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Geodata and technologies for a greener agriculture in Europe

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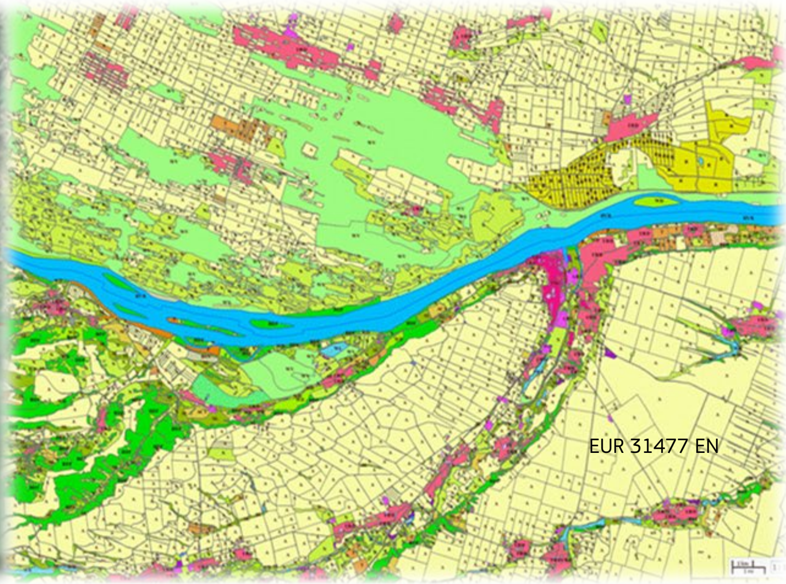

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Contents

Abstract

The Geodata and Technologies for the Common Agricultural Policy (GTCAP) team at the Joint Research Centre (JRC) has devoted the last quarter-century developing the Common Agricultural Policy (CAP) control mechanisms and assisting with the implementation of compatible innovative technologies for the CAP. In recent years GTCAP's research and development work principally focused on 1) Promote the checks by monitoring (CbM) approach as a key control system for paying agencies and 2) Make better use of new technologies, in particular remote sensing for monitoring environmental and climate requirements.

This report compiles the findings and other outcomes of the GTCAP activities on the CAP Green Infrastructure and covers two years of activities (2021 and 2022). The GTCAP's green Infrastructure work focused on activities exploring the nexus of land and the environment and employed cutting-edge technology more effectively for monitoring environmental and climate requirements. The new delivery model, central to the reformed CAP and the European Court of Auditors (ECA) recommendations, represented one of the main drivers for the activities over the last two years.

To respond to the challenge of monitoring the nexus of land and the environment, the primary focus lays on farming practices that contribute to reaching climate goals, to foster sustainable management of natural resources, and to protect biodiversity and the landscape. The work carried out has focused on the identification of the elements of these practices that should be extracted and documented to allow monitoring them.

Monitoring a farming practice entail observing the status of land cover within the unit or plot of agricultural management and any observable changes resulted from the use of the land by the farmers (as tillage, ploughing, leaving green cover on the soil, etc). Being the observed (bio) physical cover on the Earth's surface, land cover is the easiest detectable indicator of human interventions on the land and the main biophysical phenomenon constraining the use of land. Land use, in other hand, could be considered as the arrangements, activities and inputs people undertake in a certain land cover type to maintain it or produce change. Multiple land uses can coexist on the same land cover. For example, a grassland parcel (land cover) might be ploughed, harvested, mowed (three possible land uses, among many others). Standardization of the land cover/land use semantics and classification systems and elaborating the link with the visible biophysical phenomena are an essential part of the work done in the last two years.

The conceptual framework and approaches elaborated are applied and discussed in four case studies implemented in the last two years and described in this report. Each case study can be regarded as a standalone elaboration of an element of the overall framework and illustrates how the conceptual framework could be instantiated to support real world solutions. The findings show how new technologies have the potential to change the game by enabling the design of parcel- or farm-based policy measures that can be effectively monitored and therefore improve the results of the policy in environmental and climate terms. The report is addressed to stakeholders of the CAP and in particular to the ones dealing with the design and implementation of the CAP (Ministries and Paying Agencies of the Member States as well as Commission Services for Agriculture). Anyway, for the relevance of methodologies in dealing with practices with environmental and climate impacts, the report is also addressed to stakeholders generally dealing with environment and climate topics (Ministries for Environment and Climate as well as Commission Services of DG CLIMA and DG ENV).

Foreword

This report compiles the activity reports and other outcomes of the GTCAP activities on the CAP Green Infrastructure aspects to address the JRC project browser deliverable 2022, which covers two years of activities (2021 and 2022). As an overall compilation, it holds outputs from activities and some material has been reported in project reports. The work presented in this report results from the joint efforts of the GTCAP team, including its officials, contractual agents and external contractors, working on green infrastructure related items. The report has been edited by Wim DEVOS and Hakki Emrah ERDOGAN.

This report also embodies a fifth entry in an annual GTCAP reporting cycle that started in 2018; the earlier reports are:

2018: JRC115379 (IACS) and JRC115565 (CbM launch)
2019: JRC119236
2020: JRC123488
2021: JRC128255

Acknowledgements

The work presented in this report results from the joint efforts of the GTCAP team, including its officials, contractual agents and external contractors, working on green infrastructure related items. The report has been edited by Wim DEVOS and Hakki Emrah ERDOGAN.

Contributors to the different chapters are reported in the table below

(Sub) Chapter	Lead Author(s)	Contributing actors
Introduction	Vincenzo ANGILERI, Emrah Hakki ERDOGAN	Pavel MILENOV
Current development on the monitoring of the nexus of land and the environment	Vincenzo ANGILERI, Emrah Hakki ERDOGAN	Pavel MILENOV
The approach to monitor farm practices	Vincenzo ANGILERI	
The approach towards land characterization	Pavel MILENOV	Wim DEVOS, Philippe LOUDJANI
Documenting agricultural land monitoring approaches	Pavel MILENOV	Aleksandra SIMA, Rafal ZIELINSKI
Analysis of CAP interventions linking bird needs and agriculture farming practices with a focus on the Polish CAP strategic plan	Miłosz REMBOWSKI (trainee in GTCAP), Vincenzo ANGILERI, Carolina PUERTA-PINERO	Irene GUERRERO FERNANDEZ (AGRIENV team), Fernando SEDANO, Ferdinando URBANO Martin CLAVERIE (MARS4Cast team) , Stefan NIEMEYER (MARS4Cast team) , Jacopo CERRANI (MARS4Cast team)
Designing a “green cover” scenario in CbM and setting up of relevant markers	Pavel MILENOV	Rafal ZIELINSKI, Aleksandra SIMA
Application of tegon and LCML for semantic description of complex land cover types, and associated land uses – the experience of SEPLA project	Pavel MILENOV	Emanuele LUGATO, Aleksandra SIMA, Carolina PUERTA-PINERO, Vincenzo ANGILERI
Monitoring of land cover and land use in NATURA 2000 designated areas	Pavel MILENOV	Vincenzo ANGILERI, Ferdinando URBANO
Outlook, Challenges, and Opportunities	Wim DEVOS, Vincenzo ANGILERI, Pavel MILENOV, Emrah Hakki ERDOGAN	Carolina PUERTA-PINERO

1 INTRODUCTION

The European Green Deal (EGD) aims to boost the efficient use of resources, to restore biodiversity, and to cut pollution for agriculture and environment, (EC, 2019). In this context, the European Commission (EC) also proposed a nature restoration law to restore ecosystems for people, the climate and the planet, (The EU #NatureRestoration Law (europa.eu). This proposal establishes legally binding European Union (EU) nature restoration targets as a key element of the biodiversity strategy. Restoring the EU's ecosystems will help to increase biodiversity, mitigate, adapt to climate change, and prevent and reduce the impacts of natural disasters.

These strategies and policies have a considerable influence on the EU Common Agricultural Policy (EU CAP), which, by its budget, remains one of the main instruments for delivering these reforms. To this end, it has become crucial to monitor the farming practices that affect the environment. Farming practices could be viewed as the sequence of activities which the farmers undertake on their land to obtain an output in the context of a given ecosystem service.

Over the last quarter-century, the Joint Research Centre (JRC)'s Geodata and Technologies for the Common Agricultural Policy (GTCAP) team has developed CAP control methodologies and has been called upon to support innovative technologies for the CAP. Significant co-delegation and administrative agreements established with Directorate-General for Agriculture and Rural Development of the European Commission (DG AGRI) formalize the close partnership in this field. During the years covered by this report, GTCAP's research and development work principally focused on the activities that correspond to the two recommendations in the special report 04/2020 of the European Court of Auditors (ECA):

1. Promote the checks by monitoring approach as a key control system for paying agencies.

2. Make better use of new technologies for monitoring environmental and climate requirements.

In general, GTCAP undertakes research and innovation activities to acquire knowledge and develop feasible methodologies relevant to the various interrelated schemes of the CAP under the new CAP's delivery model that shifted from compliance to performance. An innovative solution relies on the monitoring of the nexus of land, environment, and climate change by using the Copernicus Earth Observation (EO). Through the monitoring of the area-based components of the Integrated Administration and Control System, it is possible to follow up the implementation of the basic income payments, conditionality, eco-schemes, and relevant agri-environment-climate commitments.

Accordingly, the GTCAP's 2021-2022 work plan: (1) addressed the technical challenges of the future Area Monitoring System (AMS) which is the regular and systematic observation, tracking and assessment of agricultural activities and practices on agricultural areas by satellite data; (2) planned research into the higher delivery of performance (with respect to farming practices with effects on environment and climate) -the core driver behind this report-; and (3) foresaw the development of methods that facilitate the increased uptake of space- and airborne remote sensing and terrestrial remote sensing (geotagged photos, unmanned aerial vehicles) to (4) achieve data interoperability with other systems and domains. Land observation methods, based on remote sensing, play a significant role in helping the domain-related conceptualization (Comber et al., 2005), characterization, identification, registration, and quantification of the many types of agricultural land and of the set of agricultural practices that are part of the GTCAP's research activities.

In 2021, GTCAP also started the "Satellite-based mapping and monitoring of European peatland and wetland for LULUCF and agriculture" (SEPLA) project in collaboration with Directorate-General for Climate Action of the European Commission (DG CLIMA), to extend the development of novel methodologies and techniques in monitoring and reporting of areas of high relevance to climate and environment, under both the CAP and the Land Use, Land Use Change and Forestry (LULUCF) legal frameworks.

The GTCAP-Green Infrastructure activities have been principally focused on the ECA recommendation to employ cutting-edge technology more effectively for monitoring environmental and climate requirements. The scope of this recommendation extends well beyond the traditional activity domain of GTCAP of controlling the occurrence of eligible agricultural activity. For novel monitoring of performance, GTCAP had developed the parcel-based check by monitoring approach.

Whereas DG AGRI applies a wider concept of policy monitoring, which emphasizes the Performance Monitoring and Evaluation Framework (PMEF), the GTCAP-Green Infrastructure activities aimed to strengthen the aspects of environmental and climate performance by compiling and analysing farm-level support schemes to:

— Develop methodologies to identify and supervise farming practices that deliver environmental and climate performance.

— Compile technical and scientific tools to facilitate the uptake of new parcel-based monitoring technologies on these farming practices.

The reported activities and findings on Green Infrastructure over the years 2021 and 2022 highlight how these methodologies can be successfully applied by the Member States in monitoring some practices and requirements contained in the interventions planned in the CAP strategic plans for the period 2023-2027. Furthermore, they show how new technologies have the potential “as game-changer" by enabling the design of parcel- or farm-based policy measures that can be monitored.

For its contents, the report is addressed to stakeholders of the CAP and in particular to the ones dealing with the design and implementation of the CAP (Ministries and Paying Agencies of the Member States as well as Commission Services for Agriculture). Anyway, for the relevance of methodologies in dealing with practices with environmental and climate impacts, the report is also addressed to stakeholders generally dealing with environment and climate topics (Ministries for Environment and Climate as well as Commission Services of DG CLIMA and DG ENV).

2 CURRENT DEVELOPMENT ON THE MONITORING OF THE NEXUS OF LAND AND THE ENVIRONMENT

Land is positioned at the intersection of significant socioeconomic and environmental issues, addressing challenges of food security and economic stability, eliminating poverty, access to water, preventing biodiversity loss, and climate change, among others (Bremond A, 2021). In addition, with rising demands on agricultural production to support more people with healthy diets, land itself plays an increasingly significant role in sustaining a broader range of services, such as flood control, water purification, cultural values, sequestering carbon emissions in vegetation and soils; and in protecting biodiversity (Daz et al. 2019). Land and carbon cycles are also strongly connected. Land contributes directly and indirectly to the amount of carbon stored within landscapes (e.g., in soils, forests, and wetlands) and greenhouse gas emissions from those stores. Human interventions in land resource management affect both carbon sequestration and emissions through shifting natural processes in the ecosystem. In this sense, the nexus between land and environment gives insight into the effects of land use actions.

This nexus was recognized in the EGD and the new CAP. In this process, the monitoring of how agricultural practices affect the environment has gained critical importance. Therefore, the GTCAP's green Infrastructure activities focused on activities exploring the nexus of land and environment. The new delivery model, central to the reformed CAP and the abovementioned ECA recommendations, represented the main drivers for the activities over the last two years (2021-2022).

To respond to the challenge of monitoring the nexus of land and environment, the primary focus lays on farming practices that contribute to reaching climate goals, to fostering sustainable management of natural resources, and to protecting biodiversity and the landscape. Dedicated analyses were performed to identify the farming practices proposed by Member States (MS) in their CAP strategic plans to target the specific objectives related to climate and environment. This work has focused on the identification of the elements of proposed practices that should be extracted and documented and to allow monitoring them.

Monitoring an agricultural (or farming) practice means monitoring the land cover within the unit or plot of agricultural management and any observable changes resulted by the annual land use. Although the terms land cover and land use are often used interchangeably, their actual meanings are quite distinct. Land cover is the observable (bio) physical cover on the Earth's surface, such as vegetation, artificial sealed surface, water, bare soil, etc. It is the easiest detectable indicator of human interventions on the land and the main biophysical phenomenon constraining the use of land. Land use, in other hand, could be considered as the arrangements, activities and inputs people undertake in a certain land cover type to maintain it or produce change (ISO/CD 19144-2, 3.1.17). It also represents the purpose the land serves; for example, recreation, wildlife habitat, or agriculture. Multiple land uses can coexist on the same land cover. In agricultural context, this means that a farming practice exerted on given land, could produce an output in terms of agricultural product, while at the same time maintain and preserve the environment. These two concepts are inherently interlinked, and their understanding evolves together with the development of the observation methods and the widespread use of remote sensing technologies. Standardization of the land cover/land use semantics and classification systems and elaborating the link with the visible biophysical phenomena are an essential part of that work.

The framework within which the green infrastructure activities operate, is consistent with the set of concepts defined in the Check by Monitoring approach and follows the three "universes of discourse" (UoD) (Devos et al., 2021) that are illustrated in Figure 1. The first UoD refers to the land-use practices in their natural environment. It deals with aspects of human activity on a unit of land and the way this land use influences and changes the biophysical characteristics of its land cover. We refer to this UoD every time when we mention activity on land, land management practice, land management unit, land phenomenon, or bio-physical characteristics. The second UoD relates to the processing of observation data and deals with the way the activities on land are captured and reflected through the observation methods sourced by terrestrial, aerial or spaceborne sensors (the so-called data processing). The third UoD relates to the information need of the end users. This varies over policies and typically involves policy measures; new CAP's Eco- schemes; and corresponding rules.

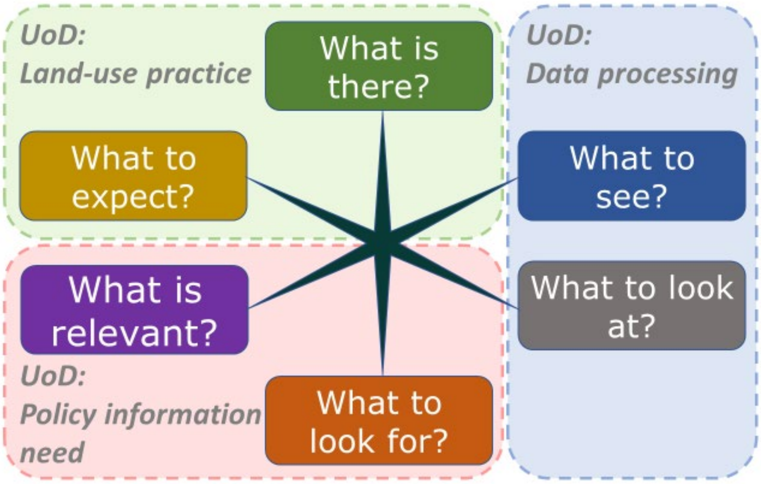

Figure 1. Simplified and adapted representation of the Checks by Monitoring conceptual framework and its three universes of discourse (UoD).

During the last two years, four case studies were implemented. Each case can be regarded as a standalone elaboration of an element of the overall framework and illustrates how the conceptual framework could be instantiated to support real world solutions. The game changing potential of the appplied new technologies is that they enable the design of parcel or farm-based policy measures. These cases hint at how this could be achieved.

A first case study screened the CAP Strategic Plan of Poland to assess the interactions of agriculture management and birds. The CAP interventions with potential effects on the birds were identified, and their monitorability through EO using remote sensing (RS) with the satellites Sentinel 1 (S1) and Sentinel 2 (S2) was discussed. (Check Section 3. 1 for further details). It focuses on the UoD of information need of end users and in particular, on the content of the CAP strategic plan in relation to biodiversity. It also touches the UoD of farming practices, with a focus on the associated observable activities that could have effect on birds.

A second case study concentrated on green cover, as one of the most frequent "land cover option" to meet the requirement for ecological focus area (EFA). It relates to practices with an effect on the environment and climate (according to the CbM outreach outcomes). In this case study, a "green cover" scenario was elaborated in a CbM-context, and relevant markers were set up (see Section 3. 2 for further details). This case covers the two UoD of land-use practices and processing of observation data.

A third case study developed the technical framework, based on the revised Land Cover Meta Language - LCML (ISO 19144-2), for semantic description of complex land cover types, such as agroforestry and peatlands under agricultural management. The peatland semantic mapping was conducted considering the results of the SEPLA project (Satellite-based mapping and monitoring of European peatland and wetland for LULUCF and agriculture), from the last two years. The main objective of the SEPLA project, carried out in collaboration with DG CLIMA and technical experts of 10 paying agencies, is to ensure a comprehensive inventory of wetlands and peatlands and to address the monitoring of their preservation and restoration. The project is not fully described in this report as specific deliverables were already published. (see Section 3. 3 for further details). This case study covers the UoD of land-use practices with a focus on land phenomenon and its bio-physical characteristics.

The fourth case study explained the monitoring the status of the grassland-dominant NATURE 2000 sites; see Section 3. 4 for further details). This case covers the complete framework with the three UoD; the user information needs are derived from the biodiversity policy.

2.1 The approach to monitor farming practices

For activities related to the Green Infrastructure, three specific objectives (SO) of the CAP are relevant:

— SO4- contributes to climate change mitigation and adaptation, as well as sustainable energy,

— SO5- foster sustainable development and efficient management of natural resources such as water, soil and air and

— SO6- contributes to the protection of biodiversity, enhances ecosystem services, and preserves habitats and landscapes.

In the new delivery model of the CAP, Member States have the flexibility to define what is needed at the national level to fulfil these specific objectives. This is done in setting the intervention logic of their CAP strategic plan. To contribute towards environmental and climate targets, farming practices proposed in the CAP strategic plan should have a positive impact on different climate and environmental issues related to the result indicators associated with the specific objectives (schematically shown in Figure 2).

By providing this link, the CAP strategic plan becomes the heart of this new delivery model where MS design the interventions, define the eligibility conditions of the interventions and establish the compliance framework for beneficiaries (Figure 2).

Each intervention requires one or more farming practices. These farming practices are specified in the interventions of the CAP strategic plans and correspond to one of three levels: conditionality, eco-scheme or agri-environmental and climate commitments.

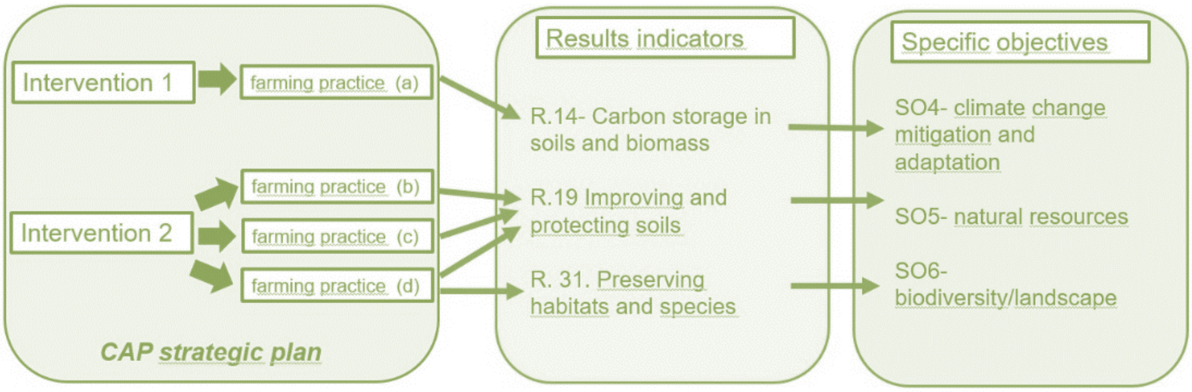

Figure 2. The link between interventions, result indicators and specific objectives of the CAP related to climate and environment.

For instance, an intervention may contain a farming practice that can contribute to the result indicator (R) "R.14- Carbon storage in soils and biomass" and therefore to specific objective SO4- climate change mitigation and adaptation (Figure 2)

A particular intervention may contribute to several result indicators at once, provided the link is direct and intervention is significant. For instance, intervention 1 (in Figure 2) can specifically support organic fertilization; Intervention 2 can be a broader intervention for improving both biodiversity and soil quality, supporting three specific practices: a) tillage along contours to avoid erosion, b) creation of furrows to avoid erosion, and c) soil cover in permanent crops.

To use innovative technologies and apply the existing CbM concepts and approach, practices related to the environment and climate should be described and documented, to ensure that they can be detected. This defines the CbM catalogue.

A specific work has been carried out to identify which elements of a farm practice, essential for their effective monitoring, should be extracted and used in the documentation of the farming practices. For instance, Table 1 illustrates the requirements that one can find in the description of a ubiquitous eco-scheme dealing with non-productive areas. This builds upon the new Good Agricultural and Environmental Conditions (GAEC) 8 on the share of unproductive areas and features. The examples in the table were extracted from the draft strategic plans of Italy, Luxembourg, and Lithuania, which hold an eco-scheme on this topic.

Table 1. The criteria in a common eco-scheme for non-productive areas and strips

land category	*geometry*	*location*	*land cover/land use*	*activity/timing*
arable	area		melliferous mixture (annual/perennial)	mowing mulching from i.e. 15th July
	strips (width: 3-30 m)	field borders	spontaneous vegetation (annual/perennial)	
		anti-erosion strips		
		along forest edge	melliferous mixture (annual/perennial)	
		along water courses		
grassland	area		(non-productive) grassland	mowing mulching (from i.e. 15th July/1st september) grazing prohibited in certain periods
	strips (width: 3-30 m)	field borders		
		along forest edge		
		along water courses		
permanent crops	inter-row		spontaneous vegetation sown grassland melliferous mixture	mowing mulching from i.e. 15th July
	outside vertical projection of the crown			

The table separates the description of the requirements according to land category, geometry, location, land cover/land use, and activity/timing that one can find in the eco-schemes of the three Member States. The scope of this separation is to identify the qualifying conditions of the intervention according to the CbM concepts.

As the analysis of the CAP strategic plans of these three countries revealed, requirements can be applied on arable land, grassland, and permanent crops (land categories). Regarding the "geometry" of the land on which the requirement can be implemented, the following options are possible: area, strips (with a width that can vary from 3 m to 30 m according to the different interventions designed by the three member states), inter-rows or areas located outside the vertical projection of the crown (generally in olive tree plantations). In some cases, these areas should be on specific locations within the farm: e.g. field borders, anti-erosion strips, along forest edges, and along watercourses. Specific land use/land cover types can be requested on the areas where these requirements apply for spontaneous vegetation or a melliferous mixture in arable land or grassland where it suffices that the land is non-productive. In permanent crops, a further requirement can be sowing grassland. It is quite common, also in many interventions other than this eco-scheme, that the farmer shall/shall not accomplish some activities, sometimes in specific periods. In the case of this eco-scheme, activities such as mulching and mowing should be accomplished only in some periods, and grazing should be forbidden in certain periods.

The detailed description of the requirement is fundamental to apply the CbM concepts.

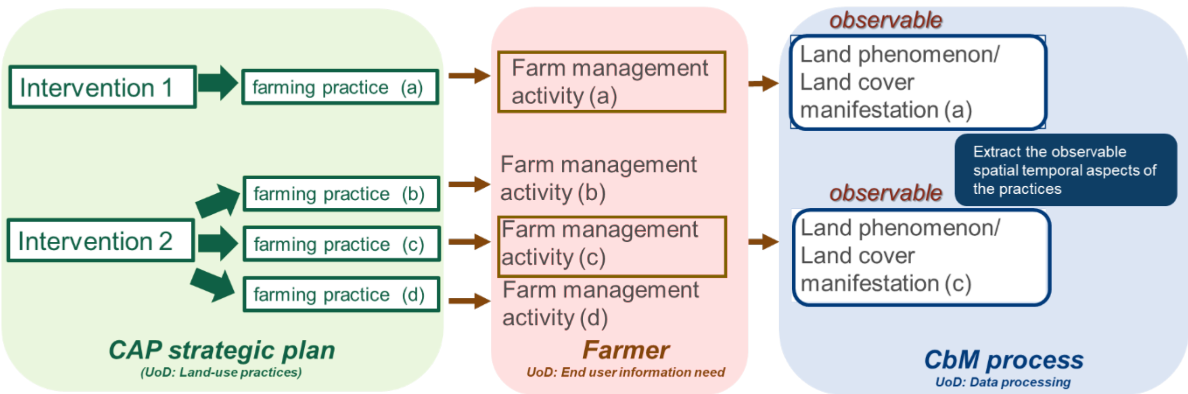

Figure 3. The relationship between CAP strategic plan content, farming practices, and the CbM process. The background colours match those of figure 1..

Figure 3 shows the link between the content of the CAP strategic plan, farmers' practices and the CbM process. The CbM looks for the land phenomenon and the land cover manifestation associated with the farming practices by extracting the spatial temporal aspects of the management activities involved.

Those practices that leave visible evidence on the ground are considered CbM-monitorable. This evidence records the manifestation of anticipated land cover conditions (revealed by an observable physical phenomenon), which were associated with the activities expected for the given practice. The type of observation method and associated source data play an essential role. In the CbM context, not only satellite data as Sentinel, but also those coming from geo-tagged photos (digital photographs with spatial information) of land cover and farming practices are a valid source (Sima et al., 2020). For a CbM-monitorable practice, it is safe to assume that when there is no visible land manifestation, there is little, or no impact on the environment either.

This monitoring framework is currently dealing with several farm practices that have a substantial effect on climate and the environment. Farm practices such as conversion-ploughing of permanent grassland, presence/absence of green cover, crop rotation, ban of burning arable stubble and mowing grassland were identified within CbM implementation and outreach initiatives with EU Member States. However, not all farming practices for the environment and climate have been considered in the methodologies.

The main activities to be carried out for those practices that were considered are:

- Identify, analyse, and describe the physical phenomena behind selected practices

- Define and develop a proof-of-concept for capturing the physical phenomena defined by applying observation methods

Under an Administrative Arrangement between DG AGRI and JRC (IMAP), JRC is finalising a classification scheme to be used on all farming practices contained in the interventions in all CAP strategic plans. Using this classification, it will be possible to inventory the farming practices implemented by the Member States in the CAP strategic plans and document their CbM potential.

The diversity of farming practices implemented by the MSs is wide. The above classification scheme, still in development, is organized in three tiers according to the level of detail in the description of the farming practice. In order to facilitate the use of the classification, all the practices are grouped by topics such as soil management, landscape, water. Tier 1 contains 44 broad classes of farming practices such as, for example, tillage, soil cover, water management practices. More detailed definitions of the practices are described in tier 2 (with 154 classes) and tier 3 (with 136 classes). This gives an idea of the broad spectrum of farm practices that one can find in the interventions of the CAP strategic plans.

Table 2. Extract of the classification scheme of farming practices for soil management

SECTION	*Farming practices Tier 1*	*Farming practices Tier 2*	*Farming practices Tier 3*
Soil management	Tillage	Low tillage	
		No tillage	
		Restriction on tillage (timing, direction in slopes..)	
	Soil cover	Mulching	
		Crop residues left on soil, leaving stubbles on the field	
		Cover crops	summer cover crop
			winter cover crop
		No burning of crop residues	
		Green cover on permanent crops	
	Machinery use	Restricted machinery usage (including timing) to avoid soil compaction	
	Other practices to combat erosion		

2.2 The approach towards land characterization

The 3 – dimensional nature of land cover (LC) implies that it is an obvious result of human activities and the major factor constraining land use (Figure 4). LC mapping still relies on traditional cartography-based two-dimensional (2-D) mapping methods, despite the evolution of sensors, information retrieval tools, and classifications. Innovations concentrate on image processing optimization and spatial (cartographic) object representation. Most mapping initiatives and harmonization efforts aim to describe reality by monitoring a set of characteristics in predetermined and not overlapping mapping primitives (mostly polygons or tessellations), rather than to directly reflect the physical three-dimensional (3-D) character of ground features. Inventories are based on a few satellite or aerial images with certain spatial, spectral, and radiometric characteristics. The field of application and territorial coverage of the land cover product, as well as the domain-specific conceptualization of the targeted biophysical phenomena define the selection of observable characteristics and their interpretation. This leads to three issues: 1) Poor semantic incompatibility 2. Insufficient description of the biophysical phenomena 3. Incomplete descriptions of the behaviour of a biophysical phenomenon.

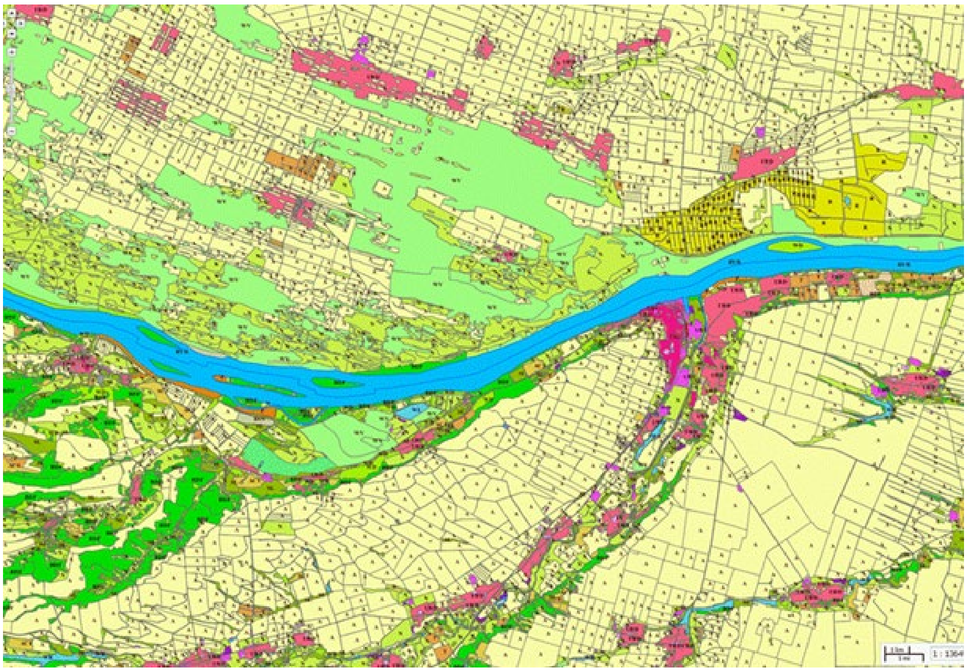

Figure 4. Extract of the common reference land cover dataset of the cross-border area between Bulgaria and Romania, used as the basis for territorial planning and development (ETC 171 project SPATIAL), https://www.cbc171.asde-bg.org/index_en.php)

A discrete tessellation is traditionally used to model the spatiotemporal aspect of biophysical phenomena over a surface on the Earth. Constrained by the cartographic size and specifications of the land cover classification system, the geometric objects of LC products often do not directly reflect a physical feature on the ground. To cope with this weakness, the semantics of the Land Cover Meta Language (LCML) (ISO 19144-2) are applied at the level of the physical features by, introducing an elementary physical body (tegon) that is intimately tied to the soil physical body (pedon).

During the revision of LCML-ISO 19114-2 and the preparation for the Land Use Meta Language (LUML)-ISO 19144-3, GTCAP contributed with its research results in the field of land cover definition and categorization, which launched the concept of a 3-dimensional physical elementary unit (tegon see box). This GTCAP input to the ISO LCML standard enlarged its capabilities for describing the vertical relationship between land cover components and closed the conceptual gap that existed between information gathered by different observation perspectives and by different data capturing methods. The introduction brought LCML in line with other European approaches in land cover and land use, such as EIONET Action Group on Land monitoring in Europe (EAGLE) or Copernicus Land Services and enabled a link between land cover, land use and ecosystem services at various degrees of data aggregation.

BOX 1 – TEGON APPROACH

A tegon is defined as a three-dimensional elementary biophysical entity that acts as a building block of any material or substrate on the Earth's surface. Tegon layers (strata) interchange material and energy with each other, with the atmosphere above, and with the soil below (Devos and Milenov, 2012). Any such building block can be represented as an n-gonal prism enclosing a nongaseous substrate with uniform biophysical and life cycle characteristics in horizontal directionsThe word "tegon" comes from Latin "to cover," tegere, tego, and tectus. The tegon, like the pedon in soil science, is the smallest measurable body that offers information on the land cover's nature and genesis and allows analysis of the layers (strata) and their relationships (Schaetzl, 2013). Tegon is considered horizontally homogenous with a life cycle and a spatial size of one to several square meters. They have one or more vertical levels (strata) of biotic or abiotic materials and a specific outer appearance. Tegons, such as pedons for soil classes, are the basic physical components of every mapping unit or class in a land cover nomenclature. Each land cover feature is considered a "polytegon" composed of a continuous sequence of such tegons. In homogenous land cover, all tegons have the same biophysical characteristics. Heterogeneous land cover is a "mosaic" of tegons with varied traits, divided into separate tegon types (Figure 5).

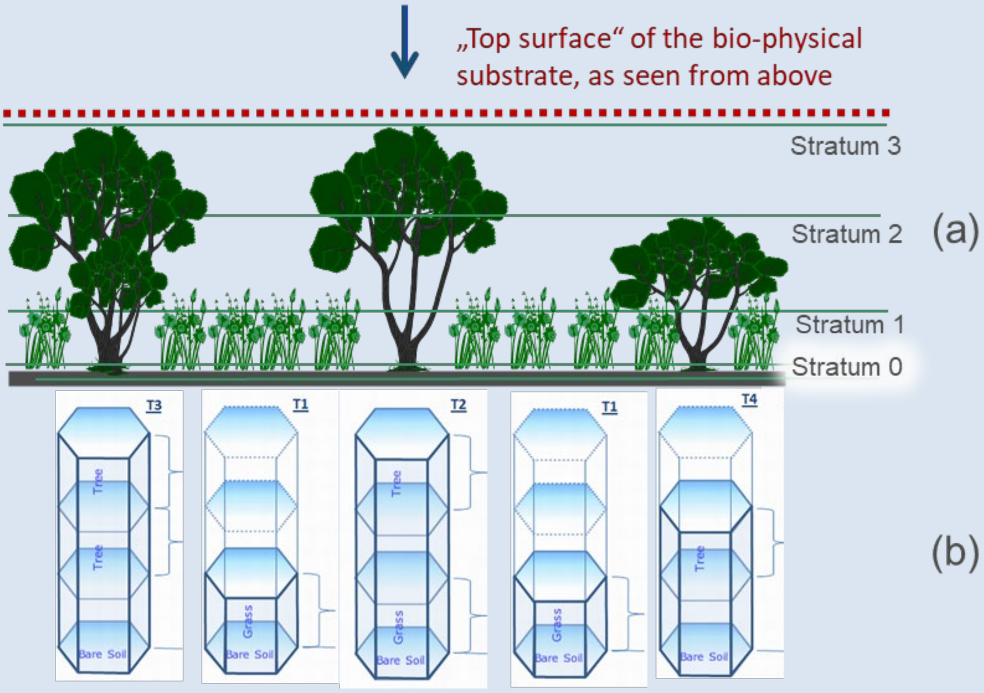

Figure 5 Theoretical illustration of the way in which a land cover feature can be modelled with tegons. (a) Physical features with variations in the spatial arrangement of material (source: "Land Cover Classification System-Classification concepts and user manual", FAO - UN, 2005) (b) The corresponding types of tegons with different numbers of strata and distributions of material in them.

A comprehensive set of tegon types could characterize every LC class. The class is a taxonomic unit associated with physical features with similar characteristics, which may be structurally represented by the mechanism of the tegon using an appropriate ontology such as the LCML (Figure 6). Land cover features cannot be smaller than the smallest tegon that builds it. A land cover feature's boundaries include all its tegons and extend to the point of contact with tegons of another feature (usually assigned to another class).

Tegon is spatially homogenous in terms of material, appearance, and life cycles. This means that although the density of its material cover may differ over its "footprint," its core biotic or abiotic aspects are uniform. An observable land cover feature can be composed either entirely of tegons of one type or of tegons of more than one type. Intensively sown pastures are examples of the former, while pastures with shrubs are examples of the latter. This association of different tegon types is functionally homogenous. Two or more intrinsically mixed tegon types form a new entity with unique functional (land use and ecosystem service) characteristics. Such polytegons are biophysically composite but functionally homogeneous (Figure 6). The composition tegons are specific and fixed to the land cover class describing the physical feature.

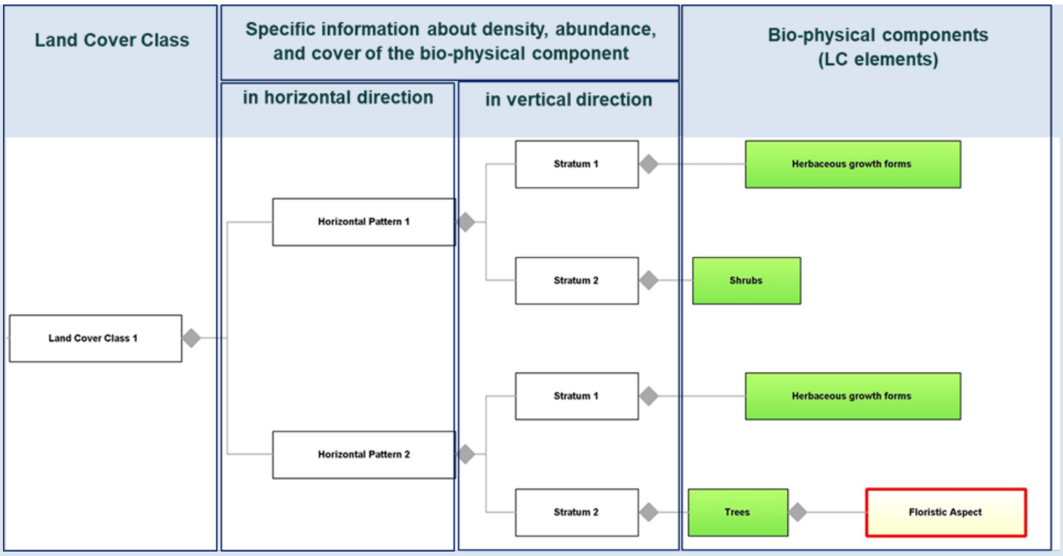

Figure 6. Structure of the LCML produced with FAO LCCS 3 software and based on the Unified Modelling Language (UML).

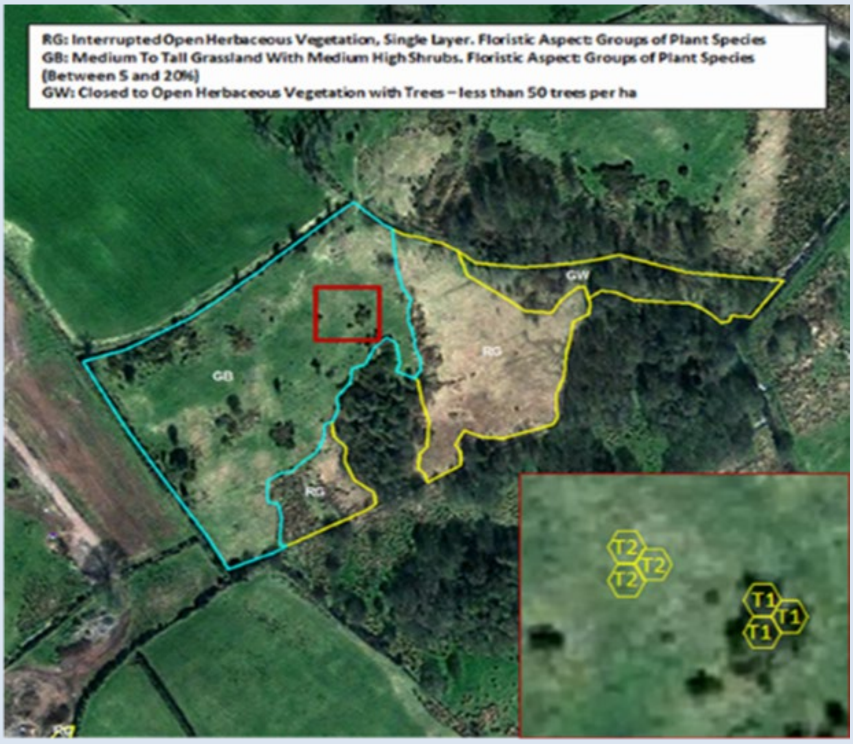

Figure 7. The geographic feature classified as GB is an example of a specific type of natural grassland used as pasture in Northern Ireland. It is a typical mixture of grasses and shrubs. The GB class can be represented as an association of two types of tegons, with a certain percentage ratio between them (the figure includes materials from © DigitalGlobe (2010), all rights reserved).

Figure 7 represents a set of semantic objects and rules (meta-language) for describing the properties and characteristics of the land cover and the respective classes used in different nomenclatures and classifications. The key elements of the model are (1) LC_Horizontal Pattern – objects describing the spatial distribution of the different land cover elements constituting the land cover class; (2) LC_Stratum – objects describing the vertical distribution of the different land cover elements constituting the land cover class; and (3) LC_Elements - metalanguage objects representing the basic and optional components of the phenomenon, described by the land cover class.

2.2.1 Operationalization of tegon concept through the international standards on geographic information

The inclusion of the "tegon" concept in the revised version of the LCML-ISO19144-2 is made through the Unified Modeling Language (UML) object structure class "LC_Horizontal Pattern". This realization allows stacking LC_Stratum objects, each consisting of a single or a group of LC_Elements into one or more horizontal pattern(s). The horizontal pattern is useful when a complex description of land cover features is needed. This is the case when a land feature is composed, in horizontal direction, of two or more distinct land cover components (elements as defined in the LCML) that are handled or perceived as a "unicum" or single polytegon instance, independent from scale constraints.

The term "unicum" thus designates a heterogeneous set of land cover elements integrated into an intrinsic mix, which is functionally homogeneous and should always be treated as a single entity in any land cover mapping/monitoring process. Typical examples of such an intrinsic mix are the agroforestry systems in Spain (dehesas) and Portugal (montado), as well as the wet grasslands with scrub and upland heather grasslands in Ireland. The main component, in these cases, is the grass, but the "character and behaviour" of the grassland is determined by the presence of scattered trees and shrubs respectively. The LC_Horizontal Pattern class permits to express relationships such as "grass under trees" (as dealt by the polytegon, defined in the tegon concept) through horizontal patterns that involve two or more strata with a distinct vertical relationship. An example with two strata, one containing trees and one containing grasses, is shown in Figure 8. The stratum representing grass can be derived from combining two tegon types, one representing grass under trees and the other plain grass.

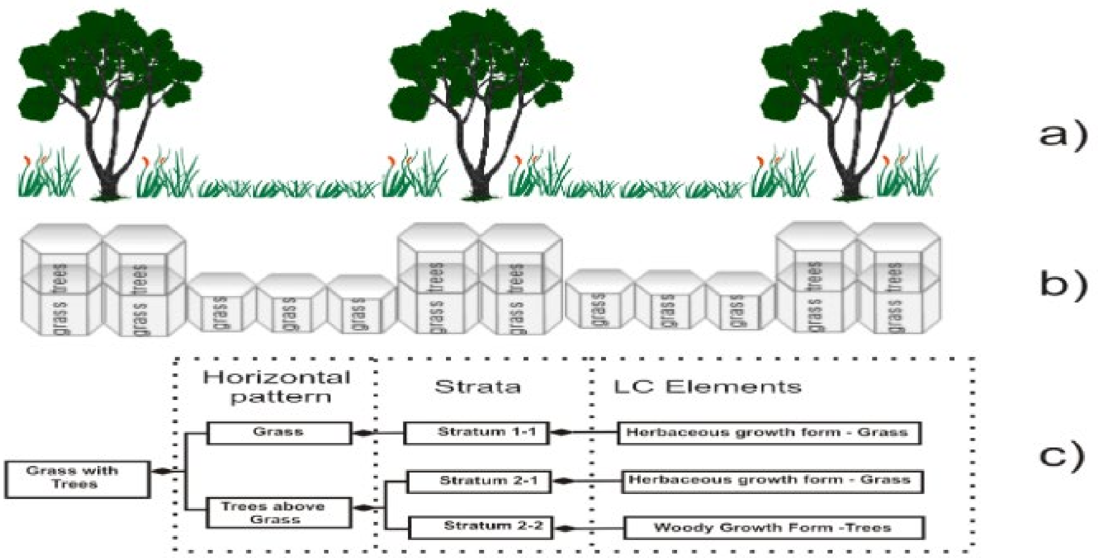

Figure 8. Use of horizontal pattern and strata in agro-forestry. (a) Grass with scattered patches of trees. The portion of the grass beneath the trees has different plant compositions and characteristics (density, height). (b) Grass with trees and grass without trees are treated as separate physical features composed of 3-dimensional elementary features (tegons). Grass under the trees has different height, since tree canopy enhances the vigour of the herbaceous layer. This results in an intrinsic (functional entity) mix between two types of land cover features having different strata; (c) it is described in LCML with the "horizontal pattern".

The analysis of the proposed LCML revision, made on the number of real use cases (Milenov, 2022) showed the following more specific advantages of the tegon:

— **It offers a better handling of the complexity of the land cover classes in a given nomenclature.** Since the biotic/abiotic nature of the material no longer applies to the class as a whole, but to the stratum, the resulting classes, based on the tegon concept, will better reflect the true three-dimensional nature of the land cover.

— **Solutions become based on purely biophysical criteria.** This allows for a clearer separation of the notions of land cover and land use. In such a way, land cover features of key importance, such as "wetlands", will be adequately described in terms of their biophysical nature, which will allow for their effective observation from space.

— **The conceptual basis is similar to that of the soil classification methodology.** The land cover substrate is a key factor in the formation of soil horizons, and the analogy with pedons (Johnson 1962) supports this relationship.

The LCML ontology becomes structured in a way that it can be used for description of any individual physical three-dimensional feature. At the same time, it ensures that the concept is compatible with the cartography-based land cover mapping processes.

The LCML, enriched with the tegon, provides a universal basis for observing land cover changes. Approaching land cover from the point of view of its stable biophysical characteristics and beyond the limitations of the rather volatile observation methods, tegon will improve the technical framework for monitoring land cover in agricultural areas.

2.3 Documenting agricultural land monitoring approaches

During the CbM outreach initiative, a project to collect monitoring challenges and field data with 17 volunteering paying agencies, the GTCAP team designed a structured template for documenting agricultural land monitoring systems. It emphasises monitorable farming practices, from a conceptual and use case point of view. It initially served a transparent, systematic and structured documentation of the key elements of agricultural land monitoring systems, which is required for information exchanges between different stakeholders (Devos et al., 2021). The modular design of the template allows for selective usage of sections. Therefore only the strictly necessary part of the system needs to be documented. Several, but not all, sections of this template have been successfully used for information exchange. The feedback collected from the project stakeholders acknowledged the feasibility of the proposed approach and was taken on board.

The design of the structure and the information elements (Figure 9) within the template complies with the latest developments in the standardized ontologies for land cover and land use, such as the revised LCML ISO 19144-2 and the future LCML ISO 19144-3. It also considers the recent standardization efforts by the Open Geospatial Consortium [1] and International Organization for Standardization [2] (19156 and 19157) on collection and quality checks of EO-based data. Nevertheless, the template remains generic enough to be applicable for any type of sensor and observation method (aerial survey, geotagged photos) in any land monitoring domain (environment, climate, territorial development).

Any paying agency responsible for a CbM implementation must communicate with CAP stakeholders and EU administration bodies, but such systematic description of a land monitoring system may also help other system designers to learn about the information flow and recover elements from documented systems. All relevant documentation is being provided on: https://marswiki.jrc.ec.europa.eu/wikicap/index.php/Main_Page.

In the specific case of CbM of CAP direct payments, the data processing mostly relies on data provided by Copernicus Sentinel-1 and Sentinel-2, and this is reflected in the current version of the template. A revision of template can easily address the inclusion of documentation on other data sources (i.e., geotagged photos, machinery tracks, etc.) and processing loops used in the monitoring process. The structured template is published as a separate technical report (JRC130662).

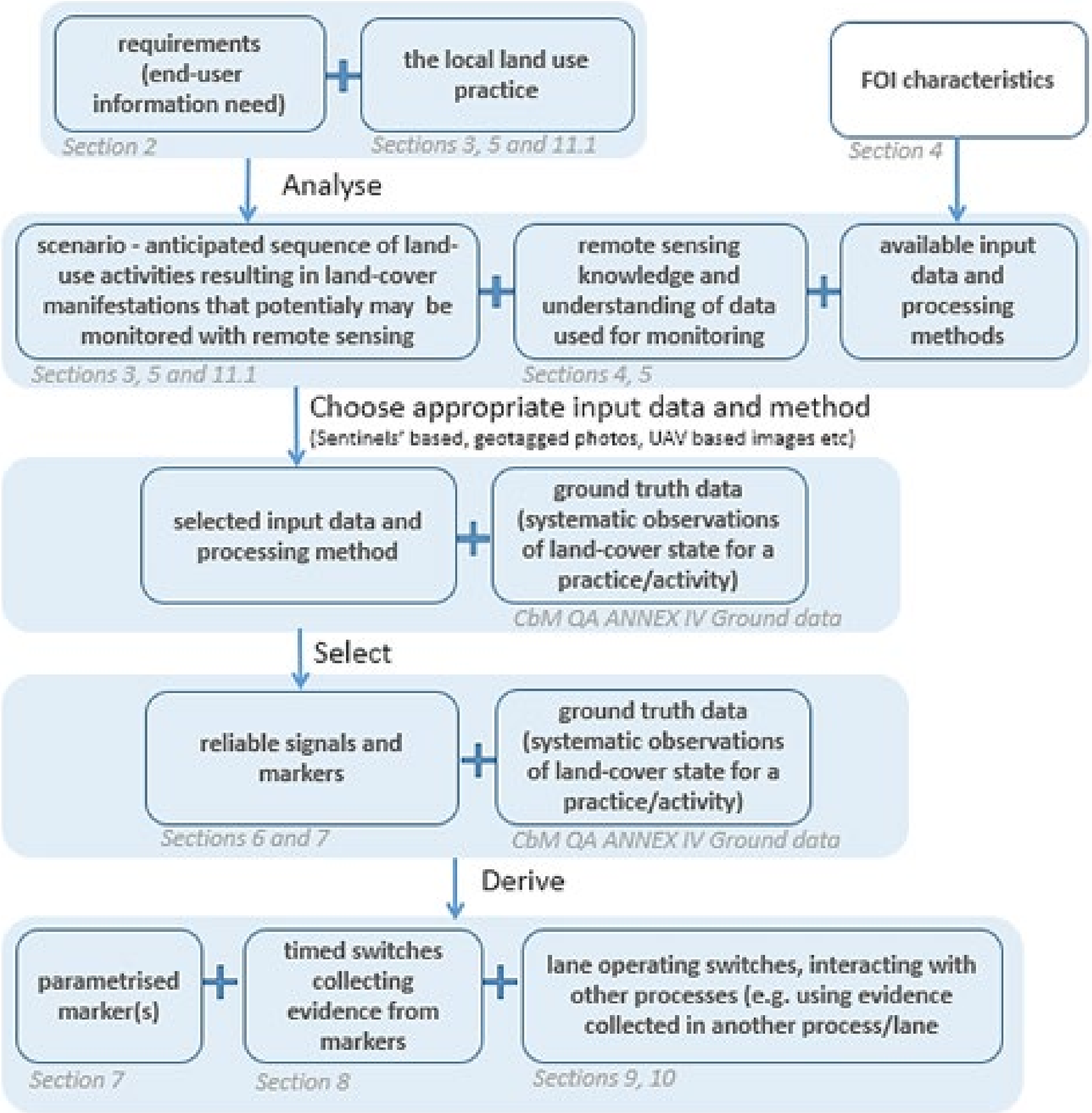

Figure 9. Workflow of land monitoring system design following the basic CbM concepts (Devos et al., 2021), with an indication of the template sections that cover the elements of the system design.

Figure 10 illustrates the diversity of cases the template is able to address through four examples of possible phenomena triggered by a farmer's activity as part of his/her farming practices. Harvest and mowing (Figure 10A and 10C) imply an almost immediate, but clearly different change in the land cover manifestation. In the grazing example (Figure 10B), the grass will be progressively eaten over time, and the resulting change will not be so sudden and homogenous (in terms of spatial pattern). Grass regrowth up to the plant height and cover required for the next mowing to happen (Figure 10D) could take several weeks. Mulching under a dense tree canopy (Figure 10E) may not be observable at all with remote sensing techniques. Pruning (Figure 10F) affects only the upped stratum occupied by woody vegetation and could be detected either through the reduced foliage of the tree crown or the increased visibility of the grass stratum located beneath.

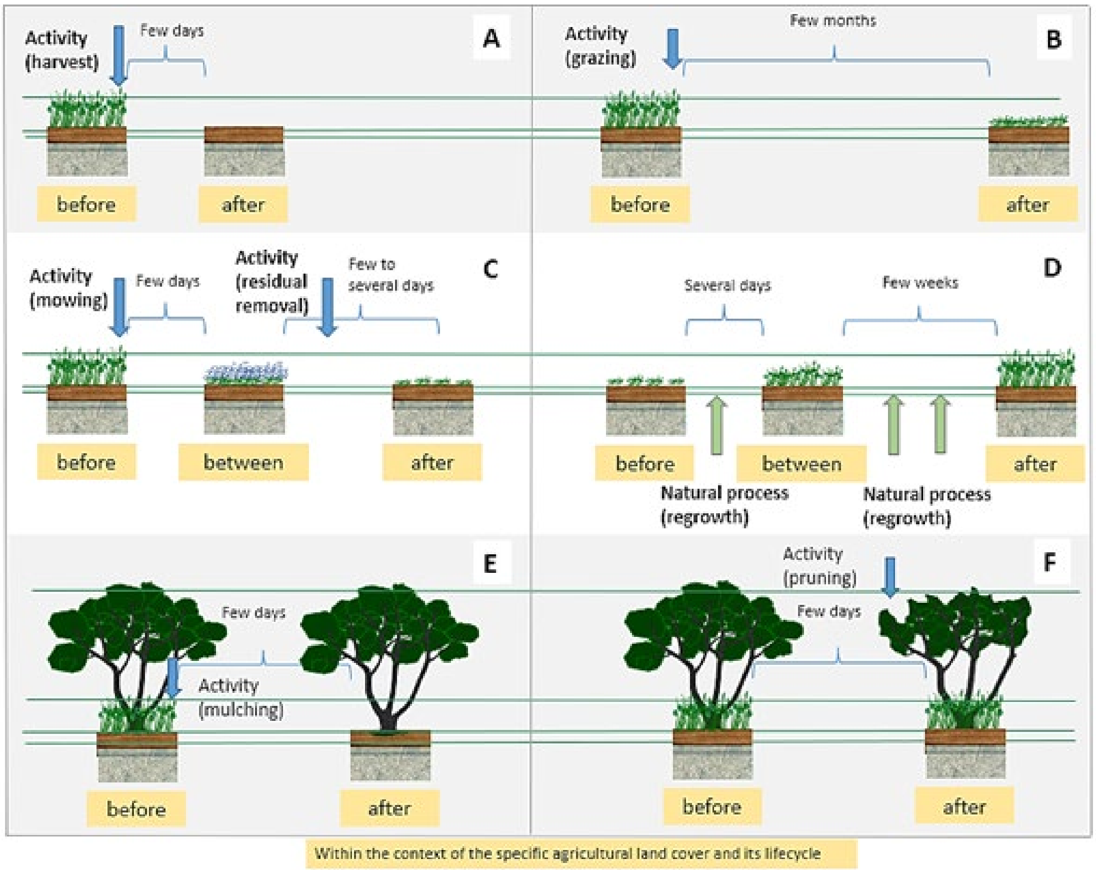

Figure 10. Examples of manifested changes in state following A) harvest of arable crop, B) grazing, C) mowing, D) grass regrowth, E) mulching and F) pruning. (given this is recovered: (Zieliński et al., 2022)

3 CASE STUDIES

This chapter discusses how the developed concept and methodologies were applied in four case studies.

These case studies stemmed from the incremental and multi-actor approach toward technology uptake and innovation ~~in the domain of EU CAP~~.. Even though focussed primarily on agriculture, much of the developed methods and tools deal with the universe of discourse of the land-use practices in a context of the natural environment. Thus, their transversal nature makes them portable and relevant for environment and climate. Each of the case studies address specific elements of the overall “business process” (Figure 1) of the monitoring of the “green” farming practices. In order to gather the information necessary to depict whether the farmer activities address the required interventions and whether the relevant satellite-based evidence could be provided. A robust extraction of the data, and their documentation could help EU MS administration to assess the feasibility of the new technologies to monitor certain farming practices and alleviate their concerns with respect to their monitorability. The four case studies could be regarded as examples of best practices on how to navigate through the process of introducing new technologies to monitor climate and environmental requirements. They also could support the relevant expert community to identify existing gaps to be further addressed.

The first case study, focuses on Polish CAP Strategic Plan. It investigates how agricultural interventions in the Strategic Plan might affect the bird species included in the Farmland Bird Index.

A second case study focuses on green cover, which is quite common and often declared by farmers as a practice that has an impact on the environment and climate. A CbM scenario "Green Cover" and corresponding markers were designed for this case study.

A third case study developed the technical framework for monitoring peatlands and wetlands under agricultural management as part of the implementation of the SEPLA project in the last two years.

Fourthly, this CbM technical framework and the experience of the SEPLA project were applied to monitoring grassland-dominant NATURE 2000 areas.

3.1 Analysis of CAP interventions linking bird protection and agriculture farming practices with a focus on the Polish CAP strategic plan

Within the European Green Deal (EGD) (EC 2019) Art 2.1.7, the European Commission aims at “Preserving and restoring ecosystems and biodiversity” (Figure 1). The EC works with the Member States to ensure that the EU Common Agricultural Policy (CAP) Strategic Plans reflects the ambition of the EGD. Art. 6 of the CAP Strategic Plans regulation, defines a Specific Objective 6 (SO 6) to “Contribute to the protection of biodiversity, enhance ecosystem services and preserve habitats and landscapes”.

could functionWithin this framework, we built up a case study in Poland by examining the Polish CAP Strategic Plan and analysing ed the planned interventions targeting the ecological requirements of the species considered for the Farmland Bird Index (FBI). The analysis covers bird functional traits and the monitorability of the identified agriculture interventions and practices. The protection measures of the bird species included in the Farmland Bird Index (FBI) were considered in scrutinizing each intervention that could affect the impact indicator “I.19. Increasing farmland bird populations: Farmland Bird Index”. The activities involved:

- Analysis of the interventions in the CAP strategic plan of Poland focussing on the interactions between bird needs and farming practices.
- Analysis of the monitorability of the above farming practices using Copernicus Sentinel satellites.

Agricultural land in Poland accounts for 70% of the country’s surface area and hosts over 11% of the European Union’s farmland bird populations (Sanderson et al. 2013). The Farmland Bird index value in Poland has declined to approximately 80% of the base (year 2000) value. While this is a better score than most any of the other Member States (Eurostat: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_bio2), a noticeable downward trend has been observed since the start of its monitoring (Wardecki et al. 2021).

Among the full list of 39 species that defined the FBI, 22 bird species are used to calculate the FBI in Poland (Box 2). Out of these 22 species, 11 suffered a population decline, 7 increased their numbers, and 4 remained stable. Several farmland-associated bird species that are not listed in the calculation of the index but that there are present in Poland, such as the Gray Partridge, are however known to be declining rapidly (Wardecki et al. 2021). The causes of this decline might include agricultural intensification and agricultural land abandonment, both resulting in the loss of the low-intensity, extensive farmland, which is vital for biodiversity, as reported by Henderson and Evans 2000, Brambilla 2019, and MRiRW 2019.

Out of the Farmland Bird Index Species in Poland, the Lapwing and the Godwit suffered the most severe declines, and their populations as of 2021 were below 30% of the 2000 level. The Godwit is currently considered critically endangered in Poland, and the Lapwing is listed as endangered (Wardecki et al. 2021).

BOX 2 SPECIES INCLUDED IN THE FARMLAND BIRD INDEX – PECBMS AND POLISH SPECIES SET

The Pan-European Common Bird Monitoring Scheme (PECBMS) lists 39 'characteristic farmland species' of birds, according to their predominant habitat use. These species are used to produce indicators on a national, regional and European scale, if present in the area in question. The 39 species mentioned in the FBI are listed below, and those used by the Common Birds Survey in Poland (22 in total) to calculate the FBI for Poland are marked in **bold.**

Eurasian Skylark *Alauda arvensis*
Red-legged Partridge *Alectoris rufa*
Tawny Pipit *Anthus campestris*
Meadow Pipit *Anthus pratensis*
Western Cattle Egret *Bubulcus ibis*
Eurasian Stone-curlew *Burhinus oedicnemus*
Greater Short-toed Lark *Calandrella brachydactyla*
White Stork *Ciconia ciconia*
Rook *Corvus frugilegus*
Common Whitethroat *Sylvia communis**
Corn Bunting *Emberiza calandra**
Cirl Bunting *Emberiza cirlus*
Yellowhammer *Emberiza citronella*
Ortolan Bunting *Emberiza hortulana*
Black-headed Bunting *Emberiza melanocephala*
Common Kestrel *Falco tinnunculus*
Crested Lark *Galerida cristata*
Thekla's Lark *Galerida theklae*
Barn Swallow *Hirundo rustica*
Red-backed Shrike *Lanius collurio*
Lesser Gray Shrike *Lanius minor*
Woodchat Shrike *Lanius senator*
Black-tailed Godwit *Limosa limosa*
Common Linnet *Linaria cannabina**
Calandra Lark *Melanocorypha calandra*
Western Yellow Wagtail *Motacilla flava*
Western Black-eared Wheatear *Oenanthe hispanica*
Eurasian Tree Sparrow *Passer montanus*
Gray Partridge *Perdix perdix*
Rock Sparrow *Petronia petronia*
Whinchat *Saxicola rubetra*
Stonechat *Saxicola torquatus**
European Serin *Serinus serinus*
European Turtle Dove *Streptopelia turtur*
Spotless Starling *Sturnus unicolor*
Common Starling *Sturnus vulgaris*
Little Bustard *Tetrax tetrax*
Eurasian Hoopoe *Upupa epops*
Northern Lapwing *Vanellus vanellus*

**Note that this report follows the scientific nomenclature used by PECBMS as of the time of writing. Attention should be taken for several of the listed species (marked with asterisks) as sometimes they might be referred with alternative synonymous scientific names in other external publications or sources.*

3.1.1 Potential impact of interventions in the Polish CAP Strategic Plan

An analysis was performed based on the CAP strategic plan of Poland, submitted to the EC in December 2021 (MRiRW 2021) that has been approved by the Commission services. From the submitted strategic plan, the farming practices included in different interventions were extracted. Those interventions, even if not defined explicitly to target the birds, could have an impact on bird populations, based on expert judgment and literature review. For that, the GTCAP team collected the requirements found in relevant eco-schemes (Table 2) and other agri-environmental and climate commitments (Table 3).

For the specific objectives SO5 "Foster sustainable development and efficient management of natural resources such as water, soil and air" and SO6 "Contributing to the protection of biodiversity, enhancing ecosystem services, and preserving habitats and landscapes" the Polish CAP plan identifies the following measures that can be relevant to farmland birds:

CSO5:

CS 5. P5. - Preventing land abandonment

CSO6:

CS 6. P1. – Protection and diversification of farmland landscape

CS 6. P2. – Sustainable application of crop protection products and fertilizers

CS 6. P3. – Crop diversification

CS 6. P5. – Extensive land management including protection needs

The degree and nature of the impact on birds may vary, depending on the interplay between the requirements of the scheme and the needs of the individual bird species (see Tables 3, 4 for specific details).

Table 3. Eco-schemes and related requirements in the CAP strategic plan of Poland that might have an impact on birds

Code	Name	Needs addressed	Requirements	Relevance to birds	Territorial scope [ha] (planned rate [EUR/ha])
I 4.1	Areas with melliferous plants	6.P1, 6.P2, 6.P3	Sowing of a mixture containing min. 2 melliferous plant species from a specific list No agricultural production (including grazing and mowing) until 31.08 No crop protection products allowed	Relevant to species which utilize field margins and fallow-like habitats, or ones feeding on invertebrates and weed seeds. See also I 4.12	3000 (269,21)
I 4.11	Water retention on permanent grassland	4.P2, 5.P2, 6.P3	Flooding or inundation on permanent grassland between 01.05 and 30.09, for at least 12 consecutive days	Creates and/or maintains habitat for species linked to wet meadows (e.g., Lapwing, Godwit).	360000 (63,15)
I 4.12	Designation of 7% of units of arable land as non-	6.P1, 6.P3	Designation of at least 7% of arable land surface as non-productive areas or objects. This includes fallow land, hedges, tree belts, individual trees, ditches, field	"Non-productive land" is a broad term and includes features beneficial to many different bird species in	300000 (19,10)

	productive areas		margins, buffer zones, buffer strips, buffer zones along woodland where crop protection products are not used, field groves, skylark plots with defined dimensions, ponds and similar features	varied ways. Tree- and hedge-nesters, fallow users and species, which require perches (like shrikes) should benefit the most, largely from the availability of feeding and/or nesting grounds.	
I 4.15	Organic agriculture	4.P1, 5.P1, 5.P3, 6.P2, 9.P2	Ecological production and appropriate utilization of the harvest Cultivation of plant species defined by national regulations Owning animals (in case of subsidies for fodder crops or permanent grassland) Animals 0,5-1,5 livestock unit/ha? (Bonus for balanced plant-animal production) Preservation of permanent grassland Appropriate training For orchards and berries – using appropriate quality planting material, yearly maintenance, minimal stocking density with up to 10% tolerance Numerous additional national standards	Some of the practices involved, like maintenance of permanent grassland, avoiding pesticides and over fertilization or crop rotation may positively affect various birds in ways dependent on the exact measures taken and the type of crop grown. For example, maintaining grazed grassland will benefit species that nest or feed in the grassland, or are drawn to the presence of grazing animals.	102530 (varies depending on crop and pre/post-conversion stage)
I 4.2	Extensive usage of animal-stocked permanent grassland	6.P5	0,3-2 livestock unit/ha permanent grassland during the vegetative period	Important for species associated with grazing animals and grazed grassland.	582000 (188,31)
I 4.4	Development and compliance with a fertilization plan	4.P1, 5.P1, 5.P3	Development and compliance with a fertilization plan for arable land and permanent grassland, based on N balance and chemical analysis of the soil + a variant with liming for soil pH <5,5 (support applied no more than once per 4 years)	Rational fertilizer use may prevent rapid early growth of sward, which may be beneficial to species, which do not deal well with tall grass, such as the Skylark.	1640000 (32,13) - regular variant 1442500 (145,84) - liming variant

I 4.5	Diversified crop structure	4.P2, 5.P1, 6.P3	At least 3 different crops on the arable land in the holding: At least 20% of sown crops are plants with a positive influence on soil organic matter balance (like legumes), or land not used for production, but where plants for green manure have been sown No more than 65% of cereals and rapeseed No more than 30% of crops with a negative influence on soil organic matter balance (like tubers)	Diverse crop structure should translate into increased biodiversity, including birds, but the exact impact depends on the crops used, their structure, surrounding landscape and more. It may also indirectly increase margin area and amount of field border features.	500000 (76,18)
I 4.8	Simplified farming systems	4.P1, 4.P2, 5.P1, 5.P2	Conserving tillage-free cultivation or strip-till No ploughing in pre-sowing and post-harvest crops Post-harvest residue is left on the field as mulch No-tillage cultivation not included	The postharvest residue is the most important here, as it may contain seeds and other elements the birds can forage on, especially in winter. Lack of ploughing may negatively impact birds which use it as an opportunity to forage, mostly on ground invertebrates (e.g., Rook).	775000 (125,62)
I 4.13	Plant production in the Integrated Plant Production system	5.P1, 5.P3, 6.P2, 9.P2	An Integrated Plant Production certificate for the particular year, confirming compliance with its methods. The methods include right crop rotation, limiting the use of crop protection products, setting up perches and other features promoting the presence of beneficial organisms and more	This eco-scheme should offer some benefits to birds in indirect ways, much like organic agriculture (I 4.15) does.	6806629 (292,13; may be increased to cover certification costs)
I 4.14	Biological plant protection	5.P3, 6.P2, 9.P2	Application of biological plant protection using microbiological products.	Reducing usage of chemical plant protection products should increase food availability for invertebrate-consuming species and reduce the	5000 (89,89)

				impact of the chemicals themselves on the birds (Boatman et al. 2004).	
I 4.9	Maintaining wooded buffer strips	4.P2, 4.P3, 5.P2, 6.P1	Declared surface is a result of: Article 22 of the EP (European Parliament) and Council Regulation (EU) No 1305/2013 from 17 December 2013 — concerns trees established in 2022 under sub measure 8.1 — Reforestation and creation of woodland, RDP 2014-2020, or Intervention "Creating wooded buffer strips" in Article 73 of the draft CAP Strategic Plans Regulation.	Vital especially for tree-nesters, may also provide cover against predators or habitat for invertebrates. However, it may deter species preferring uninterrupted open terrain.	100 (560,45)

Table 4. Agri-environmental and climate commitments and investments with related requirements in the CAP strategic plan of Poland that might have an impact on birds

Type and code	Name	Needs addressed	Requirements	Relevance to birds	No. of ha (planned unit amount per ha, in EUR)
ENVCLIM(70) - I 8.1 and 8.2	Protection of valuable habitat and threatened species on and outside Natura 2000 areas	4.P3, 6.P1, 6.P2, 6.P5, 6.P8	Management-based – mowing the right number of times, extensive pasturing, adjusting the timing of both actions to the needs of nature protection. Presence of species assessed by experts	Provides and maintains habitat for species associated with extensively cultivated grassland within and without Natura 2000 areas. Lapwings and Godwits are explicitly targeted, together with several non-FBI species.	Varies year to year (209,04-369,49) 10 variants
ENVCLIM (70) - I 8.3	Extensive use of meadows and pastures in Natura 2000 sites	4.P3, 6.P1, 6.P2, 6.P5, 6.P8	Management-based – mowing the right number of times, extensive pasturing, adjusting the timing of both actions to the needs of nature protection	Relevant to grassland- and pasture-associated species.	Varies year to year (187,87)

ENVCLIM (70) - I 8.4	Preservation of orchards of traditional varieties of fruit trees	4.P2, 6.P1, 6.P2, 6.P3, 6.P6	Maintaining multispecies or multivariety fruit tree orchards, proper maintenance and limiting the use of crop protection products	Provides habitat to orchard-associated species, like shrikes, Hoopoe *Upupa epops* or Linnet *Linaria cannabina*	Varies year to year (orchards >15 years – 475,73, new orchards – 1101,35)
ENVCLIM (70) - I 8.7	Multiyear flower strips	6.P1, 6.P2, 6.P3	Sowing of flower mixes in spring or autumn, then maintaining flower strips of prescribed length Appropriate maintenance, like mowing No plant protection products	Similar to 4.1	Varies year to year (898,88)
INVEST(73-74) - I 10.12	Creating wooded buffer strips	4.P3, 5.P2, 6.P1	Support for creating and protection of wooded buffer strips Native species, including proving ecosystem services or melliferous, adjusted to local conditions Mostly deciduous if possible Consultations with a specialist advisor	See I 4.9	387 (3102,38)
INVEST(73-74) - I 10.9.1	Development of precision farming services for protection of the environment and climate	10.P6, 5.P2, 5.P4	Support and equipment for limiting fertilizer and plant protection product use, sustainable water management, herd management, data gathering and processing	See I 4.4 and 4.14.	Total Public Expenditure - 112452,83 €, 265 operations

As already mentioned, in Poland the Lapwings and Godwits underwent the most severe declines in recent years. Therefore, they are explicitly targeted by interventions I 8.1 and 8.2, which provide support for proper management of their breeding grounds and for suitable habitats, dependent on a range of extensive farming practices to keep these habitats in good condition. In addition, permanent grasslands that are usually associated with these species are also supported by several other schemes and interventions (such as I 4.2), as well as coupled income support for grazing animals on grasslands. Most importantly, scheme I 4.11 grants funding for inundated or flooded grassland, a key environment for these two species (Birdlife International 2022). Recommendations for the conservation of both species released by the Polish Environmental Protection Agency (GDOŚ) include limiting the expansion of water infrastructure, promoting extensive meadow and pasture management, reducing human disturbance, managing predators and preventing overgrowth.

Removing individual trees or tree rows in meadowlands is also proposed, which would suggest a local ban on interventions such as I 4.9 or I 10.12 on sites where the goal is supporting the populations of the Lapwing and Godwit (Żmihorski et al. 2018).

Schemes supporting non-productive areas such as fallows, flower strips, hedgerows or wooded patches are beneficial to many farm bird species. They increase the degree of landscape heterogeneity, provide cover for both nests and the birds themselves, offer foraging grounds with seeds and invertebrates that will not be exposed to pesticides, or enhance the connectivity within the landscape. In addition, such features also help non-avian biodiversity, which brings benefits in the form of ecosystem services such as pest control (Henderson and Evans 2000, Pe'er et al. 2017, Toivonen et al. 2018). Woody elements such as patches or lines with trees and shrubs are required as nesting habitats by some species use perches. Tress and shrubs also provide cover influencing the microclimate, while also preventing soil erosion (Brambilla et al. 2009, Jacobs et al. 2022). However, a certain drawback is that they might negatively influence species requiring highly open habitats (Żmihorski et al. 2018).

The strategic plan includes several interventions related to the **protection and maintenance of permanent grassland**, that grant support, in the form of eco-schemes, agri-environmental and climate commitments and certain forms of coupled income support, mostly for grazing animals. This form of land use is essential to a range of farmland bird species, especially Godwit and Lapwing (Birdlife International 2022). Grasslands are important as both nesting and foraging habitats and often require maintenance and cultivation such as regular mowing or extensive grazing to remain attractive to birds (Atkinson et al. 2004, Wardecki et al. 2021). The maintenance prevents woody overgrowth on the grassland and limits sward height. The presence of animals can be a benefit on its own, e.g., attracting invertebrates the birds can feed on (Hoste-Danyłow 2010).

Eco-schemes aiming to **reduce fertilizer use** may cause swards to remain shorter for a longer time, enabling birds to forage more easily, especially early in the season (Toepfer and Stubbe 2001, Devereux et al. 2007). Those interventions **limiting the use of plant protection products** should lead to higher populations of invertebrates, a vital food source for most farmland bird species, especially during the critically important period when they feed their young, which usually require a high-quality invertebrate diet (Chiverton 1999, Boatman et al. 2004, Bright 2004). A lower intake of pesticide-contaminated food could also have a positive impact on the condition of the birds (Lopez-Antia et al. 2016).

3.1.2 Monitorable LCLUs linked to crops with an effect on birds

The development of the new technologies and especially the availability of Copernicus Sentinel data opened an opportunity to monitor agricultural land and farming practices. The Checks by Monitoring (CbM) allows monitoring some agricultural activities that influence the presence of birds. Methodologies have already been tested and used by some member states to monitor LC and LU on the land for those monitorable elements. Among those LCLU monitorable elements, some with an impact on birds have been specified in requirements of interventions of the Polish CAP strategic plan such as:

- Mowing

- Ploughing

- Green cover

- Maintenance of permanent grassland

- Flooding or inundation

All those elements can be monitorable at the parcel level and then be aggregated to build aggregated indices on performance, if needed. However, when using Sentinel data to detect the activities that evidence those practices, the following aspects should be also considered:

— Size and shape of the parcels. The pixel granularity for Sentinel 1 is 10 m x 10 m or 20 m x 20 m , and for Sentinel 2, it is 10 m x 10 m. This has consequences on the size and shape of the parcels that can be monitored through RS.

— Occurrence or absence of clouds throughout the year. Clouds do not affect the information that can be obtained from Sentinel 1 images. However, Sentinel 2 images on cloudy days contain no information of the land under those clouds and shadows.

— Frequency of image acquisition. The frequency of image acquisition for Sentinel 1 is 1 image in every 12 days (to date, because of the loss of one of the satellites) and 1 image every 5 days for Sentinel 2. This implies that in the best-case scenario (i.e., in the absence of clouds), the changes in the land cover occurring on the parcels can only be monitored every 5 days using only S2.

Ploughing is unlikely to have a direct impact on nesting activities for wheat or barley spring crops) in Poland. In the case of spring crops, ploughing takes place when most of the birds have not yet started breeding or even before they arrive from their spring migration. By the time preparations for growing winter wheat crops are made, the breeding season is effectively over (Grabiński 2007). However, ploughing can generate a potentially negative land cover change, such as the conversion of fallow land or grassland to arable crop. If winter wheat are sown, no cereal residue or stubble will be left on the fields for the winter, depriving wintering granivorous birds – whether sedentary or migrants from colder regions – of a vital food source in that period (Wilson et al. 1996).

Examples of potentially affected species are Yellow Hammer or Corn Bunting. On the other hand, invertebrate eaters such as Rook may prefer ploughed fields (Wilson et al. 1996, Gillings et al. 2005). Ploughing may also expose soil invertebrates to foraging birds, but in the case of ploughing before winter cereals are sown, some bird species will be preparing for their autumn migration. Spring tillage can also expose additional food to birds in a crucial period (Henderson and Evans 2000). White Storks, for example, are known to forage on ploughed fields in large numbers, even to follow agricultural machinery occasionally (Siekiera et al. 2021). The few species that might already breed in Poland while spring ploughing takes place, such as White Stork or Rook, do not nest on the ground (Storchová and Hořák 2018, Birdlife International 2022).

In order to assess the interaction between farming practices and the life-history traits of birds, we collected information on the life-history on the birds from a scientific paper published by Storchová and Hořák (2018), 'Life-history characteristics of European birds'. We took information on the length of parental care period. The risk of overlapping between breeding season and farming practices can be obtained by comparing data on timing for breeding and the time when the farming practices are expected to occur (Figure 11).

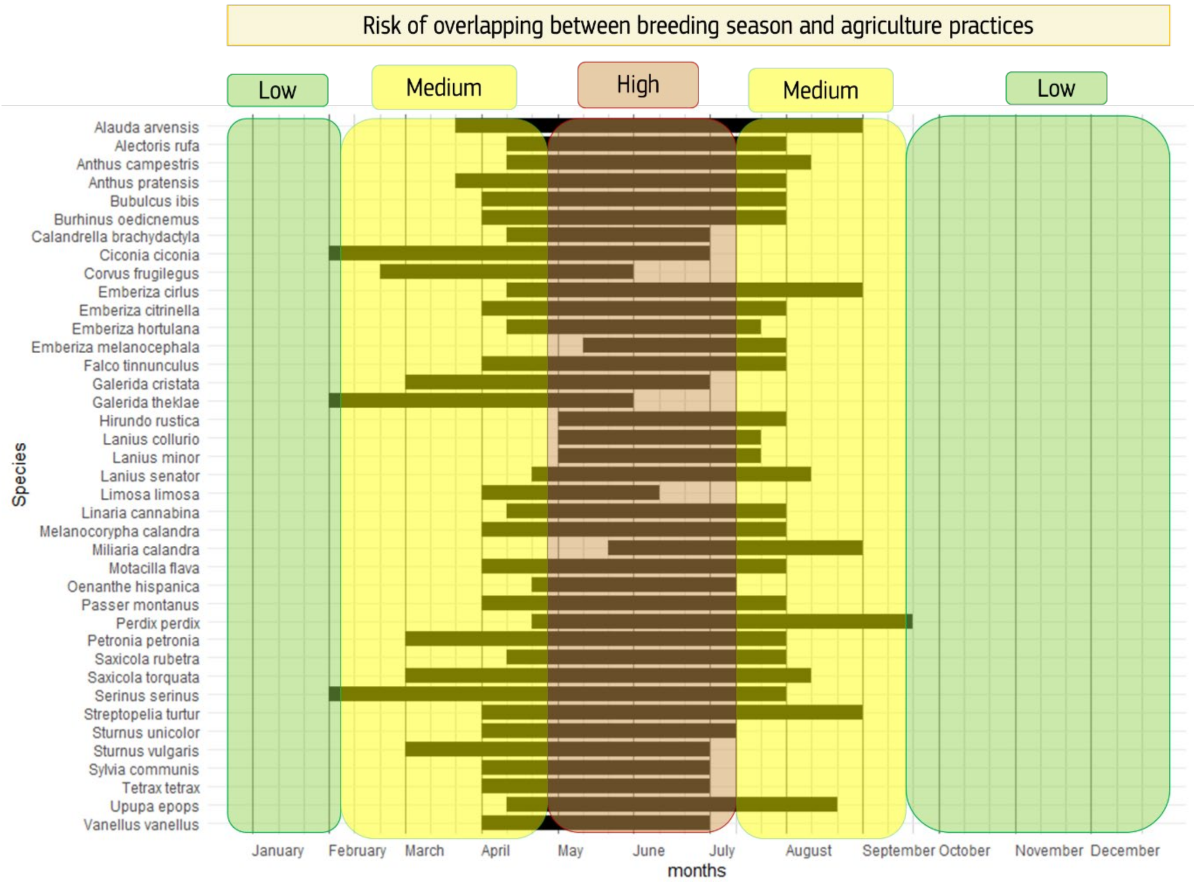

Figure 11. Time of breeding (black bars) of the 39 FBI bird species. Risk of overlapping with agriculture practices estimated (shown in coloured blocks) as the sum of species breeding at a particular time in the year

As farming practices are associated to crops, we focused on the phenology of wheat and barley – two most important cereals grown in the EU (Eurostat). Spring and winter were chosen as periods of the year where the interactions with birds' life-history traits can be investigated. As the phenology of the crops typically vary among MSs, and between years, we used the dates for emergence, flowering and maturity of the crops (i.e., expected harvest) for season 2020/2021 for each Member State (NUTS1), determined by the JRC AGRI4CAST group.

If we consider the most relevant period of the breeding season of the farmland bird species included in the Farm Land Bird Index, we can estimate the best period to monitor farming practices in the different Member States, expected ploughing and harvesting associated to spring barley and wheat and winter wheat in particular are shown in Figure 12.

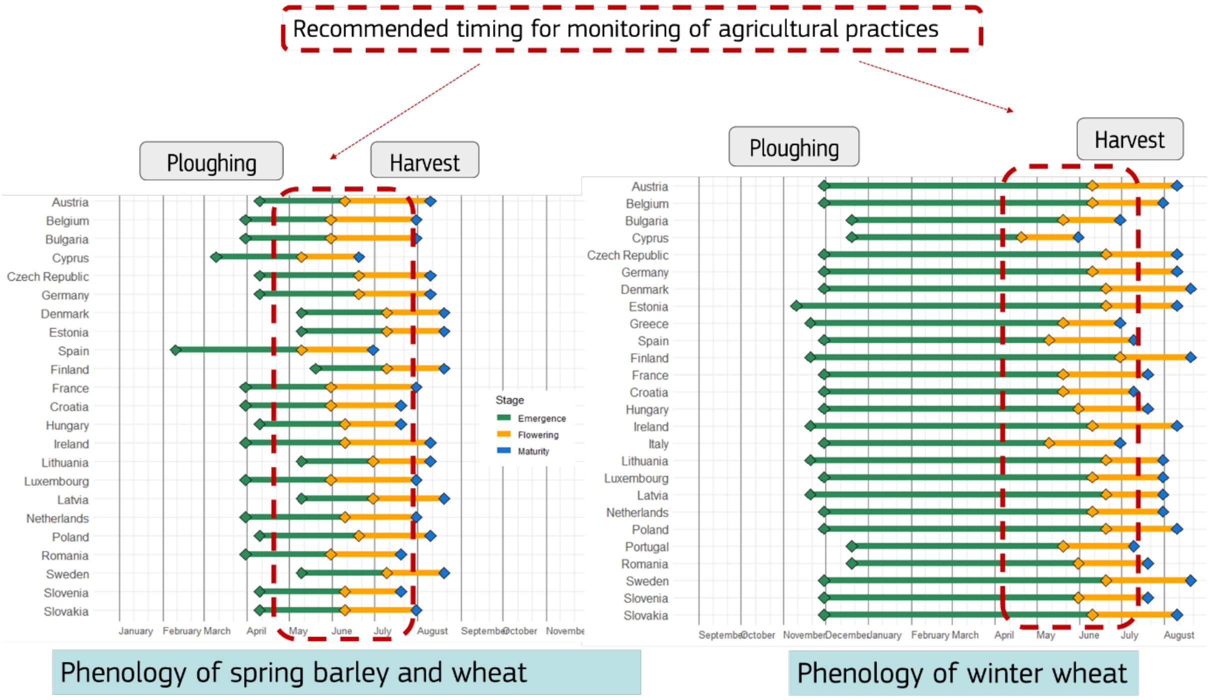

Figure 12. Recommended timing for monitoring of ploughing and harvest associated to spring barley and wheat, and winter wheat.

3.1.3 Conclusion of the case study

In the CAP, impact indicator "I.19. Increasing farmland bird populations" operates on the Farmland Bird Index. MSs design interventions in their strategic plans that aim to meet the specific objective SO6 and therefore expecting a positive effect on the farmland bird index. The development of the new technologies and the monitoring opportunities offered particularly by the CbM approach will allow monitoring the activities on land covered by these interventions.

The GTCAP team found different practices connected to the interventions that have potential effects on the ecology for farmland birds in Poland. Some of these practices have a high potential to be monitored using the Copernicus Sentinels, and for some of them, methodologies have already been developed. The analysis of the life-history of the birds gives the opportunity to define the most suitable periods for monitoring those farming practices. A monitoring system focussed on these critical periods could improve the effectiveness of the policy in achieving ecological benefits (in this case related to birds) without jeopardizing the budget on the CAP checking and adding the possibility of monitoring all the agricultural parcels, either they are within or outside the CAP.

The analysis carried out showed the potential of combining biodiversity conservation with agricultural production in a sustainable way, to be applied in both the decision-making process and in the monitoring/evaluation of the policy.

The use of new technologies and advanced data modelling might substantially contribute to integrated and holistic approaches, as already suggested by the European Court of Auditors (EC 2020, ECA 2021a, 2021b, 2022).

3.2 Designing a "green cover" scenario in CbM and setting up of relevant markers

3.2.1 Farm practices associated with green cover

Various farming practices are applied to reduce soil degradation and improve the retention of topsoil, such as intercropping, shifting agriculture, land left as fallow and green cover. Keeping the soil covered during winter or over the entire agronomic season reduces soil erosion, lowers the loss of particulate pollutants and increases soil organic matter (OECD 2001).

Maintaining green cover during specifically sensitive periods is an important farming practice that is beneficial for the environment and climate. It is an option for declaring ecological focus area, under the 'green direct payment' and it is one of the cross-compliance requirements (GAEC 4 – minimum soil cover) of the current EU CAP. It also plays a role in the future CAP conditionality, as GAEC 7 ("no bare soil in most sensitive periods"), as well as in the newly introduced eco-schemes and agri-environmental commitments under the Rural Development programme.

The detection of green cover was listed by MS as a priority practice to develop under the CbM outreach initiative. Four EU Member States expressed interest for developing markers for green cover detection: Austria, Belgium-France, Hungary, and Ireland. In response, the GTCAP team designed the practice scenario and the potential markers that capture anticipated farming activities.

By default, the scenario of green cover relates to the persistent presence of green vegetation during a well-defined period. The growth form of the vegetation is herbaceous, which can be either graminoid or forb. Often, it is a single annual crop, or crop mixture with specific plant morphology and phenology, deliberately seeded and uniformly covering the entire field. That field or land unit is by default arable land. The farming activities consist of a sequential set of actions ensuring the presence and growth of that herbaceous crop within the required period. The scenario covers a timeline from the seedbed preparation (not necessarily ploughing) and seeding until the crop removal (usually before reaching senescence). The maintenance of green cover occasionally comprises shortening the vegetation canopy through topping.

The detection of vegetation cover by remote sensing is straightforward. It can be spotted using the normalized difference vegetation index (NDVI) derived from the optical Sentinel-2 bands. The challenges in observing green cover, identified, and expressed by the EU Member States are related to the detection during the relevant period as a whole. Tthe requirement is often defined on a calendar basis, i.e., 6 weeks duration between specific start and end dates.To determine how long a parcel is covered by green cover (for example, catch crop), it is essential to capture not only the date of its harvesting but also, its sowing date. However, seedbed preparation and sowing occur mostly when the soil is bare and this state is not followed by immediate emergence and development of the vegetation cover. As a result, vegetation indices would be inappropriate to determine the date of seeding. Fortunately, Synthetic aperture radar (SAR) signals deal well with bare soil surface characteristics (such as soil roughness and its change) and are always available. Start and end dates remain difficult to determine when the green cover is preceded or trailed by green fallow.

To illustrate the possible design of a green cover scenario and relevant markers, a factious case is presented. It relates to green cover (ecological focus areas, EFA) sown in late/summer/early autumn immediately after harvesting the productive crop. The soil preparation and sowing are preceded by the presence of (senescent, in case of previous cereals) herbaceous vegetation, which is removed during harvest. The timing of the sowing of green cover and of its removal generally targets the crop calendar according to local practices. However, timing is further regulated by EFA rules which constrain the sowing and removal to be outside the period from the 15th of September to the 1st of December.

The example given in table 5 presents that fictitious scenario of green cover, including periods when listed activities/practices are likely to happen, further constrain by the applicable EFA rules. It also shows the last two stages of the preceding scenario (cereal crop cultivation). The table lists the resulting land cover manifestations occurring on the entire feature of Interest (FOI) surface (1-1 cardinality) or on a part of it (1-1.n). This cardinality will affect the homogeneity of the remote sensing signal.

Table 5. An example of a scenario of green cover considering declared land management choices.

Likely period	Trigger activities	Stages	LC manifestation	FOI cardinality
June		senescence of vegetation	presence of dry herbaceous vegetation	1-1
July August	harvest	dry vegetation removed	absence of vegetation, presence stubbles with a share of bare soil optionally covered with dry residuals	1-1
Mid of September	seedbed preparation and sowing	plant debris and stubbles removed, soil is levelled	presence of bare soil, with flat and smooth surface	1-1
October-November		growth of vegetation, crop emergence	presence of herbaceous vegetation with sparse and no uniform cover; bare soil beneath is visible	1-1..n
November		natural vegetation growth	presence of herbaceous vegetation with dense and uniform cover	1-1
Early December	vegetation removal	vegetation removed	absence of vegetation, presence of bare soil	1-1

3.2.2 Possible local disturbances

In the timespan of the scenario, the most likely local disturbances that could influence the execution of practices, the dates of phenological stages or the observation feasibility are snow cover, drought stress and eventually flooding. Usually, these disturbances affect most other lands in the direct vicinity and hence represent an element of common processing of neighbouring parcels.

3.2.3 Translate formal requirements into appropriate "monitoring process" rules

In the example of EFA green cover on arable land, the following activities are relevant:

Sowing must have been completed by September 15th.

Vegetation removal should be no earlier than the 1st of December and not later than the 15th of December in the same year.

These requirements can be translated into the following set of monitoring process rules:

- noncompliance rules: no ploughing or vegetation removal in the period October-November,
- validity rules, e.g., confirmation that activities/phenomena are valid of the entire FOI at one point of the campaign,
- compliance rules:

sowing done before September 15th

Vegetation removal occurred between 1st and 15th of December. Note: As it is done through ploughing, a confirmation of such activity might already indicate the start of a subsequent scenario.

Appropriate markers can then be selected to enable reliable conclusion on these rules, based on available image data.

3.2.4 Select the most suitable markers

For every rule identified in the previous step, knowledge of remote sensing and image processing will help to select a set of markers ("automated tell-tale observations") that offer sufficient evidence to conclude that a rule has been complied with or not. Expert judgement of such knowledge was applied to fill in table 6.

Table 6. Example of signals and markers relevant for the scenario of hay land on permanent grassland specified in the previous sections. NDVI = (NIR − RED)/(NIR + RED); NDWI = (GREEN − NIR)/(GREEN + NIR); CI red edge = (NIR-Red Edge)/Red Edge; BSI = (SWIR1 − RED)/(NIR + BLUE); SAR – Synthetic Aperture Radar.

Stage	State of land cover		Signal 1 (S1)	Signal 1 behaviour	Marker 1 (M1)	Signal 2 (S2)	Signal 2 behaviour	Marker 2 (M2)
	Pre condition:	Post-condition:						
dry vegetation removal	Dry vegetation	stubbles with bare soil	BSI	increase↑↑	dS1/dt	SAR Coherence	high	S2
Seedbed preparation (levelling of soil)	Stubbles with bare soil	Clean bare soil	BSI	increase↑	dS1/dt	SAR Coherence	increase↑	dS2/dt
growth of vegetation, crop emergence	Clean bare soil	Sparse herbaceous vegetation	NDVI	increase↑	dS1/dt	SAR Coherence	drop↓	dS2/dt
natural vegetation growth	Sparse herbaceous vegetation	Dense herbaceous vegetation	NDVI	high	S1	SAR Coherence	low	S2
Green vegetation removal	Green vegetation	Bare soil with stubbles	NDVI	drop↓↓	dS1/dt	SAR Coherence	increase↑	dS2/dt
flood	absence of surface water	presence of surface water	NDWI	increase↑	dS1/dt	SAR Backscatter	low	S2
drought stress	dense grass/higher chlorophyll content	open grass/lower chlorophyll content	NDVI	drop↓	dS1/dt	CI red edge	drop↓	dS2/dt

Prior knowledge of the markers' local sensitivity and selectivity (expressed as alpha (α) and beta (β) errors of the detection algorithm) will be essential to select the most suitable markers for an operational design.

3.2.5 Conclusion of the case study

Check by Monitoring (CbM) could be regarded as a component of the Critical Information System (CIS) set and operated by a state agency or its contractor to serve the needs of the CAP implementation (CW/CIS, 2008). As such, its design requires the identification and agreement upon the information needs related to the monitoring of the farming practices. The "green cover" use case demonstrates the capability of the scenario approach for controlled breakdown and streamline of the ample amount of satellite data into meaningful "chunks" of information in the user context, by eliminating the unnecessary processing (Devos et al., 2021). It allows for selection of the most effective and efficient markers and related satellite signals for detecting the key changes of the land cover state, evidencing the conduction of a given farming practice. Also, the upfront description of the farming practice in formal and standardized way helps greatly the system design and reduces the interaction time for IT development. Finally, it provides a common framework for information exchange between the farmer and the administration. These benefits were acknowledged by the MS administrations, participating in the CbM outreach initiative. They provided in addition some suggestions for improvement of the approach, which were considered in the elaboration of the structured template (Zieliński et al., 2022).

3.3 Application of tegon and LCML for semantic description of complex land cover types, and associated land uses – the experience of SEPLA project

3.3.1 Project background and rationale

SEPLA is a JRC.D5. GTCAP project in collaboration with DG CLIMA and technical experts of 10 paying agencies. DG AGRI is involved as an observer given SEPLA's potential for GAEC2. The main objective of SEPLA is to pave the path for a comprehensive inventory of wetlands and peatlands and to prepare for the monitoring of their preservation and restoration, using remote sensing and regularly updated geographically explicit datasets. The primary geographic scope covers the EU countries, to be extended to Iceland and Norway.

The rationale of the project stems from the specific problems (different legislation for agriculture and LULUCF prevents integrated targets and results in gaps in the reporting systems), the climate policy drivers (decrease of carbon removals in the land sector; implementation challenges), and the corresponding objective of LULUCF climate neutrality by 2035.

Among other things, the project assesses the suitability of methods for information extraction developed in the frame of the CAP Checks by Monitoring to monitor the status and evolution of the peatlands and wetlands. Such monitoring should consider the regional specificities and established local agronomic practices. It should extend the CAP methods outside the geographical scope of the CAP datasets and help compile the full territory inventories at the EU level. The project should also advance the integration of Earth observation data into the relevant modelling platforms available at JRC, to help enhancing the assessment of climate mitigation and adaptation options in the EU agricultural sector, with tailored solutions at the farm level. This could include assessment of the different options for spatial representation and ingestions of the EU and in situ data into the models. The production of a pan-European dataset on peatland or soil organic carbon is not in the project scope.

The ongoing efforts of ISO TC211 (WG7) to standardize the land cover and land use information concepts and to enable interoperable use of the relevant data and services in a machine-readable manner are also considered.

The project outputs are,

- a methodology for identification and mapping of "candidate" peatland/wetland areas for LULUCF,
- a technical report on methods and tools in support of the creation of the "The Integrated Administration and Control System (IACS) carbon theme" and
- a prototype and its derived technical guidance for EO-based monitoring of peatland/wetland.
-

3.3.2 Methodological framework

The interaction between the spatial data on soil, wetness of the land and the data on agricultural management from the Land Parcel Identification System (LPIS) and/ or the Geo-Spatial Aid Application (GSAA) and newly called Geospatial Application (GSA) requires dealing with the 3-dimensional aspect of the land cover (Figure

13). Information on the vegetation within the different vertical strata is collected during the semantic assessment and used to “map” the farming activities/practices recorded in LPIS to an appropriate biophysical (biotic or abiotic) component of the wetland land cover type.

This, presumably, will help to:

- Better understand how the given agricultural practices affect the biophysical aspect of the land phenomenon,
- Monitor the effect of agricultural practices on the environment and climate and
- Develop higher tiers for emission estimates.

The relationship between the farming activities and the biophysical aspects of the land cover is documented through the CbM template, developed in the frame of the CbM outreach, extended to cover the needs of NATURA 2000 and SEPLA.

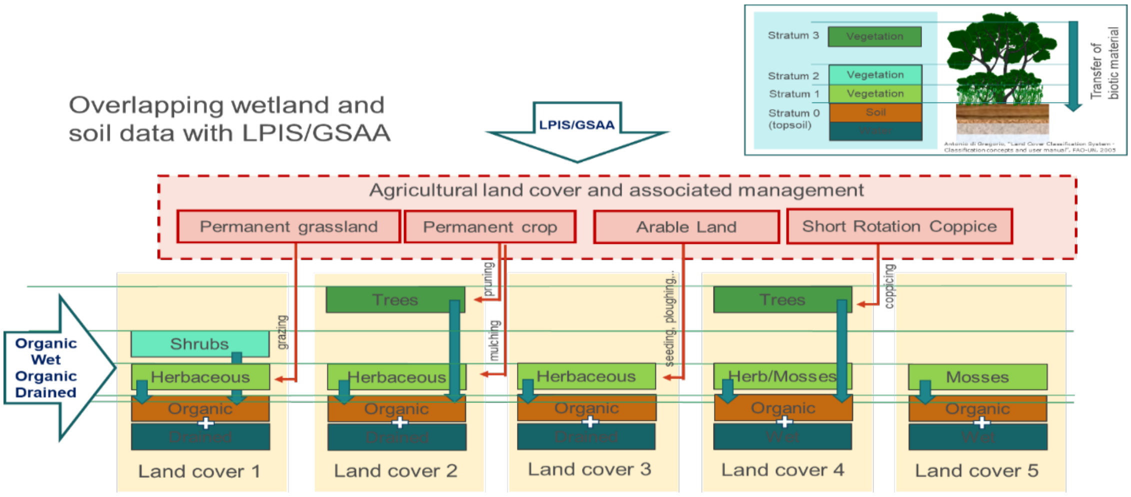

Figure 13. Interaction between the spatial data on soil and wetness and the data on agricultural management

LCML is used as the main ontology for the design of a semantic "meta-model" hierarchically structuring all essential biophysical "components" that define the land cover in agricultural lands. This ontology should also contain the morphological characteristics of the topsoil which could potentially affect the appearance, structure, as well as the behaviour of biotic aspects of the land cover. This connects "tegon" with “pedon", where the three-dimensional elementary bodies of land cover and soil respectively, act as a structural pair in the "soil–plant-ground atmosphere" system (Banov, et al., 2021). This pair concept allows for a standardized description of the relationship between land cover and soil and for the identification of the pair’s biophysical characteristics that can be observed with remote sensing.

The meta-model developed under the SEPLA uses a meta-language to describe any type of wetland/peatland, as defined by a given land cover and soil classification system. It includes the semantic elements and biophysical characteristics that characterize land cover and soil-related aspects (Figure 14). The model has been tested and adapted for land cover types associated with peatlands, which are complex biophysical systems. It was successfully applied to tackle agroforestry systems too. Every element, present in the different strata of the meta-model and associated to a particular component of the "tegon-pedon" pair, represents a specific material that has a specific behaviour and life cycle. The main presumption is that a sufficiently dense and uniformly spread set of observations will allow to derive the relationship between soil characteristics and the behaviour of land cover features. The semantic model also accounts for the different meanings of the term “substrate” in the domains of tegon (land cover inventories) and pedon (soil mapping).

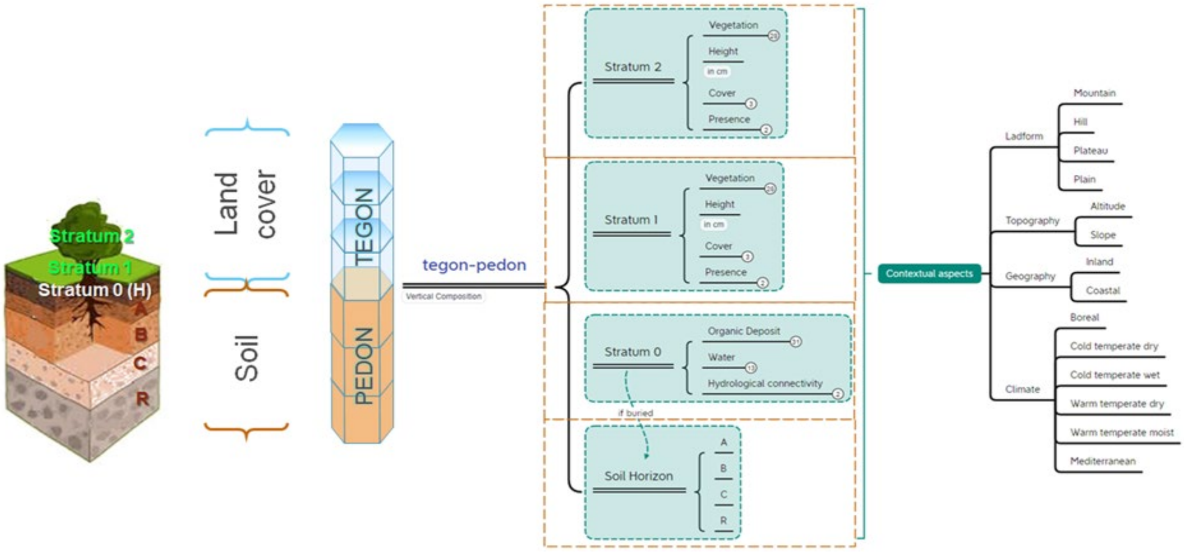

Figure 14 Semantic meta-model of the “tegon – pedon” pair (SEPLA project). The leftmost picture is from eschooltoday.com

3.3.3 Realizations of the joint tegon/LCML concept

The conceptual framework allowed for the elaboration of some specific examples of documenting complex land cover classes using LCML and the tegon concept.

The first example is of a peatland with scarce and uniformly distributed trees and some occasional shrubs belonging to the class “Spruce Mire”. It is a separate class in the Finnish peatland habitat classification.

The mire consists of an organic layer saturated with water. Patches of water appear at the surface. The dominant tree species, such as spruce, are evergreen although deciduous trees may also grow in spruce mires that are richer in nutrients. In nutrient-poor spruce mires, dwarf shrubs can be present. The presence of living and dead trees of varied sizes and ages is an important structural feature (Figure 15). The lowest vegetation layer consists of grasses and herbaceous plants or sphagnum mosses. Wetland and peatland are a land cover category where it is essential to account for the relationship between land cover (LC) elements in different strata. This is particularly valid for peatland forests, where the accumulation of dead organic material (litter) on the topsoil layer is related to the trees present above. In the Nordic European countries, peatlands could have several strata of vegetation. Some of them could be occasionally present in the given class instances.

Source: Pavel Milenov © 2012, HELM project, used with permission.

Figure 15. Example of mire with trees in Nuuksio National Park, Finland

The given peatland class was described in LCML through the principles of tegon and applying the functional entity approach based on the LC_Horizontal Pattern object (Figure 16 below). However, the spread of the trees is relatively uniform and not necessarily clustered. There is a canopy effect of the trees over the layer of grass or sphagnum mosses. The peatland could be modelled through the strata composition alone. A combination of LC elements related to organic litter and water are present in Stratum 1. Stratum 2, holding the grasses and mosses. It has the attribute “on Top of LC_Inter Strata Relationship” set to “PreviousE1”, which indicates that the elements of the stratum are directly on top of the first (lowest) element of the previous stratum. This explicit the position of the vegetation on the organic layer beneath. For Stratum 3, which holds occasional shrubs, the attribute “Presence Type” is set to “optional”. In the uppermost stratum 4, there are evergreen and deciduous trees competing for the same space. Most of the deciduous trees have a “Dead Status”.

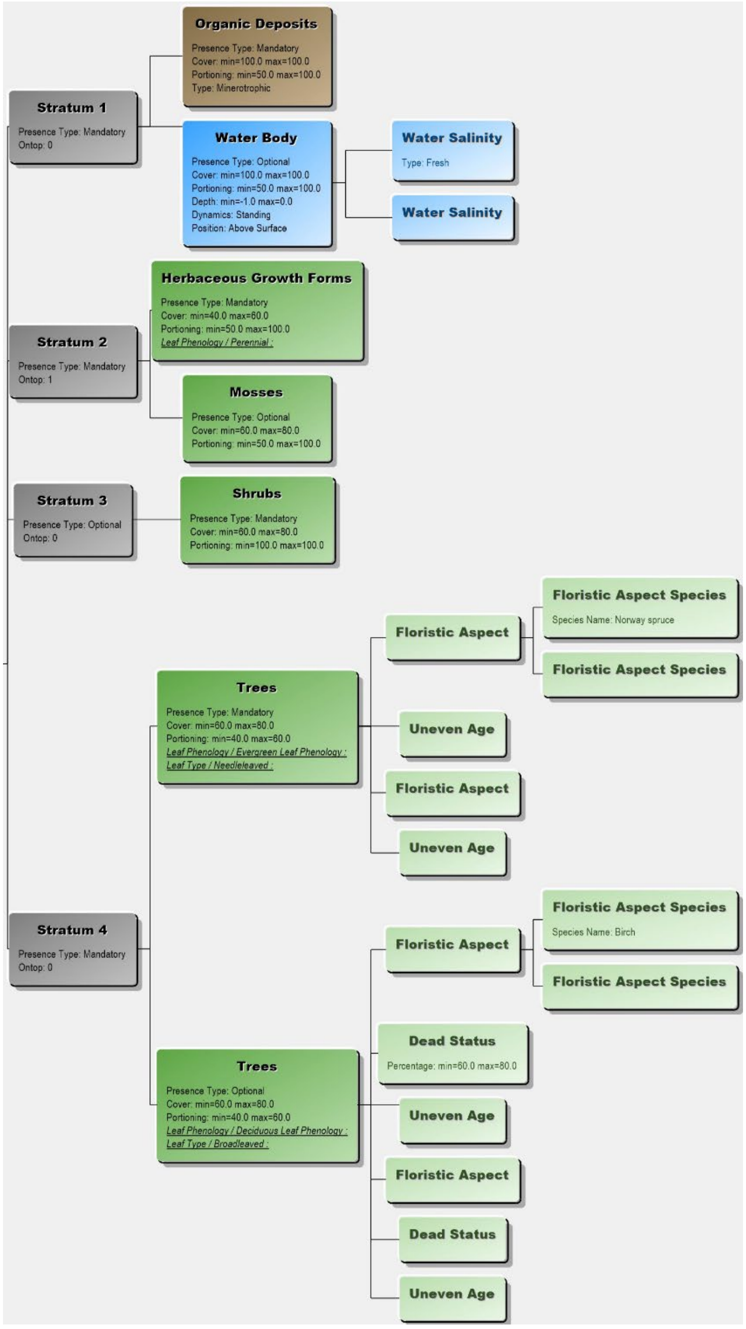

Figure 16. Example of peatland with trees and occasional shrubs class element composition (created by LCCS3tools, v1.1.0, the deposit layer is developed on top of the figure, the tree layers above at the bottom)

The second example describes a land cover class related to agroforestry, as recorded in the Land Parcel Identification System (LPIS) of Portugal (Figure 17). The sporadic occurrence of shrubs is considered of marginal relevance and not accounted for. The class encompasses seminatural grasslands with open to dense patches of oak trees. The patches of herbaceous and woody plants form an intrinsic mix, considered a "unicum". Irrespective of the applied cartographic scale, it remains a single entity from the functional point of view, representing the silvo-pastural concept of "montado". In the national LPIS nomenclature, the class description is "Woodland with Open Medium to Tall Herbaceous Layer. Floristic Aspect: Cork Oak or Holm Oak or Pyrenean Oak. At least 60% of the parcel tree cover is Quercus. Cork Oak density is minimum 40 trees per hectare/Holm Oak or Pyrenean Oak density is minimum 60 trees per hectare". In this, example authors simplify the modelling process by assuming all the tree cover is Oak (Quercus). In such grasslands with open to dense trees, the canopy density will affect the practices beneath the trees and thus has to be considered separately for the qualification and quantification of the effective grazed area. This understorey vegetation could also consist of different plant varieties and compositions and thus perform differently towards environment and climate.

Such permanent grasslands with scattered shrubs and trees are mostly subject to specific local agronomic practices (grazing, collection of vegetation usable for forage, reduced tillage, mulching, and cleaning up of scrub encroachment). In the CAP, these "mixed" grasslands are called "pro-rata grasslands" and are important in terms of its greener ambitions. The term "pro-rata" is introduced to indicate that the quantification of the areas occupied with grass is done through an application of reduction coefficient over the entire area of the mixed grassland (Milenov et al., 2018). Many European countries, especially in the Mediterranean region, spatially record such grasslands in their territory and describe their type in a local land cover nomenclature. In certain pro-rata grassland types with denser tree coverage, the vegetation condition beneath the canopy plays a significant role in the quantification of the eligible area available, as well as in the evaluation of the role of the grassland for environment and climate.

Source: Long-Term Ecosystem Research LTsER-Montado platform – Portugal, courtesy of Adriana PRINCIPE© 2013, used with permission.

Figure 17. Typical grassland with oak trees, forming an agro-forestry system called "Montado"

To model such land cover classes in LCML, through the tegon concept, the agroforestry class is treated as an intrinsic mix of 3-dimensional elementary biophysical features (tegons), each having a distinct number of strata. In the case of grassland with trees, there are two types of biophysical features: (1) one having only a single stratum with one LC element of herbaceous vegetation (grasses) and (2) one stratum with a LC element of herbaceous vegetation (grasses) and another stratum above with one LC element of woody vegetation (trees). The presence, abundance, and horizontal composition of these two types of physical features is managed in LCML through the LC_HorizontalPattern object (Figure 18).

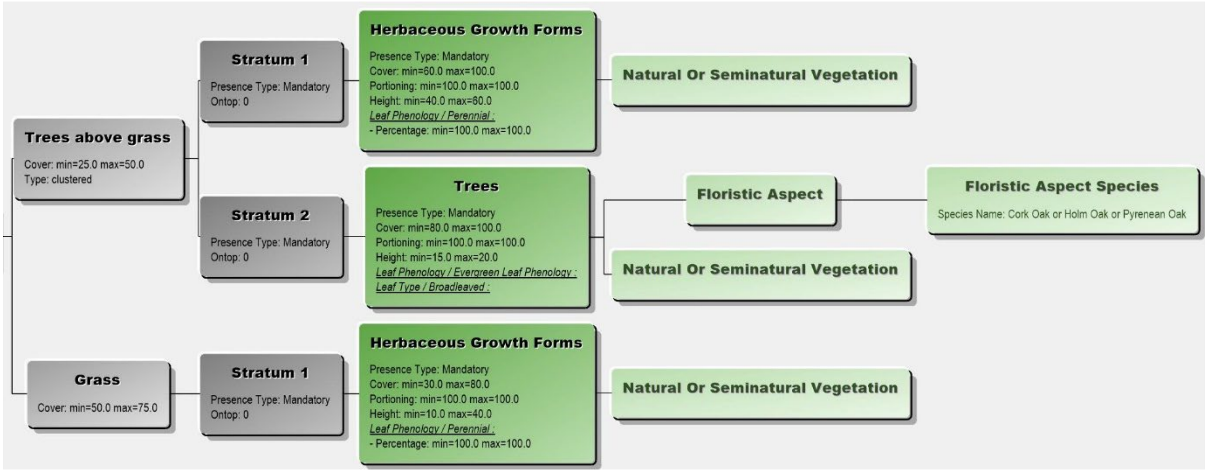

Figure 18. Example of complex agricultural land cover class element composition ((created by LCCS3tools, v1.1.0)

3.3.4 Conclusions of the case study

The realized class instances of "Spruce Mire" and "Agro-Forestry" show the potential of the tegon to structure the LCML ontology in a way that it can be used for description of complex land cover types, involving physical three-dimensional features. At the same time, it ensures that the whole concept is compatible with the cartography-based land cover mapping processes. The preservation of the information on the vertical arrangement of the observable bio-physical characteristics improves the technical framework for monitoring of farming practices related to complex agricultural land cover, such as those related to agro-forestry. It also allows for effective integration of satellite-based and in-situ observation methods (for example, geotagged photos), necessary to capture the entire aspect of the observable physical feature. The elaborated examples were included in Annex C of the revised edition 2 of the ISO 19144-2 (Classification systems – Part 2: Land Cover Meta Language).

3.4 Monitoring of land cover and land use in NATURA 2000 designated areas

3.4.1 Portability of the methods developed by SEPLA

The technical elements related to land cover capture presented above is based as much as possible on a scale invariant detection of the earth's surface material properties; its description is structured by the ISO Land Cover Meta Language. The initial extraction of data is not a priori forced into conceptualizations developed by a particular information community or by a specific application field. The overall information extraction process operates in two steps: (1) capture raw data on the core biophysical building blocks present on the surface while accounting for their spatial-temporal aspect and record them in a structural way in a database; (2) use the proper semantics and context to recombine these blocks into relevant categorical information (labelled classes, user-specific attributes, thematic spatial objects) according to user/policy needs. For the latter, combining the concept of tegon with the semantic model developed for SEPLA, has provided the appropriate basis for structuring the 3-dimensional information on land cover in LCML terms. The current version of ISO LCML also accounts for the EAGLE model, ensuring sufficient synergy with the latest development of the Copernicus Land Monitoring Services, such as Corine Land Cover Plus - CLC+ (for example, the CLC+ Instance related to LULUCF).

The technical framework of the CAP Checks by Monitoring (CbM) and the developments of the SEPLA projects were found reusable in the context of the monitoring of the status of the grassland-dominant NATURE 2000 sites, set up by the “Nature Protection” Unit of Directorate-General for Environment is a Directorate-General of the European Commission (DG ENV). The project rationale stemmed from the fact that species-rich grasslands were found among those habitats in the worst conservation status and with the highest share of deteriorating trends, together with bogs and dunes (State of Nature in the EU (2019)). The declines were a combined result of land use changes linked to agricultural intensification, urbanisation and land abandonment. To remedy the situation, the European Parliament funded a project run by DG.ENV. D3 (Nature conservation) to set up a Commission in-house monitoring system for grasslands in Natura 2000 sites. The project mapped the land cover based on the Mapping and Assessment of Ecosystems and their Services (MAES) nomenclature over 3 689 grassland-rich Natura 2000 sites, initially based on the European Environment Agency (EEA)-Copernicus local land product for Natura 2000. The land cover mapping and related change detection spanned the period from the adoption of the Habitat Directive in 1994 until 2018 and was made using EO data from Landsat and Copernicus Sentinels. The project also elaborated annual land cover maps and statistical indicators for each site. It launched a website, EU Grassland Watch, to explore land cover/land cover change (parcel and site level) and other indicators. The result was a Prototype Decision Support System for grassland monitoring in Natura 2000. Numerous synergies with CbM and SEPLA were identified during the course of the project in particular for the planned upgrade of the “grassland watch” system. These upgrades target the improvement of detection algorithms (LCLU, mowing, plowing, etc.) A better reflection of actual user needs and more cross-fertilization between the environment and climate policies. Although the land cover information in “Grassland Watch” is summarized at the level of the Copernicus Nature 2000 products (N2K) unit, there was abundant underlying information collected at the pixel level, which could be used to redesign the metrics and results reported.

GTCAP also found that the ongoing assessment made in SEPLA on the usability of the EEA datasets from Copernicus Land Service for mapping of wetland/peatland candidates could be beneficial for the development of Grassland Watch. Furthermore, the multi-actor approach applied in SEPLA, actively involving the EU MSs experts and local users, could be a model for “Grassland Watch” for building its community network. As Grassland Watch aspires to play a role as reference monitoring system, it will have to interact with any existing local monitoring system on Natura 2000. The future activities related to mapping and monitoring small ponds, foreseen by DG ENV, would directly contribute to the creation of the geospatial data in the Integrated Administration and Control System agricultural areas located in in Natura 2000 sites.

3.4.2 Monitoring of small natural water bodies

Outcomes of the JRC SEPLA project indicate that most of the wetlands and peatlands under agricultural management are in fact grasslands on organic wet soils (corresponding to histosols) used for grazing or mowing. Many of these are within Natura 2000 sites - five out of the six SEPLA test sites are partially or fully located within such sites. Many of the near-intact peatlands are low-lying areas with pool systems, used for forestry, water extraction, and grazing. The methods and tools developed in SEPLA for wetland and peatland monitoring could also be used to monitor wet grasslands and small ponds within Natura 2000 sites. Therefore, some of the outcomes of SEPLA could be reused in the environmental context. (Figures 19 and 20).

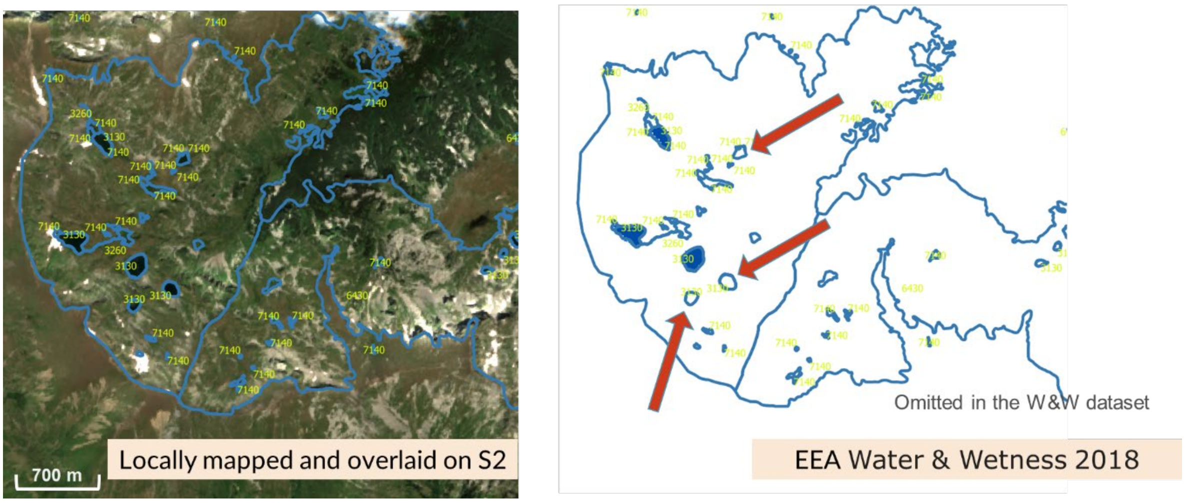

Figure 19. Identification of small persistent water bodies within N2000 (wetlands of RAMSAR type 2)

SEPLA also developed some methods to assess the land cover changes in wetlands and the potential impact of land use by studying vegetating behaviour on multitemporal Sentinel data (Figure 20). The methods rely on the recent developments regarding the definition of land cover and land use in ISO 19144-2/-3 and on the improved formalization of the link between an observation and the spatial feature of interest (ISO 19156). The revisions are particularly relevant for the evolution of the Copernicus land services by the EEA.

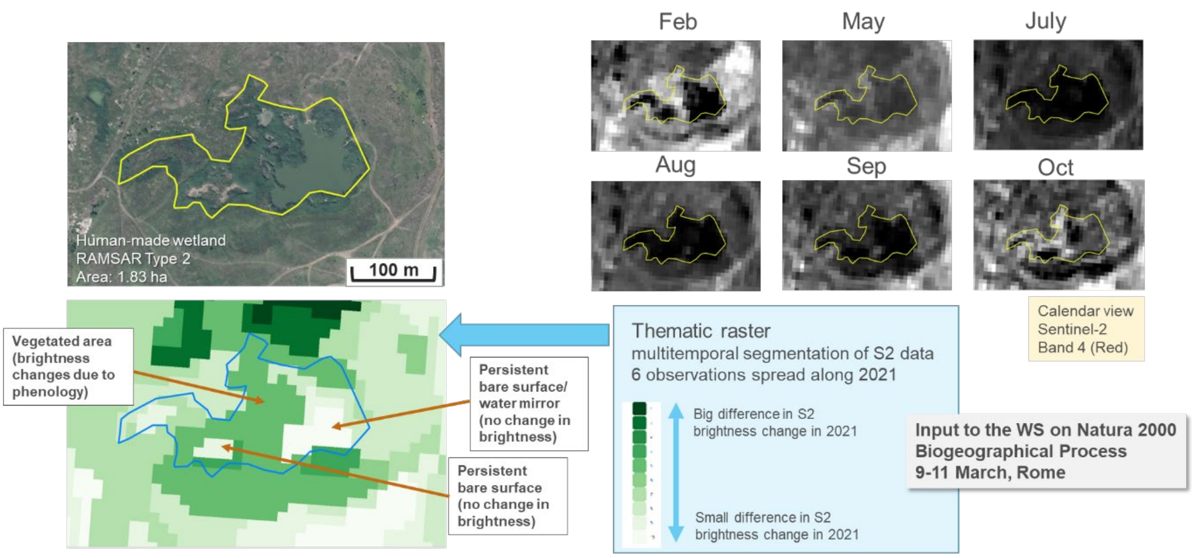

Figure 20. Mapping land cover behaviour in wetlands

3.4.3 Conclusions of the case study

The above activities demonstrated the potential for long-term development on the application of CbM methods in environmental policy context, covering biodiversity, environmental compliance and protection of N2000. They also allow the exploration of the added value of SEPLA to wetland monitoring for small ponds and wet/humid grasslands. The present study case was used as one of the cornerstones for possible collaboration with the EC services involved in monitoring of N2000 sites.

4 CONCLUSIONS

The objectives and delivery model of the new EU CAP require a strengthening of its organizational and technical structure. While the information needs of the previous EU CAP were strongly focused on compliance controls (area measurements and activity checks), those of the new CAP are oriented toward performance for the environment and climate. The new CAP has all subsidies framed by national decisions in strategic plans that focus on high-level national targets (specific objectives). This triggers a change in basic assumptions that requires the adoption of novel solutions and technologies.

Consequently, the components of the new CAP green infrastructure, as well as the basic income scheme, are based on the interventions laid down in those national strategic plans. These interventions are measures adapted to the national targets and they comprise conditionality, eco-schemes and agri-environment and climate commitments. The monitoring of interventions requires a link with the "observable phenomena", which reflects the management activities triggered by the farming practice. New opportunities created by the Copernicus Sentinels and related services could address the related information needs.

Despite the increased pace of technological development, there remain several challenges. The holistic nature of the new CAP objectives implies an integrated approach toward information flows and interoperability. This would require the increased use of European and international standards for conceptualization and mapping of agricultural land cover and land use, as well as of the related observation methods. A more consistent application of standards and structured templates for documentation will lower the development costs and ensure portability of the methods and tools to monitor farming practices. Another important aspect for the national authorities charged with implementation is the data access. The ICT infrastructure need careful consideration and planning. The presented four use cases were considered by the stakeholders as a significant step towards filling the gaps and addressing the above-mentioned challenges.

The methods and prototypes for monitoring farming practices, developed to support practical solutions, were built upon the vast experience from the past (OTSC, CbM). The weekly observations provided by the optical Copernicus Sentinels, combined with the high spatial and spectral resolution, offers the opportunity to detect and capture a range of agricultural activities in near-real time. The consistency and standardization of the satellite capturing methods enable the multiannual tracking of various phenomena such as land abandonment and afforestation, in interoperable manner using any other available spaceborne (or even airborne) sensors. , The satellite-based monitoring resolves many of the logistic difficulties considered be an obstacle to the higher environmental ambition of the current EU CAP. The Sentinel signal is most useful when it is derived from a predefined spatial object reflecting the individual unit of management, as generated through the Geospatial Application. This is because in these conditions, information extraction can be accurately targeted to information needs within the local context. Copernicus Land Monitoring Services (CLMS) could act effectively as a source of complementary data and information on the spatiotemporal aspect of land cover changes. Additionally, CLMS could offer wall-to-wall application ready data and thematic information, facilitating the portability of local solutions in a trans-boundary context.

A key success factor towards effective and efficient monitoring of farming practices will be the engagement of the technical community. A community of practice with all actors and stakeholders is essential. Working hand-in hand within that community will allow tackling challenges one party alone cannot address.

Future work in relation to farming practices could involve:

- Defining the farming practices with a positive impact on environmental and climate that can be monitored via manifestations on the parcel,
- Identifying, analysing, and formulating the physical phenomena behind these practices and develop a proof-of-concept for capturing the physical phenomena by applying observation methods. A special focus could be placed on complex agricultural management practices, such as under silvo-pastural systems.
- Developing the methods for the translation of carbon farming practices into scenarios that reflect the required activities to conclude on the relevant information needs. It also builds upon the outcomes of the SEPLA project, especially on the "IACS carbon theme" and the proposed structure for information handling at the agricultural parcel level.
- Defining the approach for the selection of the appropriate observation methods (satellite or field-based) and for setting the relevant data capturing protocols. It should also address the quality check of the

evidence collected, where relevant, and validate the outcomes. Combining image processing with artificial intelligence techniques will likely provide additional information aspects on the monitored phenomena.

These insights will increase the efficiency of the monitoring process and complement the information on land cover patterns with analyses of potential dynamic processes (such as pollination or carbon storage) associated with the identified land cover pattern. Complementary technologies, such as UAVs, GNSSs, robots, and smartphone cameras, could further increase the efficiency of the resulting system.

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List of abbreviations

CAP	Common Agricultural Policy
CbM	Checks by Monitoring
CIS	Critical Information System
CLC+	Corine Land Cover Plus
CLMS	Copernicus Land Monitoring Services
CS	Check Section of CAP Strategic Plan
IUCN	International Union for Conservation of Nature
DG AGRI	Directorate-General for Agriculture and Rural Development of the European Commission
DG CLIMA	Directorate-General for Climate Action of the European Commission
DG ENV	Directorate-General for Environment is a Directorate-General of the European Commission
EAGLE	EIONET Action Group on Land monitoring in Europe
EBCC	European Bird Census Council
EC	European Commission
ECA	European Court of Auditors
EEA	European Environment Agency
EGD	European Green Deal
EO	Earth Observation
EU	European Union
FAO	The Food and Agriculture Organization of United Nations
FBI	Farmland Bird Index
FOI	Future of Interest
GAEC	Good Agricultural and Environmental Conditions
GDOŚ	Generalna Dyrekcja Ochrony Środowiska (General Directorate for Environmental Protection, Poland)
GSAA	The Geo-Spatial Aid Application
GTCAP	Geodata and technologies for the Common Agricultural Policy
IACS	Integrated Administration and Control System
IMAP	Integrated modeling platform for agroeconomic and resource policy analysis
ISO	International Organization for Standardization
LC	Land cover
LCCS	Land Cover Classification System
LCLU	Land Cover/Land Use
LCML	Land Cover Meta Language
LULUCF	Land Use, Land Use Change and Forestry
LPIS	Land Parcel Identification System
JRC	Directorate-General Joint Research Centre of the European Commission
MAES	Mapping and Assessment of Ecosystems and their Services
MARS	Monitoring Agricultural Resources
MS	Member State

NDVI	Normalized difference vegetation index
N2K	Copernicus Natura 2020 Products
PECBMS	Pan-European Common Bird Monitoring Scheme
PMEF	Performance Monitoring and Evaluation Framework
R	Result Indicator
RS	Remote Sensing
S1	Sentinel 1
S2	Sentinel 2
SAR	Synthetic aperture radar
SO	Strategic Objective
SEPLA	Satellite-based mapping and monitoring of European peatland and wetland for LULUCF
UML	Unified Modeling Language
WP	Work Package

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