

Deliverable 5.3

Long term sustainability and replicability monitoring system

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Inclusive Outscaling of Agro-ecosystem
REstoration ACTions for the MEDiterranean

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List of acronyms

CY: Cyprus

D: Deliverable

CM: Decision Maker

DoA: Description of Action

EG: Egypt

ERLL: Ecosystem Restoration Living Lab

GA: Grant Agreement

SP: Spain

IL: Israel

IT: Italy

GR: Greece

GE: Germany

LanDS: Land Degradation Decision-Support

M: month

ML: Machine Learning

MO: Morocco

MS: Milestone

PA: Pilot Area

PAL: Pilot Area Leader

PP: Project Partners

SH: Stakeholder

SLWM: Sustainable Land and Water Management

TR: Turkey

WP: Work Package

W: Workshop

Summary

REACT4MED aims to extend the potential application of the land restoration action(s) promoted in the Ecosystem Restoration Living Labs (ERLLs) by upscaling the information gathered in the different pilot areas at the Mediterranean scale. Within the Project, WP5 is devoted to the implementation of restoration outscaling actions in the 8 Pilot Areas and assessment of cost-effectiveness. In the first top-down approach (in collaboration with WP2) the wide scale biophysical indicators were chosen and were adapted to assess the effectiveness and impact of past/ongoing projects. In the second bottom-up approach these indicators and the respective metrics co-developed in close cooperation with WP3 and formalized in the LanDS at WP4, were used to assess the impacts of new restoration actions and their outscaling in areas with similar biophysical and socio-economic conditions.

This deliverable proposes establishing a monitoring system that is based on the outcomes of deliverables 5.1 and 5.2 with the scope to develop a harmonised methodology to be able to assess the long-term sustainability of the research results in the 8 pilot areas (Cyprus, Greece, Italy, Spain, Israel, Morocco, Turkey, and Egypt). It intends to focus on the integration of different applied restoration actions and establish if there are significant differences in their application. Among the most relevant indicators to check for sustainability of the restoration actions are the status and dynamics of soil organic carbon, as a crucial characteristic of soil health, yield dynamics and trends, water use efficiency, vegetation cover trends, especially in the natural environments such grazing pastures, and the overall impacts they have on the livelihoods of local stakeholders. In fact, much of work was done in close collaboration with farmers, local extensions staff and researchers involved in all the pilot areas otherwise named as Ecosystem Restoration Living Labs (ERLL).

Obviously, each ERLL has its own bio-physical and socio-economic characteristics, and the monitoring system will try to reflect them in its own setup. Finally, the monitoring system would be a promoter for the dissemination of sustainable remediation practices such as regenerative agriculture, agroecology, agroforestry, land and water management and best management environmental practices.

The deliverable provides the framework for monitoring soil organic carbon, water use efficiency, land cover (vegetation) and yield dynamics. The monitoring system will be the long-lasting legacy of the project and will be handed over to local decision makers in the 8 pilot areas.

1 Introduction

1.1 General information

Defining an ecological monitoring system requires at least the following:

1. Identifying specific management requirements.
2. Identifying key ecological processes.
3. Determining ecological processes to be monitored and making a preliminary list of monitoring indicators.
4. Determining the final list of monitoring indicators and grading the indicators.

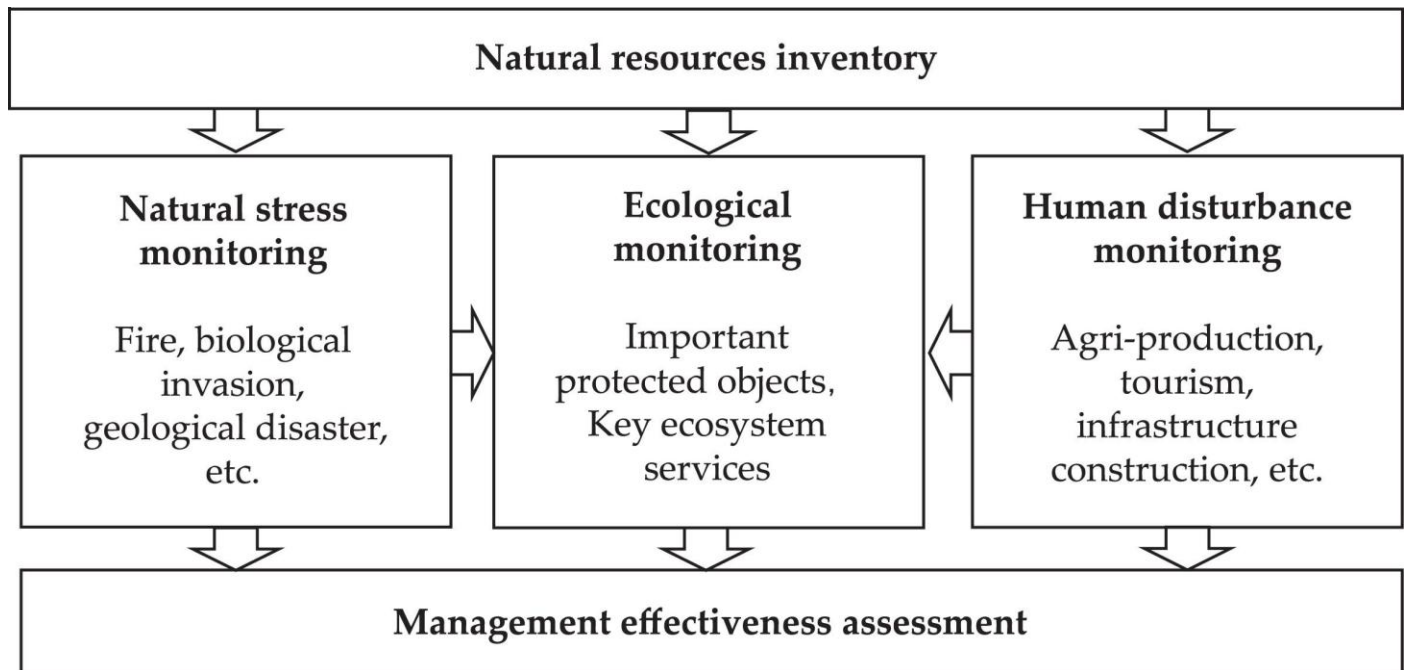
Well-designed ecological monitoring systems are increasingly recognized as compulsory for the effective management of natural resources (Jiao et al., 2022). They must be based on well-designed frameworks that highlight the importance of balancing ecological conservation and community development objectives in order to implement the trade-off analysis method and to pair key ecosystem services to the dual management objectives. They must also present a unified set of specific monitoring indicators that require matching the indicators to key ecological processes and specific management objectives. The whole approach should be implemented in combination with top-down and bottom-up approaches to encourage local communities to participate in and have access to the information generated through monitoring process. Overall, the approach should provide scientific support to policy makers to establish ecological monitoring systems and to contribute to more informed and efficient management of the natural resources, including all their types, from arable lands to fruit trees, olive groves and vineyards to grazing pastures and forests.

A comprehensive monitoring system is based on natural resources inventory that is centred on ecological monitoring, assisted by natural stress, human disturbance monitoring, and supplemented by management effectiveness assessment (Fig 1). The natural resources inventory is used to collect basic information such as the type, distribution and status of natural resources (e.g. plants, animals, land cover, etc.), to determine the baseline for conservation and management. The ecological monitoring system is the core part of a comprehensive monitoring system and is applied to understand the dynamic changes of biodiversity and ecosystems. The natural stress monitoring and the human disturbance monitoring provide information about disturbance, land use, and other agents of change, which are used in correlation analysis of ecological changes, thus helping clarify the correlation mechanism between social and ecological components. The management effectiveness assessment serves to compare them with the conservation and management objectives and to make further management decisions or necessary changes.

The comprehensive monitoring system presented in Fig. 1 is established based on natural resources inventory, where the ecological monitoring stands as the main core of the system itself, while natural and human disturbance monitoring are the auxiliary, and the management effectiveness assessment is considered as the supplement.

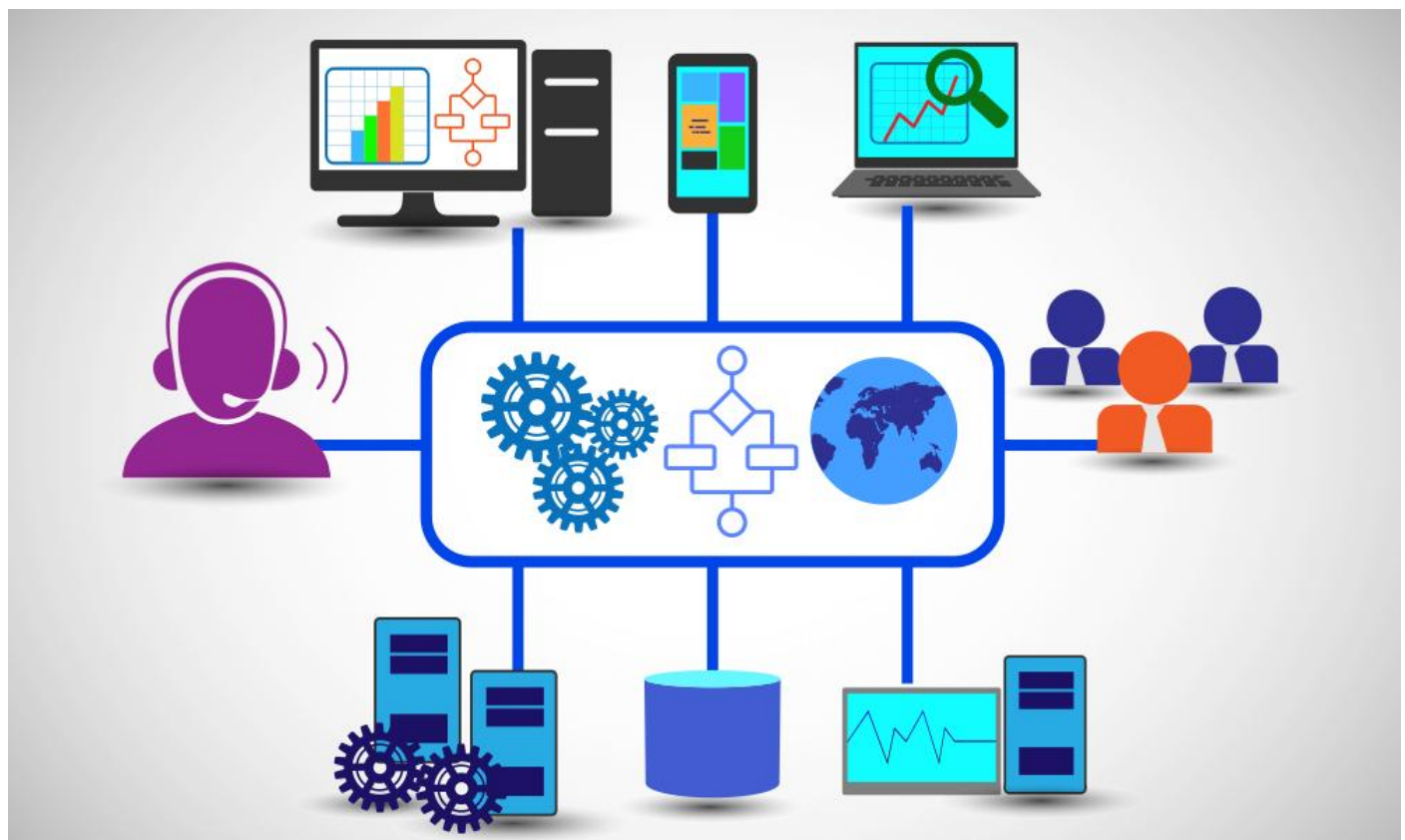
Building an ecological monitoring system requires implementation of various technical means, that must be applied through the combination of remote sensing techniques and ground monitoring. These are the key requirements for establishing solid and reliable standards for natural resources monitoring (Pasquarella et al., 2016). Nevertheless, each indicator of the monitoring system has its own characteristics that should be considered when trying to estimate progress of change, being that positive, negative or stable.

Fig 1. Natural resources inventory



Source: Jiao et al, 2022.

Fig. 2. Schematic design of a monitoring system



Open Source: Internet

2 What to monitor?

2.1 Soil Organic Carbon (SOC)

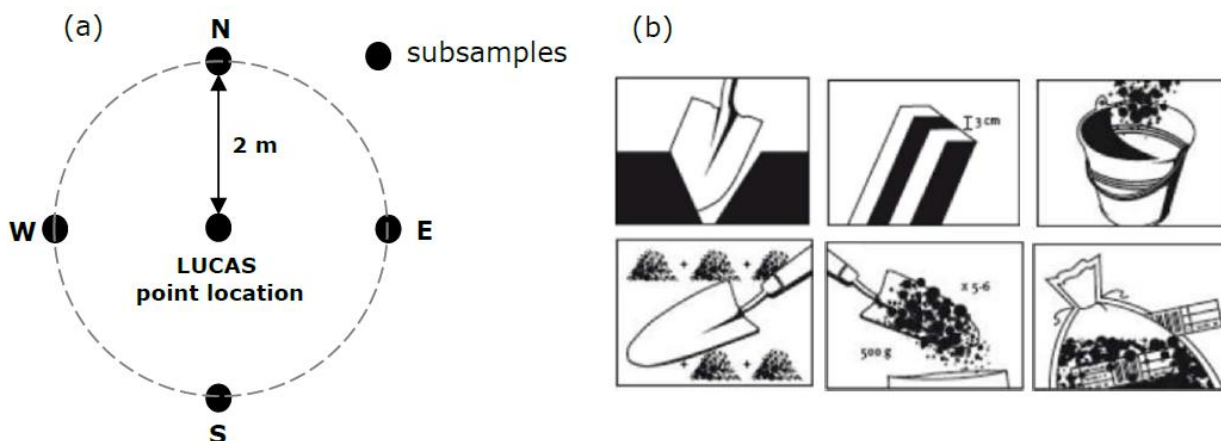
Soil organic matter (SOM), considered as the “elixir” of soil health is one of the most important characteristics of soils. SOM has a direct impact on carbon sequestration as about half of it is carbon, as well as on crop yields, water retention, soil biodiversity, C/N ratio and much more. The best way to monitor SOC is through field soil sampling at least at 20 cm depth, even though considerable amount of carbon could still be stored also at deeper depths.

Within the European Union (EU) the basic system for monitoring SOM is based on the so-called LUCAS survey or the Land Use/Cover Area frame Survey that is a harmonized in situ land cover and land use data collection exercise that extends over the whole of the EU's territory. An in-situ survey implies that data are gathered through direct observations made by surveyors on the ground. The data collected by LUCAS provides harmonised information for studying a range of socioenvironmental challenges, such as land take, soil degradation or biodiversity. The sampling design is based on the intersection of a regular 2 km x 2 km grid covering the whole territory of the EU. It is then proposed to endorse the LUCAS methodology for monitoring the status and trends of SOC also in the pilot areas of REACT4MED project.

LUCAS sampling methodology and laboratory analysis includes the collection of a composite soil sample of approximately 500 g that must be taken from five subsamples collected with a spade at each point (Toth et al., 2013). The first subsample should be collected at the geo-referenced point location; the other four subsamples must be collected at a distance of 2 m following the cardinal directions (North, East, South and West) (Figure 1a).

Before collecting the subsamples, stones (>6 cm diameter) vegetation residues, grass and litter must be removed from soil surface by raking with the spade. As shown by Figure 2b, a V-shaped hole must be dug to a depth of 20 cm using the spade and a slice of soil (approximately 3-cm thick) to be taken from the side of the hole with the spade. The slice must be trimmed at the sides to give a 3-cm wide subsample. The subsample then is placed in a bucket. The procedure should be repeated at the other four subsample sites. Finally, the five subsamples in the bucket must be mixed with a trowel. Vegetation residues and stones should be removed. Approximately 500 g of the mixed soil should be taken with a trowel from the bucket, placed in a plastic bag, and labelled to derive the composite sample. Soil samples should be allowed to air dry before the bags are sealed.

Figure 1. (a) LUCAS sampling schema and (b) summary of the sampling procedure



The samples were then should be send to a central laboratory where physical and chemical properties are to be analysed according to standard ISO methods (except for extractable Potassium). Table 1 shows the soil properties to be measured, together with the methods used. It must be noted that despite REACT4MED

project endorse the monitoring of SOC, all other soil properties could be monitored the same way. LUCAS soil sampling is done every four years, by collecting a soil sample always at the same spot. Given the size of pilot areas of the project, the grid sampling scheme is set at 500 m x 500 m. Each soil points otherwise named as Soil ID should be geo-referenced with a GPS equipment and all the information should be placed in an Excel file.

Table 1. Methods used for the analysis of physical and chemical properties in topsoil samples.

Soil properties	Method	Description
Coarse fragments	ISO 11464:2006	Sieving to separate coarse fragments (2-60 mm) from fine earth fraction
Clay, silt and sand contents	ISO 11277:1998 ISO 13320:2009	Sieving and sedimentation method Laser diffraction (in 2015 only)
pH in CaCl ₂ and in H ₂ O	ISO 10390:2005	Glass electrode in a 1:5 (V/V) suspension of soil in H ₂ O and CaCl ₂
Electrical conductivity	ISO 11265:1994	Metal electrodes in aqueous extract of soil
Organic carbon content	ISO 10694:1995	Dry combustion (elementary analysis)
Carbonates content	ISO 10693:1995	Volumetric method
Phosphorus content	ISO 11263:1194	Spectrometric determination of P soluble in sodium hydrogen CaCO ₃ solution
Total nitrogen content	ISO 11261:1995	Modified Kjeldahl method
Extractable potassium content	USDA–NRCS, 2004	Atomic absorption spectrometry after extraction with NH ₄ OAc
Cation exchange capacity	ISO 11260:1994	Using barium chloride solution to saturate samples and extract cations

At each Soil ID point data should be collected also for the following characteristics: climatic zone, date of sampling, X and Y coordinates, elevation, ploughing or not, stoniness, land cover, plant species, and land use by specifying the types of crops, as well as fruit trees, olives, and vineyards. For natural pastures or shrubs/forest the land cover types must be also specified.

After the laboratory analyses are completed and data are available, they should be stored in safe archives before being checked and validated for their quality. When the second round of sampling is completed, at the four-year period, both data should be confronted to establish trends. It should be noted that monitoring systems include long-term periods that span over several years even decades.

2.2 Water use efficiency

By definition, water use efficiency (WUE) refers to the ratio of the amount of crop yield produced per unit of water used in the agricultural practices. High values of WUE indicates that a farm or agricultural system is able to produce more yield with less water, which is essential in the context of regions facing water scarcity and climate change.

Monitoring WUE is a crucial aspect of managing water resources, and to effectively do it, the quantity and the quality of the water used need to be assessed as well as understanding the factors that influence water consumption, such as crop type, irrigation systems and soil characteristics.

Advanced techniques like remote sensing, satellite imaging and soil moisture sensors have revolutionized the ability to track and optimize water use in real-time (Yuan et al., 2017). By combining these tools and models, farmers can monitor and manage water use in a more effective manner, ultimately improving water use efficiency while reducing costs and environmental impact. Integrating data from multiple sources,

including remote sensing, soil moisture sensors, and weather forecasts, offers a holistic view of crop water use, enabling more informed decisions.

In the following are reported practical examples of tools and models to be used in order to monitor WUE in agriculture:

1. **Soil Moisture Sensors** are crucial tools for monitoring soil water content in real-time. These sensors measure the volumetric water content in the soil and provide data on whether the soil is too dry or too wet, enabling farmers to adjust irrigation schedules accordingly. These tools help improve irrigation efficiency by preventing over-irrigation, which saves water and reduces costs.
2. **Remote Sensing** such as satellite imagery and drones, offer valuable insights into crop health and water use efficiency. Platforms like Sentinel-2 (part of the European Space Agency's Copernicus program) and Landsat provide high-resolution imagery that can be used to assess vegetation cover, water stress and overall crop condition, enabling farmers to adjust irrigation strategies in real time to optimize WUE.
3. **Crop Simulation Models** integrate climate data, soil properties and crop management practices to predict crop growth, yield and water requirements. These models can simulate different irrigation scenarios and assess the impact of different water management strategies on WUE. Farmers can use these models to optimize planting schedules and irrigation timing to improve water use efficiency under various environmental conditions.

These technologies allow for more precise irrigation management, enabling farmers to deliver the right amount of water at the right time, thus reducing water waste and improving crop productivity (Irmak et al., 2016). Furthermore, the use of decision-support systems that incorporate climate data, crop growth models and water availability forecasts can help farmers make better-informed decisions about water management (Fernández et al., 2019). The adoption of water-saving irrigation technologies, such as drip irrigation and sprinkler systems, alongside monitoring tools, has proven to enhance WUE and reduce the environmental impact of agricultural water use (Pereira et al., 2012). Nevertheless, the efficiency of water use varies greatly depending on regional and crop-specific factors, underscoring the need for tailored approaches and localized monitoring systems to address the challenges faced by different farming systems.

2.3 Ecosystem functions

The effects of land use/cover and management practices on soil quality have been studied in many ecosystems (Su and Zhao, 2003; Elsacker, 2011; Moges et al., 2013; Baranian Kabir et al., 2017; Tellen and Yerima, 2018). Soil properties are highly affected by their aboveground biomass and it has been proven that higher above-ground biomass leads to better soil quality in calcareous soils (Guzmán et al., 2019). Soil management is very critical and sensitive in fragile arid and semi-arid ecosystems. Inappropriate management (e.g. the use of forests and rangelands for dryland farming and severe grazing) may lead to irreversible changes in soil properties (O'Sullivan et al., 2015). Understanding the functionality of land use/cover under various management practices can assist managers to avoid hazardous changes. Although soil quality indicators are assessed between different land uses/covers (e.g. rangeland and agricultural field), soil quality conditions may differ under a specific land use/cover due to spatial heterogeneity. Soil quality indicators have been compared between rangelands and agricultural fields, but limited studies have compared such indicators between semi-arid forests and various rangeland conditions (e.g. rangelands with different grazing impacts).

Landscape function analysis (LFA) is an indirect assessment approach which has been applied for evaluating soil surface functionality in different ecosystems, e.g. Savana, deserts, and temperate forests (Read et al., 2016; Eldridge and Delgado-Baquerizo, 2018; Gaitán et al., 2018). LFA was originally developed to establish a set of soilsurface indicators for measuring and analyzing the nature and severity of problems in

dysfunctional rangelands. (See Tongway 1995; Tongway and Hindley 2000.) Over the years the scope of LFA has greatly expanded to include methods useful for monitoring restoration trends in many different types of landscapes. (See Tongway and Hindley 2004.) It is a rapid and inexpensive tool, which provides meaningful and unambiguous indices that reflect the functioning of soil processes, and can be used in most ecosystems (Maestre & Cortina, 2004). This method uses 11 that uses readily observed indicators to assess and monitor biogeochemical functions of the landscape (see Table below). At each site, three 10 meter transects are laid out parallel to each other and 5 meters apart. Visual soil surface assessment is then conducted in each quadrat using a method as described in the Landscape Functional Analysis method developed by (Tongway & Hindley, 2004). The soil assessment should then be followed per transect, as described in (Tongway & Hindley, 2004).

Table 1: Landscape Function Analysis indicators

Indicator	Description	Stability	Infiltration	Nutrient
Soil Cover (%)	Assessing perennial vegetation cover, woody material >1 cm diameter and rocks >2 cm			
Per. basal / canopy cover (%)	Estimating basal cover of perennial plant species and/or density of canopy cover of trees and shrubs			
Litter cover, origin & incorp.	Assessing the amount, origin and degree of decomposition and incorporation of plant litter			
Cryptogam cover (%)	Assessing the cover (%) of cryptogams on the soil surface			
Crust brokenness	Assessing the soil surface crust brokenness			
Erosion type & severity	assessing the type and severity of various soil erosion			
Deposited materials	Assessing the nature and amount of transported alluvium sediments to query zone			
Soil surface roughness	Assessing the soil capacity to capture and retain mobile resources via visual categorization of its texture			
Surface resist. to disturb.	Assessing soil's resistance to disturbance			
Slake test	Assessing the stability of the soil to rapid wetting			
Texture	Classification of soil texture			

2.4 Land cover (vegetation dynamics)

Land cover change dynamics are best managed by remote sensing technologies. In Europe the CORINE land cover (Coordination of Information on the Environment) was the first instrument to monitor those changes. The programme was an effort to develop a standardized methodology for producing continent-scale land cover, biotope, and air quality maps.

Since 1990 that was the first year that CORINE was launched, it has become a flagship component of the European Environment Agency's Copernicus Land Monitoring Service, where it has provided essential information on European land cover/land use for over three decades. In its current form, the CORINE Land Cover (CLC) product offers a pan-European land cover and land use inventory with 44 thematic classes, ranging from broad forested areas to individual vineyards. The product is updated with new status and change layers every six years—with the most recent update made in 2018. CLC serves a multitude of users

and has nearly limitless potential and actual applications, including environmental monitoring, land use planning, climate change assessments, and emergency management.

In more recent years the Copernicus system was launched and within it there is the Copernicus Land Monitoring Service, also known simply as CLMS, as one of six thematic Copernicus services. The Land Cover & Land Use Mapping provides detailed classifications at various levels, including pan-European and global contexts. In Europe, high-resolution layers cover features like imperviousness, forests, and water. Globally, mapping follows the FAO's Land Cover Classification System. The fact that Copernicus also provides global coverage is very important as it could be used also by REACT4MED partners who are residing outside of Europe.

Technical characteristics of each satellite providing the data for CORINE land cover and supported by Copernicus are given at the website: <https://land.copernicus.eu/en/products/corine-land-cover>

In the context of land and vegetation cover changes within the pilot areas of REACT4MED is recommended to follow this procedure:

1. Define the boundaries of each pilot area
2. Create a GIS database with appropriate shape files and attributes
3. Enter all available data according to the year of data collection
4. Create land cover maps for the year data are available
5. Repeat the procedure in a time frame at least every six years
6. Analyze the data and define changes, if any
7. Summarize findings in appropriate reports.

2.5 Crop yield dynamics

The best way to analyse the trends of yield dynamics is to use statistical data. They should be collected from the historical archives of local administrations or farm records of each farm. Yield data analyses allow to make more informed decisions and improve growing efficiency. Field management zones constructed from multiple years of yield data are suitable for an initial assessment of potential yield and soil nutrient variability to make future crop management decisions.

Yields should be recorded in Excel files including crop type, ton/ha (or any other appropriate form of measurement), year of measurement, chemical inputs including chemical fertilizers, pesticides and any other form of inputs. Definition should be made if there is conventional, organic or regenerative agriculture. In addition, climate data should be collected along with soil data. While soil data are rather stable for a certain period, especially soil physical properties, links between yields and climatic conditions should be carefully recorded, given the strong influence climate has on crop production. For instance, drought has an enormous impact on yields, as it has been the case for Morocco over the last 4 years affecting drastically yields. Therefore, collection of these data becomes a very powerful instrument to conduct analyses and make forecasts.

High productivity and yield stability over time in combination with a reduction in the crop failure risk are the principal goals of both conventional and organic agriculture. These goals are achieved in organic agriculture through the maintenance of soil fertility and soil functions through agronomic practices such as balanced crop rotations and the application of organic amendments. Reduced tillage constitutes an important practice that limits the disturbance to the soil structure and biota, despite deep ploughing many be used in organic farming for weed control and aeration of heavy soils.

Once a database has been created, data could be used to also forecast future yields, this can be done through crop modelling models that are available like WHEATGROW that was developed by scientists in wheat based on a series of experiments in diverse management practices under different growing conditions, seasons of

growing, water availability conditions etc. The data received from such experiments which included growth, development, light interception, bio-mass accumulation, canopy development, light utilization, physiological processes, growth reducing parameters were utilized to develop the model. There are many other models available like CERES Wheat; CROPGROW-Soybean, Cropsyst, APSIM, EPIC, Fasset, CERES-MAIZE, and CERES Sorghum.

In the context of crop yield dynamics within the pilot areas of REACT4MED is recommended to follow this procedure:

1. Define major crops in the pilot area
2. Collect all available data on year basis
3. Enter the data in an appropriate Excel spreadsheet
4. Collect climate data (rainfall and temperature) based on availability, daily, monthly, yearly, decade and three-decade period
5. Collect soil data, most importantly soil organic matter (SOM), Nitrogen, Phosphorus and Potassium and any other data available
6. Collect soil maps showing soil types, and spatial distribution of major soil properties
7. Over impose on soil and climate data, the crop pattern distribution within the pilot area for each year
8. Compare same crop yield between various fields and identify reasons for increase or decrease in crop production

Should be noted that crop yield dynamics are affected by many factors and is not always easy to define the reasons for change. Nevertheless, they are very important to forecast productivity and the use of models, when the data entry into them comes from reliable sources has shown to have provided relatively good impacts.

3 Next steps

The next step in establishing monitoring systems is related to commitment and dedication. It requires that local stakeholders consider this as a valid instrument to make the right decisions in crop, soil and water management when dealing with agriculture management. At natural pastures, forests or shrubs, the most important aspects are related to land and vegetation cover that could be damaged from fires or overgrazing. Remote sensing technologies could help to monitor those changes.

4 Conclusions

Deliverable D5.3 has the goal to propose a framework for monitoring soil organic carbon, water use efficiency, land cover (vegetation) and yield dynamics. The steps to follow for their implementation are described in a practical and simple manner so that local stakeholders, including farmers, researchers, policy makers and decision makers could use them. This will be a long-lasting legacy of REACT4MED provided that will be established, implemented, improved and maintained.

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