



CLIMAAX

climate ready regions

Deliverable Phase 2 – Climate risk assessment

BioProWRAP

Greece / Region of Eastern Macedonia & Thrace (REMTH)

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Brief Description	This deliverable presents the Phase2 results of the BioProWRAP project, developed under the CLIMAAX framework, and focuses on enriching the initial wildfire-risk assessment of Phase1 through the integration of drought risk, an interconnected hazard with potential cascading effects, alongside diverse local datasets and live biodiversity inputs (crowdsourcing observations, eDNA). Phase2 also enhances public engagement and inclusion through educational workshops and guided excursions in the three high-risk, high-value areas identified in Phase1. The work was carried out by the REMTH team with continued scientific support from UTH, Greece.
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Leading Institution	Region of Eastern Macedonia and Thrace (REMTH)
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Abbreviations and acronyms.

Abbreviation / acronym	Description
BioProWRAP	Biodiversity Protection through Wildfire Risk Associated Planning
CLC	CORINE Land Cover
CLIMAAX	Climate Risk Assessment Framework
CMIP6	Coupled Model Intercomparison Project Phase 6
CPDR	Civil Protection Directorate of REMTH
CRA	Climate Risk Assessment
CTIF	The Hellenic Voluntary Firefighters Association
dVis	Digital vulnerability index
DEM	Digital Elevation Model
DEA	Data Envelopment Analysis
EASIN	European Alien Species Information Network
dH	Drought hazard
eDNA	Environmental DNA
EFFIS	European Forest Fire Information System
ESAMEA	Greek National Confederation of Persons with Disabilities
FAIR	Findability, Accessibility, Interoperability and Reusability
GBIF	Global Biodiversity Information Facility
GCM	Global Climate Model
GIS	Geographic Information System
GRIS	Global Register of Introduced and Invasive Species
H.O.I.A	Hellenic Agricultural Insurance Organization (H.O.I.A-ELGA)
JRC	Joint Research Centre
IUCN	International Union for Conservation of Nature
ML	Machine Learning
NECCA	Natural Environment & Climate Change Agency
NGO	Non-governmental organization
NGS	Next Generation Sequencing
NUTS	Nomenclature of Territorial Units for Statistics
PESPKA/RCCAP	Regional Plan for Adaptation to Climate Change
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RDF	Regional Development Fund
REMTH	Region of Eastern Macedonia and Thrace
SPBT	Society for the Protection of Biodiversity of Thrace
SSPs	Socio-economic pathways
TRY	Plant Based Database, TRY
WAST	Weighted Anomaly Standardized Precipitation

Executive summary

This deliverable presents the Phase 2 results of the BioProWRAP project, developed under the CLIMAAX Climate Risk Assessment (CRA) framework. Phase 2 was designed to enrich the initial wildfire-risk assessment of Phase 1 by integrating drought risk, incorporating improved local datasets, and adding real-time biodiversity inputs for the Region of Eastern Macedonia and Thrace (REMTH), Greece. The deliverable addresses the need for a deeper multi-hazard understanding and more robust evidence-based decision-making, while advancing the targeted biodiversity-monitoring strategy established in Phase 1.

Phase 2 builds directly upon the outputs of Phase 1 and expands them through the inclusion of high-resolution local datasets from REMTH authorities (updated wildfire and precipitation records), crowdsourced biodiversity observations (Seek/iNaturalist), and genetic biodiversity monitoring (environmental DNA metabarcoding). Drought-related indicators and climate projections were incorporated to capture the interconnected nature of hazards and their cascading impacts. This phase also strengthens public engagement through structured educational workshops and guided excursions in the three high-risk, high-value areas identified previously in Phase 1.

Key actions undertaken during Phase 2 include extensive scoping to refine objectives, integrate new datasets, and expand stakeholder participation. The Climate Risk Assessment was enhanced by:

- integrating drought risk into the wildfire-risk framework to improve multi-hazard accuracy;
- updating local wildfire and precipitation datasets;
- incorporating live biodiversity inputs from citizen science into susceptibility modelling in the form of an extra vulnerability layer of species/genera-specific flammability;
- developing a synthetic metabarcoding dataset to support future biodiversity-risk integration;
- conducting stakeholder engagement through meetings, questionnaires, social media, newsletters, workshops, and field excursions;
- selecting the CLMcom_CLM climate model for short-term projections (2021–2040);
- producing updated wildfire risk maps using vulnerability and exposure data from JRC and OpenStreetMap.

The main findings indicate that wildfire remains a very high-priority risk for REMTH, characterized by critical severity, immediate urgency, and low to medium resilience capacity across several NUTS3 regions. Drought emerges as a moderate-priority hazard with substantial severity, particularly affecting agricultural and water-dependent areas. The integration of biodiversity data provides new insights into ecological vulnerability and supports the development of a long-term biodiversity-monitoring strategy.

In conclusion, Phase 2 delivers an expanded, locally adapted, and multi-hazard climate-risk assessment that significantly enhances the evidence base for regional adaptation planning. It demonstrates the added value of integrating local datasets, citizen-generated biodiversity information, and climate projections into the CLIMAAX workflows.

Phase 3 will focus on designing targeted adaptation measures for REMTH, prioritising vulnerable areas, strengthening biodiversity monitoring and preservation, and operationalizing the emerging risk-monitoring system to support long-term regional resilience.

1 Introduction

1.1 Background

Eastern Macedonia & Thrace is a Greek administrative region (REMTH), rich in natural resources, that oversees the entirety of Thrace and the eastern part of Macedonia, making up to 10.7% of Greece. REMTH is covered in 15.6% by forests (European Forest Fire Information System; EFFIS), including areas of enormous ecological value like four national parks (Dadia Forest, Rodopi Mountain Range, Evros Delta, Eastern Macedonia & Thrace National Park) and other protected or socioeconomically important areas (Nestos Delta, local population villages, etc.). REMTH forests have been devastated by wildfires, losing 174,8kha (EFFIS) only in 2023. Consequently, the vulnerability of REMTH has significantly increased, while the available resources have been rendered limited, since they are distributed to respond to numerous pressing challenges. All the above make wildfires the primary climate-related risk of REMTH, making the need for sustainable wildfire prevention and mitigation planning imperative. Interconnecting risks like drought are also of high importance since they can have cascaded effects exacerbating the wildfire risk. However, economic and technological constraints, along with limited high-resolution and accurate data, restrict access to comprehensive risk and vulnerability assessment. Within this context, through the CLIMAAX program, BioProWRAP (Biodiversity Protection through Wildfire Risk Associated Planning «BioProWRAP») aims to bring climate risk and biodiversity data together to not only prevent future wildfires but also establish a sustainable biodiversity monitoring plan that will prioritize high-risk, high-value regions. This systematic plan will enable future forest management and restoration efforts, increasing regional climate adaptation and enhancing forest resilience.

1.2 Main objectives of the project

Phase 2 of the BioProWRAP project represents a critical step towards strengthening climate resilience in REMTH, as it advances from preliminary scoping (Phase1) to a data-driven and locally adapted climate risk assessment (CRA). Local datasets from REMTH, as well as biodiversity data produced by citizen science observations (SeekbyiNaturalist), were used to support this advanced analysis, ensuring an accurate representation of local conditions.

The main objectives of Phase 2 are to:

- Enrich the wildfire-risk assessment with additional pre-existing and real-time local data for precise risk mapping, including REMTH and citizen-generated biodiversity data.
- Expand the CRA to an additional interconnecting hazard (relative drought) to deliver a comprehensive, multi-hazard adaptation strategy for REMTH.
- Develop a new wildfire-risk strategic assessment plan based on data tailored to REMTH's ecological and socio-economic impact.
- Strengthen citizen participatory processes through crowdsourced biodiversity monitoring methods and targeted excursions in three high risk-high value selected areas (Phase 1).
- Support local economic resilience by promoting nature-based solutions, sustainable land management, and community-driven adaptation actions that benefit local economies.

Expected Benefits of Applying the CLIMAAX Handbook and the inclusion of local data/models in Phase 2:

- Enhanced CRA quality from enriched local data.
- Enhance stakeholder climate risk awareness, especially wildfire risk among farmers, local communities, NGOs and businesses, as well as their involvement in practical adaptation strategies.

- Benefit from strategic resource allocation by prioritising personnel, equipment and monitoring efforts based on local climate risk data, enabling more cost-effective and targeted interventions.
- Equip REMTH with local data-based insights and best-practices for monitoring biodiversity alongside fire risk and other related risks, enabling continuous learning and improvements in prevention and mitigation planning.

1.3 Project team

The core team of the BioProWRAP project is composed of following members (Table 1-1):

Table 1-1 Project Management and Core Team of BioProWrap Project.

<i>Name</i>	<i>Department</i>	<i>Expertise</i>	<i>Assignment in BioProWrap</i>
Konstantinos Chouvardas (Msc, Med, MBA)	Civil Protection Department	Mechanical Engineer, Director of Civil Protection Department at REMTH	Operational coordinator and Project Manager, overseeing administrative work, stakeholder engagement and representing REMTH in the Project Coordination Committee and project meetings.
Spyridon Arseniou (PhD)	Department for Regional Policy Planning	Agronomist, Civil Servant of REMTH, Deputy Head of the Department for Regional Policy Planning	Administrative work, scheduling meetings, participation in all project actions and represents REMTH in project meetings.
Leonidas Skerletopoulos, (Msc, MBA)	REMTH	Administrator, Marketing and Communications specialist, Special Advisor to the Governor of REMTH	Engaged across all project activities with authority to represent REMTH at project meetings.
Sevastos Mavridis (MSc)	Procurement Department, Financial Directorate, REMTH	IT Engineer, Head of the Procurement Department, Financial Directorate, REMTH	Administrative work, Staff and Timeline management, coordinates procurement processes participation in all project actions and represents REMTH in project meetings.
Fotoula Kyrkoudi (MSc)	Budget and Fiscal Reporting Department, Financial Directorate, REMTH	Financial administrator, Head of the Budget and Fiscal Reporting Department, REMTH	Financial management, budget documentation, participation in all project actions and represents REMTH in project meetings.
Maria Hassanidou (BSc)	Civil Protection Department, Evros Regional Unit	Agronomist	Project management participation in all project actions and represents REMTH in project meetings.
Emmanouil Kargiotidis (BPA)	Civil Protection Department, Rhodope Regional Unit	Administrator-Accounting	Administrative support. Participation in all project actions and represents REMTH in project meetings.
Orestis Chatzopoulos (MSc)	REMTH	Consultant - Geotechnical - Economist	Project Management and Administrative support
Elisavet Papatheodorou (MSc)	REMTH	Forester, specialization in data management	Collection and processing of local data.

Prof. Christos Nakas	Department of Agriculture Crop Production and Rural Environment, UTH	Biostatistician-Biometrician, Head of the Laboratory of Biometry, UTH	Scientific support in statistical analysis and big data modeling.
Ioanna Karamichali (PhD)	Department of Agriculture Crop Production and Rural Environment, UTH	Biochemist-Biotechnologist Bioinformatician. Postdoc Researcher, Laboratory of Biometry, UTH, specialization in biodiversity, Next Generation Sequencing (NGS) data management, and bioinformatics	Scientific Project Coordinator. Literature review, local data collection, result interpretation, reporting. Scientific analyses and the application of the CLIMAAX Climate Risk Assessment (CRA), CLIMAAX workflows' operations, workflow code adjustments, data transfer, Next Generation Sequencing (NGS) data management and output analysis.
Eleni Stefanidou (PhD student, UTH)	Department of Agriculture Crop Production and Rural Environment, UTH	Agronomist, specialization in plant molecular analysis and soil monitoring	Scientific fieldwork coordinator of the nature excursions along REMTH. Dissemination and outreach support.

1.4 Outline of the document's structure

This document begins with an introduction that sets the context by presenting the background of the BioProWRAP project in the Region of Eastern Macedonia & Thrace, outlining its main objectives, and describing the document layout. Following the introduction, the document proceeds with the climate risk assessment (CRA) methodology, starting with the scoping phase—based on Phase-1 outputs but enriched with newly incorporated local datasets and expanded stakeholder mapping. The analysis then moves into risk exploration and continues with focused analyses on wildfire hazards. Subsequent sections describe the incorporation of novel biodiversity data generated through citizen-science observations (crowdsourcing) and molecular metabarcoding methods. Data management, curation, and incorporation within the CLIMAAX toolbox methods are extensively described. Next the document shares the updated risk assessment findings, comparing them with Phase 1 results and highlighting the added value of local data incorporation. In the closing section, it synthesizes Phase 2 conclusions, reviews progress against initial milestones, and outlines how these insights will guide the next project phases. Finally, the appendices provide supporting materials and a comprehensive reference list, ensuring that every method and result remains transparent and verifiable.

2 Climate risk assessment – phase 2

Following the CLIMAAX Framework, this document describes all Scoping, Stakeholder engagement, Risk Exploration, Risk Analysis, Key Risk Assessment and Monitoring & Evaluation steps of the CRA Phase 2 for REMTH.

2.1 Scoping

The scoping phase focused on enriching the Phase 1 multi-risk assessment by adding an evaluation of an interconnected hazard of major regional importance, whose cascading effects further exacerbate wildfire risk in REMTH. Stakeholder engagement included structured stakeholder meetings, three educational workshops, and three guided excursions to the high-risk, high-value forest areas identified in Phase 1. This broad scoping approach expanded stakeholder participation, deepened understanding of key regional risks, and enabled practical involvement of stakeholders and the public in data collection through data exchange and the generation of live biodiversity observations.

2.1.1 Objectives

The principal objective of the BioProWRAP Climate Risk Assessment is to deliver a clear, data-driven understanding of wildfire risk across REMTH and to guide targeted forest-biodiversity monitoring beyond the national assessment systems currently in place. In Phase 2, this objective was strengthened through the integration of high-resolution local datasets and real-time biodiversity inputs into the CLIMAAX workflows. The phase focused on implementing targeted biodiversity monitoring in the high-risk areas identified in Phase 1, using both citizen-science observations (Seek by iNaturalist) and molecular methods (eDNA metabarcoding). It also aimed to maximise risk-assessment accuracy by incorporating updated wildfire records, local precipitation data, and live biodiversity information, while enhancing public engagement through educational workshops and guided excursions. The multi-hazard dimension of the CRA was expanded through the inclusion of drought risk, supported by strategic partnerships with REMTH authorities, CPDR, academic institutions, and NGOs.

Phase 2 is expected to support regional policy-making and adaptation planning by providing science-based insights that strengthen long-term resilience strategies. Systematic biodiversity monitoring contributes to forest-ecosystem resilience, while improved data management and biobank-related activities may generate socio-economic benefits for the region. The strategic plan developed for REMTH can also serve as a transferable model for other regional authorities. Several limitations influenced the assessment, including:

Difficulties in integrating new local data into the existing datasets: This issue was addressed through the inclusion of live, citizen-generated data collected via crowdsourcing methods.

Selection of final sampling areas: Due to landslides and unsafe access conditions in the Frakto region, a different sampling area had to be selected. Based on the wildfire risk assessment and the identification of hotspots areas during Phase 1, Paggiao–Mesoropi region was chosen as an alternative sampling location.

Difficulty in identifying diverse stakeholders: This issue was addressed through on-site dissemination, our targeted email campaign, and the live use of Google Forms shared to participants in order to collect expressions of interest for both Workshops and excursions.

2.1.2 Context

Climate risks in REMTH have intensified in recent years, affecting biodiversity, ecosystem balance, and key economic sectors such as agriculture, forestry, and tourism, making targeted adaptation measures increasingly important. Until now, climate risks have been managed through fragmented studies and baseline civil-protection plans, supported by the Regional Plan for Adaptation to Climate Change (RCCAP, 2022) and strengthened by new legislation (Law 5281/2026 “Active Battle”), which enhances institutional learning and accountability. BioProWRAP enriches this framework by integrating updated wildfire records, land-cover data, climate projections, and live biodiversity inputs (eDNA, Seek by iNaturalist) into the CLIMAAX workflows, enabling evidence-based decision-making and more precise prioritization of high-risk areas. Continuous data acquisition from citizens and NGOs reinforces community engagement and supports long-term resilience, while the project’s outputs complement—rather than replace—existing institutional responsibilities. Looking ahead, REMTH should be able to undertake adaptation interventions in the operational, ecological and governance-level. These include: wildfire-risk modelling, strengthened early-warning and preparedness systems, enhanced biodiversity monitoring using local and crowdsourced data, and systematic community engagement to build awareness and capacity. At the same time, the establishment of a unified regional coordination body, responsible for overseeing risks, ensuring consistency across prevention, and response actions would effectively address the current fragmentation of responsibilities. Such a body based on integrating scientific data (BioProWRAP) will further ensure effective prevention and prompt action.

2.1.3 Participation and risk ownership

Stakeholder engagement began in Phase 1 with the first stakeholder meeting [Annex A10 (A10.1.1-A10.1.3)], which helped identify an initial network and highlighted the importance of citizen participation for awareness and local data collection. In Phase 2, this process was expanded through a targeted communication campaign that included three educational workshops and three field excursions in the high-risk, high-value areas identified in Phase 1 (Annex A, B). Stakeholders were reached through a targeted campaign; customized workshop programs (Annex A1.1-A1.5), printed promotional material (Annex A2.1-A2.4), email outreach to public authorities, universities, NGOs and agencies (Annex A3.1-A3.4; A5.1-A5.12; B5.1-B5.15); website announcements; social media posts (<https://linktr.ee/bioprowrap>, (Annex A7.1-A7.6; B13.1-B13.4); Youtube channel (Annex D2) and shared excursion content. This coordinated effort enabled the identification of diverse stakeholder groups, whose participation and roles are illustrated in the organigram below and in (Annex A8.1-A8.3, B11.1). Those that finally participated in the project are shown in grey colour. Their responsibilities and their interconnections are also included (Annex E13). Responsibility for wildfire-risk management in REMTH is distributed across multiple administrative levels and agencies, depending on the phase of the risk-management cycle and the specific legal framework. REMTH together with its Civil Protection Directorate contributes to regional wildfire-risk management and prevention. At local level risk identification and management responsibility belongs to municipalities and local forest services. Their role consists in informing the population, supporting vulnerable groups, documenting available resources and implementing local protection plans. In addition, the Ministry of “Climate Crisis and Civil Protection” and the General Secretariat for Civil Protection provide an operational framework, by issuing guidelines, plans and wildfire-risk prediction maps at national level. They are also

coordinating the national mechanism whenever required. The Hellenic Fire Service holds the primary operational role in suppression and incident management. To complement this framework, the BioProWRAP project downscales wildfire-risk assessment into regional level by utilizing ML algorithms and integrating existing local data from REMTH with real-time novel data produced through crowdsourcing (Seek/iNaturalist) and genetic (eDNA metabarcoding) for biodiversity monitoring. The project's results further support a better understanding of areas where fire risk is combined with high ecological value. In a similar context, the evaluation mechanisms established under Law 5281/2026 provide an institutional feedback loop after major incidents and at the end of each fire season, ensuring that operational lessons and evidence-based findings are systematically incorporated into future planning and response design. Furthermore, the integration of vulnerable groups and exposed areas, in the context of Forest Fires in REMTH are essential for effective wildfire-biodiversity management. Vulnerable social groups are: 1. elderly and people with disabilities, represented mainly by the Greek National Confederation of Persons with Disabilities (ESAMEA), and municipal social services as well as by all administrative units of the National Health System, 2. livestock breeders, farmers, and beekeepers represented by agricultural, production, and beekeeping associations alongside the Hellenic Agricultural Insurance Organization (H.A.I.O) and 3. Visitors and tourists in high-exposure areas supported by municipalities, tourism organizations, and hotel associations. Exposed areas in REMTH (Dadia, Evros, Nestos, Vistonida, Rhodopi) are represented by local management units of the Natural Environment & Climate Change Agency (NECCA). Forest services and the Decentralised Administration of REMTH; academic institutions and NGOs (i.e, WWF Greece, KALLISTO). The information about the level of risk is available from the institutional framework for civil protection, the daily Fire Risk Forecast Map, and the National Forest Fire Risk Assessment Map. Whether risk is acceptable depends on the local need to protect life, communities and critical infrastructure. In practice, high-risk areas are not considered tolerable without reinforced mitigation, positioning BioProWRAP as a key decision-support tool.

2.1.4 Application of principles

The BioProWRAP project applies core EU principles of social justice, equity, inclusivity, and precaution. Forest areas selected in Phase 1 were chosen for their proximity to communities, ensuring representation of vulnerable groups, while participation in project activities followed Gender Equality Plan (GEP) guidelines. Inclusive communication formats were used, including hybrid and asynchronous education and the development of an audio-visual documentary with subtitles. Proven CLIMAAX workflows and transparent documentation ensure high methodological standards, while the integration of local REMTH data with citizen-generated biodiversity inputs strengthens stakeholder inclusion and prediction accuracy. Continuous updates of the CRA with new observations and official regional data support a flexible, data-driven approach that adapts to evolving conditions.

2.1.5 Stakeholder engagement

The project engaged a diverse group of stakeholders, including municipal authorities, the Hellenic Fire Service, vulnerable and exposed rural groups (farmers, livestock producers, beekeepers), forestry and agronomy services, academic institutions (UTH, DUTH), students, self-employed professionals, and major NGOs such as WWF Greece, the Hellenic Red Cross, the Hellenic Rescue Team Rodopi, CTIF, and the Society for the Protection of Biodiversity of Thrace (Annex A10.3.1-A10.3.2). These stakeholder groups participated across different BioProWRAP activities,

including three educational workshops held in Drama, Volos and Xanthi, and three field excursions in Prasinada, Paggaio–Mesoropi and Dadia–Lefkimi–Soufli, supported by the UTH research team. The workshops were conducted as follows (Annex A): **1st BioProWRAP Workshop: 13 March 2026, Drama, Large Amphitheatre, School of Agricultural and Forestry Sciences, DUTH, 2nd BioProWRAP Workshop: 19 March 2026, Volos, Department of Agriculture, UTH, 3rd BioProWRAP Workshop: 31 March 2026, Xanthi, Amphitheatre of Civil Engineering, DUTH**–Co-organised by the Region of Crete, REMTH, DUTH, and the Municipality of Xanthi (Annex A4.1-A4.5, A11.1-A11.3). In total, 87 participants (Annex A9.1) contributed to the workshops, which covered climate-risk assessment, CLIMAAX methodologies, wildfire-risk modelling, and live biodiversity-monitoring techniques (Seek/iNaturalist, eDNA), reinforcing the project’s educational, participatory, and community-driven character. All visual material related to the Workshops, together with the presentation files and the accompanying photographic documentation, is compiled in Annex A. It also contains the detailed list of the 1st and 2nd BioProWRAP Workshop participation list and the corresponding certificates of attendance (Annex A8.1-A8.3, A9.1). During all Workshops, a detailed workflow video was presented to participants, providing a step-by-step explanation of the methodology and ensuring full clarity regarding the procedures demonstrated (Annex D1). At the end of each Workshop a designed evaluation form was created using the online application Google Forms to collect participant feedback (Annex A6.1-A6.6). All ethical standards were upheld, ensuring full anonymity. The analysis of the demographic characteristics of the participants i.e. gender, age, professional status, as well as additional questions, are described in detail in Annex A6.

An additional main purpose of the Workshops was to inform and identify excursion participants. As part of this effort, a Google Form was shared at the end of each Workshop, in order to collect expressions of interest (Annex B1.1-B1.6). The form was also disseminated electronically, both through the project’s official social media channels and via targeted email campaigns to collaborating local authorities, academic institutions, and other related companies. To ensure the safe and effective implementation of the field excursions, an experimental design was prepared by the Laboratory of Biometry (UTH) (Annex B2.5.1) research permits were secured from the Ministry of Environment and Energy, and the North Stars safety team was assigned to support all field operations (Annex B8.2-B8.4). One month prior (21/2/2026) to the excursions, North Stars conducted on-site mapping of the selected forest areas (Prasinada, Fraktos, Dadia) using digital navigation tools and GPS devices; due to severe access hazards in Fraktos, this site was replaced with Paggaio–Mesoropi, which offered safer conditions and stronger educational value. The final three selected forest areas are shown in detail in Annex B2.1-B5.9. A detailed excursion schedule was sent individually to each participant, including comprehensive instructions to ensure the successful completion of the activities (Annex B7.1-B7.3). The three educational excursions (14/3/2026 Prasinada; 21/3/2026 Paggaio–Mesoropi; 28/3/2026 Dadia–Lefkimi–Soufli National Park) were one-day activities supported by Koutsintas Travel, which ensured safe transport to all forest sites (Annex B4.1-B4.3). During each excursion, participants carried out two core tasks: species identification using the Seek by iNaturalist app–enhanced through a friendly competition to encourage engagement—and active citizen participation in eDNA sample collection following the methods introduced during the training workshops (Fig.2.1).

Before each excursion, participants received email instructions, safety briefings from the North Stars team, and individual field-kit bags. Attendance was checked, a unique QR-code system linked participants to the corresponding BioProWRAP iNaturalist project, and practical guidance on



Fig. 2.1. Species identifications on site using the Seek by iNaturalist app.

sampling equipment was provided. A dedicated Viber group (Annex B10.1-B10.3) ensured real-time communication throughout the activity. In total, 62 participants were actively engaged throughout all stages of the excursions, as illustrated in the photos below (Fig. 2.2.- 2.4), which capture their collaboration with the research team and their active involvement in the sampling process (Annex B4.1-B4.3). Notably, the area in Dadia represents a burned forest landscape affected by the 2023 wildfire, as well as the gradual signs of forest regeneration in several parts. A detailed list of all participants is provided in Annex B12.2.1. According to the experimental design developed by the Lab of Biometry (UTH), the hiking route and its corresponding sampling points (P00–P05) of the three selected forest areas are shown in detail in Annex B9.1.

Use of Project Outcomes by Stakeholders:

- **Regional Authority of REMTH:** Enriched wildfire risk assessment with new local data for updating climate adaptation strategies, and land-use policies. grounded in local data rather than generic national datasets.
- **Civil Protection of REMTH:** Strengthening the regional strategic plan for wildfire risk, exposure patterns, and vulnerability insights, enabling more accurate preparedness and resource allocation.
- **Hellenic Fire Service of REMTH:** Improvement in surveillance and early intervention.
- **Academic and research institutions:** New knowledge acquired becomes the basis for further research on climate risks, giving the possibility for academic international collaborations.
- **NGOs:** Improving the precision of their conservation actions.
- **Forest Services REMTH:** Helping them prioritize monitoring, restoration, and management activities in forest protected areas.
- **Stakeholders with disabilities:** Benefit from inclusive participation, providing access to the documentary, and improved awareness of local climate risks.
- **Local and rural communities:** Provide clear, accessible instructions to help residents recognise early wildfire signs and know how to respond safely. Raising awareness on environmental issues, contribution in collecting additional biodiversity data so they can actively participate in the design of the post-wildfire risk assessment carried out by REMTH.
- **Tourism and travel agencies:** Hotspot-specific risk insights to design safer visitor routes, seasonal guidance, and educational materials for protected areas.

Challenges Encountered and Mitigation Measures

- **Rural stakeholder engagement:** Hybrid workshops, targeted email campaigns, live Google Forms during excursions, and choosing sampling locations near rural populations to encourage participation were all used to overcome the initially low rural participation.

- **Weather and Sampling constraints:** affected both fieldwork and workshop attendance, requiring schedule adjustments and contingency planning. These issues were addressed through careful experimental design and the development of statistically valid alternative sampling solutions.



Fig. 2.2.: Educational excursion at Prasinada, Drama showcasing the Northstars team guiding participants and the active citizen involvement in all processes.

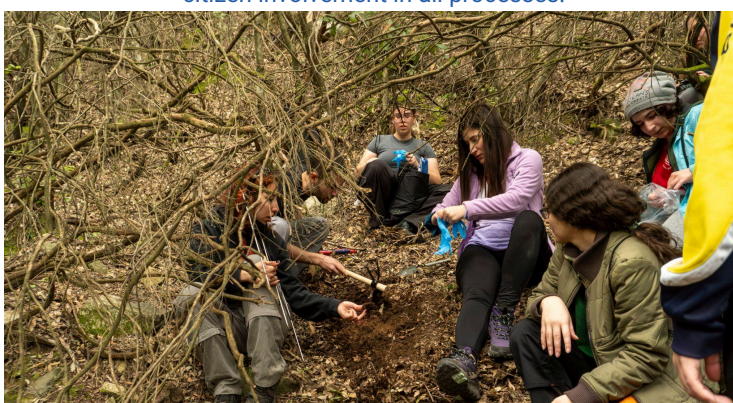


Fig. 2.3.: Educational excursion at Mount Paggaios-Mesoropi on 21 March 2026, documenting the full sampling workflow and highlighting the active engagement of citizens throughout all field activities.



Fig. 2.4. Educational excursion at Dadia-Lefkimi-Soufli Forest National Park on 28 March 2026, documenting the sampling activities and highlighting the active participation of citizens throughout all stages of the fieldwork.

2.1.6 Results Seek by iNaturalist

From the three distinct BioProWRAP Projects created (*BioProWRAP Prasinada*, *BioProWRAP Paggaios-Mesoropi*, *BioProWRAP Dadia*), valuable statistical data were collected. In Prasinada, participants recorded 105 observations, corresponding to 53 species and 139 identifications. At Mount Paggaios-Mesoropi, the number of observations were also high (112), the number of species was 49, with 146 identifications. In Dadias Forest, 91 observations, 47 species, and 102 identifications were recorded. A corresponding map is also presented, illustrating all recorded

observations from the excursions, together with contributions from the wider iNaturalist community via the Seek app, across the broader REMTH region (Annex G6). All analytical details and the corresponding reviewer observations are presented in Annex G5-G6, where the full set of evidence, clarifications, and supporting material is documented.

2.1.7. Results DNA metabarcoding

The samples collected from the three forest sampling areas were analyzed by primary genetic metabarcoding (ITS) analysis i.e DNA extraction-DNA quality-Library preparation-Library quality analysis- Sequencing-Quality assessment of sequencing data- Bioinformatic analysis (Fig 2.5.). Additional images illustrating all laboratory analyses are provided in Annex C5. Sample quality control was performed prior to downstream processing. The methods applied for assessing DNA integrity, purity, and concentration. All soil samples met the minimum thresholds required for successful amplification and library preparation. To characterize plant biodiversity in soil environmental DNA (eDNA), amplification targeted the ITS2 region using custom plant-specific universal primers. The primers were selected based on the plant-specific metabarcoding framework described by Ariza (2024) in Applied Vegetation Science. Accordingly, the primer sequences used in this study are presented in Table 1-1, and were employed to ensure high-resolution detection of plant taxa in soil samples.

Table 1-1: Primers used in this study

Primer name	Primer sequence
UniPlantF	(5'-TGTGAATTGCARRATYCMG-3')
UniPlantR	(5'-CCCGHYTGAYYTGRGGTDC-3')

All PCR reactions were carried out with 15 µL of Phusion High- Fidelity PCR Master Mix; 0.2 µM of forward and reverse primers, and about 10 ng template DNA. Thermal cycling consisted of initial denaturation at 98°C for 1 min, followed by 30 cycles of denaturation at 98°C for 10 s, annealing at 50°C for 30 s, and elongation at 72°C for 30 s and 72°C for 5 min. These conditions were optimized to ensure high-fidelity amplification of the ITS2 locus across diverse plant taxa PCR products were purified using magnetic bead-based purification. Purified amplicons were quantified, and equimolar pooling was performed based on measured concentrations. Target bands were verified through PCR product detection procedures. Following successful amplification and verification of DNA quality, library construction was performed using standard high-fidelity procedures. Amplicons generated with the selected plant-specific ITS2 primers were purified via gel electrophoresis, and the resulting fragments underwent end-repair, A-tailing, and ligation with Illumina adapters. Adapter-ligated fragments were subsequently PCR-amplified, size-selected, and purified to obtain high-quality sequencing libraries. Sequencing libraries were prepared using standard indexing procedures. Library concentration was assessed using Qubit fluorometric quantification and real-time PCR, while fragment size distribution was evaluated using a Bioanalyzer. Indexed libraries were pooled and sequenced on NovaSeq 6000 or DNBSEQ-G99 platforms, depending on effective library concentration and required data output.

Based on the measurements obtained from the Quawell UV-Vis spectrophotometer [Q5000 – Quawell Technology Inc., U.S.A., (Annex C5.1.1), as well as from the gel electrophoresis (Annex C5.3), it is evident that the samples from the final trial exhibited a high profile of DNA quality and quantity. All experimental trials are presented in Annex C5.

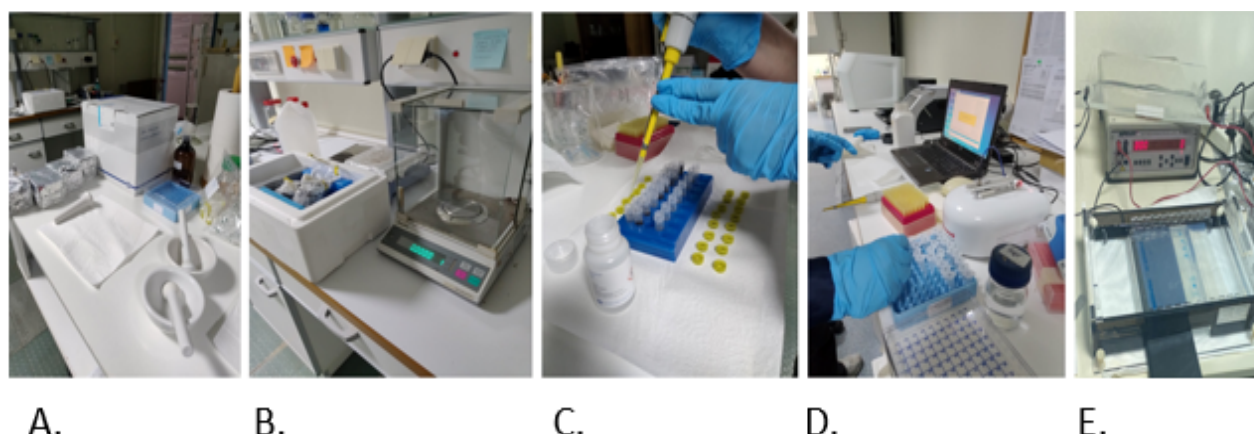


Fig 2.5. Description of all steps involved in the primary genetic metabarcoding (ITS) analysis of forest soil samples conducted by the project's research team at the Laboratory of Biometry, UTH A. Clean workspace and proper preparation prior to DNA isolation. B. Weighing 250 mg of soil sample according to the Macherey-Nagel™ NucleoSpin Soil kit protocol. C. Addition of lysis buffer to the samples following the manufacturer's instructions. D. Measurement of OD (260/280, 260/230) using the Quawell UV-Vis Spectrophotometer Q5000 to assess DNA quality and quantity. E. Gel electrophoresis for visualisation of DNA bands under UV-light [Annex C: (C3-C5)].

The samples that gave meaningful sequencing results represented successfully all three areas of interest, providing 58 raw data files in the format of fastq files, which were merged (FLASH v1.2.11) and cleaned (fastp v0.23.1) creating 29 fastq files representing the overwhelming majority of the sites sampled (only the M3 site did not give any meaningful sequencing results). All 87 fastq files were submitted into the Sequence Read Archive (SRA) of the National Center for Biotechnology Information (<https://www.ncbi.nlm.nih.gov>), and can be trucked back using the submission ID SUB16463285 (Annex G1). The merged fastq files were further analysed within the Galaxy platform (<https://usegalaxy.org/>) and mainly the Qiime2 tools (v.2026.1.0+q2galaxy.2026.1.0) available. The pipeline build for this analysis included the analysis steps: 1)Import of FASTQ data, 2)DADA2 (v1.38.0+galaxy1) denoising to identify the representative sequences, known as amplicon sequence variants (ASV), as well as their number of occurrence or counts, 3)ITS2 taxonomy assignment utilizing the ITS2 Global Plant sequence database ([10.5281/zenodo.7970045](https://doi.org/10.5281/zenodo.7970045)), 4)Removal of unassigned ASVs, 5)Grouping samples by site, 6)Visualization (barplots) and dataset export for external processing. The species level barplot with the taxonomy legend can be found in detail in Annex C2.1-C2.2, C7. This barplot presents the ASVs presence/absence counts that correspond to known plant taxonomies. During this analysis 1517 unique ASVs with known plant taxonomy were detected, corresponding to 136 unique plant species and 146 unique genera. The final dataset was focused on the taxonomic data on the genus and species level, and combined them with area specific metadata, like the sampling site coordinates and the sampling dates. The final dataset was used to replace the synthetic dataset in the ML wildfire hazard workflow and the analysis was repeated.

2.1.8. Feedback from Field Excursions participants

At the end of each excursion, a dedicated evaluation form was created using Google Forms and accessed via QR code to collect participant feedback (Annex B6.1-B6.8). In the evaluation form demographic characteristics of the participants, including gender, age, professional status, as well as additional questions, are also included. Below, we highlight one of the most critical questions and the corresponding responses (Fig 2.6). After the evaluation assessment, a certificate of attendance was provided to all participants for both workshops and excursions (Annex A9.1, B12.1).

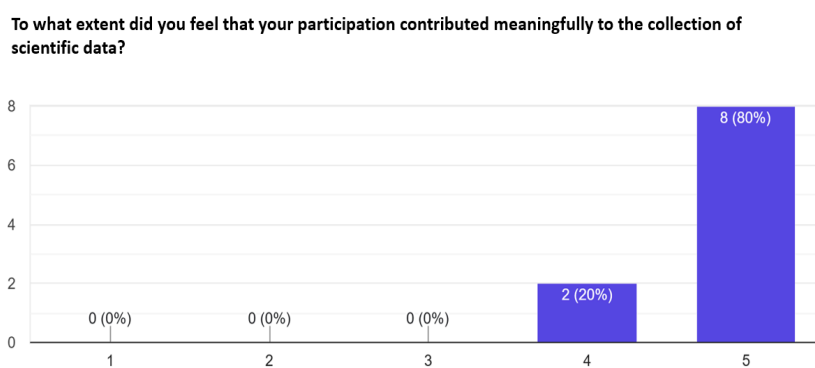


Fig 2.6. A, B, C shows the livestreaming response rates (%) to the question: *To what extent did you feel that your participation contributed meaningfully to the collection of scientific data?* based on participant feedback from the excursion field trips in Dadia-Lefkimi-Soufli National Forest Park. All remaining evaluation material is provided in Annex B6.1-B6.8.

At the 2nd Stakeholders' Meeting, BioProWRAP results were formally presented to regional authorities, civil-protection bodies, NGOs, and scientific partners, focusing on validating findings and integrating additional datasets into REMTH's strategic planning. An evaluation form was given to the participants (Annex A10.2.5-A10.2.6). Stakeholders will use the results to strengthen regional adaptation strategies (REMTH), improve preparedness and resource allocation (Civil Protection, Fire Service), refine conservation actions (NGOs, Forest Services), support research (academia), and enhance awareness among vulnerable groups, rural communities, and tourism agencies. Key challenges, like the limited rural engagement and data sharing constraints, were addressed during open discussion sessions (Annex A10.2.1-A10.2.4).

2.2 Risk Exploration

In this chapter, we describe the risk exploration expansion, aiming to enrich the preliminary wildfire risk assessment developed in Phase 1. Apart from adding the consideration of the hazard relative drought, in this phase, the assessment moves from broad regional awareness to a more refined examination of climate threats, reinforced with newly integrated local datasets, including "live" biodiversity data, accompanied by stakeholder insights. This step ensures that subsequent modeling and risk analysis are grounded in the realities of REMTH ecological, socioeconomic, and infrastructural context while remaining responsive to stakeholder priorities and emerging local data, keeping in the forefront the protection of local biodiversity.

2.2.1 Screen risks

Our work focuses on strengthening long-term biodiversity protection in REMTH, a region where major climate-related hazards—especially wildfires and drought—interact and intensify. Wildfires remain the dominant threat, particularly after the 2023 megafire that burned over 96,000 ha and affected key Natura 2000 sites such as Dadia, Rodopi, Evros Delta, Frakto, and the Nestos–Vistonida–Ismarida complex. These areas host exceptional biodiversity and support local economies, while nearby rural communities face heightened vulnerability due to limited resources and land-based livelihoods. Copernicus projections confirm increasing fire-danger days and worsening summer droughts. By incorporating local historic wildfire and precipitation data and "live" biodiversity inputs from citizen science and eDNA into the CLIMAAX workflows, REMTH can design more effective action plans, grounded on local monitoring, to safeguard ecosystems and enhance regional climate resilience.

2.2.2 Choose Scenario

A regional climate risk assessment is a product of estimated hazard, exposure, and vulnerability. Scenario exploration was mostly applied within the hazard workflows. Those scenarios were later extended towards the risk assessment as the results of different hazard estimations. Both selected hazards—wildfire and drought—were assessed under all available climate - future scenarios in the CLIMAAX toolbox. For wildfire, future projections from the ECLIPS-2.0 dataset were used, with all models (Annex E12). Specific attention was given to the CLMcom_CLM model, which was selected after extensive screening (both Phase 1 and 2, Annexes E7, E11). The CLMcom_CLM is a Regional Climate Model (RCM), which is based on the Community Land Model (CLM), developed and maintained by the Climate Limited-area Modelling Community (CLMcom). The CLMcom_CLM is part of the CORDEX initiative and is widely used for downscaled regional climate projections. It is characterized by its good handling of temperature extremes and it has been widely used in the European region with solid performance. During our screening, this model was proven to be most consistent regarding near-future predictions (Phase 1 Deliverable, Annex E11), while the MPI_CSC_REMO2009 was a close second (Phase 1 Deliverable, Annexes E11, E12). Both models that performed well are nested within the same Global Climate Model (GCM) known as CLMcom_CLM. In principle, CLMcom_CLM and MPI_CSC_REMO2009 are downscaled regional versions of MPI-ESM-LR, which is widely used because it performs well in European and Mediterranean regions and it has robust precipitation and temperature dynamics, characteristics that explain the good performance we observed in both CLMcom_CLM and MPI_CSC_REMO2009. The historical baseline (1991–2010) aligned with NASA records, and both RCP4.5 and RCP8.5 were explored across multiple future periods, with 2021–2040 prioritized for near-term biodiversity monitoring. Socio-economic vulnerability layers (population, ecological, economic) were used to capture how climate, vegetation, and human factors jointly shape wildfire risk. The drought workflow was introduced during Phase 2, to complement the wildfire risk assessment that remains the focus of this project, as the main climate-related risk faced by the REMTH region. Relative drought hazard for REMTH was calculated as the probability of exceedance of the median of the regional severe precipitation deficits for the historical reference period 1981-2015, and for future projection periods (2031-2060; 2071-2100). Pre-processed data were used for both the historic workflow and the future projections. More specifically, the ensemble average from ISIMIP 3b bias-adjusted atmospheric climate input data (Lange and Büchner, 2021) was used, which provides harmonized atmospheric inputs specifically designed for climate-impact modelling. The precipitation data was the average of five CMIP6 global climate models (GCMs; GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, UKESM1-0-LL), for three paired socio-economic and climate-forcing scenarios (SSP-RCPs) combinations (SSP126, SSP370, SSP585) consistent with IPCC AR6 (Intergovernmental Panel On Climate Change (Ipcc), 2023). Drought hazard was furthermore quantified using the Weighted Anomaly Standardized Precipitation (WASP) index (Carrão et al., 2016), which captures precipitation-deficit severity by summing weighted standardized monthly anomalies relative to seasonally defined thresholds. These thresholds were defined by dividing multi-annual monthly observed rain using the 'Fisher-jenks' classification algorithm. The analysis was accomplished for each NUTS3 regional areas without and with the integration of local precipitation data for the REMTH region and the years 1930-2010.

2.3 Regionalized Risk Analysis

2.3.1. Regionalize Wildfire Risk Analysis

To adapt the CLIMAAX risk workflows to the specific environmental and socio-economic context of REMTH, both hazard workflows (wildfire and drought) were fine-tuned using local datasets. For wildfire, the hazard workflow was customized by integrating high-resolution local wildfire records (Hellenic Fire Service, Annex G1, G3) along with the NASA historic wildfire data (Annex G1) (Fig. Annex E13, 1), as well as –critically– “live” biodiversity data produced through crowdsourcing (Seek/iNaturalist; Annex G5) and eDNA metabarcoding (Annex G1, G4). These biological datasets were transformed into species- and genus-level flammability rasters by utilizing reference datasets from Global Biodiversity Information Facility (GBIF; www.gbif.org, Annex F1, F2) and FLAMITS (Ocampo-Zuleta et al., 2024), allowing the model to incorporate vegetation-specific flammability as a dynamic predictor of burn potential.

2.3.1.1. Species/Genus - Flammability Master File Creation

A unified Observation-FLAMITS-GBIF reference file was created to standardize biodiversity annotations by harmonizing taxonomic names, reconciling species and genus-level matches, and aggregating flammability traits. All information was consolidated into a single master table that supports reliable annotation of crowdsourced (G5) and eDNA data (E2, G4) utilizing public external databases (Annex F), and the process is embedded in the ML wildfire-hazard pipeline for future semi-automatic updates.

2.3.1.2. Construction of a Species-Level Fire Susceptibility Index

To quantify plant flammability at the species level, we constructed a composite fire susceptibility index based on the FLAMITS experimental flammability dataset (accessed 6/2026). FLAMITS provides species-specific measurements across multiple fire-response dimensions. Because no single variable captures the full flammability trait, we integrated all available numeric traits into a unified index using standardized scores (Z-scores). All numeric flammability variables present in the FLAMITS dataset were included in the analysis. These variables represent four ecologically meaningful dimensions of plant flammability:

- Ignitability (e.g., time to flaming, time to smoke, time to maximum heat release rate)
- Combustibility (e.g., flame height, flame intensity, mass loss rate, energy flux)
- Sustainability (e.g., flaming duration, smouldering duration, smoke duration)
- Consumability (e.g., burnt biomass, percentage mass loss, calorific value)

This approach ensured that the final index captured the multidimensional nature of plant flammability rather than relying on a single trait. Since traits differed in units, scales, and variances, each numeric variable was standardized using Z-scores:

$$z = \frac{x - \mu}{\sigma}$$

where:

x is the observed value,

μ is the trait mean, and

σ is the standard deviation.

This transformation placed all traits on a comparable scale and prevented variables with large numeric ranges (e.g., calorific value) from dominating the index. For ignitability traits where lower values indicate higher flammability (e.g., time to flaming), Z-scores were multiplied by -1. This

ensured that, for all traits, higher standardized values consistently represent higher fire susceptibility. For each species, the final fire susceptibility score was calculated as the mean of all available standardized trait values:

$$\text{Susceptibility}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} z_{ij} \quad \text{Where:}$$

where n_i is the number of traits available for species i .

This method is robust to missing data because each species is scored using only known-to-date traits, avoiding the need for imputation or exclusion of sparsely measured species. Finally, to facilitate interpretation and integration into downstream modeling, the composite index was rescaled to a 0–1 range using min–max normalization, where 0 represents the lowest and 1 the highest relative fire susceptibility.

2.3.1.3. “Live” Data Annotation

The flammability master file was used to annotate both crowdsourced, synthetic and metabarcoding data (Annex E3, E9, and E10, respectively), enabling real-time integration of species information into the wildfire-risk model. Crowdsourced observations from iNaturalist (BioProWRAP Umbrella) were cleaned and filtered to research quality, while soil samples collected during the excursions were processed for eDNA analysis. Because extreme weather and sequencing failures delayed final metabarcoding outputs, a synthetic eDNA dataset was generated using excursion coordinates and nearby plant records (within 2 km) to simulate realistic detections. This capability has been integrated within the wildfire hazard workflow (Annex E1), allowing full development and validation of the wildfire-risk pipeline—trait annotation, spatial integration, and risk scoring—before the real eDNA results could become available, ensuring continuity and readiness for final data integration. Meanwhile, the sequencing of the samples and the bioinformatics analysis of the raw sequencing results were accomplished in parallel. The final metabarcoding data were adjusted to the format of the synthetic dataset (Annex G4) and were directly implemented into the same workflow. Only species or genera with known flammability z-scores were represented in the flammability raster (Annex E8-E13) resulting in 1357 total observations (1272 from crowdsourcing and 85 from metabarcoding) and 256 unique plant species (163 unique genera) with known flammability traits. The flammability z-scores identified were ranging from 0.163314-0.650720, with a mean equal to 0.332095 (0.063930 std, and quantiles 0.291552 for 25%, 0.344461 for 50%, and 0.362444 for 75%). This indicates that observed local species/genera of known flammability are on the lower scale of flammability in their majority, indicating a capacity for wildfire resilience while maintaining local biodiversity. The final flammability raster utilized during the susceptibility to wildfire modeling can be found in Annex E8. Based on the overall flammability scores, a flammability-based density map was also created (Fig. 2.7., Annex E13), indicating the general areas where concentrated species or genera of high flammability scores were observed. The areas within high flammability density regions are the main north part of REMTH, which includes important protected areas and Natura 2000 parks (Rodopi Mountain Range, Simyda, Pyramis Koutra, Frakto Virgin Forest, Falakro Mountain), along the southern part of the region around the area of Kavala, which also includes protected areas (Paggaios Mountain, Kolpos Palaïou, Thasos). Both of those areas (Prasinada, Paggaios) were selected during Phase 1 as high-wildfire-risk areas, meaning that there seems to be a correlation between high in calculated wildfire risk regions and regions rich in plant populations of significant flammability traits. This correlation reveals another novel layer within wildfire hazard interconnection, which is rooted in “live” biodiversity observations

and the constant biodiversity monitoring via novel methods and citizen science. This observation is well supported by literature, since plants serve as the primary fuel for wildfires, and their flammability characteristics can greatly differ on a species level, directly influencing fire ignition and behavior, such as fire spread speed and fire intensity (Bowman et al., 2009; Jian et al., 2024; Navarro-Cano et al., 2024; Ocampo-Zuleta et al., 2024; Schwilk, 2015; Tumino et al., 2019). We consider these findings indicative of the added value of the constant biodiversity monitoring and the integration of “live” biodiversity data within the wildfire risk assessment workflow, and we expect those data to contribute towards more robust and accurate future predictions, accompanied by a much higher local resolution.

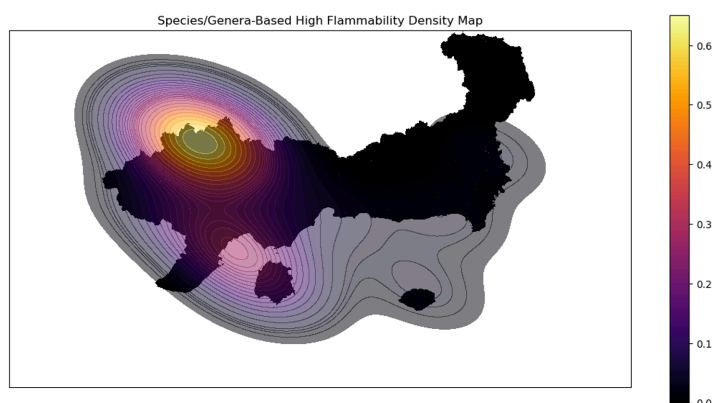


Fig 2.7. *Species-Genera Flammability Raster: Flammability density map indicating REMTH areas with concentrated high in flammability species or genera.*

2.3.1.4 Novel Integration of Flammability Susceptibility Index

In Phase 2, the wildfire workflow was modified by adding local wildfire data from the Hellenic Fire Service (Annex G1, G3) during the climate model training. Another critical implementation in the same step was also the integration of a novel susceptibility index that is characterized by 1) multisourced monitoring, 2) rich local historic data, 3) high resolution, and 4) scientifically sound and observed correlation with wildfire risk. This susceptibility index is the plant species-genera-based flammability raster that we developed within the framework of Phase 2 of the BioProWRAP project, which was accomplished in two critical steps:

1) Integration of “live” biodiversity local data into the hazard assessment workflow. In this project’s context, live data include time series of plant species observations in specific locations of the region. Those observations are sourced by iNaturalist and are based on the observations of the public, as they can be found in the BioProWRAP playground (https://www.inaturalist.org/projects/bioprowrap_playground) created for this project within the iNaturalist social platform. The BioProWRAP playground includes the total number of observations in the area (24.093). During Phase 2, those observations were precisely enriched in the areas identified by Phase 1 as high in wildfire risk and ecological value (protected forest areas) while remaining accessible to the broader public. The targeted observation through the public was an action that was accomplished during three field excursions with a significant number of participants (~60). The reliability of the observations, however, was also enhanced by introducing molecular plant identification via the detection of signature DNA molecules (ITS2 genetic markers) into soil samples of the area. This approach does not only aim at the enhancement of the climate risk assessment through the species-level flammability added susceptibility layer (analyzed below), but it can also significantly broaden climate adaptation strategies by allowing local population

engagement and local species monitoring and management efforts. Those strategies will be further explored and analyzed within the scope of Phase 3.

3) Addition of a susceptibility layer based on the calculated flammability of the identified plant species or genera, observed via crowdsourcing (iNaturalist playground + excursions) and ITS2 metabarcoding (soil sampling during the excursions). The plant taxonomy was annotated using the Global Plant sequence database ([10.5281/zenodo.7970045](https://doi.org/10.5281/zenodo.7970045)) and curated using the Global Biodiversity Information Facility (GBIF; www.gbif.org), allowing for the assignment of the flammability index. This is a Z-score-based multidimensional standardized flammability index based on known species-level plant flammability traits sourced from the FLAMITS database (Ocampo-Zuleta et al., 2024).

The flammability variable was spatially rasterized, converting it into a georeferenced raster at 100-meter resolution, aligned with the coordinate reference system and grid previously used. The resulting GeoTIFF provides continuous surfaces that depict how flammability varies across the landscape, either based on species-level information or genus-level aggregation (Annex E8). This raster was added as a new predictor in the susceptibility model, alongside climate variables (temperature indicators: MWMT, TD, DDbelow0, DDabove18, MAT, Tave_sm, Tmax_sm; heat and moisture interaction indicators: AHM, SHM; precipitation indicators: MAP, PPT_at, PPT_sm, PPT_sp, PPT_wt) from the ECLIPS-2.0 dataset, land cover (Corine; CLC2018), topography, and historic wildfire frequency (Annex G1, G3). This step is important because it allows ecological information—specifically, the intrinsic flammability of the vegetation present at each location—to be integrated directly into spatial fire-risk modelling. Flammability can be used as a predictor in the susceptibility model, improving the model’s ability to capture fine-scale variation in burn potential that is not explained by topography or land cover alone. In more detail, areas with high densities of flammable species (e.g., Pinus, Juniperus, Cistus, Phillyrea, Quercus spp.) receive higher susceptibility values, based on measured species-level flammability traits, even when climate-only models showed moderate susceptibility. This can also act in reverse, since low flammability of local plant populations translates as wildfire and climate change resilience. By converting point-based biodiversity observations into harmonized raster layers, we create a bridge between ecological data and geospatial risk assessment, enabling a more biologically informed understanding of wildfire dynamics in the region, while enhancing adaptation capabilities that could focus on biodiversity monitoring, protection, and climate change resilience restoration.

2.3.2. Regionalize Relative Drought Risk Analysis

Our work focuses on strengthening long-term biodiversity protection in REMTH, a region where major climate-related hazards—especially wildfires and drought—interact and intensify. The relative drought workflow was introduced during Phase 2, to complement the wildfire risk assessment that remains the focus of this project, as the main climate-related risk faced by the REMTH region. For drought, the relative hazard assessment workflow was fine-tuned by incorporating local precipitation records (1930–2010) from the Ministry of Rural Development and Food (accessed 4/2026), in addition to the data of the average precipitation of five CMIP6 global climate models. The local precipitation records were used to correct biases in CMIP6/ISIMIP precipitation and refine the WASP drought index. As a result, the adjusted historic drought hazard recalibrated future drought risk per NUTS3 region. This ensured that drought hazard estimates reflected regional hydrological patterns, agricultural dependencies, and local climatic variability, even for NUTS3 regions that were not represented by historic data previously (by the average of five CMIP6 global

climate models precipitation data). These are the cases of the Thasos and Kavala areas, areas of also high wildfire risk, that could benefit by the relative drought assessment. In parallel, integration of 80 years of local rainfall data revealed stronger spatial variability, reducing drought hazard in Evros, while increasing it in Rodopi. This demonstrates the added value of local hydrological data for accurate drought-risk estimation.

2.3.4. Indirect impacts

GBIF contributes location-based ecological and conservation traits, such as species occurrence status and threat status. Those attributes were considered as possible vulnerability data that could play a significant role in forest conservation planning. Even though those attributes associated with each taxon were retained in the species/genera - flammability masterfire, GBIF records simply did not contain populated fields for threat status or occurrence status for observed taxa, rendering the dataset of poor related data richness. This approach will be revisited by incorporating better-informed reference datasets, like the [IUCN red list](#), but also datasets on invasive species such as [GRIIS](#) or [EASIN](#), enriching and preserving a full ecological signal that will significantly improve biodiversity monitoring planning. Additionally, data on species-based fire and drought resistance could also be implemented in the pipeline using related datasets like TRY (Kattge et al., 2020) which includes species-based data on functional traits like tolerance to drought, fire, temperature, and waterlogging, as well as habitat characterization and species occurrence range (native vs invasive). Species-based drought resistance data incorporation could interconnect biodiversity monitoring and long-term protection and conservation with the drought risk assessment, similarly to the connection that has already been accomplished with biodiversity monitoring and the wildfire risk assessment.

2.3.4. Workflow #1: Hazard Assessment for Wildfire - ML Approach (ECLIPS dataset) - fine-tuning to local context

Table 2-3-1 Data overview workflow #1: Hazard Assessment for Wildfire - ML Approach (ECLIPS dataset)

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
1) Historical Fire Data: NASA dataset plus local fire dataset from the Hellenic Fire Department were used for 1991–2010, 2) Species/genus-level flammability rasters (ecological hazard modifiers) from annotated “live” data.	Joint Research Centre (Costa et al., 2020), including layers: Population, Ecological, Economic, and Ecological - Economic vulnerability	1) Land Cover Data 2) OpenStreetMap via Overpass Turbo data for Hospitals, Hotels, Schools, Primary/Secondary /Tertiary roads, Shelters 3) NUTS level data	Mainly Maps of historic and future projections of calculated susceptibility, hazard, and risk for categorized vulnerability, including Population, Ecological, and Economic vulnerability. NUTS level and categorized vulnerability for roads analysis were also performed. Change risk maps are also included.

The analysis notebooks can be found fully commented in Annex E1. The complete pipeline implementation timeline of specific workflows can be found in Annex E6.

2.3.4.1. Hazard assessment

The hazard assessment for REMTH begins with an examination of wildfire susceptibility under historical climate conditions (1991–2010). This baseline is essential for understanding and modeling how past climatic patterns, vegetation structure, and landscape configuration have

shaped wildfire behavior in the region. By establishing how REMTH historically responded to wildfire-related drivers, we can more accurately interpret future projections and identify areas where climate change may amplify existing risks. The wildfire hazard assessment is based on the susceptibility models created. In Phase 2 we enriched the dataset of historic local wildfires, and we evolved the susceptibility modeling by incorporating a species/genera based flammability index of "live" plant biodiversity data, as a novel susceptibility raster introduced during the model training step, as analyzed in detail above. The maps below present the spatial distribution of wildfire susceptibility and wildfire hazard (Fig. 2.8-2.9) for the two emission pathways RCP 4.5 (moderate emissions, Fig.2.8) and RCP 8.5 (high emissions, Fig.2.9) for the CLMcom_CLM regional climate model (other models are presented in Annex E3, E7). Each figure includes the calculated susceptibility (A) and hazard (B) based on the historical time horizon selected (1991-2010), as well as four time horizons (C:2011-2020, D:2021-2040, E:2041-2060, F:2061-2080) used for model-based projections. This allows a clear comparison between near-future and long-term calculated climate impacts, highlighting clear patterns of elevated susceptibility and, in extension, hazard across the region. Based on the historical data (Fig. 2.8-2.9 A and B) three high susceptibility zones are clearly visible in the area south of Drama, the central south area of REMTH, covering most of the East Macedonian and Thrace National Park, and finally the whole eastern part of the region that includes Orestiada, Didymoticho and a large portion of the National Part Dadias-Soufliou. The susceptibility zones remain the same for both RCPs, with RCP 8.5 showing higher and broader susceptibility zones. Susceptibility projections seem to work well closer to the historical time horizon, with the horizon 2011-2020 serving as a control period in comparison to the historic visualization. This comparison indicates the consistency of the model. This effect remains true also for the period 2021-2040, the period of most importance for our project, since we are interested in targeting areas that are of immediate wildfire risk during the design of our action plan in Phase 3. The time horizons further in the future show lower consistency and broader zones of generally lower susceptibility, indicating lower prediction significance. The hazard maps utilize the calculated susceptibility to reflect observed or modeled fire activity in the form of higher or lower wildfire hazard. Low-susceptibility zones –particularly the forested zones of Evros and Rodopi—appear prominently in yellow in the historic hazard map. Areas of higher susceptibility directly correspond to large portions of REMTH that are classified as very high-hazard areas, shown in red; this is mostly the lower south area of the region. Lower hazard classes (orange and yellow) appear in mountainous areas of high altitude. Interestingly, hazard increases rapidly in the projected scenarios, independently from the time horizon or RCP used. The dominance of high-hazard classes in almost the entirety of the region underscores the region's long-standing vulnerability to wildfire events, even before the intensification observed in recent years.

2.3.4.2. Risk assessment

The wildfire risk assessment for REMTH reveals a consistent and slow but escalating pattern of climate-driven risk across population, economic, and ecological dimensions. Building on the historic susceptibility and hazard baseline, the integration of future climate projections (CLMcom_CLM, RCP 4.5, Annex E7 also includes the analysis for CLMcom_CLM, RCP 8.5, Annex E3 includes more models) shows that wildfire risk intensifies slowly but steadily over time, expanding spatially and affecting increasingly larger portions of the region (Fig. 2.10). The results highlight how climate change interacts with settlement patterns, economic activity, and ecological sensitivity, producing a multi-layered risk landscape that becomes progressively more severe from

the near-future to the late-century horizon. The RCP 4.5 projections reveal distinct vulnerability patterns across population, economic, and ecological systems in REMTH. Population, economic, and ecological risk show small increases in future projections, with the effect being more pronounced when comparing the historical risk with any future projection, especially for the population and the ecological risk.

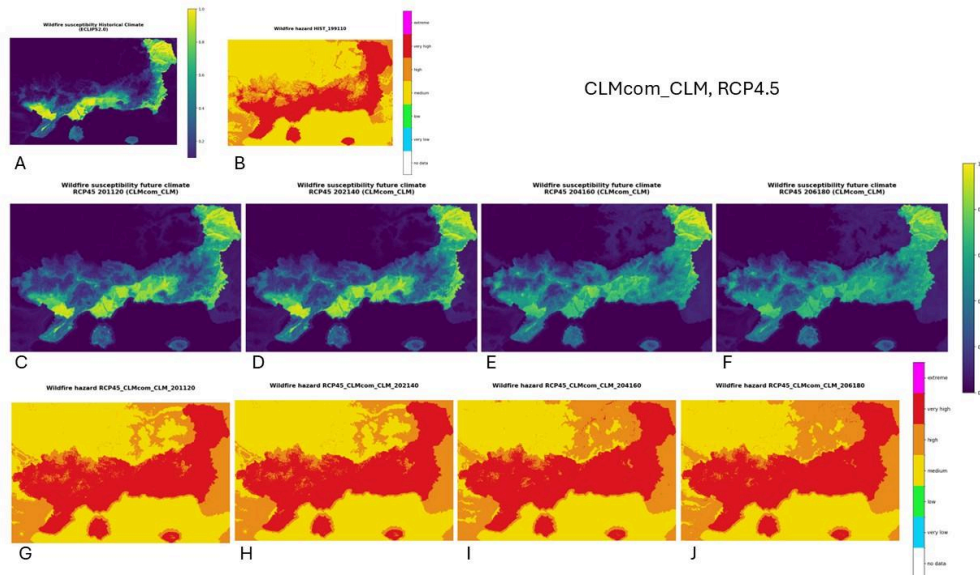


Fig. 2.8. Spatial distribution maps of REMTH for RCP 4.5 (moderate emissions). A. Historic (1991–2010) susceptibility based on climate, wildfires and species-genera flammability. High-susceptibility zones appear prominently in yellow. B. Associated historic hazard. High to very high hazard is indicated with orange and red. C-F. Projections of susceptibility based on the historic model. G-J. Associated historic hazard of the region. Four time horizons are presented (2011-2020, 2021-2040, 2041-2060, 2061-2080).

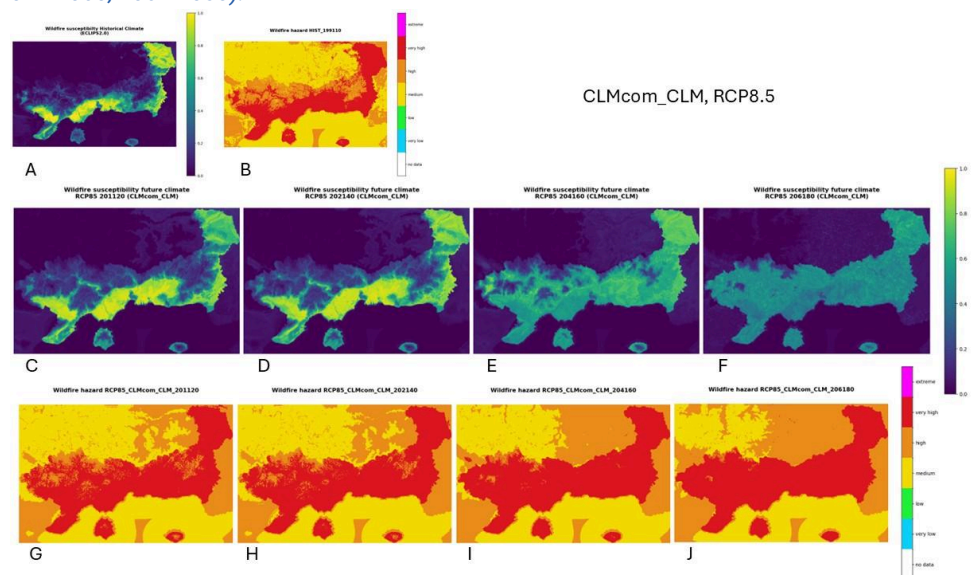


Fig 2.9. Spatial distribution maps of REMTH for RCP 8.5 (high emissions). A. Historic (1991–2010) susceptibility based on climate, wildfires and species-genera flammability. High-susceptibility zones appear prominently in yellow. B. Associated historic hazard. High to very high hazard is indicated with orange and red. C-F. Projections of susceptibility based on the historic model. G-J. Associated historic hazard of the region. Four time horizons are presented (2011-2020, 2021-2040, 2041-2060, 2061-2080).

Forested and significant protected ecological areas are transitioning or remain high in risk across all future periods. This pattern indicates low ecological resilience, driven by repeated wildfire events. Comparing the three vulnerability dimensions, ecological systems exhibit high long-term sensitivity,

economic systems show high vulnerability, and population risk increases gradually and remains significant in rural communities.

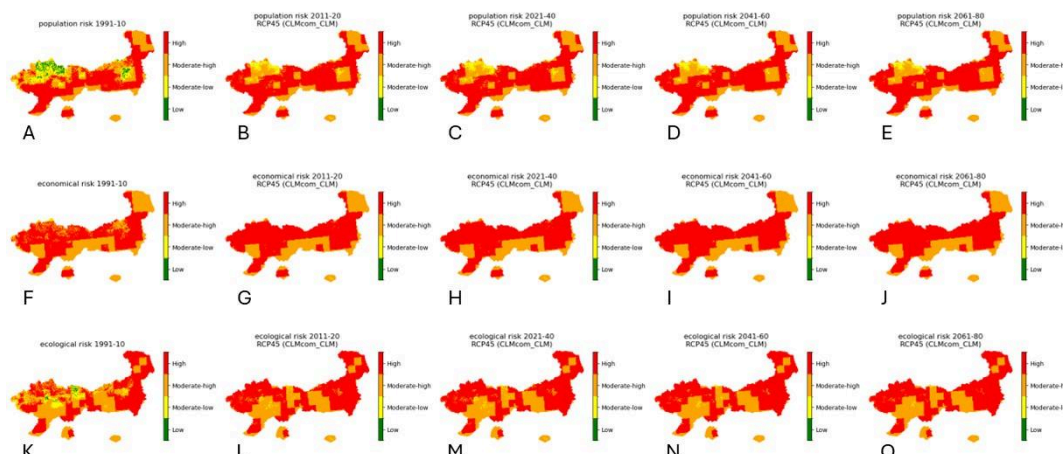


Fig 2.10. Risk dimension maps under the RCP 4.5 scenario: A 1-5. population, B 1-5. economic, and C 1-5. Ecological. Each column represents a different time period (historic, 2011-2020, 2021-2040, 2041-2060, 2061-2080). The color scale ranges from green (low risk) to red (high risk).

Together, these results highlight the need for differentiated adaptation strategies tailored to each vulnerability domain. Finally, Fig.2.11-2.14 synthesize these trends based on the CLMcom_CLM model (RCP 4.5), illustrating how susceptibility (Fig.2.11), hazard (Fig.2.12) and risk for three vulnerability categories (Fig.2.13: economic, Fig.2.14: Population, Annex E7: Road Network) change in comparison to the historic estimations across the time period 2021-2040 (More projections can be found in Annex E7). The red color illustrates increases in comparison to the historic estimations, while the blue color illustrates reductions. In each case Fig. A represents the change degree observed in Phase 1, while Fig. B represents the change degree observed in Phase 2, while local data of wildfires and the species-genera flammability novel susceptibility index were introduced. These illustrations are of great value to pinpoint specific areas in imminent risk but also showcase the degree of change in the susceptibility, hazard, and risk estimation when local data are introduced. The comparison between historic conditions and the 2021–2040 period under RCP 4.5 shows a clear spatial intensification of wildfire-related pressures across REMTH. Susceptibility increases (red areas) mainly in forested and mountainous zones, previously protected due to their higher altitudes, indicating that climate conditions are becoming more favorable for ignition and spread.

Hazard change follows a similar pattern, with several regions transitioning from stable to increased hazard, reflecting climate-driven shifts in temperature and dryness. Sectoral vulnerabilities also rise: economic risk increases in agricultural and forestry-dependent areas, population risk grows in rural communities with limited adaptive capacity, and road-network risk intensifies along critical transport corridors. These patterns highlight that climate impacts are not uniform—vulnerable sectors experience disproportionate increases, reinforcing the need for targeted adaptation measures. The influence of the newly introduced local datasets becomes evident when comparing Phase 2 outputs with the Phase 1 baseline. In Phase 2, the integration of species-level flammability and local precipitation records produces measurable and spatially coherent changes across susceptibility, hazard, and risk. This is most obvious in Fig.2.11 (B), where the susceptibility increases precisely in zones where flammable species and genera were detected through crowdsourcing and metabarcoding (see Fig.2.7), such as the areas around Kavala and the northern border of the Eastern Macedonia region.

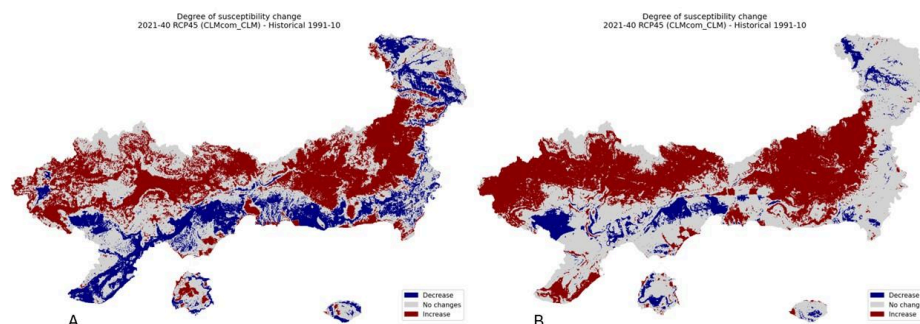


Fig. 2.11. RCP 4.5 scenario under the CLMcom_CLM model for the time period 2021-2040. The red color illustrates increases in comparison to the historic estimations, while the blue color illustrates reductions. Degree of susceptibility estimation (A: Phase 1, B: Phase 2).

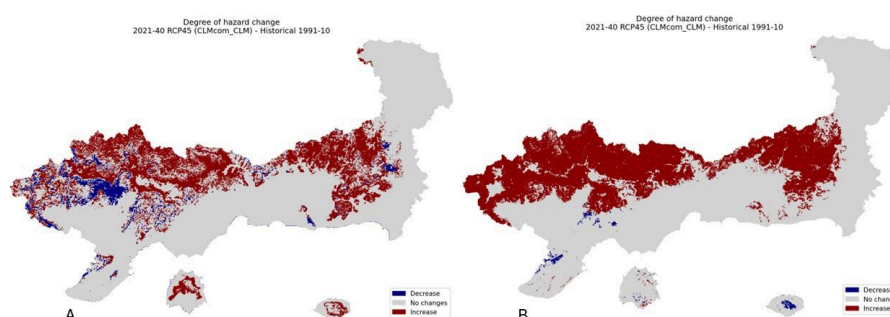


Fig. 2.12. RCP 4.5 scenario under the CLMcom_CLM model for the time period 2021-2040. The red color illustrates increases in comparison to the historic estimations, while the blue color illustrates reductions. Hazard change degree estimation (A: Phase 1, B: Phase 2).

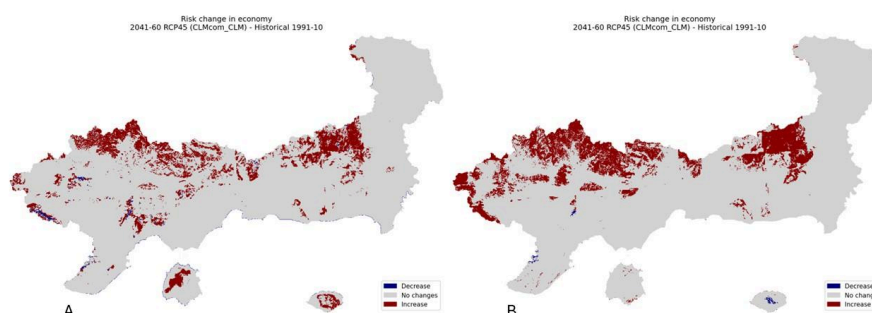


Fig. 2.13. RCP 4.5 scenario under the CLMcom_CLM model for the time period 2021-2040. The red color illustrates increases in comparison to the historic estimations, while the blue color illustrates reductions. The risk is estimated for the economic vulnerability category. (A: Phase 1, B: Phase 2).

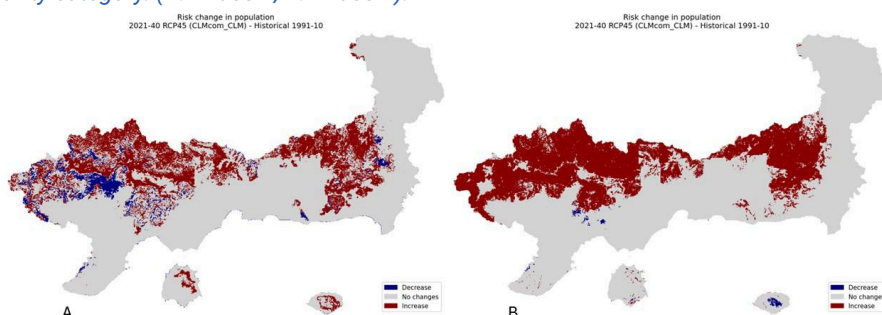


Fig. 2.14. RCP 4.5 scenario under the CLMcom_CLM model for the time period 2021-2040. The red color illustrates increases in comparison to the historic estimations, while the blue color illustrates reductions. The risk is estimated for the Population vulnerability category. (A: Phase 1, B: Phase 2).

These increases were not present in Phase 1 (Fig. 2.11, A), demonstrating that flammability traits meaningfully alter the susceptibility surface. The hazard maps in Fig. 2.12 follows these susceptibility changes for the northern border of the Eastern Macedonia region, showing higher

hazard values in the northern part of REMTH, where the highest intensity flammability zone was detected (Fig. 2.7), while lower in flammability zones showed reduced hazard, especially in coastal areas—patterns that indicate that the novel flammability index could possibly affect the wildfire resilience of the area, a finding with significant extensions towards future ecological resilience strategies.

The risk maps (Figs. 2.13–2.14) propagate these changes into population and economic risk dimensions, revealing higher risk in regions where susceptibility and hazard intensify. In both cases, the area of the most significant increase in risk overlaps once more with the higher in flammability zone, indicating that flammability is a significant driver of the final risk estimates. In parallel, newly added wildfire data, do not seem to affect the estimations in this manner, since no new wildfire events have been introduced into the altered flammability index areas (Annex E13). High flammability zones significantly change the results, since climate-land cover only models treat vegetation as homogeneous large zones; however, REMTH forests are not homogeneous—they contain highly flammable shrubs (*Cistus*, *Phillyrea*, *Juniperus*) resinous conifers (*Pinus brutia*) drought-sensitive species (*Quercus frainetto*). By adding the species-level flammability the fuel characteristics are explicitly represented. Susceptibility becomes ecologically realistic; hotspots become more spatially precise, and hazard increases in areas with flammable vegetation even if climate risk is moderate. Those findings also address any uncertainties regarding whether species-level flammability could alter the risk assessment.

2.3.5. Hazard #2 - Relative Drought

Table 2-3-2 Data overview workflow #2: Hazard Assessment for Relative Drought

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
ISIMIP 3b bias-adjusted CMIP6 precipitation projections (historic 1981–2015; future 2031–2060 & 2071–2100). SSP-RCP combinations: SSP126, SSP370, SSP585. Ensemble of five CMIP6 GCMs. Local historic precipitation data (1930–2010) for REMTH.	Proxy indicators representing the economic, social, and infrastructural factors of drought vulnerability (GDP-per-capita, rural population) (Naumann et al., 2014)	NUTS-level spatial data from the European Commission (cropland waterstress population)	Relative Drought Hazard (dH) Index Absolute drought hazard (WASP) Relative drought risk of each NUTS3 region (historic 1981–2015; future 2031–2060 & 2071–2100). For SSP-RCP combinations: SSP126, SSP370, SSP585.

The analysis notebooks can be found fully commented in Annex E2. The complete pipeline implementation timeline of specific workflows can be found in Annex E6.

2.3.5.1. Hazard assessment

The relative drought workflow quantifies drought hazard by estimating the probability that a region will experience severe precipitation deficits relative to a historical reference period. In this analysis, drought hazard (dH) is calculated using ISIMIP 3b bias-adjusted CMIP6 climate inputs, before and after integrating local historic precipitation records. This integration ensures that global climate projections are anchored to the region's long-term hydrological reality, improving the accuracy and relevance of the hazard estimates. Higher dH values indicate a greater likelihood of experiencing

drought conditions that are more severe than what historically occurred. This approach captures relative drought severity, making it possible to compare drought hazard across time periods and socio-economic scenarios. The analysis incorporated the historical period of 1930–2015, and two future periods, 2031–2060 (near-future) and 2071–2100 (far-future). Three socio-economic pathways (SSPs) combined with RCPs were also considered (Zhang et al., 2023). More specifically, SSP126 (sustainability pathway), SSP370 (regional rivalry), and SSP585 (fossil-fuel intensive development) were selected to represent low, medium, and high-emission futures, allowing for local exploration of drought hazard evolution under different global development trajectories. In addition to the relative drought hazard index, raw WASP (Weighted Anomaly Standardized Precipitation) values were also used as a measure of absolute drought hazard (Annex E13, Fig. 3).

2.3.5.2. Risk assessment

The risk assessment is based on the calculated drought hazard, the relative exposure derived through Data Envelopment Analysis (DEA), and the vulnerability index (dVis), which incorporates two socio-economic vulnerability indicators: GDP-per-capita-based vulnerability and the degree of rural population in each region. The relative drought risk for each NUTS3 region—computed as the product of drought hazard, exposure, and vulnerability—is presented in Fig. 2.15 A–G. The results display relative drought risk classes ranging from 1 (low risk, 0–0.2) to 5 (high risk, 0.8–1), visualized as shades of red, with darker tones indicating higher drought risk.

Fig. 2.15 A shows the historic risk distribution, while Fig. 2.15 B–G illustrate future conditions for two projection periods, 2031–2060 (near-future) and 2071–2100 (far-future), across all three socio-economic pathways: SSP126 (sustainability pathway; B and C), SSP370 (regional rivalry; D and E), and SSP585 (fossil-fuel-intensive development; F and G). The same analysis was repeated after the integration of local precipitation historic data of the period 1930–2010 (accessed on 4/2026) (Fig. 2.15 A'–G'). The calculated risk based on the historic data (A') differs greatly from the previous analysis (A), indicating a much more significant drought risk, especially in the area of Evros. Even though historical drought levels seem high for REMTH, this is possibly an artifact caused by local data overrepresentation of the region.

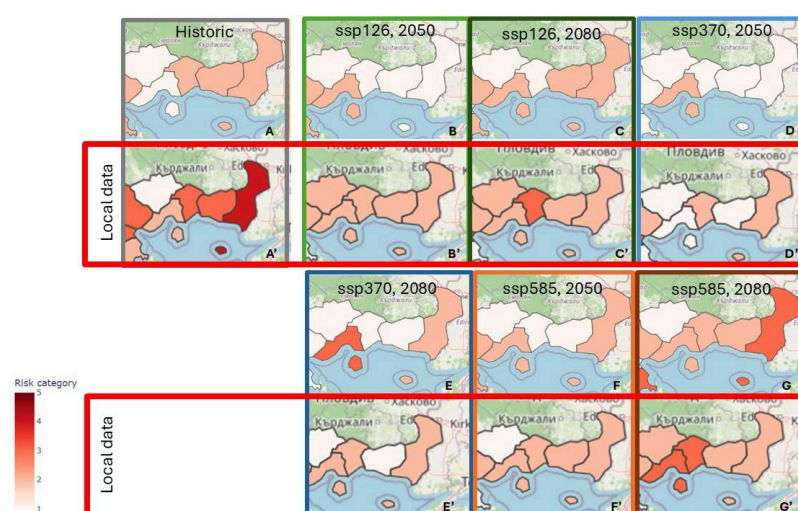


Fig. 2.15. Relative drought risk. A. Historic drought risk, A'. Historic drought risk after including local data. B–G represent groups of two future scenarios, 2031–2060 (2050-near-future) and 2071–2100 (2080-far-future), for all three SSPs, SSP126 (sustainability pathway, B and C), SSP370 (regional rivalry, D and E), and SSP585 (F and G). B'–G' represent the same time horizons and SSPs, after the inclusion of local data. The risk classes range between 1 (low risk, 0–0.2 risk) to 5 (high risk, 0.8–1) and are presented as shades of red (darker tones indicating higher drought risk).

This uncertainty is addressed by the screening of all future time horizons and SSP scenarios that consistently show mostly low drought risk, with the exception of the region of Xanthi and the region of Kavala, which in some far-future scenarios (ssp126 and 585 for Xanthi, and ssp585

scenario for Kavala) show moderate drought risk. Additionally, local data seem to moderate the extreme risk previously observed for Evros, which, in comparison to the previous estimation, now shows a lower relative risk estimation. The same observations can be made in Annex E13 Fig.5, which compares relative drought risk before and after incorporating local precipitation data into the hazard calculation. The implementation of the local historic data assists significantly with the analysis since it increases the region's NUT3 representation, adding historic data for Thasos and Kavala, and even though it seems to overrepresent the region of Evros, it leads to the correction of future high-risk drought predictions for the same area, leading to the prediction of a more moderate risk. The same effect can be observed for all regions, apart from Xanthi, which seems to indicate higher drought risks after the implementation of the local data. In conclusion, the regions Xanthi and Kavala could benefit from action plans to combat drought risks before they cause significant problems, especially given the high wildfire risks identified for both regions, above.

2.4 Key Risk Assessment Findings

2.4.1. Severity

The results of the multi-hazard assessment indicate that REMTH faces substantial to critical severity for wildfire risk, while drought risk is mostly mild. Wildfire severity remains high across all future climate scenarios, with large forested and biodiversity-rich areas consistently falling into the very high hazard class. Drought severity also increases under future SSP pathways, particularly in the regions of Xanthi and Kavala, two regions that are also characterized as very-high wildfire hazard regions. The combined effect of intensified hazards and expanding exposure means that several NUTS3 regions experience persistent high-severity conditions, especially Rodopi, Kavala, Xanthi and Evros. These findings highlight that climate-related impacts in REMTH are not episodic but structural, affecting core ecological and socio-economic systems.

2.4.2. Urgency

The urgency assessment shows that REMTH requires immediate action for wildfire risk, especially when it comes to ecological risks and the protection and preservation of forest areas and biodiversity. More action is also needed for the risk of drought, especially for Xanthi. Wildfire projections under both RCP4.5 and RCP8.5 demonstrate rapid escalation of hazard and risk, leaving little room for delayed interventions, including the immediate reduction in emissions, which seem to accelerate climate risks for both wildfires and drought. Regions with high rurality and low GDP per capita exhibit faster increases in vulnerability, raising the urgency for targeted adaptation measures. The results collectively indicate that REMTH must prioritize short-term operational responses for wildfire and medium-term planning responses for drought.

2.4.3. Resilience Capacity

The resilience capacity is medium to low across most NUTS3 regions. Rural areas with limited economic resources—captured by the vulnerability indicators `Overall_gdpcap` and `Overall_rural`—possess limited ability to absorb or recover from climate impacts. Forested ecosystems, already stressed by repeated wildfire events, demonstrate low ecological resilience, particularly in Dadia. However, the detection of many low-flammability-score local plant species and genera indicates a natural build-in resilience to wildfire of the local vegetation, indicating the capacity of enriching such species without disturbing the natural biodiversity of the forests of REMTH. Conversely, more urbanized or coastal regions show substantial resilience, benefiting from

diversified economies and stronger infrastructure. Overall, resilience capacity remains uneven across REMTH, reinforcing the need for differentiated adaptation strategies.

2.4.4. Risk Priority

Integrating severity, urgency, and resilience capacity leads to a clear risk priority ranking for REMTH. Wildfire risk is classified as a very high priority, driven by critical severity, immediate urgency, and low resilience in key ecological and rural zones, especially in Evros, Rodopi, and the higher-altitude areas of north REMTH, where the risk remains very high or will increase significantly in the imminent future. Drought risk is ranked as a moderate priority, particularly in agricultural and water-dependent areas where exposure and vulnerability amplify future hazard trends, especially for the region of Xanthi. Also, drought is a connected-to-wildfire-risk which could significantly increase wildfire hazard and hinder wildfire risk management action plans, adding to the drought risk priority. The comparison of relative drought risk before and after incorporating local precipitation data confirms that two NUTS3 regions—Kavala and Xanthi—are characterized as areas of mild relative drought risk. These priority rankings provide a structured basis for REMTH to allocate resources, strengthen monitoring, and design targeted adaptation interventions.

2.4.1 Mode of engagement for participation

Phases 1–2 results were presented at the online 2nd Stakeholders' Meeting, followed by an open discussion on the CRA's value for REMTH and future Phase 3 participation. A Google evaluation form gathered feedback and expressions of interest (Annex A10.2.5-A10.2.6). Stakeholders highlighted key priorities: strengthening citizen-science monitoring (apps, weather stations), improving training on digital tools and CRA interpretation, aligning the action plan with civil-protection frameworks, safeguarding seed material through biobanks, and establishing open data repositories with a central coordinating body (Civil Protection or NECCA).

2.4.2 Gather output from Risk Analysis step

All outputs presented in this report are used for the risk evaluation, including the historic and future wildfire susceptibility and hazard maps, the drought hazard and relative drought-risk indicators, the sector-specific risk layers (population, economy, ecology, roads), and the change-detection analyses comparing historic conditions with recent and future periods. These outputs collectively inform the assessment of severity, urgency, resilience capacity, and risk priority for REMTH. By integrating both CLIMAAX workflow results and newly incorporated local datasets, the evaluation captures how hazards evolve over time, how exposure and vulnerability differ across NUTS3 regions, and where climate-related risks intensify under different emission scenarios. This comprehensive evidence base supports a robust and transparent risk-evaluation process aligned with the CLIMAAX Key Risks Protocol.

2.4.3 Assess Severity

Wildfire severity in REMTH is consistently high—both historically and under future climate scenarios—due to dense fuels, difficult terrain, and repeated ecological damage in areas like Dadia, Rodopi, and the Evros Delta. These fires cause long-lasting habitat loss and major disruptions, placing wildfire risk in the substantial-to-critical severity range. Drought severity also increases in several future pathways, especially in agricultural and water-dependent ecosystems, and further amplifies wildfire danger. Stakeholders confirm these impacts, noting major effects on daily life, economic stability, and environmental integrity, as well as gaps in training and risk awareness. In

line with CLIMAAX, wildfire remains the region's highest-severity hazard, while drought is moderate but strongly aggravates fire risk and must be addressed alongside it.

2.4.4 Assess Urgency

Wildfire risk in REMTH requires immediate action: severity rises sharply under all future scenarios, and the region's forest-urban interfaces and critical infrastructure make impacts sudden and potentially irreversible. Wildfires escalate within hours, threatening lives, ecosystems, and the economy, and stakeholders consistently call for urgent preparedness, monitoring, and prevention measures. Drought risk requires more action: it develops slowly but has persistent impacts on agriculture, water availability, and ecosystem stability. Although moderate in severity, drought significantly increases wildfire susceptibility, demanding medium-term planning, resource management, and continued stakeholder engagement.

2.4.5 Understand Resilience Capacity

Resilience in REMTH ranges from medium to low, with rural areas showing the weakest capacity due to limited resources, dependence on climate-sensitive livelihoods, and low access to training. Forest ecosystems in Dadia, Rodopi and the Evros Delta also exhibit low natural resilience after repeated fires and drought stress, though the low flammability of local plant species offers opportunities for strengthening recovery. In contrast, urban and coastal regions demonstrate higher resilience thanks to stronger infrastructure, diversified economies, and established civil-protection mechanisms. Existing plans (RCCAP, prevention strategies, forest-management actions) and BioProWRAP's data-driven approach improve regional resilience, but gaps remain in funding, training, governance coordination, and unified regional oversight.

2.4.6 Decide on Risk Priority

Wildfire constitutes a Very High Priority risk for REMTH, driven by critical severity, immediate urgency, and low to medium resilience capacity in several NUTS3 regions. The rapid escalation of wildfire hazard under future scenarios and the high exposure of settlements and critical ecosystems reinforce this top-priority classification.

Drought is assessed as a Moderate Priority risk. Its escalation is slower, with moderate severity, more action needed, and medium to low resilience capacity, especially in agricultural and water-dependent areas. Its persistent nature and cascading impacts (e.g., reduced crop yields, water scarcity, increased wildfire susceptibility) elevate its priority level.

2.5 Monitoring and Evaluation

Phase 2 strengthened REMTH's wildfire-risk understanding by combining CLIMAAX datasets with high-resolution local data, real-time biodiversity inputs, and the addition of drought as a second hazard. Despite challenges in integrating large local datasets, the project maintained strong coordination among academic teams, authorities, NGOs, and citizen groups, who validated results and emphasized the value of participatory workshops and citizen-generated biodiversity data. Local wildfire, precipitation, and biodiversity datasets improved risk interpretation, though further eDNA and socio-economic data would enhance future assessments. Overall, Phase 2 increased public awareness, institutional readiness, and evidence-based decision-making, forming a solid foundation for Phase 3 adaptation planning, with final outcomes to be disseminated through publications, visual materials, social media, and an accessible documentary.

2.6 Work plan Phase 3

Phase 3 builds on the refined multi-hazard assessment, additional biodiversity traits, and stakeholder-validated datasets from Phase 2. Its main purpose is to convert the Very High Priority wildfire risk into specific adaptation measures. Key actions include: development of a systematic plan for biodiversity-monitoring using citizen-science and eDNA data, strengthening the planning of local adaptation with regional authorities, capacity building of stakeholders through targeted training and improved data-sharing and monitoring systems across institutions.

Activity F3.1 – Development of Targeted Adaptation Measures

This activity will convert the validated Very High Priority wildfire and drought risks identified in Phase 2 into actionable, locally relevant adaptation measures for REMTH. The goal is to ensure that improved hazard and risk assessments are translated into actionable interventions that are fully aligned with the Regional Climate Change Adaptation Plan (PeSPKA) and contribute to strengthening PeSPKA through data-based, biodiversity-focused adaptation planning. The BioProWRAP project core team will synthesize Phase 2 outputs and work with regional authorities and stakeholders (REMTH, Civil Protection, Forestry Services, NECCA) to co-design feasible adaptation measures. These discussions will be supported by the thematic expert groups established in Phase 2, through continued online consultations, updated data sharing, and knowledge-exchange sessions.

Activity F3.2 – Systematic Biodiversity-Monitoring Plan (M3.1)

A key goal of Phase 3 is to develop a systematic biodiversity-monitoring plan, with priority given to vulnerable ecosystems identified in Phase 2. This plan is vital for long-term ecological resilience and early detection of wildfire-related impacts. The plan will incorporate citizen-science observations from Phase 2 excursions, ITS metabarcoding results (Milestone M2.2), multi-hazard assessment, and stakeholder-validated datasets. The monitoring framework will be co-developed with decision-making centers. The team will work with regional authorities and different stakeholders—REMTH Civil Protection, municipal authorities, forestry offices, and national agencies (YPEN, GSCP)—to integrate risk-informed tools into existing workflows.

Activity F3.3 – Continuation of Stakeholder Engagement (M3.1 - M3.2.)

Stakeholder engagement remains essential for interpreting Phase 3 outputs, validating adaptation priorities, and ensuring feasibility of proposed measures. The thematic expert groups will continue through online meetings and consultation activities.

Limitations and Aspects Not Studied

Phase 3 will not include infrastructure-level planning, as works such as fire-break construction or hydrological interventions require specialized technical studies beyond the project scope. It will also not involve physical implementation of adaptation measures, focusing instead on planning and institutional coordination. Pilot-scale physical implementation of ecological adaptation measures will be provided, since they have been accomplished within the scope of Phase 1 and 2 (risk-based targeted biodiversity monitoring via crowdsourcing and metabarcoding, as well as local population engagement). Finally, Phase 3 will not deliver comprehensive regulatory reform; only targeted policy recommendations will be produced.

3 Conclusions Phase 2- Climate risk assessment

This report concludes the Phase 2 of the BioProWRAP project, during which we successfully advanced the climate risk assessment for REMTH by enriching the Phase 1 analysis with the addition of the relative drought risk assessment, a significant hazard that can have cascading effects that further enhance wildfire risk. The integration of drought as an additional hazard is a significant step toward a more comprehensive multi-risk assessment, strengthening the scientific basis for future adaptation planning.

Additionally, local data were also incorporated into both risk assessments, updating wildfire and precipitation local historic records. A significant novelty of our work was the incorporation of live biodiversity inputs created through crowdsourcing (Seek by iNaturalist) into the wildfire susceptibility modeling, interpreting them as an additional vulnerability layer based on normalized z-scores of species/genera-specific flammability. We plan to further enhance this layer by incorporating biodiversity data sourced through environmental DNA analysis via metabarcoding, but also expand it by incorporating additional novel species-specific trait layers like resilience to fire, drought, and temperature or exposure layers like species threat level and local occurrence. Risk management was accomplished by the creation of a synthetic metabarcoding dataset, allowing us to bypass extreme weather and technical problems that delayed metabarcoding final data, enabling the development and testing of the novel flammability-included wildfire susceptibility modeling independently. A masterfile of species/genera observations and flammability scores was created, allowing for species and genera flammability annotation, independently from species name variations and levels of taxonomy identification. Both risk management and annotation solutions have been incorporated within the wildfire hazard assessment pipeline, allowing for result replication and additional applications.

The incorporation of real-time biodiversity observations provided added ecological insight, supporting the identification of high-value, high-risk areas for future monitoring. The preliminary key findings indicate that wildfire remains a very high-priority risk for REMTH, with critical severity, immediate urgency, and low to medium resilience capacity in several NUTS3 regions. Drought emerges as a moderate-priority risk, with moderate severity and more action needed, particularly in agricultural and water-dependent areas. Phase 2 also addressed several challenges. One of the main challenges was the Integration of high-resolution local datasets into the CLIMAAX workflows. Data transformation into formats compatible with the CLIMAAX tool was challenging because each agency structures and formats its datasets differently. In addition, limited systemic sharing infrastructure further constrained data collection and deeper modeling, affecting the resolution of the analysis.

Stakeholder identification initially proved difficult, but targeted on-site dissemination, structured communication campaigns, and digital expression-of-interest participation forms successfully broadened participation and ensured representation across diverse key sectors.

Regarding the excursions, unsafe access conditions in the Virgin Forest area of the Frakto region required a revision of the initial planning. Based on the wildfire risk assessment developed in Phase 1, Paggaio–Mesoropi was selected as a safe and suitable alternative. An additional challenge encountered in the sequencing phase of biological samples. Several samples required repetition due to insufficient DNA yield or quality issues, resulting in delays and additional laboratory work.

Stakeholder feedback underscored the importance of expanding local data integration and strengthening public engagement through crowdsourcing in order to enhance their awareness about climate issues, and the overall effectiveness of future multi-hazard assessments.

Finally, Phase 2 delivered a more detailed understanding of REMTH's climate risks, improved the accuracy of risk and vulnerability mapping, and strengthened evidence-based decision-making. These results form a solid foundation for Phase 3, where targeted local adaptation measures will be developed in order to address the identified risks, with a particular focus on biodiversity monitoring and preservation, prioritizing vulnerable areas of REMTH.

4 Progress evaluation

The outputs of this deliverable directly inform the planned Phase-3 activities, as the refined multi-hazard findings, updated priority scoring, and stakeholder-validated datasets now guide the development of targeted adaptation measures, systematic biodiversity monitoring, and the final integration of risk-informed planning tools.

Table 4-1 Overview key performance indicators

Key performance indicators	Progress
[2] workflows successfully applied on Deliverable 1 (Phase 1)	1. Hazard Assessment for Wildfire - Machine Learning Approach (ECLIPS dataset) (Completed) 2. Risk Assessment for Wildfire (Completed)
[>3] workflows successfully applied on Deliverable 2 (Phase 2)	1. Refined Hazard Ass. for Wildfire - ML (ECLIPS) (Completed) 2. Refined Risk Ass. for Wildfire (Completed) 3. Hazard Ass. for Relative Drought (Completed) 4. Risk Ass. for Relative Drought (Completed) 5. Refined Hazard Ass. for Relative Drought (Completed) 6. Refined Risk Ass. for Relative Drought (Completed)
[>9] stakeholders engaged (Phase 1-3)	NGOs: WWF Greece, Hellenic Red Cross, Hellenic Rescue Team Rodopi, Hellenic Voluntary Firefighters Association-CTIF, Society for the Protection of Biodiversity of Thrace (SBPT), NECCA and other environmental groups and community associations. Municipal authorities: Mayor Office, Civil Protection REMTH, Hellenic Fire Service REMTH, Forestry offices, Police, Ministry of Environment and Energy (YPEN). Forestry and Agronomy: The National Forestry of REMTH and several agronomists. Self-employed professionals: Tourism, Food, agriculture, and Oenology. Academia: UTH, DUTH. Minorities-local communities: Rural Communities.
[5] organisations involved in nature excursions(Phase 2)	Municipal authorities: Mayor's office, Civil Protection REMTH, Self-employed professionals: Tourism, Food, agriculture, and Oenology, Forestry and Agronomy: The National Forestry of REMTH and several agronomists, Academia: UTH, DUTH, NGO's: SPBT.
[5] communication actions taken to share results with your stakeholders (Phase 1: 2, Phase 2: 1, Phase 3: 2)	1) Stakeholders introductory meeting (Completed) 2) CLIMAAX workshop in Barcelona (Completed) 3) 3rd Stakeholder Meeting of the European RESIST (Completed) 4) 2nd Stakeholder meeting (Completed)
[3] community-led biodiversity monitoring excursions organized (Phase 2)	1) Prasinada (Completed) 2) Paggaio-Mesoropi (Completed) 3) Dadia-Lefkimi-Soufli (Completed)
[3] educational programs and workshops (Phase 2)	1) 1st BioProWRAP Workshop, Drama (Completed) 2) 2nd BioProWRAP Workshop, Volos (Completed) 3) 3rd BioProWRAP Workshop, Xanthi (Completed)
[11] dissemination actions (Phase 1: 2, Phase 2: 7, Phase 3: 2)	Publish project in REMTH's Civil Protection Agency, Press release , Development of a customized Work Program for each workshop, Design of specialized printed material (flyers, posters), Email campaign to key stakeholders (Both Workshops and Excursions), Prior and after Workshop-Excursion promotion through website and social media posts on the project's (LinkTree), Screening of a documentary film accessible to

Key performance indicators	Progress
	everyone, including people with visual or hearing impairments (In progress). CLIMAAX initiative publication . Dr. Ioanna Karamichali has confirmed her participation in the EU CAP Network brokerage event "From practice to impact: building Horizon Europe collaborations for agriculture and rural areas", presenting the BioProWRAP project as the Scientific Coordinator (In progress, Annex J1).
[>66] social media posts and digital campaigns to disseminate project progress (Phase 1-3)	More than 66 social media posts and digital dissemination actions were completed across Phases 1–2. Posts in dedicated social media: Facebook , Instagram , LinkedIn , LinkTree , iNaturalist , Youtube . Publication of excursion material on the social media pages of collaborating partners (REMTH, CDPR, Koutsintas Travel, North Stars).
[10] tasks successfully implemented (Phase 1: 2 tasks, Phase 2: 6 tasks, Phase 3: 2 tasks).	T1.1, T1.2, T2.1, T2.2, T2.3, T2.5, T2.6 (Completed) T2.4 (Completed) T3.1, T3.2 (In Progress)
[1] adaptation proposal of systematic biodiversity monitoring (Phase 3)	In Progress
[2] articles in regional media mentioning the project (Phase 2,3)	Publication by the online news portal Magnesia news (Completed, Phase 2).
[2] scientific publications (Phase 3).	In Progress. Accepted for participation in the 19th International Conference on Energy and Climate Change in Athens, Greece. The corresponding paper will be submitted for review (Phase 2, Annex I1).
[2] policy recommendations submitted to regional and national authorities (Phase 3).	Not started

Table 4-2 Overview milestones

Milestones	Progress
Milestone 1 (M1.1): Stakeholders introductory meeting	Achieved
Milestone 2 (M1.2) Testing the wildfire workflows	Achieved
Milestone 3 (M1.3) Procurement launched for subcontracting services (scientific support, field & lab work)	Achieved
Milestone 4 (M1.4) D1.1 – Implementation of the CLIMAAX common methodology for multi-risk assessment and analysis of the results report completed	Achieved
Milestone 5 (M2.1) Workshops and natural excursions completed (soil, biodiversity, climate risk assessment data), 60+ participants and 9+ Stakeholder identified and engaged	Achieved
Milestone 6 (M2.2) Lab results from ITS metabarcoding finalized	Achieved
Milestone 7 (M2.3) D2.1 – Refined regional/local high-resolution analysis and risk assessment and comparison of results report delivered	Achieved
Milestone 8 (M3.1) Biodiversity adaptation strategies identified	In progress
Milestone 9 (M3.2) D3.1 – Contribution to local adaptation strategies and improved risk management plans report delivered	In progress

5 Supporting documentation

The supplementary documentation can be found in Annex K, where the full analytical Annex list is provided. All outputs produced are shared in the Zenodo repository (10.5281/zenodo.22754323).

Those outputs are listed below, arranged in the same order as in Zenodo:

ANNEX A:	Workshops
ANNEX B:	Excursions
ANNEX C:	METABARCODING
ANNEX D:	VIDEO
ANNEX E:	Workflows_Results
ANNEX F:	External Databases
ANNEX G:	Local_Data
ANNEX H:	Sampling_Coordinates
ANNEX I:	Scientific publications_Congress
ANNEX J:	Confirmation of participation at EU CAP Network brokerage event
ANNEX K:	Annex_List

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