation and the Survival and Growth of Conifer Seedlings in Old, Nonreforested Clear-Cuts. Ca. J. Res., 17, S. 944-950. https://doi.org/doi.org/10.1139/x87-147

36. Amaranthus, M., & Perry, D. (1989). Rapid Root Tip and Mycorrhiza Formation and Increased Survival of Douglas-Fir Seedlings after Soil Transfer. New For., 3(3), S. 259-264. https://doi.org/10.1007/BF00028933
37. Huang et al., Y. (2016). Pervasive Effects of Wildfire on Foliar Endophyte Communities in Montane Forest Trees. Microb. Ecol., 71(2), S. 452-468. https://doi.org/10.1007/s00248-015-0664-x
38. Agbeshie, A. (2022). Review of the Effects of Forest Fire on Soil Propertie. J. For. Res., 33(5), S. 1419-1441 https://doi.org/10.1007/s11676-022-01475-4
39. Li et al., G. (2013). Isolation and Identification of Phytate-Degrading Rhizobacteria with Activity of Improving Growth of Poplar and Masson Pine. World J. Microbiol. Biotechnol., 29(11), S. 2181-2193. https://doi.org/10.1007/s11274-013-1384-3
40. Khan et al., Z. (2015). Increased Biomass of Nursery-Grown Douglas-Fir Seedlings upon Inoculation with Diazotrophic Endophytic Consortia. Forests, 6(10), S. 3582-3593. https://doi.org/10.3390/f6103582
41. Pfabel et al., C. (2012). Impact of Ectomycorrhizal Colonization and Rust Infection on the Secondary Metabolism of Poplar (Populus Trichocarpa × Deltoides). Tree Physiol., 32(11), S. 1357-1364. https://doi.org/10.1093/treephys/tps093
42. Beniusyte et al., E. (2023). Genotype-Dependent Jasmonic Acid Effect on Pinus Sylvestris L. Growth and Induced Systemic Resistance Indicators. Plants, 12, S. 255. https://doi.org/10.3390/plants12020255
43. Macardar Angier, V. (2016). EP Patentnr. EP3504965B1. https://patents.google.com/patent/EP3504965B1/en
44. Pérez-Rodríguez, J., & Messelink, G. (2023). Artificial shelters enhance the establishment of the aphidophagous predator Scymnus interruptus on sweet pepper plants. Biological Control(177). https://www.sciencedirect.com/science/article/pii/S1049964422002754
45. GOSSGE EU-Project. (2019). Proyecto prospección y control de la plaga Gonipterus del eucalipto en Galicia, Asturias y Cantabria. (G. -G.-A. EUCALIPTO, Hrsg.) Abgerufen am 12. 01 2023 von http://asefoga.org/wp-content/uploads/2019/10/Manual-Formativo-GOSSGE-Profesionales3.pdf
46. Bürdek, B. (2002). Diseño: historia, teoría y práctica del diseño industrial (3. Ausg.). Barcelona: Gustavo Hili.
47. Key, C. H., & Benson, N. C. (2006). Landscape assessment (LA). FIREMON: Fire effects monitoring and inventory system, 164, LA-1.
48. Rouse, J., R. Haas, J. Schell, and D. Deering. Monitoring Vegetation Systems in the Great Plains with ERTS. Third ERTS Symposium, NASA (1973): 309-317.
49. Caselles, V., Lopez Garcia, M. J., Melia, J., & Perez Cueva, A. J. (1991). Analysis of the heat-island effect of the city of Valencia, Spain, through air temperature transects and NOAA satellite data. Theoretical and Applied Climatology, 43, 195-203.
50. García, M., Alloza, J., Mayor, Á., Bautista, S., & Rodríguez, F. (2014). Detection and mapping of burnt areas from time series of MODIS-derived NDVI data in a Mediterranean region. Open Geosciences, 6(1), 112-120.
51. M. Senande-Rivera, D. Insua-Costa, and G. Miguez-Macho, ‘Spatial and temporal expansion of global fire activity in response to climate change’, In Review, preprint, Mar. 2021. doi: 10.21203/rs.3.rs-143619/v1.
52. P. Jain, S. C. P. Coogan, S. G. Subramanian, M. Crowley, S. Taylor, and M. D. Flannigan, ‘A review of machine learning applications in wildfire science and management’, Environ. Rev., vol. 28, no. 4, pp. 478–505, Dec. 2020, doi: 10.1139/er-2020-0019.
53. E. Chuvieco et al., ‘Historical background and current developments for mapping burned area from satellite Earth observation’, Remote Sens. Environ., vol. 225, pp. 45–64, May 2019, doi: 10.1016/j.rse.2019.02.013.

54. L. Knopp, M. Wieland, M. Rättich, and S. Martinis, ‘A Deep Learning Approach for Burned Area Segmentation with Sentinel-2 Data’, Remote Sens., vol. 12, no. 15, p. 2422, Jul. 2020, doi: 10.3390/rs12152422.
55. D. Q. Tran, M. Park, D. Jung, and S. Park, ‘Damage-Map Estimation Using UAV Images and Deep Learning Algorithms for Disaster Management System’, Remote Sens., vol. 12, no. 24, p. 4169, Dec. 2020, doi: 10.3390/rs12244169.
56. J. Florath and S. Keller, ‘Supervised Machine Learning Approaches on Multispectral Remote Sensing Data for a Combined Detection of Fire and Burned Area’, Remote Sens., vol. 14, no. 3, p. 657, Jan. 2022, doi: 10.3390/rs14030657.
57. X. Hu, Y. Ban, and A. Nascetti, ‘Uni-Temporal Multispectral Imagery for Burned Area Mapping with Deep Learning’, Remote Sens., vol. 13, no. 8, p. 1509, Apr. 2021, doi: 10.3390/rs13081509.
58. S. T. Seydi, M. Hasanlou, and J. Chanussot, ‘Burnt-Net: Wildfire burned area mapping with single post-fire Sentinel-2 data and deep learning morphological neural network’, Ecol. Indic., vol. 140, p. 108999, Jul. 2022, doi: 10.1016/j.ecolind.2022.108999.
59. O. Ronneberger, P. Fischer, and T. Brox, ‘U-Net: Convolutional Networks for Biomedical Image Segmentation’, ArXiv150504597 Cs, May 2015, Accessed: Feb. 11, 2021. [Online]. Available: http://arxiv.org/abs/1505.045**97**
60. Z. Zhou, M. M. Rahman Siddiquee, N. Tajbakhsh, and J. Liang, ‘UNet++: A Nested U-Net Architecture for Medical Image Segmentation’, in Deep Learning in Medical Image Analysis and Multimodal Learning for Clinical Decision Support, vol. 11045, D. Stoyanov, Z. Taylor, G. Carneiro, T. Syeda-Mahmood, A. Martel, L. Maier-Hein, J. M. R. S. Tavares, A. Bradley, J. P. Papa, V. Belagiannis, J. C. Nascimento, Z. Lu, S. Conjeti, M. Moradi, H. Greenspan, and A. Madabhushi, Eds. Cham: Springer International Publishing, 2018, pp. 3–11. doi: 10.1007/978-3-030-00889-5_1.
61. M. M. Pinto, R. Libonati, R. M. Trigo, I. F. Trigo, and C. C. DaCamara, ‘A deep learning approach for mapping and dating burned areas using temporal sequences of satellite images’, ISPRS J. Photogramm. Remote Sens., vol. 160, pp. 260–274, Feb. 2020, doi: 10.1016/j.isprsjprs.2019.12.014.
62. M. M. Pinto, R. M. Trigo, I. F. Trigo, and C. C. DaCamara, ‘A Practical Method for High-Resolution Burned Area Monitoring Using Sentinel-2 and VIIRS’, Remote Sens., vol. 13, no. 9, p. 1608, Apr. 2021, doi: 10.3390/rs13091608.
63. F. H. Maskouni and S. T. Seydi, ‘Forest Burned Area Mapping Using Bi-Temporal Sentinel-2 Imagery Based on a Convolutional Neural Network: Case Study in Golestan Forest’, in The 8th International Electronic Conference on Sensors and Applications, Nov. 2021, p. 6. doi: 10.3390/ecsa-8-11291.
64. V. S. Martins, D. P. Roy, H. Huang, L. Boschetti, H. K. Zhang, and L. Yan, ‘Deep learning high resolution burned area mapping by transfer learning from Landsat-8 to PlanetScope’, Remote Sens. Environ., vol. 280, p. 113203, Oct. 2022, doi: 10.1016/j.rse.2022.113203.
65. V. Kashtan and V. Hnatushenko, ‘Deep Learning Technology for Automatic Burned Area Extraction Using Satellite High Spatial Resolution Images’, in Lecture Notes in Data Engineering, Computational Intelligence, and Decision Making, vol. 149, S. Babichev and V. Lytvynenko, Eds. Cham: Springer International Publishing, 2023, pp. 664–685. doi: 10.1007/978-3-031-16203-9_37.
66. M. Coca, I. C. Neagoe, and M. Datcu, ‘Hybrid DNN-Dirichlet Anomaly Detection and Ranking: case of Burned Areas Discovery’, IEEE Trans. Geosci. Remote Sens., pp. 1–1, 2022, doi: 10.1109/TGRS.2022.3207311.
67. A. Farasin, L. Colomba, and P. Garza, ‘Double-Step U-Net: A Deep Learning-Based Approach for the Estimation of Wildfire Damage Severity through Sentinel-2 Satellite Data’, Appl. Sci., vol. 10, no. 12, p. 4332, Jun. 2020, doi: 10.3390/app10124332.

68. K. Tansey and D. Wolfs, ‘Copernicus Global Land Operations “Vegetation and Energy CGLOPS-1” - Algorithm Theoretical Basis Document’. Jun. 27, 2017. Accessed: Dec. 04, 2021. [Online]. Available: https://land.copernicus.eu/global/products/ba
69. Giglio, Louis, Justice, Christopher, Boschetti, Luigi, and Roy, David, ‘MCD64A1 MODIS/Terra+Aqua Burned Area Monthly L3 Global 500m SIN Grid V006’. NASA EOSDIS Land Processes DAAC, 2015. doi: 10.5067/MODIS/MCD64A1.006.
70. Pettinari, M. L., Lizundia-Loiola, J., and Chuvieco, E., ‘ESA CCI ECV Fire Disturbance: D4.2 Product User Guide - MODIS, version 1.0’. 2020. [Online]. Available: https://www.esa-fire-cci.org/documents
71. L. Giglio, J. T. Randerson, and G. R. van der Werf, ‘Analysis of daily, monthly, and annual burned area using the fourth-generation global fire emissions database (GFED4)’, J. Geophys. Res. Biogeosciences, vol. 118, no. 1, pp. 317–328, 2013, doi: https://doi.org/10.1002/jgrg.20042.
72. G. R. van der Werf et al., ‘Global fire emissions estimates during 1997–2016’, Earth Syst. Sci. Data, vol. 9, no. 2, pp. 697–720, 2017, doi: 10.5194/essd-9-697-2017.
73. Giglio, Louis, ‘VIIRS/NPP Burned Area Monthly L4 Global 500m SIN Grid V001’. NASA EOSDIS Land Processes DAAC, 2019. doi: 10.5067/VIIRS/VNP64A1.001.
74. J. San-Miguel-Ayanz et al., ‘Comprehensive monitoring of wildfires in Europe: the European forest fire information system (EFFIS)’, in Approaches to managing disaster-Assessing hazards, emergencies and disaster impacts, IntechOpen, 2012.
75. ‘Historic Perimeters Combined 2000-2018 GeoMAC’. https://data-nifc.opendata.arcgis.com/datasets/nifc::historic-perimeters-combined-2000-2018-geomac/about (accessed Jan. 26, 2023).
76. ‘Historic Perimeters 2019’. https://data-nifc.opendata.arcgis.com/maps/nifc::historic-perimeters-2019 (accessed Jan. 26, 2023).
77. L. Colomba et al., ‘A Dataset for Burned Area Delineation and Severity Estimation from Satellite Imagery’, in Proceedings of the 31st ACM International Conference on Information & Knowledge Management, Atlanta GA USA, Oct. 2022, pp. 3893–3897. doi: 10.1145/3511808.3557528.
78. M. Franquesa et al., ‘Development of a standard database of reference sites for validating global burned area products’, Earth Syst. Sci. Data, vol. 12, no. 4, pp. 3229–3246, Dec. 2020, doi: 10.5194/essd-12-3229-2020.
79. H. Huang et al., ‘Separability Analysis of Sentinel-2A Multi-Spectral Instrument (MSI) Data for Burned Area Discrimination’, Remote Sens., vol. 8, no. 10, p. 873, Oct. 2016, doi: 10.3390/rs8100873.
80. L. Giglio, L. Boschetti, D. P. Roy, M. L. Humber, and C. O. Justice, ‘The Collection 6 MODIS burned area mapping algorithm and product’, Remote Sens. Environ., vol. 217, pp. 72–85, Nov. 2018, doi: 10.1016/j.rse.2018.08.005.
81. M. Sdraka et al., ‘Deep Learning for Downscaling Remote Sensing Images: Fusion and super-resolution’, IEEE Geosci. Remote Sens. Mag., vol. 10, no. 3, pp. 202–255, Sep. 2022, doi: 10.1109/MGRS.2022.3171836.
82. M. Liu, Q. Shi, A. Marinoni, D. He, X. Liu, and L. Zhang, ‘Super-Resolution-Based Change Detection Network With Stacked Attention Module for Images With Different Resolutions’, IEEE Trans. Geosci. Remote Sens., vol. 60, pp. 1–18, 2022, doi: 10.1109/TGRS.2021.3091758.
83. M. Liu, Q. Shi, J. Li, and Z. Chai, ‘Learning Token-Aligned Representations With Multimodel Transformers for Different-Resolution Change Detection’, IEEE Trans. Geosci. Remote Sens., vol. 60, pp. 1–13, 2022, doi: 10.1109/TGRS.2022.3200684.
84. J. Tian, D. Peng, H. Guan, and H. Ding, ‘RACDNet: Resolution- and Alignment-Aware Change Detection Network for Optical Remote Sensing Imagery’, Remote Sens., vol. 14, no. 18, p. 4527, Sep. 2022, doi: 10.3390/rs14184527.

85. J. Yu et al., ‘Wide Activation for Efficient and Accurate Image Super-Resolution’, ArXiv180808718 Cs, Dec. 2018, Accessed: Mar. 23, 2021. [Online]. Available: http://arxiv.org/abs/1808.08718
86. R. C. Daudt, B. L. Saux, and A. Boulch, ‘Fully Convolutional Siamese Networks for Change Detection’, ArXiv181008462 Cs, Oct. 2018, Accessed: Oct. 05, 2021. [Online]. Available: http://arxiv.org/abs/1810.08462
87. H. Chen and Z. Shi, ‘A Spatial-Temporal Attention-Based Method and a New Dataset for Remote Sensing Image Change Detection’, Remote Sens., vol. 12, no. 10, p. 1662, May 2020, doi: 10.3390/rs12101662.
88. H. Zheng et al., ‘HFA-Net: High frequency attention siamese network for building change detection in VHR remote sensing images’, Pattern Recognit., vol. 129, p. 108717, Sep. 2022, doi: 10.1016/j.patcog.2022.108717.
89. H. Chen, Z. Qi, and Z. Shi, ‘Remote Sensing Image Change Detection With Transformers’, IEEE Trans. Geosci. Remote Sens., pp. 1–14, 2021, doi: 10.1109/TGRS.2021.3095166.
90. J. Ho, A. Jain, and P. Abbeel, ‘Denoising Diffusion Probabilistic Models’. arXiv, Dec. 16, 2020. Accessed: Jul. 12, 2022. [Online]. Available: http://arxiv.org/abs/2006.11239
91. Alloza, José & Garcia-Barreda, Sergi & Gimeno, Teresa & Baeza, Manuel & Vallejo, Ramon & Rojo, Leopoldo & Martínez, Araceli. (2014). Guía técnica para la gestión de montes quemados. Protocolos de actuación para la restauración de zonas quemadas con riesgo de desertificación.
92. Martin, D. M. (2017). Ecological restoration should be redefined for the twenty-first century. Restoration Ecology, 25(5), 668-673.
93. Pereira, P., Francos, M., Brevik, E. C., Ubeda, X., & Bogunovic, I. (2018). Post-fire soil management. Current Opinion in Environmental Science & Health, 5, 26-32.
94. Riley, L. E., Steinfeld, D. E., Winn, L. A., & Lucas, S. L. (2015). Best management practices: An integrated and collaborative approach to native plant restoration on highly disturbed sites. Natural Areas Journal, 35(1), 45-53.
95. Mauri, E., & Pons Ferran, P. (2019). Handbook of good practices in post-wildfire management: How to mitigate or avoid the negative impact of salvage logging in Mediterranean forests. Universitat de Girona. Servei de Publicacions.
96. Burton, P. J., & Macdonald, S. E. (2011). The restorative imperative: challenges, objectives and approaches to restoring naturalness in forests.
97. Rist, L., Campbell, B. M., & Frost, P. (2013). Adaptive management: where are we now?. Environmental conservation, 40(1), 5-18.
98. Williams, B. K. (2012). Reducing uncertainty about objective functions in adaptive management. Ecological Modelling, 225, 61-65.
99. Hetemäki, L., Hanewinkel, M., Muys, B., Ollikainen, M., Palahí, M. and Trasobares, A. 2017. Leading the way to a European circular bioeconomy strategy. From Science to Policy 5. European Forest Institute.
100. “US Businesses, Governments and Non-Profits Join Global Push for 1 Trillion Trees” https://www.weforum.org/press/2020/08/us-businesses-governments-and-non-profits-join-global-push-for-1-trillion-trees/ (Accessed: Nov. 17, 2023).
101. “EFFIS Fire Severity Mapping” https://effis.jrc.ec.europa.eu/apps/effis_current_situation/ (Accessed: Nov. 17, 2023).

## A Holistic Fire Management Ecosystem for Prevention, Detection and Restoration of Environmental Disasters

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