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Deliverable 2.2

EO-driven Essential Variables

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1. Executive summary

This report corresponds to the deliverable D2.2 ("EO-Driven Essential Variables") that is the final output of Task 2.2, within ECOPOTENTIAL Work Package 2 (WP2, "Conceptual Scientific Framework"). It provides a general conceptual approach for the application of Essential Variables for the monitoring of different thematic areas (e.g. biodiversity, climate, ecosystems) and applies this framework to a set of 15 ECOPOTENTIAL storylines. These Storylines focus on internationally recognised Protected Areas in Europe, European Territories and beyond, including mountain, arid and semi-arid, and coastal and marine ecosystems. Following the work previously developed in the Deliverable 2.1 and building on the experience gained from implementing this framework across realms, this Deliverable goes beyond previous work by doing a systematic review across Storylines and by identifying the major challenges that underplay the general application of the framework here presented. This report provides recommendations on how Essential Variables can be used to complement/fill local knowledge gaps for the monitoring and management of Protected areas.

A significant aspect is the bottom-up approach followed here, that contrasts with the top-down and global orientation of the current development of the essential variable framework. The followed bottom-up approach can therefore strengthen the role that conservation sites can play in building a conservation monitoring network across scales, in line with the ambitions of both ECOPOTENTIAL and GEO BON. The essential variables were developed using experts as the centre of decision making (Figure Aa) and focussed on producing lists of variables that were created according to data availability and the experts' interpretation of their value for monitoring change. More recently, this approach was substituted by the recognition that users' needs had to be reflected in the identification and selection of these variables (Figure Ab). Examples include the matching of essential variables with the Sustainability Development Goals and/or the Aichi Targets (Geijzendorffer et al., 2017; 2015) Nevertheless, this approach still placed the centre of decision making on the experts and also with the final output being a list of variables that would be the priority for monitoring. Within ECOPOTENTIAL we developed and implemented a question-oriented framework that focuses on system description, including both biotic and abiotic components (Figure Ac) and, although it highlights the role of user needs, it is not limited just by current data availability but rather by current knowledge of the system dynamics.

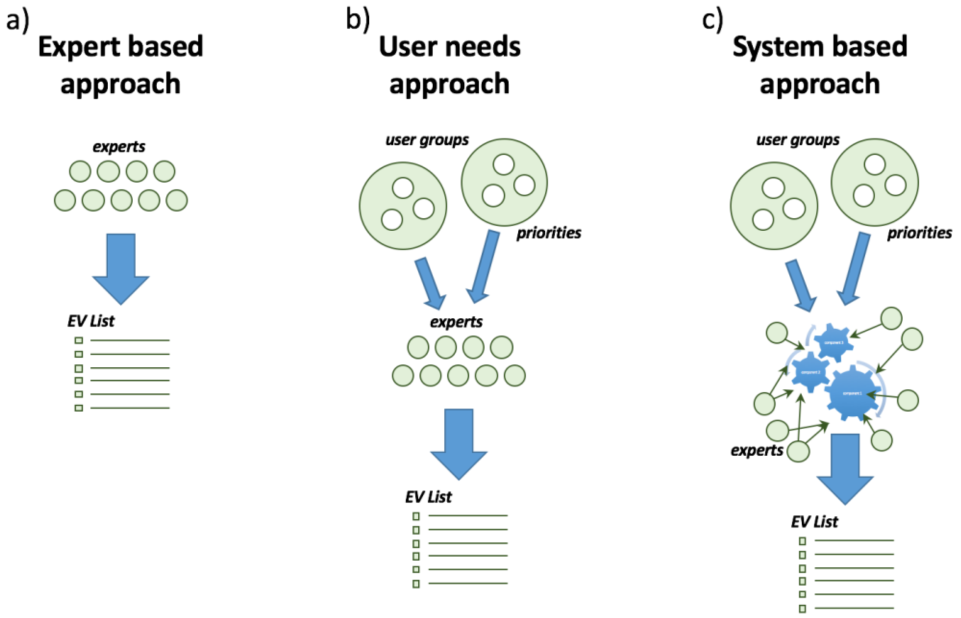


***Figure A** different approaches implemented to obtain essential variables lists: a) expert based approach; b) user needs approach; and c) system based approach.*

In the end, this approach also aims to get a variable list but opens up the process to a wider group of stakeholders, because it requires a system description, and allows to develop a multi-scale exercise that focuses on the understanding of the systems described.

Across the different Storylines a shortlist of seven essential variables were obtained based on the identification of the same variable across storylines, i.e. across questions, conservation goals. This shortlist includes "Ecosystem extent and fragmentation", "Precipitation", "Population abundance", "Taxonomic diversity", "Land use", "Land cover", and "Net primary productivity". The selection of these variables will be used to inform other exercises and WPs within ECOPOTENTIAL and will also frame part of the development of the work program. It is important to notice that many, if not all, of these variables already inform critical modelling aspects related to the quantification and understanding of ecosystem service provision. At the same time, this deliverable describes how, given current developments, essential variables will be integrated within the remote sensing architecture developed within ECOPOTENTIAL. Nevertheless, the selection of these essential variables was not limited to remote sensing approaches and included also *in situ* relevant data.

The results highlight the need and opportunity for this framework to contribute to:

i) the optimization of logistic and financial resources;

ii) make measurements comparable across conservation goals and protected areas;

iii) optimize the use of modelling approaches;

iv) identify capacity building needs of protected area managers' researchers and other practitioners;

v) give a direct reply to high level conservation policy reporting needs.

At the same time, it underlines the issues related to the scalability and cross comparison of datasets. This is particularly relevant for datasets that are normally collected without a specific focus on comparability across sites, regions or nations. Future work will pick on these identified knowledge gaps and will develop guidelines to overcome these issues across protected areas and regional boundaries.

2. Introduction

2.1 Main objectives

Deliverable 2.2 comes at a phase of ECOPOTENTIAL where concrete links between in-situ and remote sensing monitoring products are being explored and described in relation to specific conservation goals and/or research questions. This phase provides the possibility to do a comparative study across protected areas/storylines investigating common traits of conservation monitoring across the wide range of Europe's environmental gradient. This comparative analysis allows us to discriminate not only across ecosystem types but also across realms, ultimately providing a strong contribution to the definition of monitoring systems that target specific conservation goals (targeted monitoring) and that at the same time provide valuable information to monitor biodiversity and ecosystems across boundaries (surveillance monitoring).

Following the developments made in Deliverable 2.1, using essential variables, this Deliverable assesses all available ECOPOTENTIAL Storylines and, with the direct involvement of the partners and conservation managers responsible for each storyline, allows to:

i) Describe the main conservation goals/research questions that rise from each storyline;

ii) Identify the most relevant causal relations that allow to describe the processes behind the conservation goals/research questions; and

iii) Provide a functional representation of the main data flows that allow to monitor and assess a given conservation status or reply to a given research question.

Finally, it will address the availability of monitoring strategies (from in-situ to remote sensed monitoring) that target the identification of remote sensing products/methods that can be directly used and operationalized by conservation managers.

2.2 Identification and role of essential variables in the context of European protected areas

Protected areas face multiple challenges that go beyond the conservation of specific species against a single threat. To be able to manage this complex challenge, enhanced knowledge is required about all relevant aspects of a given ecosystem and to be able to identify and monitor the conservation status and main drivers/pressures related to the ecosystem in question. In addition, for many protected areas in Europe, conservation objectives are larger that conservation areas and even national borders. By identifying a core, common, set of variables that allow to monitor current conservation goals we aim to take advantage of the latest advances in Earth Observation methods, approaches and technologies in order to support a European, cross boundary, Earth Observation monitoring network that focuses on conservation areas and their challenges.

2.2.1 The role of GEO in the definition of essential variables by Societal Benefit Areas

The concept of Essential Variables (EVs) is increasingly used in Earth Observation communities to identify those variables that have a high impact to detect biodiversity and ecosystem change and should have priority in designing, implementing and maintaining observation systems and making data and products available.

GEO Societal Benefit Areas (SBAs) can contribute to the design of EO based indicators useful for Sustainable Development Goals (SDG) targets. Importantly, the community processes in several SBAs to identify relevant EVs can be a template for a system-based approach to develop indicators based on available sets of EVs. The review of the set of expert-based EVs developed in several GEO communities provided in *ConnectinGEO 2016, D2.2. EVs current status in different communities and way to move forward* (http://ddd.uab.cat/record/146882) revealed that there is considerable overlap between EVs identified by different communities. In particular, the core set of EVs common to several communities should be considered for complementary SDG indicators. This strength the need for system-based approaches that combine several dimensions of the social-ecological system in order to identify the variables that are more relevant, and therefore essential, to the description of such systems.

The total number of EVs reviewed within ConnectinGEO was of 118. Some of the EVs were actually not just a single variable, but rather a cluster of several variables. These were grouped in seven of the new GEO Societal Benefit Areas (SBAs), namely Biodiversity and Ecosystem Sustainability, Disaster Resilience, Energy and Mineral Resources Management, Food Security and Sustainable Agriculture, Public Health Surveillance, Sustainable Urban Development, Water Resources Management, plus Climate as a cross-cutting thematic area in the new GEO Work Plan Strategy. Within those GEO SBAs those variables were further regrouped in the following 11 themes (adopted for the *ConnectinGEO workshop "Towards a sustainability process for GEOSS Essential Variables", Bari, 11-12 June 2015*): Agriculture, Biodiversity, Climate (and Carbon cycle), Disasters, Ecosystems, Energy, Health, Human Settlements, Oceans (and Marine Ecosystems), Water and Weather.

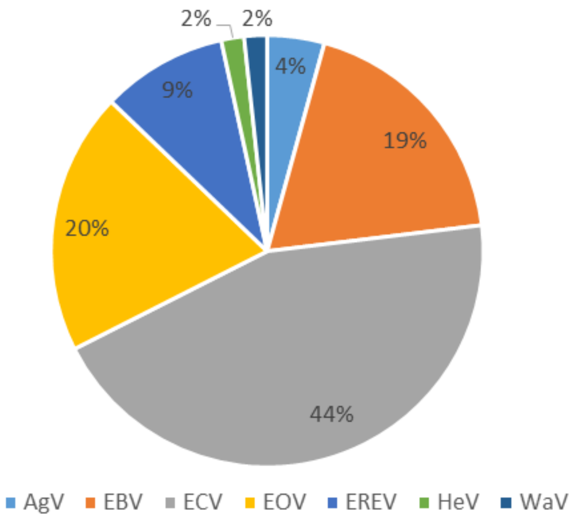


Figure 1. Percentage of EVs by theme

Following that analysis, it was concluded that the community that has defined the highest number of EVs is currently the Climate group, led by the Global Climate Observing System (GCOS), covering – with its

ECVs (Essential Climate Variables) – one third of the total number (see

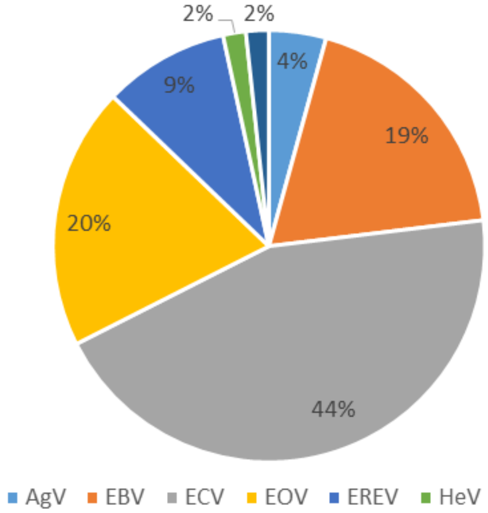


Figure 1). Moreover, most of the ECVs are relevant to the other GEO SBAs or themes. Other communities already working on a mature set of EVs are Weather, led by the WMO and the Global Atmosphere Watch (GAW) and Ocean, led by the Global Ocean Observing System (GOOS). The EV discussion and related work is growing fast in the Biodiversity and Energy communities, while in other areas, like Agriculture, Disasters, Ecosystems, Health, and Urban Development, the work on specific EVs is still in the initial stage.

Out of the 118 EVs listed, many are relevant to more than one area. In particular, the most often listed variable is Temperature, in the three different systems' components (air, water and soil). Then there is Carbon in its different forms, like CO_2 in air, CO_2 partial pressure in water, and all the relevant different forms of carbon along the carbon cycle in the different system components. The next variable is Pressure, again related to different systems' components, like atmosphere, sea and water chemical composition. Subsequent variables are (again in different system components) Wind, Solar Irradiance, Precipitation, Humidity, as well as some water specific variables, like Ocean Acidity and Oxygen. It is evident that the majority of these variables are related to the Climate (and Weather) and Water (particularly Ocean) areas. In particular, most of the ECVs are relevant to other GEO SBAs, and a couple of them (Temperature and Precipitation) are virtually relevant to all of the new GEO SBAs, being affected by, and affecting (directly or indirectly and at different level) all of the following areas: Agriculture, Biodiversity, Climate, Ecosystems, Disasters, Energy, Health, Water, Weather, and also Urban Development.

2.2.2 Using variables to measure, model and monitor protected areas

Monitoring biodiversity, ecosystems and the services provided by them often involves the implementation of expensive monitoring programs that combine in-situ surveillance from different sources and entities. When establishing a monitoring program, conservation managers face the challenge of balancing available financial and human resources between monitoring and operational activities. This often results in reduced monitoring programs with limited usefulness and encompassing nature. To overcome these problems, managers often choose to instead focus their attention on key species or conservation objectives, overlooking a more complete understanding of the system they are describing. At the same time, the conservation objectives devised for each specific protected area should be in balance with, and contribute for, other levels of conservation strategy, including regional/national conservation policies and international conservation goals (e.g. Aichi Targets and Sustainable

Development Goals). This means that monitoring efforts should be able to contribute not only for the protected area goals but also to higher level conservation goals.

The combination of these two aspects emphasizes the need to identify specific variables that allow for the monitoring of a particular ecosystem or species, not in one site, but across multiple protected areas, in order to respond to the needs of overarching conservation goals. As highlighted before, the concept of Essential Variables focuses on identifying these variables across themes, realms and institutional boundaries. In the case of protected areas, using this approach would contribute directly to:

i) **optimizing logistic and financial resources:** protected areas have usually important constraints in terms of financial and logistic resources and the identification and prioritization of specific (essential) variables is an important step to reduce budget deficits. At the same time, this implies a sufficiently detailed description of the ecological processes related to a specific conservation goal/research question across multiple sites.

ii) **making measurements comparable across conservation goals and protected areas:** by establishing a concrete set of essential variables for a specific conservation goal, managers ensure a comprehensive description and monitoring of that goal. By implementing the same approach to several conservation goals, managers guarantee that the benefits generated by a monitoring program can be multiplied across conservation goals, making management and monitoring more effective.

iii) **optimizing the use of modelling approaches:** in many cases (e.g. the ones related to ecosystem functioning and services variables) there is an inherent difficulty to obtain direct measurements of specific ecological variables. In several cases researchers and managers rely on modelling approaches to overcome this issue. By implementing an approach that allows to identify essential variables it is also possible to identify shared modelling needs and be a precursor to the development and implementation of comprehensive modelling frameworks that consider several reporting needs at the same time.

iv) **identifying capacity building needs:** identifying essential variables can help to target capacity building needs as it allows to first focus on the relevant variables to describe a specific system, and then identify specific technical, thematic or scientific subjects that need to be successfully addressed.

v) **providing input to high level conservation policy reporting needs:** establishing a concrete group of variables that can be commonly assessed across conservation goals and across protected areas allows local monitoring systems to contribute directly to national and international monitoring efforts. This decentralized approach needs specific guidelines that structure and standardise monitoring efforts (e.g. across a given country or across Europe) but has the potential to maximize the outcomes from local monitoring efforts in protected areas to go beyond borders, ecosystem types and realms.

As mentioned before, developing and implementing a monitoring system that responds to the needs of protected areas managers implies that a significant amount of information is collected, organized and made available. Today, conservation managers can rely not only on in situ data but also on remote sensing observations to provide information relevant to the protected areas. This includes most of the available satellite products currently available (e.g. Sentinel or Landsat) and other institutional monitoring programs (e.g. meteorological information based on a combination of stations and satellite data). If the connection to these other data resources is considered, the identification of essential variables is even more critical to sort out the most relevant datasets available, and needs to be coupled with the ability to identify the specific data source that better represents a given variable.

2.2.3 The ECOPOTENTIAL storylines in the context of European protected areas

The ECOPOTENTIAL Protected Areas (PAs) are distributed over the whole continent of Europe, including European islands in the Mediterranean and overseas (Fig. 2). These PAs sample the great variety of ecological conditions and address the most important biogeographical regions across Europe (Fig. 3). A range of particularly vulnerable ecosystems such as semi-arid drylands, coastal areas and mountain ecosystems is included. ECOPOTENTIAL is aiming to assess the state and future development of these sites based on existing information and data, making best use of Remote Sensing observations and developing ecosystem models capable to incorporate Earth Observation data and aimed at predicting future ecosystem conditions. Through this approach, a large portion of European biological diversity is addressed.

Here, we illustrate the representativeness of the ECOPOTENTIAL PAs for the conditions of the European network of protected areas and also for the overall climatic conditions and biogeographical regions of Europe. This overview is mainly based on the Database on National Designated Areas (EEA 2016) and on the very comprehensive World Database on Protected Areas (IUCN-WCPA and UNEP-WCMC 2016). Please note that a single ECOPOTENTIAL PA may comprise more than one protected area extracted from these databases. For instance, the Wadden Sea and Dutch Delta as it is part of ECOPOTENTIAL includes several protected areas of various designations (Fig. 2). Moreover, almost all the single ECOPOTENTIAL PAs belong to different categories simultaneously (e.g., National Parks and World Heritage and Natura 2000 sites). Therefore, as here we analyze and count the PAs by category and not by geographical site, the number of protected areas that are included in this analysis and assigned to ECOPOTENTIAL differs from the number of geographical sites that take part to ECOPOTENTIAL as the same geographical site may be counted more than once.

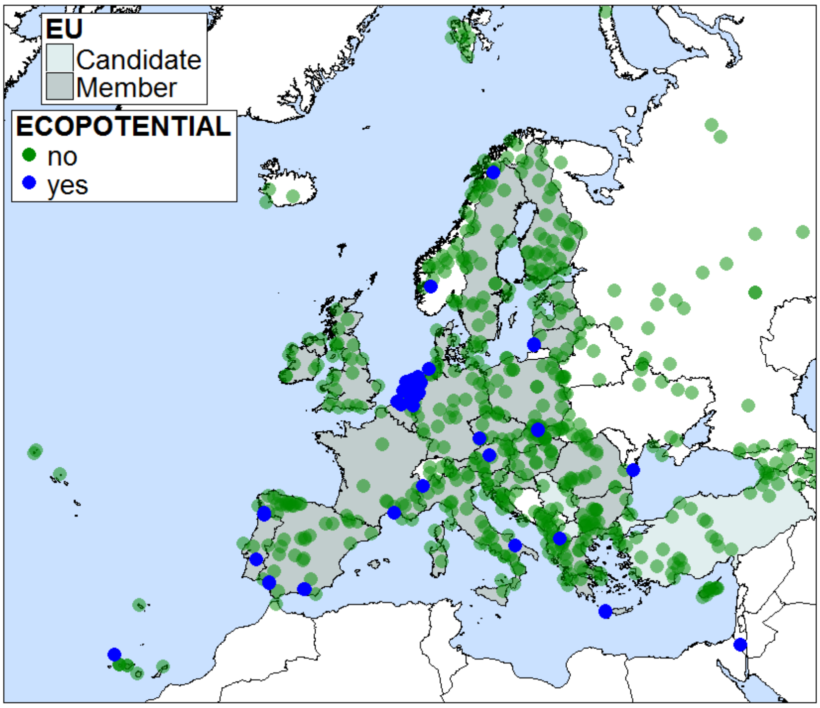


Figure 2. Spatial scatter of European protected areas. National Parks, UNESCO Man and Biosphere Reserves, and Natural UNESCO World Heritage Sites are shown (green), as well as the distribution of ECOPOTENTIAL Protected Areas of these and additional categories (blue). Additional categories of protection comprise Natura 2000 sites, Nature Reserves, and Cultural and Mixed UNESCO World Heritage Sites. The PA “Wadden Sea and Dutch Delta” in ECOPOTENTIAL actually comprises several PAs.

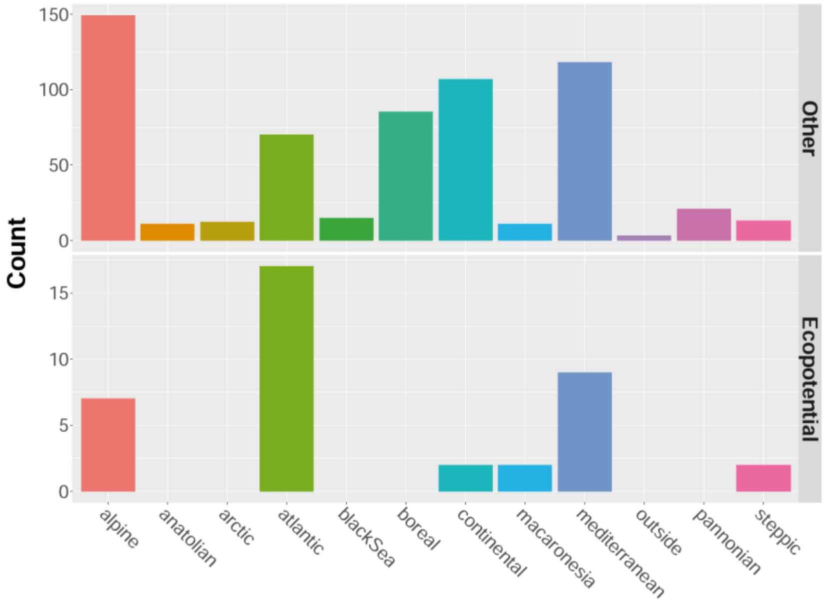


Figure 3. Assigning European protected areas to European Biogeographical Regions (EEA 2015). Upper row represents all European protected areas designated as National Parks, UNESCO Man and Biosphere Reserves, and Natural UNESCO World Heritage Sites except of those within ECOPOTENTIAL. Lower row represents European protected areas within ECOPOTENTIAL only.

The climatic space of the European continent and of the ECOPOTENTIAL PAs is calculated based on 2.5 arc min grid cells (approx. 5 km), excluding Kazakhstan and Greenland, but including Iceland, Svalbard, Canary Islands, Açores, Turkey, Russia to the Ural Mts. Sources for climatic information are Hijmans et al. (2005) for Annual Mean Temperature, Annual Precipitation, Jones et al. (2009) for Solar radiation and Trabucco & Zorner (2009) for Potential Evapotranspiration.

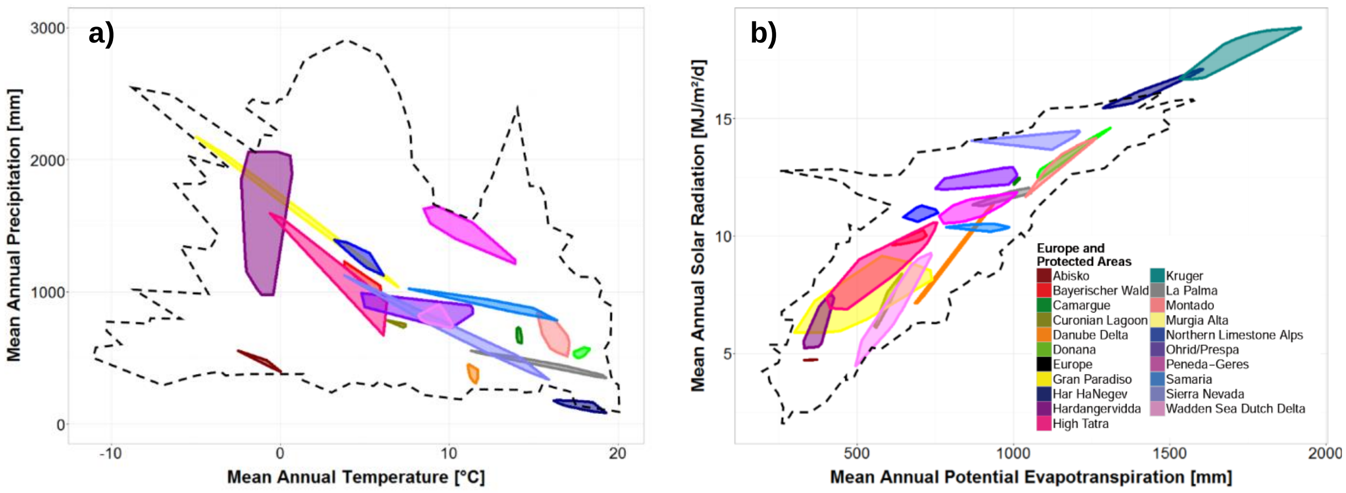


Figure 4. Climatic conditions that are covered by ECOPOTENTIAL protected areas within the European continent in terms of: a) mean annual precipitation and temperature based on time period 1960-1990 (Hijmans et al. 2005) and b) mean annual solar radiation (based on time period 2000-2010, Jones et al. 2009) and mean annual potential evapotranspiration (based on time period 1950-2000, Trabucco & Zomer 2009). For comparison, also Kruger (South Africa) and Har HaNegev (Israel) are included. The dashed line represents the boundary that envelopes the mean annual precipitation and temperature values for Europe.

The results of our analysis show that the selection of ECOPOTENTIAL PAs properly represents several characteristics of European terrestrial PAs; a paper containing a full discussion is in preparation. Generally, the selection of ECOPOTENTIAL PAs satisfies the criterion to assess a wide range of characteristics of the terrestrial environments of Europe. The range of European climatic conditions is correctly captured (Fig. 3 & 4): an important fact in face of the current and expected climatic changes. Some deficit has been identified in representing arctic environments. Additional needs may exist in representing boreal forest ecosystems, but most PAs in that type of environment do not comply to the major criteria of ECOPOTENTIAL selection, such as global importance. For most of the PAs participating in ECOPOTENTIAL, a set of storylines were defined in the first six months of the project. Such storylines are narratives describe the real-life issues of the project's Protected Areas.

The storylines focus on one particular ecological aspect relevant for the conservation of one or more Protected Areas, describing the ecosystem services provided, the cross-scale topics that need to be addressed, the demands for Earth Observation data to be used in ecosystem modelling, for future protections, as well as for policy and capacity building. They are aimed to be broad yet locally relevant, engaging with stakeholders and decision-makers, forming the basis for further operational work in the field. The storylines are co-designed with the Protected Area staff and managers to respond to specific, user-driven questions and they will evolve over time following the demands of stakeholders and as new knowledge is generated.

Currently, about 15 Storylines are active, ranging from high-altitude grasslands as life support systems to wild herbivores to the distribution of Cetaceans in the Pelagos Sanctuary between France, Italy and the Principality of Monaco.

The storylines are intended to both address specific issues of relevance to the Protected Areas of the project, and to become pilot studies to be used for a methodological approach to how scientific research and the use of Earth Observations can support concrete ecosystem management and conservation goals.

Each Storyline includes a part devoted to the definition of what are the critical variables for the problem addressed, that is, a minimum set of variables whose knowledge is necessary for characterizing the ecosystems under study and their temporal changes. Such locally-defined critical variables can then be framed in terms of Essential (Biodiversity, Climate, Ocean) Variables (EVs), with the aim of detecting whether and how EVs can be used to describe such applied goals, whether there are some EVs that are common to many different storylines and/or types of ecosystems, how such EVs can be detected and measured through Remote Sensing and in situ data, and finally whether new EVs (not yet included in the standard lists) are necessary to describe ecosystem functioning. In this way, a link between the practical needs and the Essential Variables approach has been established and explored.

2.2.4 Important but not essential: accommodating for Protected Area heterogeneity

As described in section 2.2.3., European protected areas preserve a considerably wide range of ecosystems from marine areas to high altitude mountains. This diversity of ecological and environmental conditions constitutes a major issue when trying to establish a cohesive set of essential variables. Independent of that, several research papers/projects (e.g. COnnectingGEO, EUBON) have been able to identify variables that can be considered essential for a particular thematic area (e.g. essential biodiversity variables) or that can even be essential across several of them (e.g. ecosystem extent). Despite these efforts, it is important to underline that for different levels of decision making (i.e. from protected area management to global conservation policy) essentiality can have slightly different representations and eventually consider different type of relevant information. For example, for a given protected area manager, relying on citizens' science data on species distribution may not be an option while for global policy making this could be an important source of data that can be used to reduce the limitations of current official species distribution datasets. At the same time, water dynamics may be essential for a given protected area (e.g. a wetland) but not at the level of global policy making.

From this view, we have to find ways to structure local (i.e. protected area based) monitoring programs in a way that these could be relevant and adequately inform different levels of decision making from local to global. The first challenge that we face with this approach is that designing such monitoring programs cannot be done accurately from a top-down approach if local concerns and engagement are not taken into consideration. By default, a purely top-down approach imposes high level needs without careful consideration regarding local utility, implementation and operational capacity. This has the potential to disrupt and place intense pressure on protected areas resources making monitoring systems unresponsive to protected area needs and resulting in practically ineffective approaches. Instead identified variables should be relevant for the lowest level of decision making (in this example the protected area level) and hierarchically aggregated to the highest level of decision making. This approach would limit the identification of variables that are only relevant for a given level of decision making and also allow for the identification of variables that are essential across levels of decision making.

By identifying essential variables bottom-up from the protected areas needs, monitoring systems become more operational and more easily justified and maintained. Following this approach, it is expected that protected areas will identify a higher number of essential variables for the pursuit of their conservation goals than the ones identified at a higher level of decision making. From level to level, although important, some variables lose their essentiality aspect, becoming less relevant for the assessment of each levels' conservation goals. This highlights the need to have a collaborative approach and constructive dialog between the different levels of decision making that allows to establish monitoring standards that go across ecosystems, borders and thematic areas.

In general, a combination of the the bottom-up and top-down approaches would probably be ideal, because top-down systems can identify important knowledge gaps that would remain unnoticed if one relies completely and solely on local perceptions. This is what ECOPOTENTIAL is trying to do, offering Remote Sensing products for questions that spring from local needs but also offering new knowledge that managers may have not realized they could have access to and how it could be used.

2.2.5 The three-tiered approach identify Essential Variables relevant at different scales

Each protected area has its own set of variables that are needed to monitor its progress and ecosystem state. Essential protected area variables (EPAV) are those critical variables that are common to all protected areas. To organize the range of variables used across PAs and to distill the essential variables from these, we use three tiers of variables:

1) ESSENTIAL PROTECTED AREA VARIABLES (EPAV): those that are common to all PAs,
2) NEAR-ESSENTIAL PROTECTED AREA VARIABLES (NEPAV): those that are similar across many PAs, but may differ in the units used, temporal or spatial scale, or other dimensions. These variables could become EPAVs if we broadened the definition of existing EVs or if PAs were to agree to changes that would achieve a common definition across all PAs.
3) ANCILLARY PROTECTED AREA VARIABLES (APAV): those that are relevant for only a subset of protected areas.

To illustrate these three tiers, consider four fictional storylines (Table 1). All of the storylines include Population Abundance as an Essential Variable for their protected area. Population Abundance, then, would be considered as a Tier 1 Candidate for an Essential Protected Area Variable.

All four fictional storylines consider some measure of air temperature but three storylines indicated upper air temperature as an EV and two PAs cited atmospheric surface temperature as an EV. Air temperature, broadly defined, would be a candidate for a Near-Essential Protected Area Variable. We may find that ESSENTIAL VARIABLES exist across PAs within a geographic realm (e.g. terrestrial PAs versus marine PAs), or within a BIOME (e.g. PAs in mountain forests, deserts, and open ocean ecosystems) but not all will be shared across all PAs. For instance, CO_2 is cited by all four fictional PAs as an essential variable, but Storyline 2 – a coastal storyline – only indicates that the partial pressure of CO_2 in the ocean water column is of interest as an essential variable. In this case, while CO_2 broadly defined could be considered a Near-Essential Variable for all PAs, it might make more sense to consider CO_2 (atmosphere) as a terrestrial Essential Protected Area Variable. Harmful algal bloom is suggested as a potential Essential Variable for only one protected area and thus would be considered an Ancillary Protected Area Variable.

Table 1. A Three-Tiered Organization of Proposed Essential Variables for Protected Areas

	Population abundance (species population)	pCO2 (ocean surface)	CO2 (atmosphere)	Temperature (atmosphere surface)	Temperature (upper air)	Harmful Algal Bloom
Storyline 1 (mountains)	✓		✓		✓	
Storyline 2 (coastal)	✓	✓		✓		✓
Storyline 3 (desert)	✓		✓	✓	✓	
Storyline 4 (boreal)	✓		✓		✓	
Tier 1: Essential Protected Area Variable	EPAV: Population Abundance		Terrestrial EPAV: CO2 Atmosphere			
Tier 2: near Essential Protected Variable		NEPAV: CO2	NEPAV: Temperature			
Tier 3: Ancillary Protected Area Variable				APAV: Ocean Current		

3. Identification of essential variables across realms

Building on what was developed in Deliverable 2.1, here we followed a bottom-up approach starting from the needs identified in the storylines that were developed within ECOPOTENTIAL. In this context, we collected information of 15 different storylines and went through five steps to fully develop an analysis framework and to identify not only the essential variables needed but also the relevant data sources. These steps are explained below.

The use of narratives contributes to the identification of monitoring priorities that target specific system components critical to the understanding of the social-ecological system being described. Such narratives have been widely used to facilitate communication between stakeholders engaged in biodiversity conservation (e.g. Rounsevell *et al.* 2006; Visconti *et al.* 2010) and beyond (Metz et al. 2007; Freshwater 2009). These narratives contribute to effectively describe the main aspects and causal relations within the social-ecological system being managed, including their related threats and drivers, and the key biodiversity and ecosystem elements and functions that are critical to meet the conservation goals set by stakeholders and managers. The use of narratives can help in the identification of monitoring priorities that target specific system components critical to the understanding of the social-ecological system being described. Therefore, these narratives have to represent the causal relations between the system components, connect to well described indicators, and rely on a concrete list of essential variables that allow for their assessment (Figure 5).

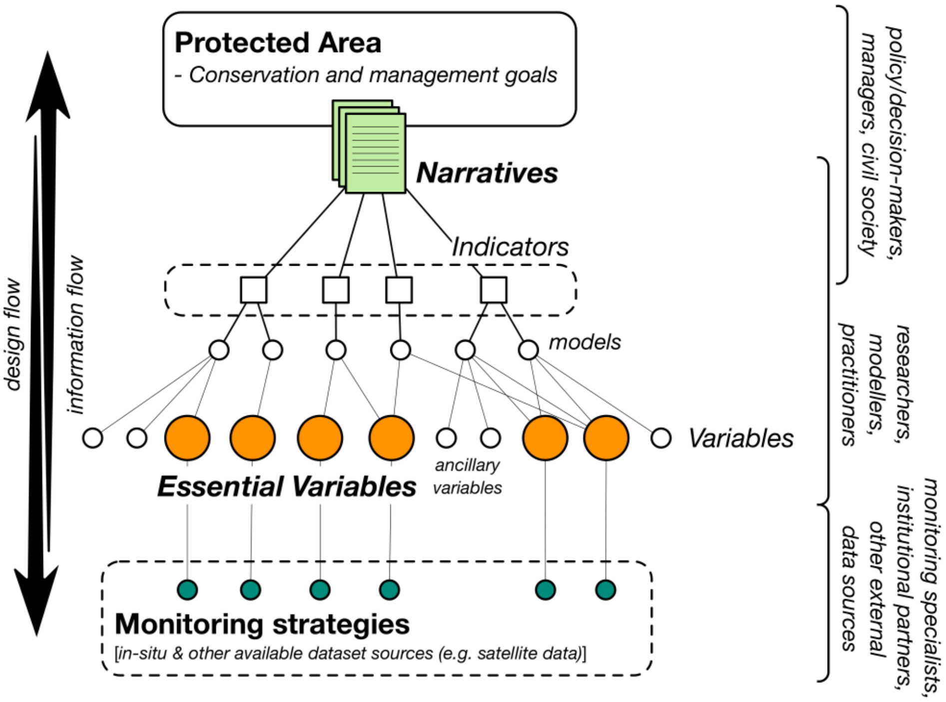


Figure 5. *Schematic representation of the process to identify essential variables and data monitoring strategies. Starting at the conservation goals defined for a given protected area, this process goes through the description of narratives that allow for the identification, description and cross-referencing of key indicators, and available models to create a short list of essential variables that allows to calculate the selected indicators. After close consideration of the available methods to measure the selected variables, a short list of data priorities is then created and monitoring strategies can then be defined.*

Indicators are used to assess the state and trends of the defined conservation goals and can be used to provide meaningful information to conservation managers and local/regional decision-makers. Therefore, indicators have to be defined jointly by decision-makers, managers, researchers, and the indicator developers in an interactive and interdisciplinary exercise. Once indicators and related **models** are selected and defined, the search for data for the variables (including essential variables) that allow for the computation of indicators can begin. It is important to underline that the same variable can, often, be used as input data for several models and indicators (e.g. topography for hydrologically related models), be used to support the narrative directly, and may even have conflicting interpretations (within different conservation areas) regarding progress towards specific conservation goals.

Once identified which of the used variable are essential, the **essential variables** need to be described, including the relevant spatial and temporal precision, accuracy, and extent. This will allow for the definition of monitoring strategies and significant data collection needs that may include not only the information already collected by the protected area itself, contributing to the definition of an *in situ* monitoring scheme, but also other information gathered from external data sources (e.g. satellite data, national geographic information systems, and even other *in situ* data from nearby areas, etc.). By focusing on a concrete, but limited set of essential variables that is absolutely necessary to monitor the trends of a given protected area, managers are able to collect a robust set of data, from within and beyond its boundaries, facilitating the creation of a regular time series of data suitable for analysis. This process will help to identify the potential technological, methodological, knowledge and capacity building needs that have to be addressed to ensure the timely and continued indicator implementation process.

The monitoring of social-ecological systems provides feedback to managers and helps to synthesize empirical observations regarding how the original narrative has emerged and might unfold in the future (Folke et al. 2005). Therefore, the process to identify essential variables is a priority setting process and not an exclusion process.

To render these concepts operational, storylines were used as illustrative examples and a set of broad criteria was set up to allow for the identification of essential variables across storylines, as no predefined lists of essential variables were given to any of the partners involved. We identified five selection criteria:

- ***EVs must be observable and sensitive to change:*** *EVs must include variables that can be monitored (within feasibility) using either in-situ or remote sensed approaches (or a combination of both) and should be sensitive to change in order to be part of a proper monitoring system. It is often the case that some variables, due to feasibility limitations, cannot be directly properly monitored and modelling strategies are implemented without diminishing their essentiality for the system description;*
- ***EVs can include core system variables:*** *corresponding to variables related to system elements that affect the entire system described (e.g. in the Pelagos example, whale distribution) and/or that are affected by a significant number of variables identified within the described narratives (e.g. in the Montado example, cork production);*
- ***EVs must be scalable:*** *the correct definition of EVs can ultimately go across the borders of conservation areas and allow for more systematic (e.g. national, international) monitoring schemes, remaining relevant across different spatial and thematic scales;*
- ***EVs can include variables that are unique to a given system or ecological process:*** *conservation areas include very diverse systems, often with unique traits that define their conservation status. Therefore, the identification of EVs can also include system specific variables that will hardly occur or have the same relevance in other distinct systems (e.g. cork production (Montado example) and whale distribution (Pelagos example));*

- ***EVs should be ecosystem agnostic:*** *although different types of instrumentation and/or data gathering methods may apply, variables should always be defined in a way that allows for a description of a given reality across ecosystems. As an example, species richness can be simply defined as the total number of species in a given place and moment in time. This simple definition can be extended across realms to the point that it is possible to obtain a spatially complete global map of species richness* (Leadley et al. 2014).

In previous research (e.g. Bojinski *et al.* 2014) the criteria for "essentiality" has already been established for the identification of EVs for climate and broad biodiversity classes. Here we move a step further in materializing the specific needs of conservation management, protected areas, and their use and application across scales and environmental conditions or realms. Thus, not all these criteria are mutually exclusive, but provide structured guidelines to orient the identification and definition of EVs within the scope of conservation monitoring.

Given the heterogeneity and the number of available storylines, we were not able to have critical mass to do an analysis per system, following Deliverable 2.1. Rather, we placed all storylines together in order to find high level commonalities that could be looked across protected areas and provide a systematic description of all ecosystems included in ECOPOTENTIAL.

3.1 Converting storylines to fully developed system representations

Evolving from Deliverable 2.1, we now included 15 storylines including seven mountain areas five marine and coastal areas and three arid and semi-arid areas that are representative of the wide range of conditions, conservation goals and research questions that are considered within ECOPOTENTIAL. These include the following Protected Areas:

1) Hardangevidda;
2) Peneda Gerês National Park;
3) Swiss National Park and Landshaft Davos;
4) Gran Paradiso National Park;
5) Ohrid/Prespa;
6) Sierra Nevada National Park;
7) National Park Kalkalpen;
8) Pelagos;
9) Wadden Sea;
10) Danube Delta;
11) Camargue;
12) Har Hanegev;
13) Kruger National Park;
14) Montado systems.

Following the Essential Variables approach, these storylines were described according to their main objectives, indicators, variables and data used to study and assess the defined objectives. The most relevant causal relations were also identified and a general system description was created to help steer the identification of essential variables across ecosystem types (Figures 7 to 21).

For this general description of each storyline, general guidelines were given to the selection of variables (see previous section for further details) but these guidelines did not intend to constrain the bottom-up process of describing the social-ecological system. Also, although several lists of essential variables can be found, the researchers and practitioners involved in the storylines were not asked to specifically follow any given list to allow them to identify variables according to their system description. Nevertheless, we asked that a definition was to be provided for each variable identified, allowing for an overall aggregation of the variables identified. This aggregation was made based on the list of essential variables from section 2.2.1 in an effort to harmonize between the initiatives of different European projects.

Hardangervidda

Hardangervidda National Park is the largest mountain plateau in Europe, located in southern central Norway. The landscape of the Hardangervidda is characterised by barren, treeless, and shrubby moorland interrupted by numerous lakes, streams and rivers, but the current projected warming may enable forest to recolonize the area if the grazing pressure is reduced. The main purpose of the National Park is to protect a section of a valuable high mountain plateau and its cultural environment, and to allow for sustainable grazing and outdoor activities, such as hunting, and hiking, while securing living areas for the stock of Wild Reindeer. Wild reindeer influence ecosystem processes (e.g. Olofsson et al. 2004), but are also for their economical and recreational value for hunters and landowners. Many factors are known to affect reindeer populations. Tourism and human infrastructure have been shown to affect reindeer migration and movement corridors directly and indirectly, in both the short and the long term (Panzacchi et al. 2013). Population fluctuations of reindeer are also affected by climatic variation, as high population growth rates have been linked to dry winters, and climate effects are probably more important at high population densities (Aanes et al. 2000). It has also been suggested that the suitability of winter pastures determines the effect that hunting has on population regulation, where reindeer with access to good winter conditions are regulated by hunting, and those with access to poor conditions are regulated by bottom-up processes (Tveraa et al. 2007). During the winter reindeer are dependent on finding lichen pastures not covered by snow and ice, while they rely on summer pastures particularly in the south and west of the National Park (Strand, Bevanger et al. 2006). Snow cover strongly affects lichen biomass and lichen heath development (Skogland 1978; Odland et al. 2014), and lichen cover is known to be reduced by high precipitation and altitude (Odland et al. 2014). High long term grazing pressure, particularly in combination with summer and all-year-round grazing is also known to reduce lichen biomass (Kumpula et al. 2014) . However, moderately grazed ridges have been suggested to be richer in species than un-grazed areas (Vistnes and Nellemann 2008).

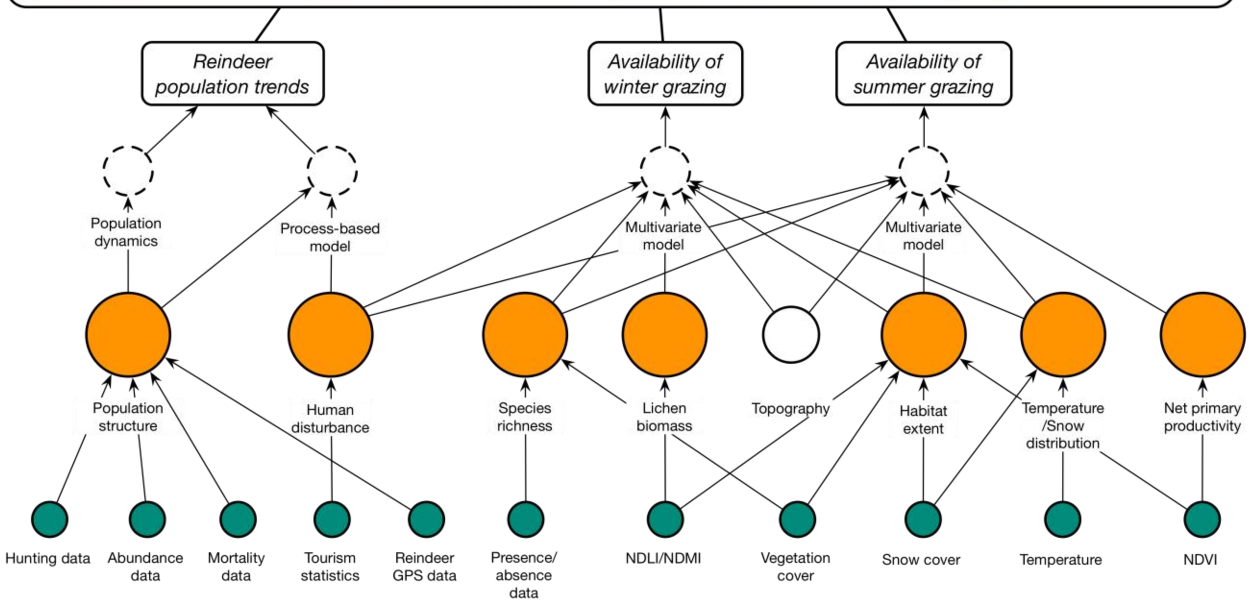


Figure 6. *Diagram representing the storyline developed for the Hardangervidda National Park, including the identification of essential variables at the storyline level.*

Peneda-Gerês National Park

Many mountain areas across Europe are undergoing rapid global change impacts. The interaction between factors, which have taken the form of loss, expansion and relocation of habitats, changes in phenology and physiology of vegetation, fire-vegetation dynamics, climate change, and invasion by non-native plants, among others, will have profound effects on biodiversity and ecosystem functioning, potentially compromising the supply of valuable benefits from mountain-protected areas. The **Peneda-Gerês National Park (Portugal)** represent a mountain-protected area, where the decline of the traditional agro-pastoral system of upland areas has enabled widespread scrub encroachment and produced changes in fire regimes, which may be aggravated under future climates. The socio-ecological transitions described above have been joined by a shift in the primary societal expectations from mountain areas; more specifically, that these expectations are nowadays mainly related to two groups of benefits: conservation of natural heritage, and supply of regulating and cultural ecosystem services. The supply of benefits from these two groups can be severely impacted by the condition and dynamics of vegetation cover, which is therefore seen as a promising proxy to inform on the state and trends of those benefits. Forcing models of selected benefits from the two above groups in the Peneda-Gerês protected area against four main drivers (land use (change), climate (change), fire regime, and invasion by non-native plants), with various socio-ecological scenarios related to the main drivers, and subsequent trade-off analyses, it would allow to identify ‘win-win’ solutions for the focal benefits.

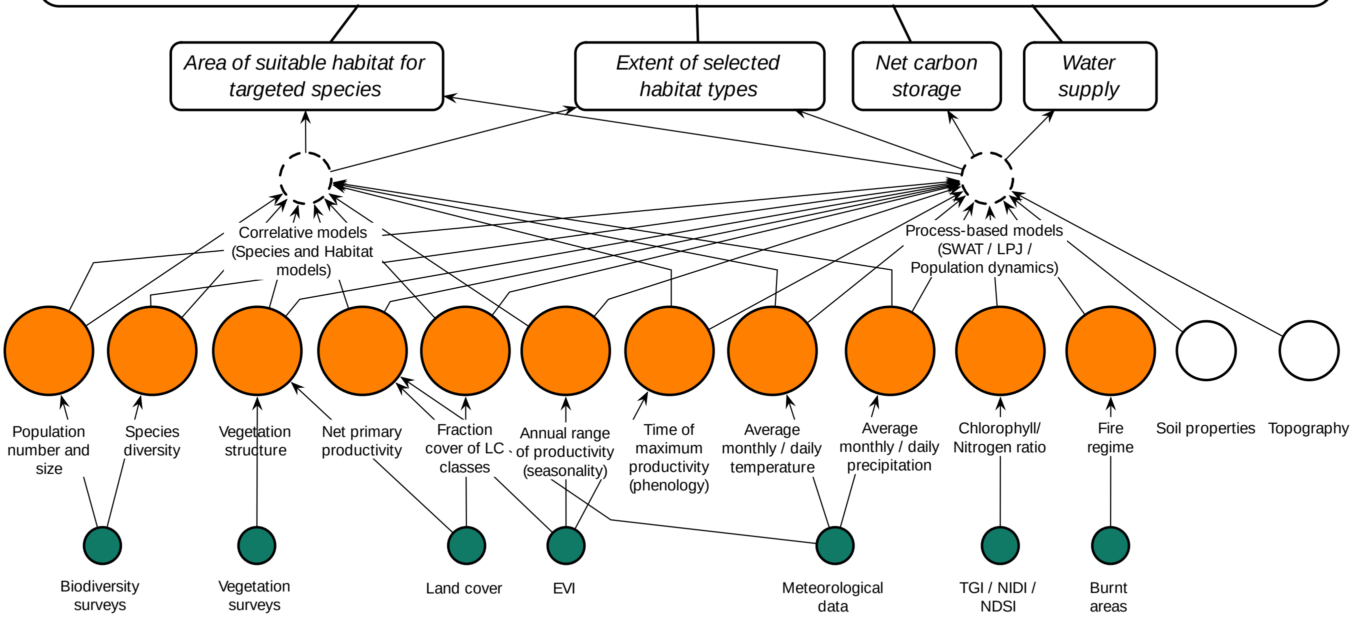


Figure 7. *Diagram representing the storyline developed for the Peneda-Gerês National Park, including the identification of essential variables at the storyline level.*

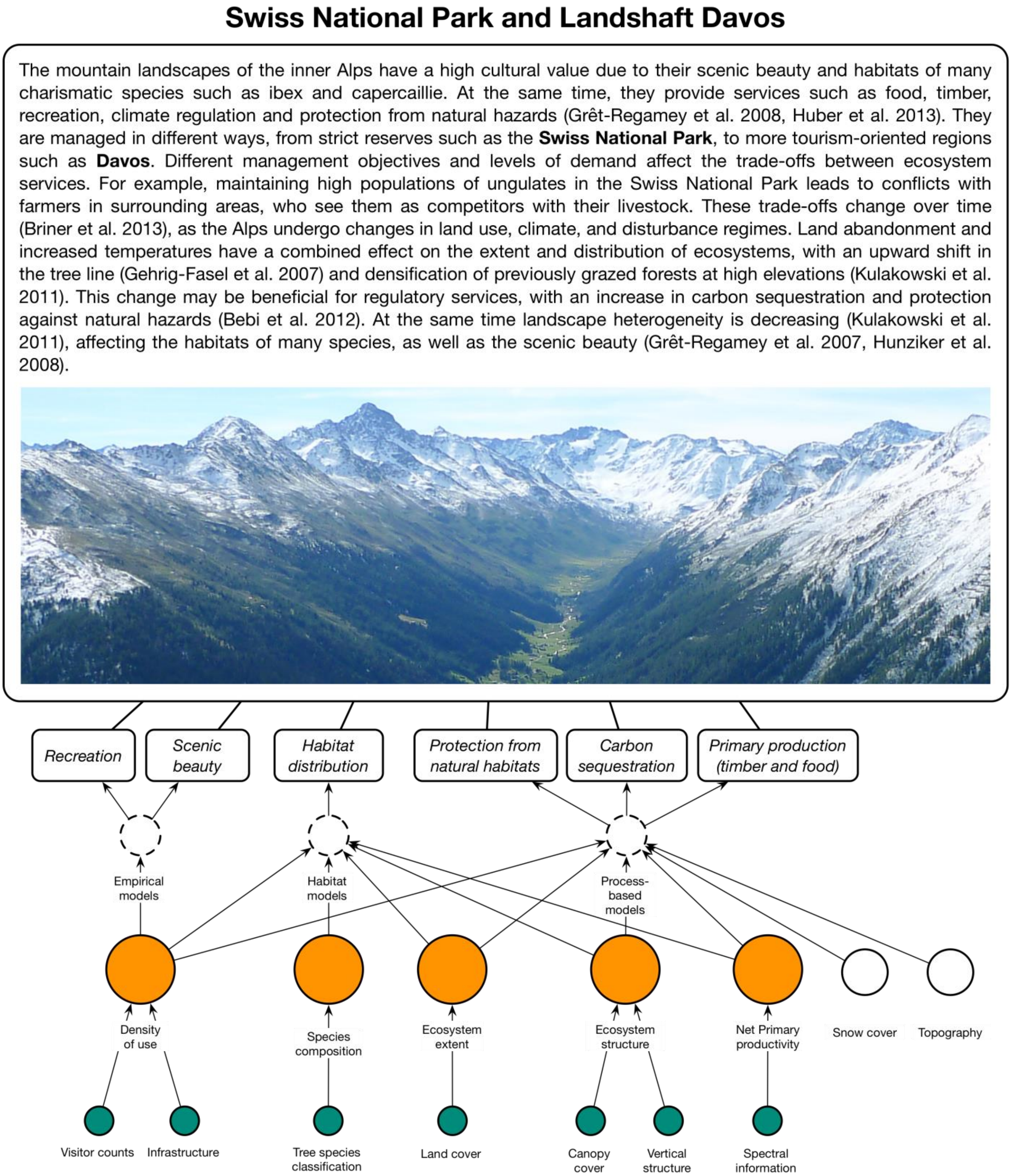


Figure 8. *Diagram representing the storyline developed for the Swiss National Park and the Landshaft of Davos, including the identification of essential variables at the storyline level.*

Gran Paradiso National Park

The Gran Paradiso National Park is characterized by the presence of significant high-altitude environments, and hosts the original surviving population of Alpine ibex (*Capra ibex*). Both Alpine ibex and Alpine chamois (*Rupicapra rupicapra*) rely on high-elevation meadows to forage during spring-summer, to face the effort of reproduction and to gain weight before winter. Mountain grasslands, however, are semi- natural habitats, whose appearance partly derives from agro/ pastoral activities. The progressive abandonment of practices such as mowing and grazing from these areas causes modifications to grasslands (in terms of species composition and richness) that can affect its forage value for mountain wild herbivores. Moreover, fragmentation due to increase of woodlands may negatively influence the interchange of grassland species. Abandonment of traditional land management may also affect nitrogen plant concentration and mineralization, soil organic carbon fraction and the net ecosystem CO_2 and CH_4 exchange. Climate change is another risk factor for mountain grassland, leading to an upward shift of alpine plant species, with consequent community composition changes and local extinctions. In addition, increasing temperatures can lead to higher evapotranspiration rates, with direct consequences on soil moisture and vegetation structure. The decline of soil water availability induces an increasing reduction of nutrient uptake and carbon assimilation with a consequent slowdown in plant growth. The reductions in snow cover alter the frequency of soil frost events and the dynamics of freeze-thaw cycles. This could influence a range of ecosystem properties, including rates of nutrient cycling and, hence, CO_2 . Water and carbon fluxes between soil, vegetation and atmosphere are only partially known for mountain grasslands, also owing to the complex geological matrix, to the wide variations in soil depth and sub-soil characteristics, and to the unknown response of the fluxes to extreme impact events and climate variability. In addition, global warming and consequent shifting of plant phenology is expected to mismatch mountain ungulates breeding with plant growing season. The advance in the start of growth season, possibly due to an earlier snowmelt, during the last 30 years can be one of the reasons for the reduction of the Alpine ibex population, owing to the lower kid survival during those years. All these modifications can seriously affect both traditional landscape and herbivores demographic parameters, in turn limiting the possibility of sustainable tourism, associated with the presence of populations of wild ungulates and pristine grassland conditions.

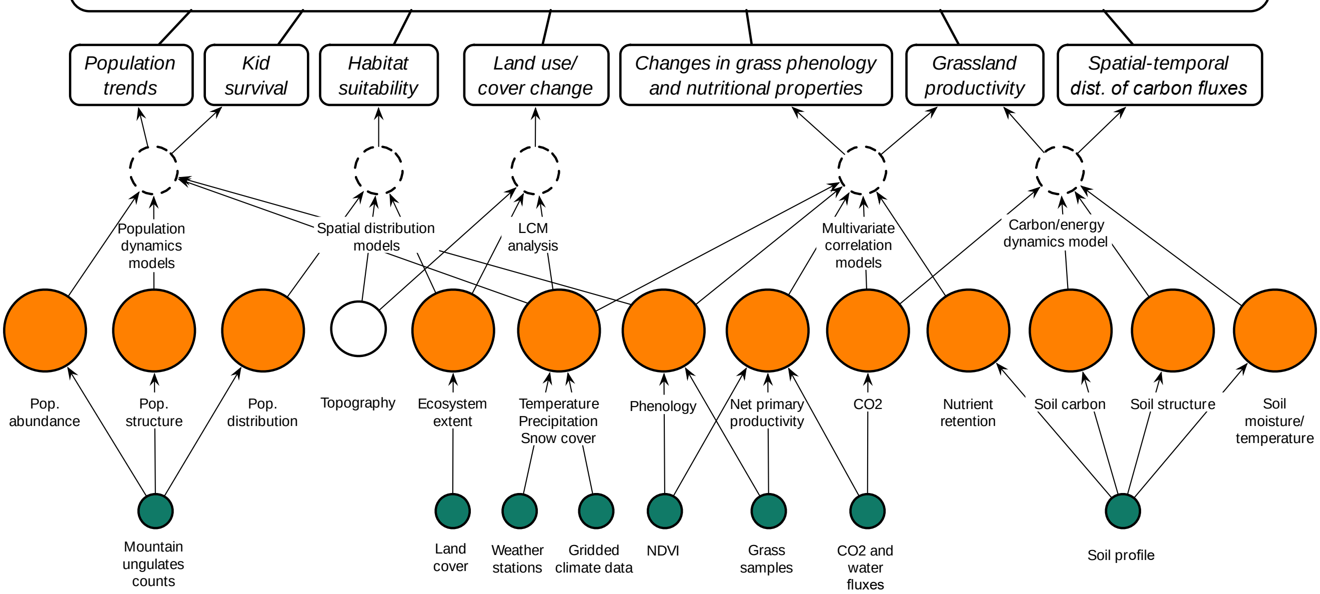


Figure 9. *Diagram representing the storyline developed for the Gran Paradiso National Park, including the identification of essential variables at the storyline level.*

Lakes Orhid and Prespa

Lakes Orhid and Prespa, located at the borders of Greece, Albania and the FYR of Macedonia, show unique geological and ecological characteristics. They form the Ohrid-Prespa Transboundary Biosphere reserve. Macedonian part of Ohrid is also Unesco World Heritage site. The lakes belong to the same watershed and are hotspots of freshwaters biodiversity. Ohrid is the habitat for more than 210 endemic species of high economical and cultural value, among which a number of so called “living fossils”. Approximately 1.200 native species are known from the lake, including 586 animals. Among the endemic species, 182 are animals the rate of endemism is estimated at 36% for all taxa and at 34% for animals. Among the several ecosystem services provided by the lake, the most characteristic one is thus the provision of the habitat for endemic species. The habitat, and consequently the incredible diversity of the lake, is subject to some major threats, as eutrophication, habitat destruction, growth of tourism, introduction of alien species, overfishing and climate change. Those pressures are affecting the population of many endemic species directly (fishing) and indirectly through modification of the habitat. Many authors describe a biodiversity crisis for the lake. The most important of the endangered endemic species is the Ohrid Trout (Salmo letnica) because of its economic importance and because it is considered an iconic species. Tourism is causing modification of the coastline due to the increase of artificial infrastructures, thus restricting the nesting habitat for fishes, while agriculture and the increase of pressure from population lead to an increase of discharges of nutrients from wastewater and from fertilisers, which induce eutrophication whose effect on the Dissolved Oxygen concentration will be amplified by the predicted increase of temperature. Further studies might be conducted to link the hydrological balance to a chemical and an ecological trophic model for understanding what is the effect of changes of the physical characteristics of the lake on the habitat, on the trout population and more generally on the lake biodiversity. The conservation of the lake biodiversity is a priority for the local governments because of the ecosystem services that it sustains. Being a transboundary lake, it also faces many challenges posed to guarantee a joint management strategy able to cope with the environmental pressures that threaten the lake.

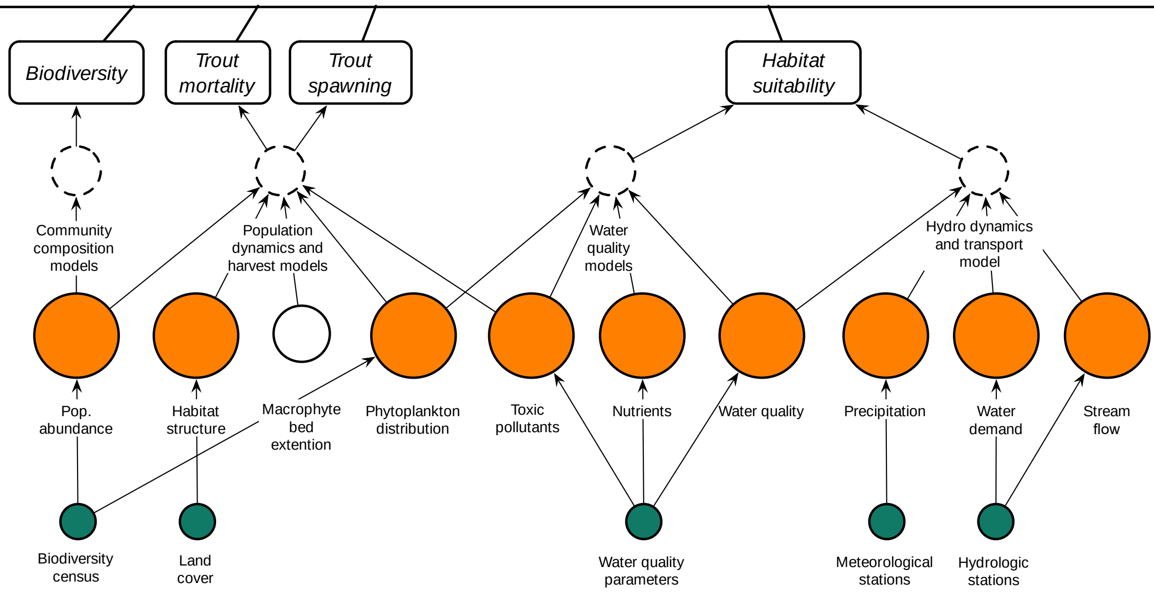


Figure 10. *Diagram representing the storyline developed for the Ohrid/Prespa lakes, including the identification of essential variables at the storyline level.*

Ancient irrigation channels as management tools to buffer the impact of climate change in Sierra Nevada ecosystem services

The National Park of Sierra Nevada contains a dense network of irrigation channels that were built during the IX century to provide water for mountain crops, pastures as well as to recharge aquifers. Nowadays these networks of irrigation channels are key for the maintenance of the biodiversity of this mountain area through a broad number of ecosystem services. Furthermore, this network is extense enough (1000 km) to modify the hydrological cycle of the mountain. Thus, our overarching hypothesis is that the network of irrigation channels impacts the functioning of some ecosystems that depend on water in summer. This storyline assesses the role of the channels as facilities that artificially increase the water availability in target habitats. More specifically we are expecting changes in the following issues:

• Biomass production: We expect an increase in plant productivity in those areas where vegetation is watered by irrigation channels. This change is expected to occur in a short temporal span (year). Biomass production will be assessed by Net Primary Production (NPP) trends, tree size and habitat distribution indicators.

• Plant phenology: Changes in water availability can cause temporal changes in primary production. E. g.: earlier maximum in primary production. This change is expected to occur in a short temporal span (year). Temporal and spatial water availability and phenology trends indicator will be used to assess the effects on plant phenology.

• Changes in forest structure: Forests watered by channels during decades are expected to show changes in their structure. We expect bigger trees in areas affected by irrigation channels. This change is expected to occur in a long temporal span (decades). We will estimate this effect using tree size and tree growth indicators.

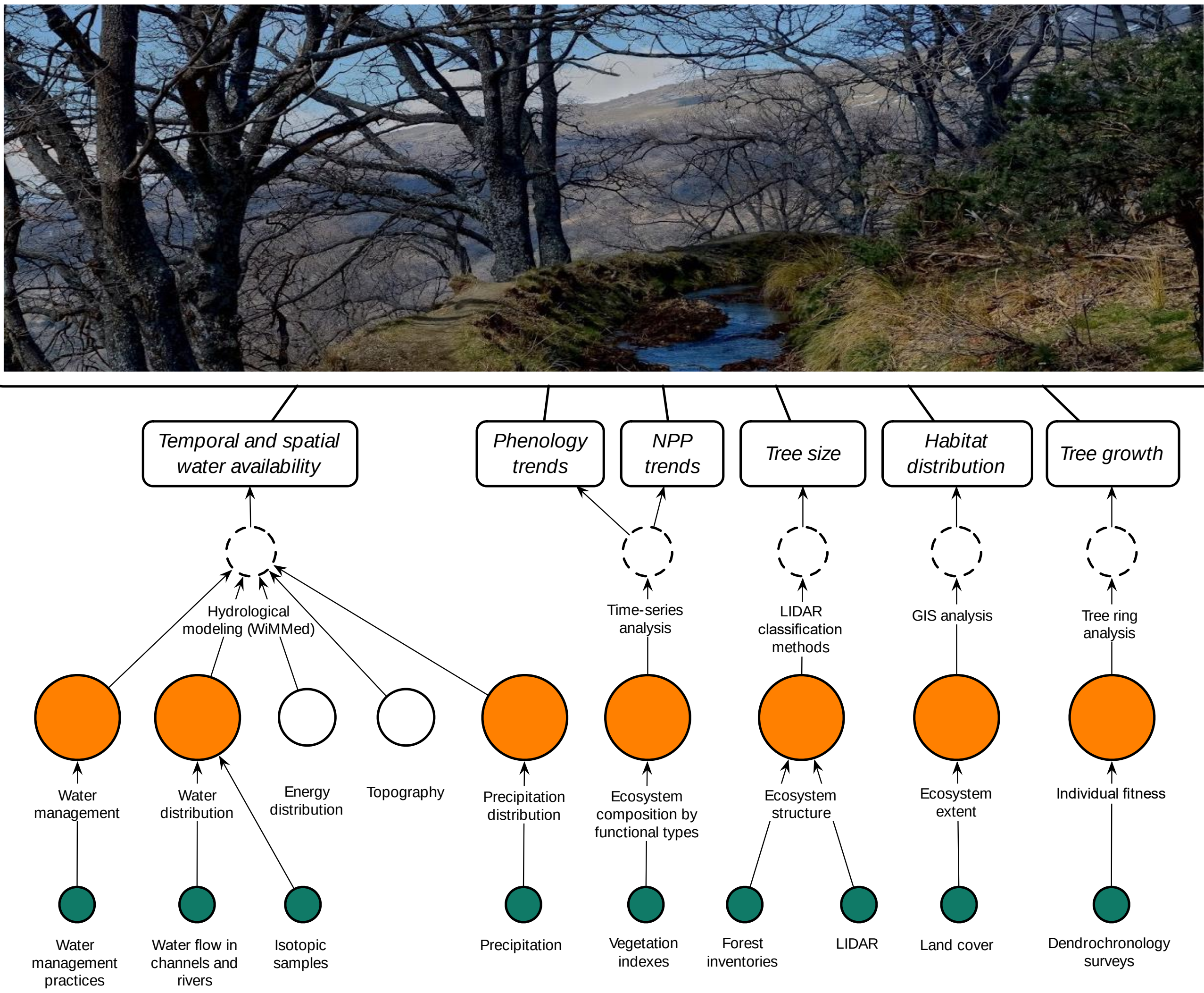


Figure 11. *Diagram representing the storyline developed for Sierra Nevada (ancient irrigation channels), including the identification of essential variables at the storyline level.*

Managing mountain forests undergoing changing disease / disturbance dynamics

Mountain forests in the Northern Limestone Alps in Austria have been fundamentally changed through hundreds of years of exploitation and management. Besides large-scale clear cutting due to high wood demand from industry and households, the natural composition of trees was altered in many areas with planting monoculture Norway spruce forests aiming for maximal economic return, mainly due to timber, pulp and paper production. Yet, these forests are less resilient to disturbances brought by direct and indirect impacts of climate change such as drought, storm events and insect infestations (e.g. bark beetle on Norway spruce) (Seidl et al. 2014, Zang et al. 2014). Monoculture forests are also less diverse as to their non-woody plant and animal species (Neumann & Starlinger 2001). Climate change is already and will very likely impact the park's forests in several ways in future. Warming might cause upward shift of suitable habitats for tree, plant and animal species (Peñuelas et al. 2013, Thom et al. 2017). Expected higher temperature together with more severe droughts likely will tighten water deficits during summer and thus increase the vulnerability of trees to insect infestation and natural hazards like wildfires (Seidl et al. 2014). As a result, tree mortality might increase, possibly more so for tree species with low water use efficiency (such as Norway spruce). Climate, tree composition and forest structure are intimately linked to forest growth, carbon and nutrient cycling (Kurz et al. 2008). Temperate mountain forests currently act as a carbon sink thereby mitigating CO2 emissions (Pan et al. 2012, Kobler et al. 2016), but there is no guarantee that this may be maintained in future (Lindroth et al. 2009, Nabuurs et al. 2013, Frank et al. 2015). Increased frequency and extent of forest disturbances might also pollute the groundwater, which is an important drinking water resource in the area (Hartmann et al. 2016). Furthermore, it has been shown that insect outbreaks and storm events alter biodiversity (Thom et al. 2017) and they will challenge the human perception of how the park's recreation forests need to look like (Beudert et al. 2015).

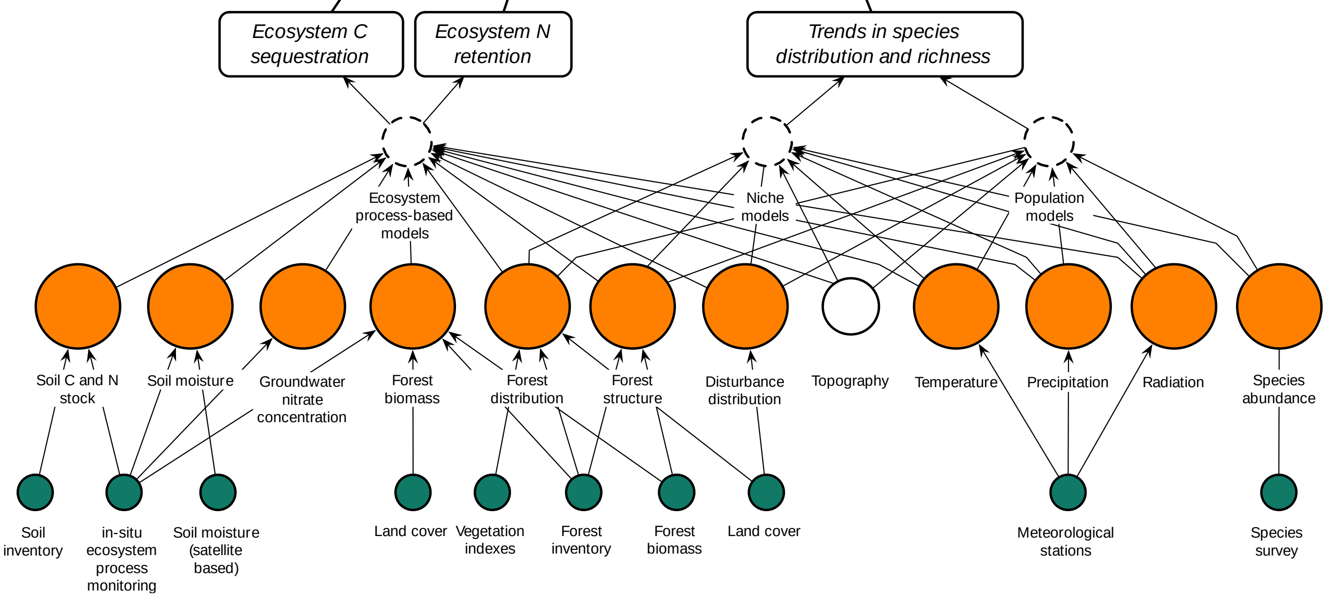


Figure 12. *Diagram representing the storyline developed for the Northern Limestone National Park, including the identification of essential variables at the storyline level.*

Temporal evolution of ecosystem services in Sierra Nevada

Human activities have heavy consequences on ecosystem structure and function decades or centuries after they have occurred (Foster et al., 2003). The variation in anthropogenic use have conditioned the capacity of mountain ecosystems to produce ecosystem services over time, resulting in trade-offs between provisioning, regulating and cultural services. So we aim to know the past and present situation regarding the trade offs amount different ecosystem services (provisioning and regulating). These tools will help decision makers to determine where and how they can allow different types of agricultural practice and land uses in Sierra Nevada. The main purpose is to facilitate the management based on ecosystem services (ES). Provisioning services will be quantified by the production of agricultural products and livestock in the last decades by the rural economy. Regulating services will be evaluated using WiMMed model (Herrero et al., 2009). WiMMed (Watershed Integrated Model in Mediterranean Environments) is a physically-based, fully distributed hydrological model. The main tools used to assess land use scenarios ES Bundles and ES trade-offs are: bayesian belief network, GIS analysis, database queries, r egression and multivariate models.

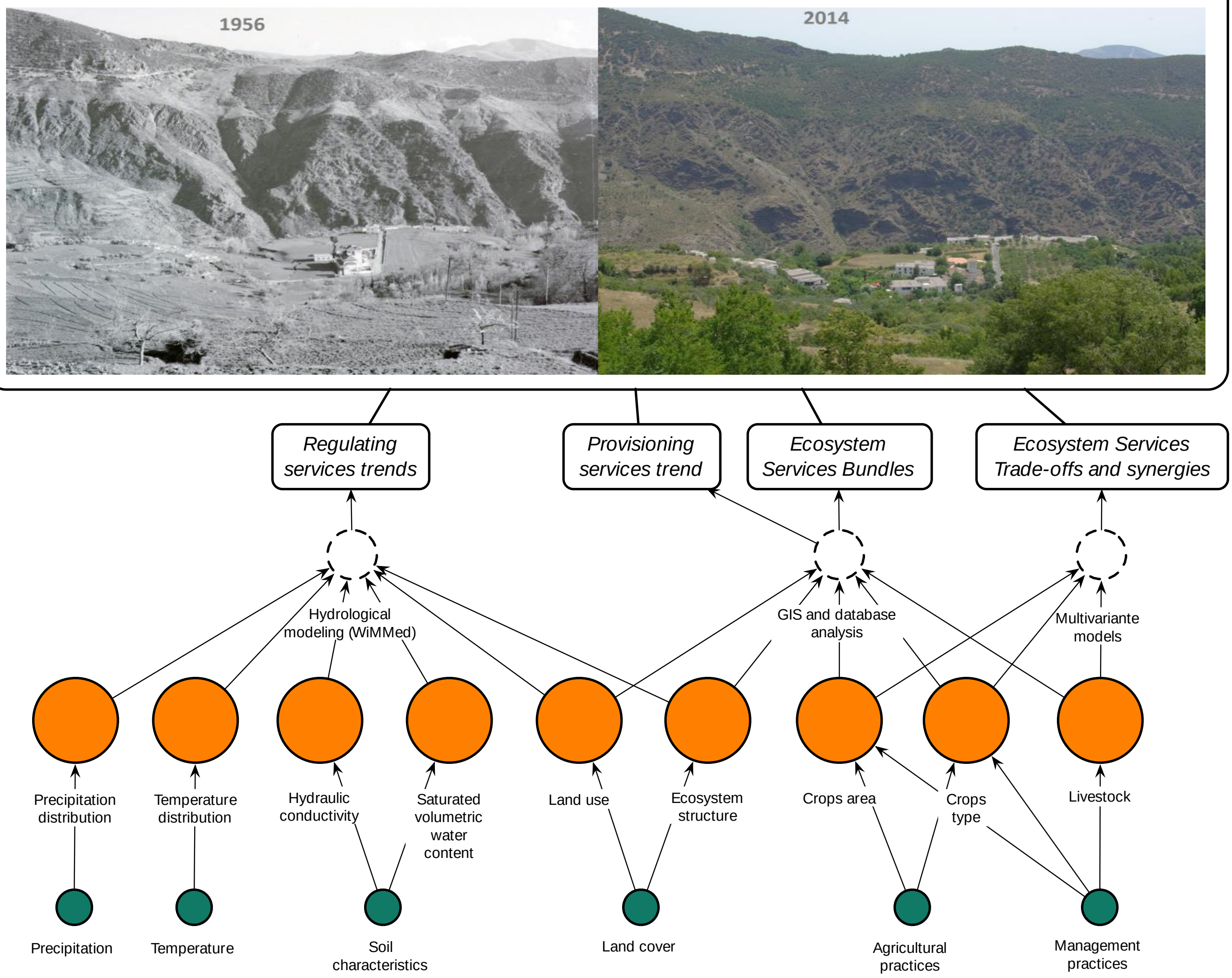


Figure 13. *Diagram representing the storyline developed for Sierra Nevada (temporal evolution of ecosystem services), including the identification of essential variables at the storyline level.*

Pelagos

The **Pelagos Sanctuary for marine mammals** (Panigada et al. 2008; Azzellino et al. 2012) occupies a large area (87 500 km2) between Italy, Monaco and France and is one of the most significant areas for feeding and breeding of fin whales (Balaenoptera physalus) and striped dolphins (Stenella coeruleoalba) in the Mediterranean Sea. Despite the establishment of a Marine Protected Area in 1999, the population of cetaceans in keeps declining due to unregulated human activities and environmental problems (e.g. ship strikes, forage overfishing) (Coll et al. 2010; Coll et al. 2012). The decline of cetacean populations affects among others the benefits the local communities gain from tourism and the existence value of these species (O'Connor et al. 2009). The distribution of fin whales and dolphins within the Sanctuary is also determined by biophysical conditions (e.g. bathymetry, sea surface temperature and chlorophyll a concentration) and biological parameters (e.g. fish biomass and the nutritional needs of whales and dolphins). Ecological functions that occur within the ecosystem (e.g. primary productivity) can determine the feeding habitat of whales and dolphins. The presence of these species can be used to assess tourism recreation potential and the number of tourists and whale watching activities in the area reflects the current recreational value of the area. At the same time, due to consumption demands, several fishing or shipping routes exist and are expected to result in changes in the socio-ecological system of the Pelagos Sanctuary with negative impacts to the whale and dolphin populations.

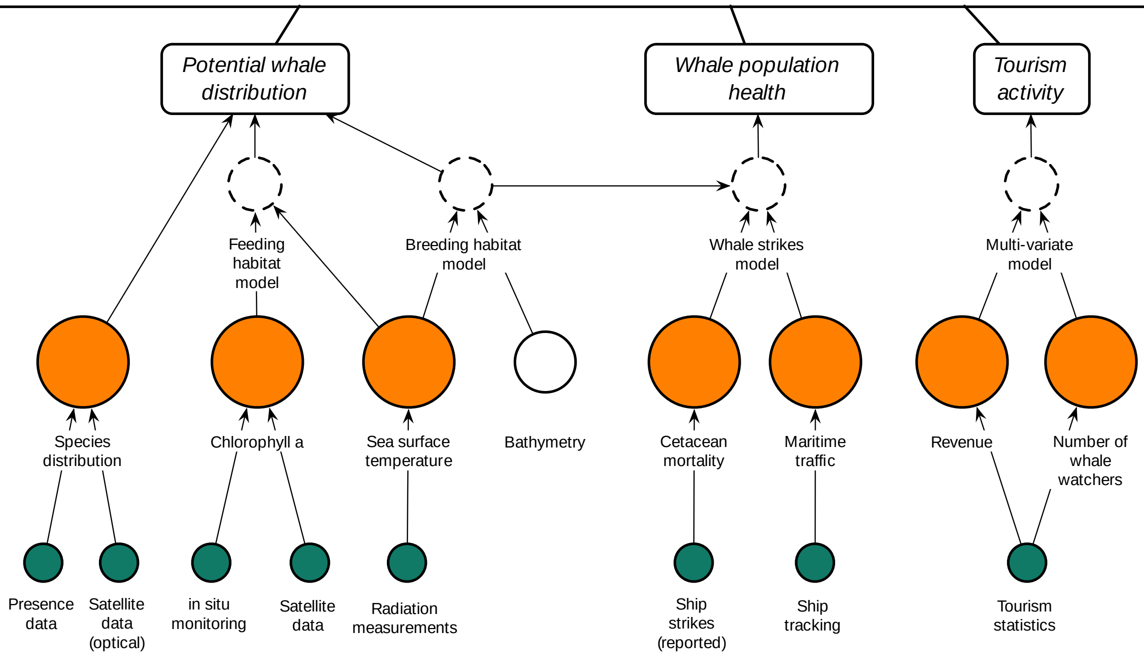


Figure 14. *Diagram representing the storyline developed for the Pelagos Sanctuary for marine mammals, including the identification of essential variables at the storyline level.*

Wadden Sea

The **Wadden Sea** is an international, highly productive estuarine area, and one of the largest coastal wetlands in the world (UNESCO, World Heritage Convention). Abutting continental Europe, the protected area borders Germany, the northern portion of the Netherlands, and western Denmark. This coastal area is a biodiversity hotspot due to its positioning as a convergence point of multiple domains, including terrestrial, fresh water, brackish and marine habitats (Common Wadden Sea Secretariat). This multi-faceted combination allows for the support of a wide breadth of biota and is characterized by extensive tidal mud flats, saltmarshes, and deeper tidal channels between the mainland and the chain of islands which denote the outer boundary between the Wadden and North Sea. This mosaic of systems interacts dynamically due to wind, wave, tidal and riverine/runoff forcing functions, resulting in the creation of different types of coastlines which more than 10 million birds call home for varying lengths of time, often on migratory routes between nesting grounds near the North Pole and wintering sites as far south as Africa (ECOMARE). Influxes of water from rivers systems which empty into the North Sea are transported by coastal flow to the Northern Netherlands and the Wadden Sea, combining with the fluxes already present within the system, producing elevated levels of nutrients. These higher levels of nutrients can cause elevated levels of primary productivity, and subsequently higher secondary production as well as eutrophication. The higher production impacts the functional and structural relationships in ecosystems. Over last decade, nearly half of the breeding birds have continued their decreasing trends in portions of the Wadden Sea. For migratory birds, decreasing trends of several species have changed to stable or increasing numbers, especially for Arctic-breeding species, however, some bird species are still decreasing. There are some indications that overfishing, as well as insufficient large roosting and moulting areas affect numbers and distribution of migratory birds.

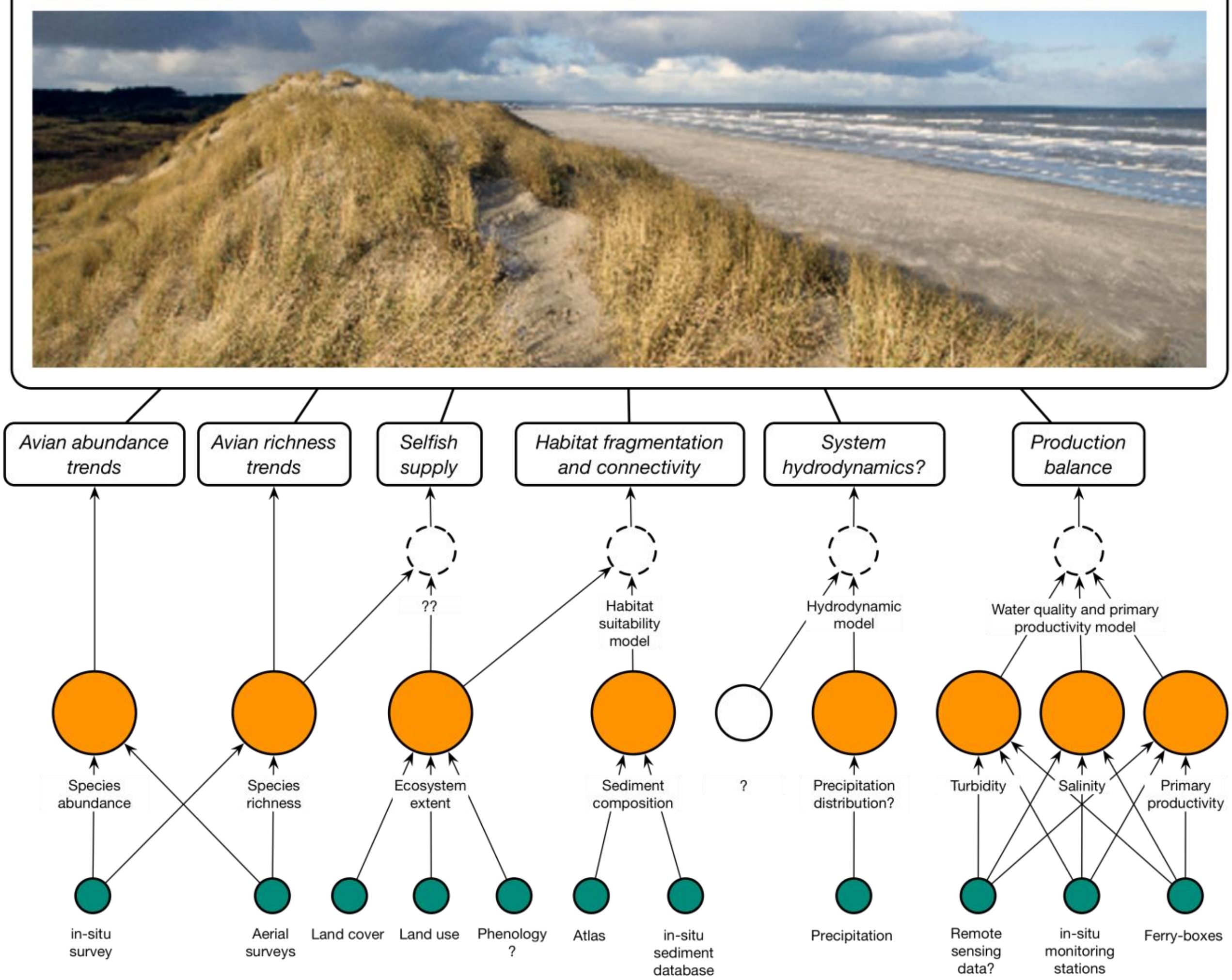


Figure 15. *Diagram representing the storyline developed for the Wadden Sea, including the identification of essential variables at the storyline level.*

Danube Delta

Danube Delta is one of the largest wetlands, still well conserved in Europe listed not only under the EU Habitat and Bird directives but also under UNESCO Man and Biosphere program and the RAMSAR convention. Compact and large wetlands areas create a complex landscape that hosts a high biological diversity characterised by the large number of bird and fish species, but also by the rich cultural characteristics of local communities and their traditions. These aspects are attracting a large number of tourists willing to enjoy nature by doing row boating, sport fishing and birdwatching. Over the years, but especially in the late 1960 the Lower Danube River was subject of intense embankments and as a result more than 80% of the former floodplain was transformed for agricultural purposes with important consequences on the functioning of the floodplain (reduced area for fish spawning and feeding, reduced capacity for flood protection, reduced capacity for nutrient storage and other pollutants) and also the Danube Delta. The impact of damming was complex from changes in the discharge, water depth, and suspended solids. This in turn had an effect upon the primary and secondary production and generated transition of the lakes ecosystems between clear and dominated by macrophyte to turbid lakes dominated by phytoplankton as main energy inputs. The mentioned changes are reflected in the trends of the fish population (change in the structure and also in biomass) but also in the bird populations and in water quality. The proposed storyline explores the link between aquatic ecosystem productivity (primary and secondary) and touristic attraction of the ar ea.

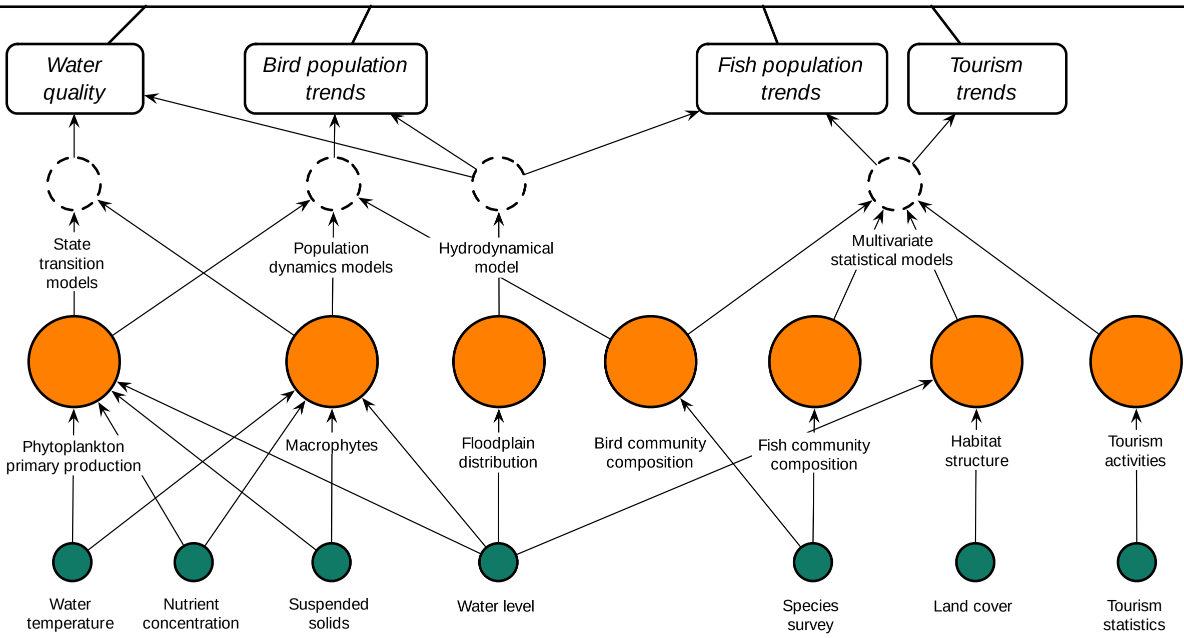


Figure 16. *Diagram representing the storyline developed for the Danube Delta, including the identification of essential variables at the storyline level.*

Evolution of wetland functions and services in the Camargue

The Camargue Biosphere Reserve in the Rhône delta covers 145 000 ha inland, including various wetland types intermingled with agro-systems dominated by rice, an irrigated crop. Through a complex network of irrigation and drainage channels, about 400 millions m3 of water are pumped each year from the Rhône to compensate for river embankment and avoid soil salinisation. This water, primarily pumped for rice farming, is also used for increasing wetland services in terms of ecotourism, wildfowl hunting and reed harvest, as well as for irrigation of pasture meadows. This results in a wetland gradient spreading from continental-type permanent freshwater ponds to Mediterranean temporary brackish pools. While such a hydrological heterogeneity contributes to the overall Camargue biodiversity, it also puts the typical Mediterranean flora and fauna at risk. In semi-permanent and brackish wetlands, seasonal variations in water levels are particularly crucial for the maintenance of emerged and submerged macrophytes and their associated fauna (Bolduc and Afton, 2004; Osland et al., 2011). Various factors such as increased salinitiy in the Rhône, global market evolution of rice or biofuels, could result in profound modification of management practices by wetland stakeholders and farmers with important positive or negative repercussion on the functioning and biodiversity of these ecosystems. Climate change could also impact wetlands by altering the extent, duration and inter-annual variability of wetland flooding associated with rainfalls. Development of monitoring tools based on earth observation to monitor recent evolution and simulate future projections in wetland hydrology and the service they provide are thus essential.

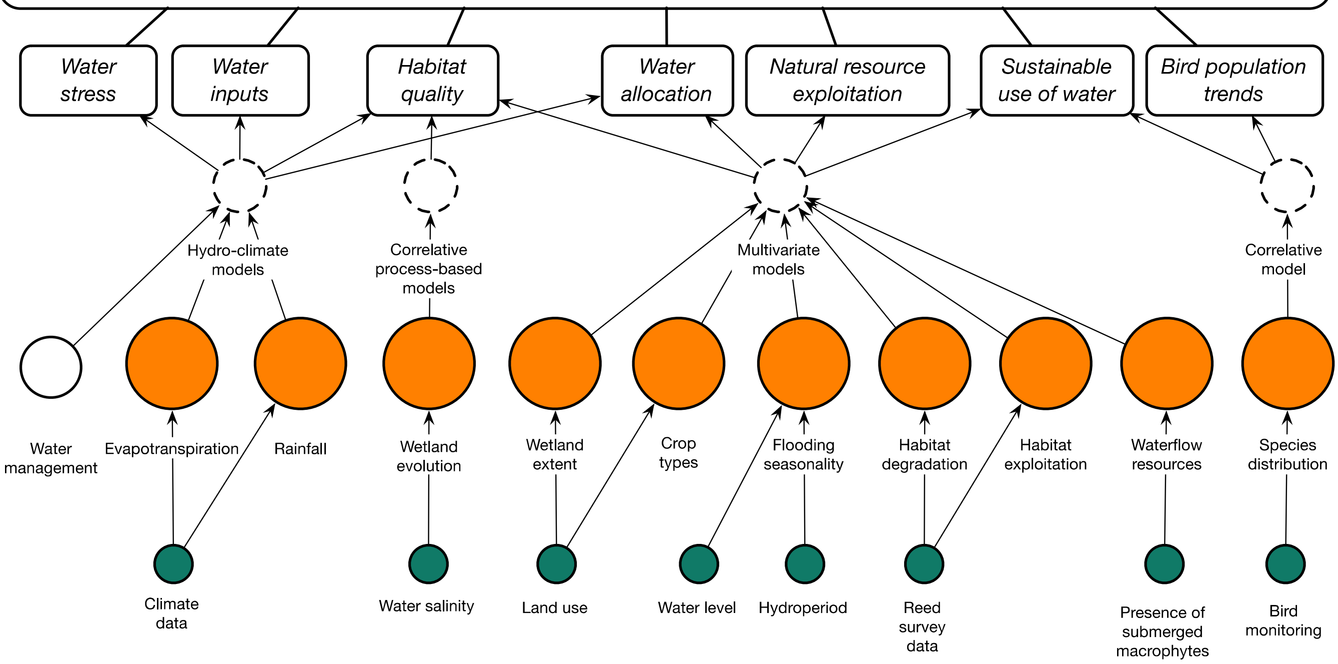
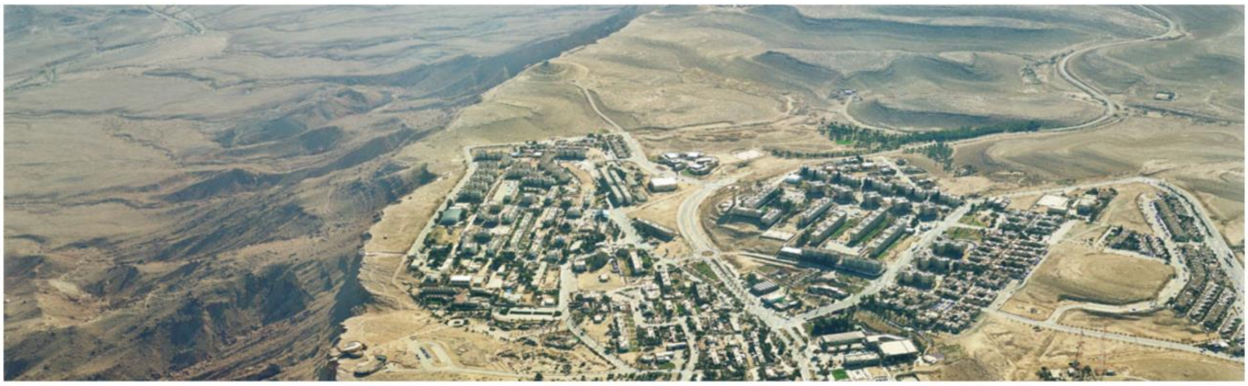


Figure 17. *Diagram representing the storyline developed for the Camargue Biosphere Reserve, including the identification of essential variables at the storyline level.*

Har Hanegev

Har HaNegev, a typical arid rocky dryland (rainfall 90mm/year), is a cultural landscape that links together human and natural elements (Evener et al., 1982). The cultural landscape is functioning as a hydro-geo-eco-socio system. The biophysical sub-system is a network of interactions among, geodiversity, soil moisture diversity, vegetation pattern, species diversity, functional diversity and ecosystem functioning driven by rainfall and surface runoff patterns (yair and Raz-Yassif, 2004; Yair and Shachak, 1982). The social sub-system is a network of isolated settlements that occupied a part of the landscape (Ornstein et al., 2016). Their location at the watershed and the grazing and farming activities by the settlers in the open space affect the water flow and productivity of the entire landscape (Avni et al., 2006). Har HaNegev management goal is aimed at integrating human structures and natural biophysical elements to form a functional socio-ecological system that maximizes primary productivity that enables sustainable co-existence of humans in settlements, and high diversity of plants (500 species) and animals (350 species) in protected areas and the non-protected open space (Ward and Olsvig-Whittaker, 1993). There are two types of human settlements that are integrated in the natural setting: (i) ancient abandoned human settlements, which include ancient cites and their associated agricultural area, which are situated mainly in the dry-valleys. The ancient farmers altered the water flow and productivity on a large spatial scale by constructing channels on the slope and terraces in the valleys in order to collect runoff from the slopes, to support agricultural production in the valleys. They are at present the main source of primary production for the natural elements; (ii) new settlements that include: small towns, rural settlements and homestead farms that have considerable effect on the distribution and abundance of species; functional diversity of species and spatial and temporal distribution of primary productivity.



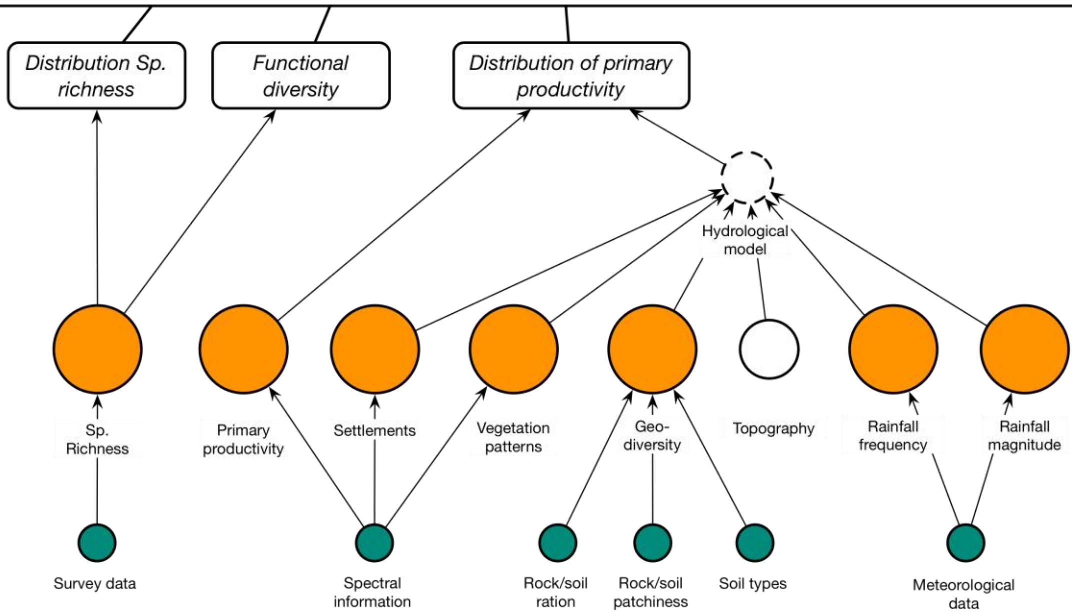


Figure 18. *Diagram representing the storyline developed for the Har Hanegev, including the identification of essential variables at the storyline level.*

Kruger National Park

The **Kruger National Park** (KNP) is a semi-arid ecosystem supporting high levels of biodiversity and also benefits from ecotourism that contribute substantially to the South African economy. In addition, areas surrounding are occupied by rural communities who solely rely on natural resources for their daily sustenance or livelihoods – including food and energy security (Shackleton et al. 2002). The location of KNP is well placed in the savanna ecosystems with open canopy forests (about 50% or less tree cover) made of heterogeneous layers of grass and woody plants (Ben-Shahar and Coe 1992). The woody component or tree cover plays a key role in ecosystem functioning, impacting on the fire danger, rates of transpiration and biomass production, nutrient cycling, soil erosion, carbon sequestration and water distribution, and more widely on food and energy security (i.e. fuel wood). While the grass component, plays a crucial role in the provision of grazing areas for livestock and wild herbivores (Prins and van Langevelde, 2008; McNaughton, 1990), the bush encroachment impacts negatively on availability of grass or grazing resources (O'Connor et al. 2014), for herbivores including wildlife and livestock (Grant and Scholes, 2006; Treydte et al. 2007; Ludwig et al. 2008). About 90% of rural community relies on fuelwood as their main source of energy and livestock production as their mainstay for livelihood. Cutting down of trees (i.e. illegal logging outside the park) and elephant pushovers are the main factors affecting the tree cover and densities, hence reducing potential for carbon sequestration and fuelwood availability .

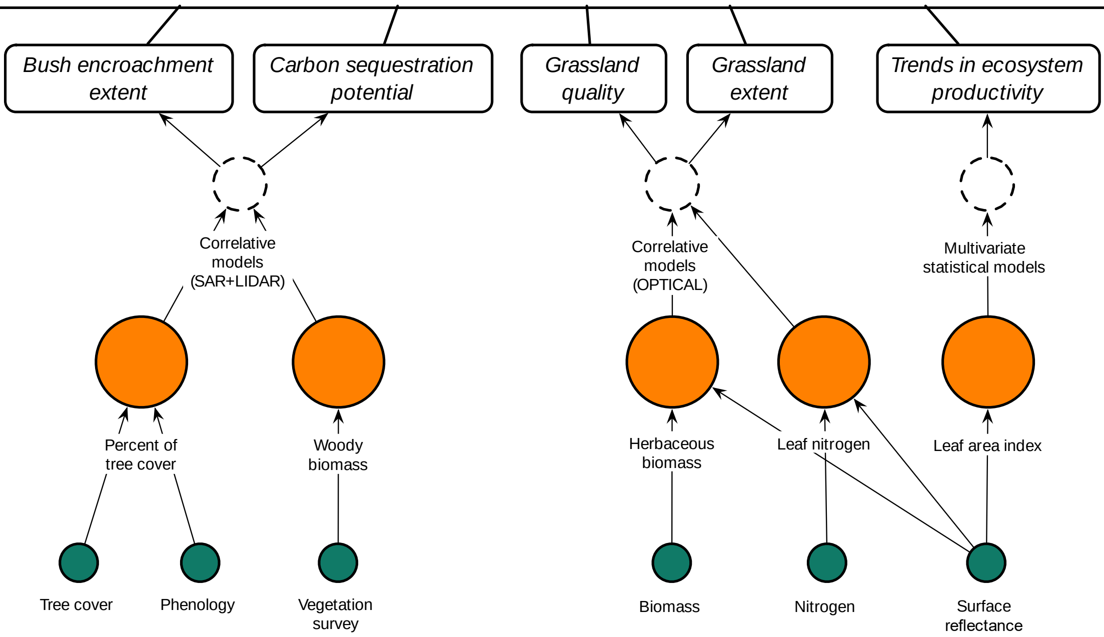


Figure 19. *Diagram representing the storyline developed for the Kruger National Park, including the identification of essential variables at the storyline level.*

Montado

Montado is a High Nature Value wood-pasture system characteristic of the Mediterranean Basin that is listed under the EU Habitats Directive (Habitat type 6310 "Dehesas with evergreen Quercus spp"). This traditional socio-ecological system generates multiple ecosystem services (Pinto-Correia et al. 2011, Bugalho et al. 2011, Plieninger et al. 2015). Among these, cork production and the conservation of charismatic and protected wildlife and habitats are of overarching relevance for ecosystem management. The long-term sustainability of the montado ecosystem is currently threatened by declining trends in stand density caused by adult tree mortality and deficient tree recruitment (Acácio and Holmgren 2014, Almeida et al. 2015). The Common Agricultural Policy (CAP) and market pressures have affected management practices, namely an increase in cattle density and grazing pressure, which leads to soil compaction, loss of vegetation cover, and a decline in natural regeneration (Bugalho et al. 2011, Almeida et al. 2015, Guerra et al. 2016). At the same time, destructive soil tillage for pasture sowing and shrub control are contributing to soil degradation and also preventing natural regeneration (Pinheiro et al. 2008). Soil degradation also restricts soil water infiltration, thus aggravating the effects of a shift in precipitation regime and of more frequent droughts that lower water availability in the growing season (Ramos et al. 2015). The simultaneous increase in tree mortality and decline in recruitment not only affects cork production in the long term, but also causes changes in habitat structure with reduction of tree density, loss of tree cover and fragmentation of the system (Acácio and Holmgren 2014, Almeida et al. 2015). These structural changes can eventually lead to changes in ecosystem extent and distribution in the landscape, with impact on the abundance and distribution of threatened species.

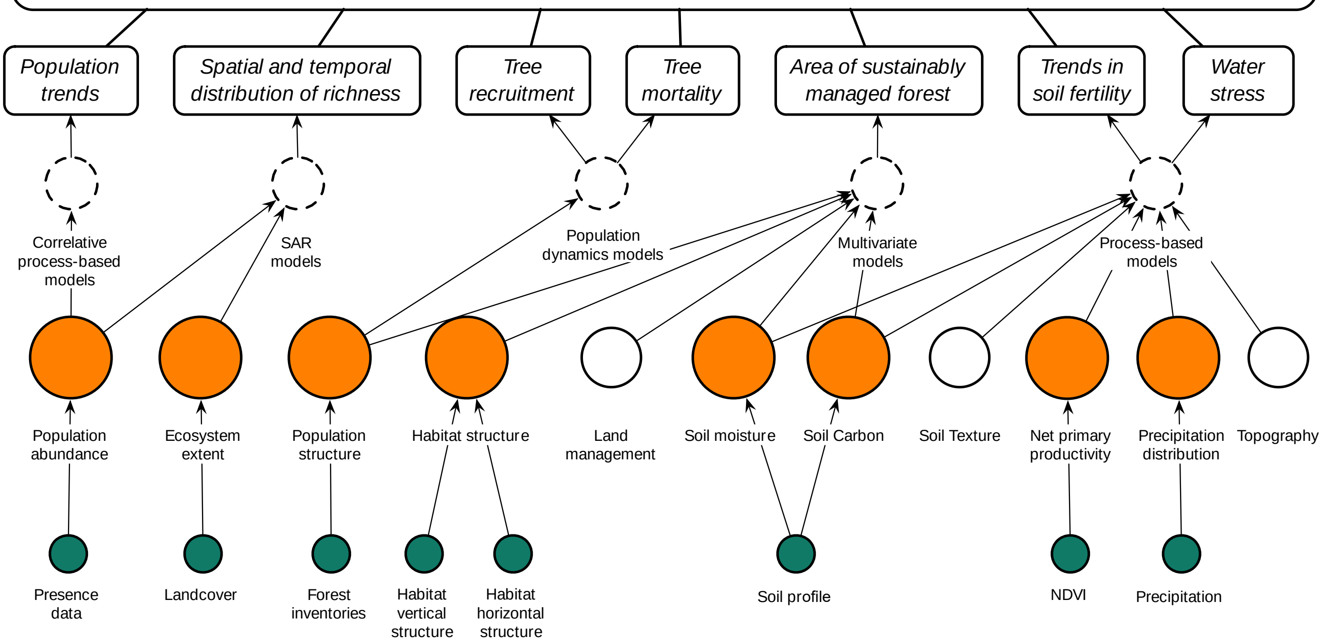


Figure 20. *Diagram representing the storyline developed for the Montado region in the South of Portugal, including the identification of essential variables at the storyline level.*

3.2 Synthesis of essential variables across realms

From the description of the selected storylines, 53 different variables were identified and, from these, 45 variables were considered locally important for the description of the different conservation goals/research questions. Annex 1 summarizes the full list of the variables that were mentioned in the storylines and their definitions as provided by the partners involved in the design of the storylines. Notice that it was not required that the storylines choose from a menu of essential variables to allow for flexibility and local prioritization in the development of each Storyline. Instead, the storylines identified and defined the variables they considered to be essential. Following the 3-tiered approach, we see that there are almost no variables that were identified as essential across all storylines (tier 1) and only a few that occurred precisely in the same way in more than one storyline. Nevertheless, there were many variables that were described in very similar ways across many storylines. Using this "bottom-up derived" list of variables, and based on the definitions provided, we assigned the storyline-provided variables to the list of essential variables provided in Deliverable 2.1. The identification at the local level of a high number of variables is closely related to the complexity and differences between the ecological systems described together with the different local priorities and according to the installed technical capacity of each protected area being assessed. Nevertheless, variables were quite similar across systems and research initiatives. Without changing the actual meaning, some could be improved so that the same variables were indeed collected across many places (e.g. precipitation is identified as amount in some storylines and spatial distribution in others). In other cases, these near essential variables can be seen to be different ways/conditions of measuring similar variables (e.g. sea surface temperature and air temperature).

For each near essential variable, we consider three major dimensions. The first relates to whether an identified variable loosely falls within a higher level "essential variable" even if the specificity of the variable differs across protected areas. For example, a number of different types of precipitation variables were proposed by the storylines. The second dimension is the degree to which these higher level essential variables are shared across storylines. Finally, the third dimension reflects differences in the implantation and collection of these variables in terms of what is being measured (dimension, thematic extent, units, etc.) and how (e.g. differences between in-situ, remote sensing or combined approaches).

Table 3 provides a summary of the level of overlap between the most frequently identified, higher-level essential variables across the different storylines (see Annex 1 for the assignments). For these re-assigned variables, it is possible to identify a clear group of variables that are not only used to describe half of the ECOPOTENTIAL storylines/protected areas but also show striking similarities in the way and place that they are collected and used. These include "ecosystem extent", "precipitation", "population abundance", and "taxonomic diversity". Although "taxonomic diversity" was not directly mentioned by all storylines, this variable can sometimes be directly deduced from "population abundance" when the later refers also to species composition and, therefore, be obtained by an increased number storylines. Nevertheless, many protected areas collect information on population abundance of selected species and not with more extensive biodiversity surveys, potentially hampering the ability to cross pollinate other variables with relevant information. These are the variables that systematically mentioned in a higher number of storylines and that at the same time can be to some extent compared across the same storylines.
As expected, due to the nature of conservation sites, within this shortlist of essential variables 3 of them correspond to previously identified essential biodiversity variables and the forth (precipitation) relates to most hydrological processes that being addressed in several storylines. While "topography" is not usually considered an essential variable, it also occurs in several storylines. All together, these variables also reflect the assessment approaches that are being taken in several storylines, with a strong focus on

process-based modelling (mainly some sort of hydrological modelling) and on biodiversity modelling (either species or ecosystems).

Table 2. Identified essential variables based on the outputs from the developed storylines. Values represent the frequency of each variable in relation to the other variables identified with a high degree of commonality across the storylines (e.g. "population abundance" was mentioned in 7 storylines where also "precipitation" was mentioned). Bold lines indicate the variables that can be obtained across a higher number of storylines.

Essential Variables	EBV: Ecosystem Extent and Fragmentation	ECV: Precipitation	EBV: Population Abundance	EBV: Taxonomic Diversity	EREV: Land use ***	ECV: Land Cover	EBV: NPP
EBV: Ecosystem Extent and Fragmentation	8	7	7	4	5	3	3
ECV: Precipitation		8	7	5	5	3	3
EBV: Population Abundance			7	4 *	4	2	2
EBV: Taxonomic Diversity				7 *	4	3	3
EREV: Land use **					7	4	4
ECV: Land Cover						6	4
EBV: NPP							6

* An important remark has to be made here as many protected areas collect information on population abundance of selected species and not with more extensive biodiversity surveys. This may hamper the ability to cross pollinate other variables with information.
** According to its description this variable also includes land cover (to some extent), including urbanization, hydrology, and grid descriptions.

Although the final objective of using essential variables is to be able to represent the same ecological/environmental properties across ecosystems and realms, it is important to note that these essential variables differ across marine and terrestrial realms – most commonly shared essential variables are concentrated in terrestrial and (some) coastal systems. Although this can be an artifact introduced in this analysis due to a reduced number of storylines being evaluated, it is important to note that some distinctions may have to be considered when identifying essential variables to describe global ecosystem/environmental change.

At the same time, a second set of variables was identified. Although with less consistency across sites, these include "land use", "land cover", and "NPP". These are often used as to assess impacts, in the case of the first two variables, or to obtain measurements of ecosystem function, in the case of NPP. Together with "surface temperature" (that was less identified than the previous variables although it has a similar degree of overlap across storylines), these constitute a second layer of variables due to their overlap and ecosystem significance. In the case of the first group of essential variables, looking at the data collection strategies enunciated by the storylines, half of them could be obtained using mainly remote sensing techniques, while this second group of variables is mostly obtained from remote sensing. This suggests that a multi-layered monitoring system can have significantly positive implications for the budget allocated to monitoring programs by protected area managers.

The selection of these variables, particularly land cover and land use, as identified in ConnectingGEO and defined within the storylines, also shows the emergence of key ontological issues related to the definition of each concept/variable. In fact, several storylines use “ecosystem extent”, “land cover”, and “land use” as interchangeable concepts/variables depending on the focus of the storyline and, therefore, on the professional background and installed capacity of the people involved in its design. Clarifying these issues, is critical for a large-scale implementation of this approach to other protected areas and conservation sites.

The selection of these 7 essential variables in a pool of 45 variables considered shows the diversity of information needed to clearly represent this group of storylines and protected areas. Thirty-eight of these variables fall within Tier-3, the ancillary protected area variables that are required to understand ecosystem and ecosystem service change within a protected area, but are not shared across a large number of areas. Indeed, if the scope of consideration is reduced to a realm, biome, or smaller biogeographic unit, it is likely that these locally important variables would rise to the level of being essential variables within that unit. Coming from a local/regional perspective, social-ecological systems can be developed and described with more depth, allowing for a better understanding of how these systems work but at the same time for a broader/high-level integration (e.g. within biomes) that underlines the general impacts of global change and pressures/drivers at local scales.

Therefore, the process for selecting essential variables cannot be seen as an exclusion process but rather a high-level priority setting process that can help frame current and future monitoring systems for conservation and non-conservation areas. This process can also help integrate an ecosystem approach with other analytical frameworks being currently applied to support conservation management. At the same time, this process has a clear value for managers, researchers and other decision makers to invert the current decision making process that is based on preferential lists of monitoring variables and instead to build monitoring systems that focus on the essential elements of key ecosystem processes. This shift could eventually permit the assignment of variables that were now identified as only of local importance (e.g. water quality, habitat structure) to a higher plane of importance, as they can serve different purposes and conservation objectives.

3.3 Main challenges of a bottom-up approach

Essential variables are often described as key environmental descriptors that allow for a representation of trends of social-ecological systems at multiple scales. To make further progress in this direction, several authors and research projects developed top-down approaches for the identification and selection of essential variables that led to more or less extensive lists of potential essential variables that can be used across scales and ecosystems. Nevertheless, it is still to be demonstrated that these lists of essential variables maintain their relevance and consistency across scales and that information can be collected (both from remote sensing and in situ sources) to properly calculate all variables identified, stimulating methods development for variables for which crucially information is needed.

To assess the consistency across scales of the relevance of these variables, within ECOPOTENTIAL we followed a bottom-up approach focused on obtaining ecosystem level representations within which it is possible to identify locally relevant variables and assess how they can inform high level essential variables (see previous section). Although it provides relevant insights on the dynamics and necessary information to describe each ecosystem, a bottom-up approach is not impervious to potential limitations. These include: i) the need for standardization across ecosystems; ii) the need for standardization across scales;

and iii) how high level essential variables informed by local efforts can provide consistent descriptions of the state and trends of ecosystems and biodiversity.

Standardization across ecosystems

Across ecosystems there is a variety of elements that have to be considered for standardization. At the top of the list there is the fact that even within the same ecosystem, across protected areas there is a number of different (but often convergent) conservation goals and approaches. This can generate challenging limitations to obtain consistent descriptions across protected areas of the same type and, even more problematic, across ecosystem types. From the experience gained within ECOPOTENTIAL, the complexity and diversity of approaches to the description of social-ecological systems may be inversely related to the diversity of stakeholders involved in the process.

Another aspect is related to data collection and usage across ecosystems and protected areas. Our results show that different storylines have significantly different methodological approaches to data collection, diverging directly with the type, resolution and methodological approach (i.e. remote sensing and in-situ). Parallel to the bottom-up approach followed in the Storylines, ECOPOTENTIAL is also making a significant effort to provide a standardized, remote sensing based, collection of datasets common across protected areas (that will be described in the deliverables of WP4 and WP8). Once finished, this effort will provide the necessary protocols to allow other protected areas to collect information that can be comparable within their country and/or region. This effort will constitute the backbone of a cross ecosystem conservation monitoring system that consistently uses comparable datasets and information.

Finally, across the board protected areas have a wide range of specific conservation goals. Nevertheless, the ecosystem based approach here implemented shows the potential of having cross-cutting conservation goals that go beyond specific protected and ecosystems but at the same time can be informed having in account the local interests and monitoring efforts.

Standardization across scales

The ability to create and maintain a cross ecosystem conservation monitoring system that consistently uses comparable datasets and information requires standard data collection and usage protocols that go beyond specific ecosystems. This major cross-cutting task would also allow, or at least promote, cross-scale assessments and data integration. Section 3.2 already provides a first description of how consistent the selection and integration of locally important variables is, but for cross-scale data integration an assessment of how consistent conservation goals across spatial scales are still needs to be undertaken. This step is critical to understand how locally relevant variables can inform high level essential variables and, with that, high level conservation goals.

Cross-scale integration of remote sensing products and information may still require the definition of specific protocols and approaches but a bigger issue is posed for in situ data. Moving across scales using in situ data requires not only standardized protocols but also that the same type and level of information is collected. A clear example of this issue can be illustrated using species distribution data as many protected areas only collect information on specific flag species (eventually flag groups) and these differ between protected areas. Aggregating all this information at a higher level is not only challenging but, often, also impossible.

3.4 Essential variables across scales

The bottom-up identified EV show the strong advantage to be highly adapted to the local needs of individual PAs. Despite a certain overlap between the EV identified for individual PAs, they do not automatically qualify as EVs for a monitoring across scales including a large-scale, Pan-European coverage. Main challenges for EVs valid across scales include:

(1) the significance of the selected variables beyond the specific local situations,
(2) the spatial resolution of the monitoring and the consistency between in-situ data, high-resolution remote sensing products (e.g. Sentinel) with coarser resolution imagery (e.g. MODIS products), and
(3) the temporal resolution of a representative monitoring network with appropriate repetition rates to distinguish between short-term variability versus long-term changes.

To address the all three challenges, it requires a systematic evaluation of EV across datasets and scales to ensure that feasible and meaningful information can be provided also across Europe. Building on the concept of EV, Deliverable 8.5 on large-scale monitoring is going to assess the current state of large-scale monitoring in Europe and options to improve it. Based on discussion between WP2 and WP8 partners, the following variables from the bottom-up identified set of EVs are considered most relevant and feasible for large-scale monitoring and are presently a key focus of this work:

- Ecosystem extent and fragmentation
- Precipitation
- Land cover
- NPP
- Population Abundance
- Taxonomic diversity

Continued collaboration between WP2 and WP8 is envisaged to consolidate the selection of EV for large-scale monitoring and to re-consider whether this selection would then also be valid to capture processes at the scale of individual PA. Furthermore, questions about the compilation of adapted lists of EV for different ecosystem types (e.g. aquatic/ terrestrial), and the potential to include cross-scale interaction between local ecosystems and some of the large-scale controls will be discussed.

4. Identification of remote sensing approaches to quantify essential variables

4.1 From selected essential variables to a remote-sensing monitoring framework

The direct and indirect retrieval of primarily terrestrial and marine/coastal biogeophysical variables at spatial resolutions and temporal frequencies that are appropriate for approaching each PA essential variable is a main aim in ECOPOTENTIAL that has been achieved in WP4. Also, the EODESM system for the extraction of thematic maps and indicators from multiple scale EO data has been developed through ECOPOTENTIAL. This system allows a) land cover classification based on previous biogeophysical variables, both thematic (e.g., leaf type, water state) and continuous layers (e.g., hydroperiod, canopy cover) and b) the detection of change based on LCCS categories, component codes and biophysical variables. A full description of the EODESM system is provided in Deliverable 4.2 but a summary is given below.

4.1.1 Classification of land covers

The EODESM system using the Food and Agricultural Organisation's (FAO's) Land Cover Classification System (LCCS) was developed using LCCS Version 2 and can be modified to integrate the more recent Land Cover Macro Language (LCML). The LCCS taxonomy is hierarchical and allows for the progressive classification of comprehensive range of land covers at the ground level and also from earth observation (EO) data. The LCCS system has been used as the basis for EO-based classifications in many studies but the approach has typically been to establish training areas for the 'end classes' of the taxonomy (such as broadleaved evergreen forests). The EODESM takes a different approach in that it follows the sequences of classifications through the hierarchy using derived products from EO data but also other ancillary spatial information, such as cadastral and urban maps, models (e.g., of hydrology) and knowledge (Figure 22). The EODESM system is particularly attuned to ingest biophysical information obtained from remote sensing data.

The EODESM system accepts up to 45 inputs (e.g., relating to hydroperiod, leaf type, cadastral information), with these provided as thematic and continuous (typically biophysical) layers (Table 2). Many of these are derived from remote sensing data (Table 2), including optical, radar and lidar imagery, but can also be obtained from other sources. The EODESM system can ingest locally derived layers (e.g., by the user through supervised classifications) or those extracted from European or global datasets (e.g., the University of Maryland's tree cover density layer or the European Commissions' (EC) Joint Research Centre (JRC) global hydroperiod). Thematic layers are recoded to achieve appropriate input to the EODESM system, whilst continuous layers are summarised into different categories within the system (e.g., relating to canopy cover or hydroperiod). Once entered, the system automatically translates the inputs to individual LCCS codes (e.g., A4 for shrubs, A5 for forbs), combines these to form a string (e.g., A3.A10.B2.C1.D1.E1.F1.F9.G7) and then translates the string to a descriptive name (in this case, Trees closed canopy (>70-60 %) tall (14-30 m) continuous broadleaved evergreen with 2^{nd} layer supporting open canopy 7-3 m in height). An example of the classification is provided in Figure 23 for the Camargue in southern France.

For many regions, a diverse range of other variables (Table 2) can be obtained from EO data but these cannot be used to establish the LCCS categories. Nevertheless, they can be included as attributes within the EODESM system and used to provide additional descriptors of land covers and also changes. The outputs from the EODESM system can also be used to describe additional variables (Table 3).

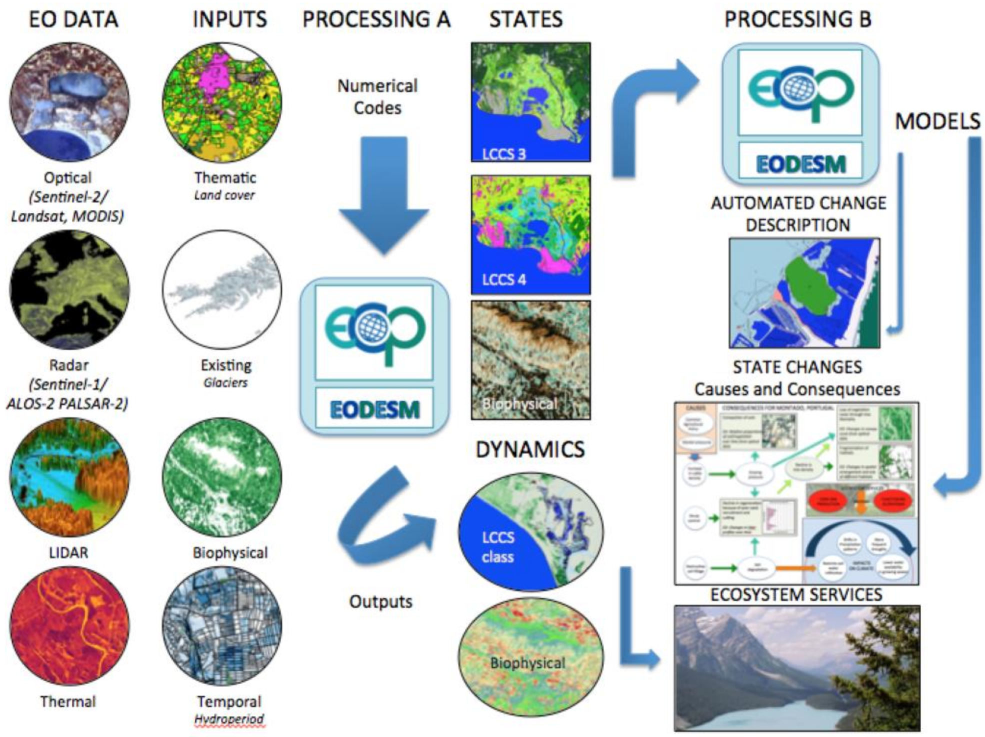


Figure 22. An overview of the EODESM system.

Table 2. Essential Variables retrieved from EO data and used as direct input to the EODESM system.

Essential variable	Description
Agriculture	Crop Area Crop Management and agricultural practices Crop Phenology
Biodiversity	Phenology (Species traits) Physiological traits (Species traits) Vegetation height
Climate	Glaciers and ice caps (Land) Ice sheets (Land) Lakes (Land) Phytoplankton (Ocean surface) Snow cover (Land) Suspended particulates (POC, PON or POM) and PIC ++ laboratory, beam attenuation, backscatter, acidifiable, beam attenuation (Biogeochemical)
Renewable Energy	Tidal (min, max, sea surface elevation) Urbanization
Water	Water quality

Table 3. Essential Variables retrieved from EO data that provide additional descriptions of land cover

EV	Description	EV	Description
Climate	Above-ground biomass (Land) Albedo (Land)	Agriculture	Crop Type
		Biodiversity	Net primary productivity (Ecosystem function)

	FAPAR (Land)
	LAI (Land) Ocean colour (Ocean surface) Permafrost (Land)
	Phytoplankton (Ocean surface)
	Precipitation (Atmosphere surface) Sea ice (Ocean surface) Sea level (Ocean surface). Sea state (Ocean surface) Sea-surface temperature (Ocean surface) Soil moisture (Land) Surface current (Ocean surface) Wind speed and direction (Atmosphere surface)

	Population structure by age/size class (Species populations)
Ocean	Chlorophyll (Biology and Ecosystems) Coral Cover (Biology and Ecosystems) Large marine vertebrates: abundance/distribution (Biology and Ecosystems) Zooplankton, Krill biomass/abundance (Biology and Ecosystems)
Renewable energy	Elevation, Orography Land surface temperature Ocean bathymetry Wave, height, direction, period

Table 4. Essential Variables that can be derived from the EODESM system

Essential Variable	Description
Biodiversity	Disturbance regime (Ecosystem function) Ecosystem composition by functional type (Ecosystem structure) Ecosystem extent and fragmentation (Ecosystem structure) Habitat structure (Ecosystem structure) Population structure by age/size class (Species populations) Secondary productivity (Ecosystem function) Species distribution (Species populations) Species interactions (Community composition)
Climate	Fire disturbance (Land) Land cover, including vegetation type (Land) River discharge (Land) Water use (Land)
Ocean	Mangrove Area (Biology and Ecosystems) Salt Marsh Area (Biology and Ecosystems) Seagrass Area (Biology and Ecosystems
Renewable energy	Land use, Land cover, including urbanization, hydrology, grid description Urbanization
Health	Famine early warning Short term forecasting of coAs inputmmunicating diseases

4.1.3 Land cover, land use, habitats and ecosystems

Many of the protected areas require information on the extent of different land covers and, in several cases, habitats and ecosystems as well as land use and functional types. The following clarifies the meaning of these. The EODESM system classifies land covers but the classes can be translated to a number of habitat taxonomies (e.g., the General Habitat Categories, Annex I Habitats), particularly if additional information (e.g., context, soil type) is available.

Land cover is defined as the physical material that is on the earth's surface and includes rock, water, vegetation (forests, shrubs, lichens) and artificial structures.

Land use describes how an environment is modified by humans and includes farming, forestry, urban development and irrigation.

A ***habitat*** describes the natural home or environment of a living organism that provides all of the conditions needed for survival (food, water, shelter and space). An example might be small ponds, low shrublands and grasslands.

An ***ecosystem*** is comprised of all living organisms within a unit area and the physical, chemical, geological and hydrological environment they live in and interact with, and the way they impact on each other. As an example, a bog (the ecosystem) might be comprised of pools, low shrublands and grasslands (the habitats) and the fauna and flora that form, depend on and interact with different components. For the purposes of risk assessment, ecosystems are normally defined as assemblages of species within a particular area, environment or habitat, plus the physical, chemical and geological environment.

The ***functional types*** of ecosystems are regarded as groups of species or populations that perform the same or similar functions or sets of functions.

4.1.3 Environmental variable usage within EODESM.

Based on the analysis of the protected area requirements within Section 3.1, this section provides an overview of the types of environmental variables that are required and outlines how these are utilized with EODESM.

The EODESM system is based on the principle that landscapes are comprised of a number of component 'elements'. For example, a forest is comprised of plants of a particular life form (e.g., trees, shrubs, grasses, forbs, lichens, mosses), structure (height and cover, which varies horizontally and vertically) and leaf type (broadleaved, needle-leaved or aphyllous) but also vary in terms of the function (e.g., phenology and productivity). Water may be of varying states (liquid, semi-frozen or frozen) but also move at different velocities, be of differing depth and contain constituents in different concentrations. In many cases, earth observation data can be used to obtain this information and this is recognized in the EODESM system. Examples are provided in the following subsections.

Agricultural areas

Within the protected areas considered, agricultural land is described in terms of crop type and also the area of coverage. Many crop types can be discriminated from earth observation data, primarily through differences in spatial but also temporal differences in surface reflectance but radar backscatter (particularly using those acquired at higher X- and C-band frequencies). However, the main reasons why discrimination is achieved is because of the different foliar chemistries, cell structures and moisture contents of the individual plants and also how these are configured in three dimensions. The characteristics of the underlying surface (e.g., soil type, moisture content), which are influenced by the patterns of planting and treatments, are also important. By using different earth observation sensors to describe the different characteristics of the plants and the underlying surface, different crop types and also management practices and regimes can be discriminated.

Natural vegetation

A wide range of descriptors of natural vegetation were indicated by the protected area managers and scientists with these focusing primarily on structure (e.g., cover, height, leaf area index), biomass (herbaceous and woody), function (foliar chemistry and nutrients) and species type and distribution. Such information can be obtained from data acquired by optical, radar and lidar, either singularly or in combination. As an example, forests can be described on combinations of cover and height derived from optical reflectance and lidar data (e.g., tall closed forests or low open woodlands). Additional measures can be used to describe the functioning of ecosystems including net primary productivity and leaf flush, build up and fall as a function of temperature and day length.

Water states and dynamics

The majority of protected areas requested information on the extent of water within the landscape but also the characteristics of this water. As examples, data on water quality, levels, temperature and pollutants were needed in the Danube Delta and Lakes Ohrid and Prespa. Such information can be provided primarily from optical and thermal sensors, including through inference (e.g., the presence of algae might indicate eutrophication whilst sediment loads might indicate discharge of mine waste). In the case of the Camargue, knowledge of the movement of water through the landscape was essential although this was over varying time periods (daily to seasonal). Daily and summarized flow data typically requires reference to hydrological gauges but hydrological modeling using high quality DTMs (e.g., generated from interferometric SAR or LIDAR) can also allow flowing and standing waters to be differentiated but often within the confines of a channel. Over the broader landscape, maps of the extent of water can be derived from optical and radar data (e.g., Landsat/Sentinel2 and Sentinel-1) and then combined over a season or year to generate hydro-period maps. When these are compared over time, changes in hydro-period may indicate a net drying or wetting of all or parts of a landscape.

Within protected areas located in mountainous areas, information on the distribution and amount of snow and ice cover was needed (e.g., for Gran Paradiso and Swiss National Parks). Whilst snow maps can be generated from moderate spatial resolution data, these are often of insufficient spatial resolution and hence coarser spatial resolution sub-daily or near daily mapping from sensors such as MODIS is often considered sufficient. However, optical, SAR and also thermal sensors can provide information on snow condition and physical characteristics.

Bare ground

Whilst information on the extent of bare ground itself, there was a need for detailed information on soil properties, including carbon, moisture, structure, temperature and texture. Such information is difficult to obtain from remote sensing data as often the soil is covered by vegetation. However, in semi-arid and desert areas such as Ha Negev and Murgia Alta, there is sufficient exposure of soil to allow retrieval of some elements, namely moisture and temperature.

Marine environments

Within marine protected areas (primarily the Pelagic Marine Reserve), common data requirements included sea surface temperature (SST), suspended solids, dissolved organic matter, phytoplankton distribution with this indicated in part by the amounts of chlorophyll-a. The majority of these data can be captured by earth observing sensors that operate on a sub-daily to near daily basis (e.g., MODIS, AQUA, MERIS) and at relatively coarse spatial resolution (typically 250 m to 1 km). Knowledge of the distribution of cetaceans and other marine species was also considered important and aerial surveys or even very high resolution (VHR) satellite imagery can provide opportunities for locating, identifying and counting individuals.

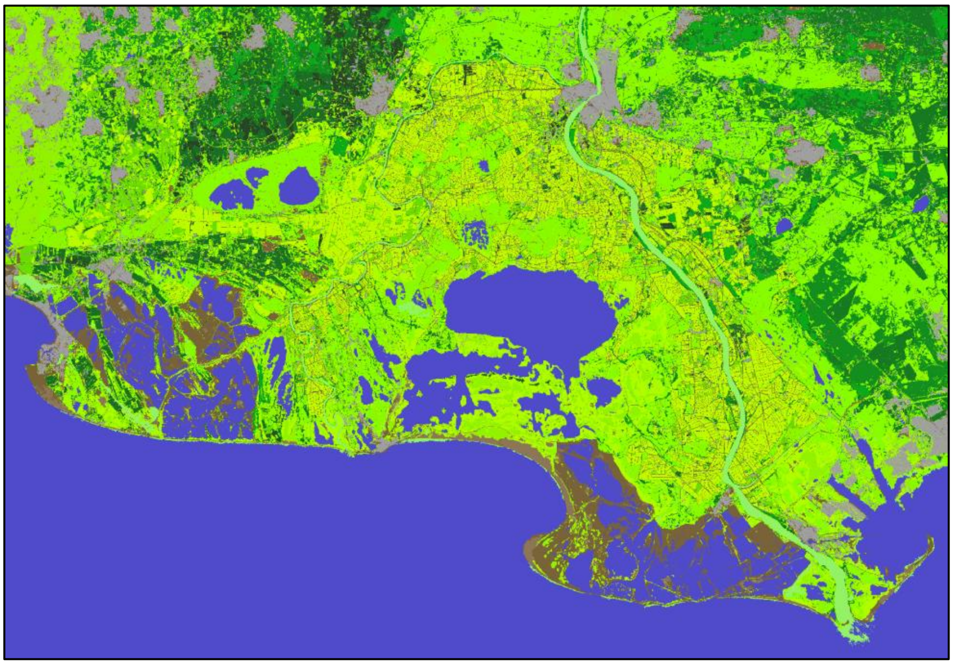


Figure 23. EODESM Classification of land covers in the Camargue, southern France. Over 200 classes are represented with each associated with a detailed description according to the LCCS taxonomy. These broadly relate to water (blue), bare ground (brown), urban areas (grey), agriculture (light greens) and natural vegetation (darker greens).

4.1. Classification of change

A consideration for detecting change is that this can occur at different frequencies and affect different landscapes. A review of the data requests from the protected areas indicated that a wide and diverse range of information was needed, with some overlap (Figure 24). The requested data were also linked to the types of information that could be obtained from remote sensing data (Figure 25a), with these including vegetation indices but also thematic and continuous variables that related to bare ground, vegetation, water, atmosphere, oceans, change regimes and landscape classifications. Most of the protected areas were interested in information on elevation and bare ground but also land cover. However, in order to address these, earth observation data need to be acquired at different temporal frequencies and this is illustrated in Figure 25b. Whilst some datasets were only needed every decade (e.g., elevation), others were needed on a daily basis, with these including snow cover, cloud cover and sea surface temperature).

Description	CM	DD	GP	HD	HN	KP	MO	NL	OP	PG	SN	SW	WS
Crop types	•										•		
Crops area											•		
Land cover		•											
Ecosystem composition by functional types											•		
Ecosystem/habitat extent			•	•			•				•	•	•
Ecosystem/habitat structure							•		•		•	•	
Vegetation patterns					•								
Vegetation structure										•			
Annual range of maximum productivity (seasonal)										•			
Phenology			•										
Net Primary Productivity			•	•	•		•			•		•	•
Chlorophyll/nitrogen ratio										•			
Leaf area index						•							
Leaf nitrogen						•							
Biomass (herbaceous)						•							
Biomass (woody)						•		•					
Forest distribution								•					
Forest structure								•					
Tree cover percent						•							
Lichen biomass				•									
Fractional cover of land cover classes										•			
Geodiversity					•								
Groundwater nitrate concentration								•					
Macrophyte bed extension									•				
Nutrient concentration		•											
Nutrients									•				
Saturated volumetric water content											•		
Sediment composition													•
Settlements					•								
Species composition												•	
Species distribution	•									•			
Land surface temperature			•	•				•			•		
Time of maximum productivity (phenology)										•			
Topography			•	•	•		•	•		•	•	•	
Turbidity													•
Water distribution											•		
Water levels		•											
Water quality									•				
Water temperature		•											
Flooding seasonality	•												
Stream flow									•				
Suspended solids		•											
Snow cover			•									•	
Snow distribution				•									
Wetland evolution	•												
Wetland extent	•												

Description	CM	DD	GP	HD	HN	KP	MO	NL	OP	PG	SN	SW	WS
Bathymetry										•			
Chlorophyll a										•			
Phytoplankton distribution									•				
Salinity													•
Sea surface temperature										•			

Figure 24. A summary of specific requests considered in Section 3.1 for each protected area related to the storylines.

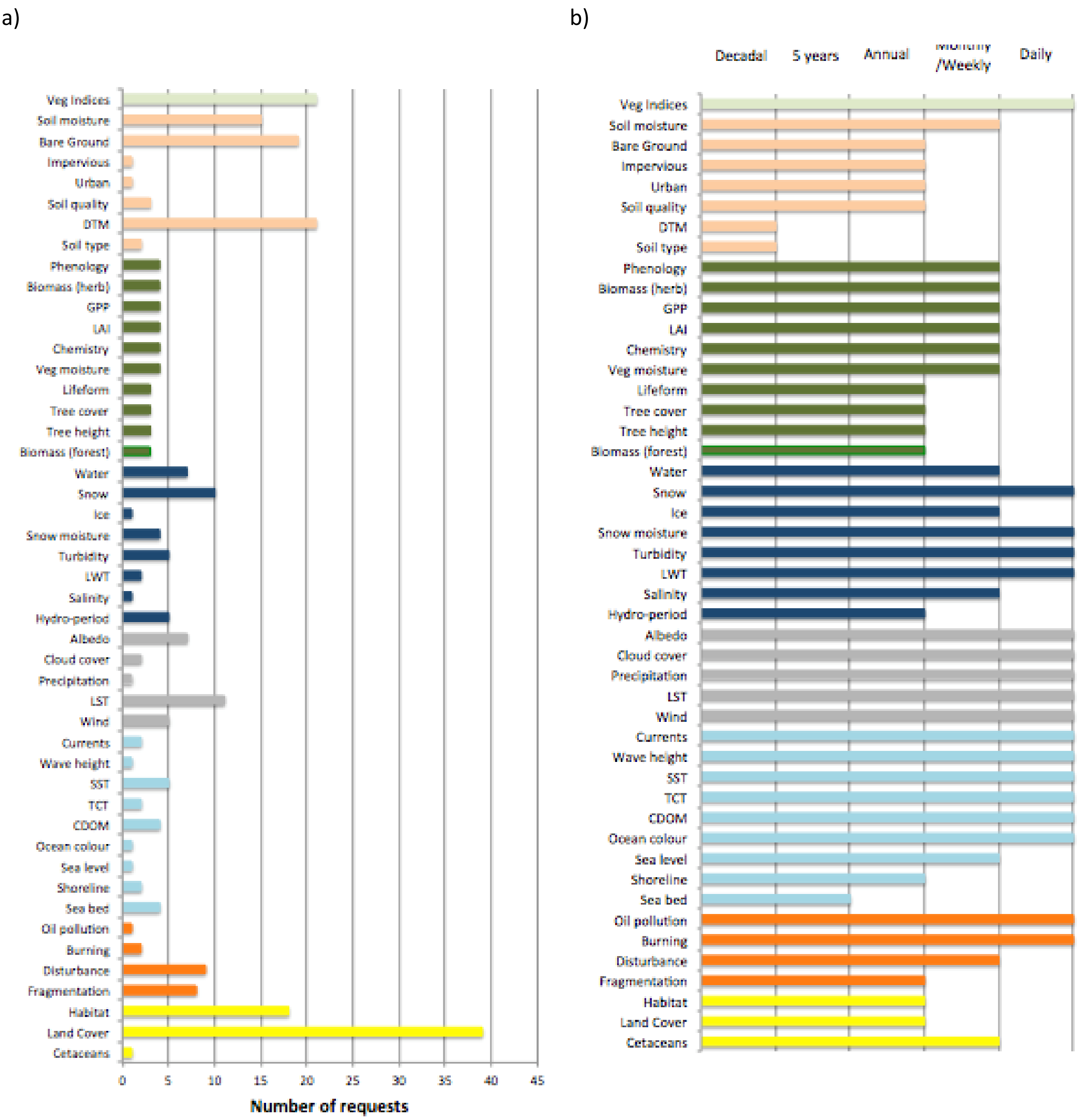


Figure 25. Remote sensing products within ECOPOTENTIAL discriminated by: a) the number of requests for different environmental layers from all protected areas and b) the frequency of earth observation data needed to capture these.

A full description of the EODESM change detection module will be provided in Deliverable 4.3 but a summary is given below. Classifications of land covers are generated for a single period of time (either a date but more often a year) and then changes are subsequently quantified by comparing class codes but also variables on subsequent dates or periods. As such, the EODESM system allows different temporal frequencies of change to be considered as and when they occur and the classification therefore becomes dynamic. For example, the annual hydro period of a wetland may change from 292 to 182 days, which translates to a change in class from B1 (9 months) to B8 (4-6 months). This is illustrated further in Table 5, which conveys how change can be detected. In the case of A, a change in both the class code (in this case, leaf type) and also canopy cover (%) provide evidence of, for example, selective logging). In B, a late snow fall event might cover a frozen (but temporary) lake but the hydro-period is increased to over 3 months.

Table 5. An example of the methods used to detect change.

	Thematic	Continuous	LCCS code (Period 1; P1)	Component code (P1)	Component code (P2)	Change	Biophysical change
A	Leaf type (with codes 1 & 2)	Canopy Cover) (0-100	A12.A4.A10.B4.C1.D1.E2	A4	A3	(A4 > A3) Trees to Shrubs	(80 % > 40 %)
B	Water State (1,2,3)	Hydroperiod (1-365)	B28.A1.B4.C1.D2	A1	A3	(A1 > A3) Water to Snow	<4 to 4-6 months

4.1.3 Causes and consequences of change.

A unique element of the EODESM system is the automated description of change events and processes and their association with a cause and consequence. Future developments are focusing on providing a preliminary assessment of impacts on ecosystem services to guide future modeling and also identifying areas with potential for restoration of ecosystems. The concepts and their linkages within the ECOPOTENTIAL project are outlined in Figure 6.

As illustration, Figure 26 outlines for selected protected areas the main storylines and the causes and consequences of the changes that are the focus of ECOPOTENTIAL. The table also highlights the changes (to and from) with the EODESM system that are relevant to monitoring and quantifying such changes (in both thematic classes and continuous variables) and, of note, is that only a proportion of the changes that are occurring within the landscape need to be considered. Furthermore, the same classes can be used to address issues across several of the protected areas.

4.1.4 Conclusions and further information

The EODESM system is described in Deliverable 4.3, with examples provided for the different protected areas. Of note is that the classifications are:

- Consistent within and between protected areas.
- Are highly detailed and comprehensive with the level of detail determined by the quality and diversity of the datasets used as input.
- The classification of land covers and change can be applied at any scale but a nominal 10 m spatial resolution has been selected as this aligns with that of the Sentinel-1/2 sensors.
- The temporal dynamics of the landscape can be quantified even if rates and types of change vary across the landscape.

However, when detecting change, the capacity of earth observation data to provide information at appropriate spatial and temporal frequencies needs to be considered.

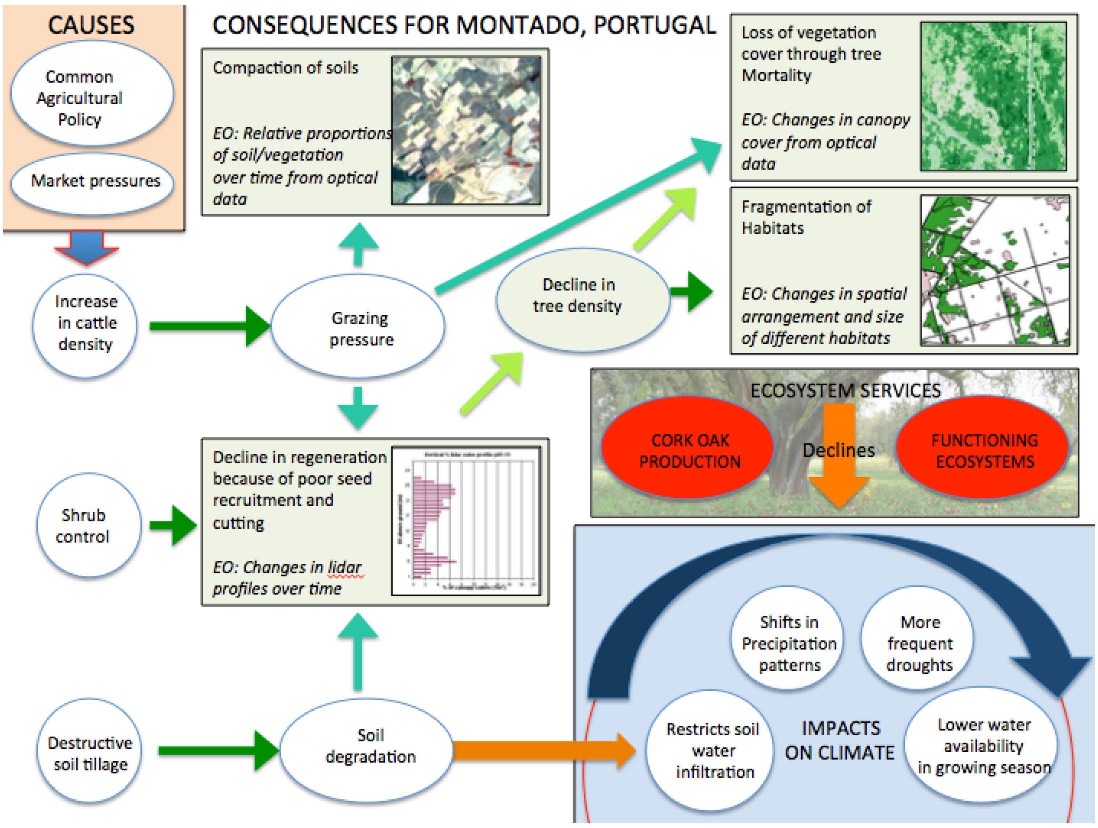


Figure 26. A diagrammatic representation of the concepts behind the EODESM system and its integration within the ECOPOTENTIAL Project.

The software used to implement the EODESM system is open source and provided at no cost (with a commons license). The approach is also user friendly and can be applied to any area globally provided the input data are available.

5. Discussion

One of the greatest challenges faced by protected area managers is to set up, implement and maintain long-term repeated measurements of conservation relevant information (e.g. Stephenson et al. 2015). The identification of EVs is a useful way to prioritize data collection efforts needed for operational and policy-relevant conservation monitoring systems. It allows to focus resources, identify capacity building and data needs, and mediate the negotiation process across stakeholders clarifying the relationships and processes being studied and the relevant resources that are needed to sustain the assessments. Also, setting monitoring priorities across protected areas can provide important comparative information for conservation managers, particularly if done across similar sites. With this information, conservation managers can underpin their needs (e.g. data, resources, capacity building) and compare them across protected areas with similar and/or very different objectives and pressures.

The exercise that was implemented for this deliverable allowed for a higher concretization of the studies and objectives that were proposed. By doing so, it also contributed to a more general thought process on what datasets and remote sensing monitoring strategies (see section 4) could support these studies and, more generally, a broader scope of conservation areas. Although this discussion just started, it already underlined the need and ability to converge under a common data assimilation strategy as a first step for comparability across protected areas, regions and realms. Future work within WP2 will focus on further develop the ideas here explored and also on including other earth observation approaches (e.g. in-situ data collection). WP4 and WP5 already gave important steps in this direction but further integration is needed under the current system-based conceptual approach.

Independently of the advantages of using this approach there are still important bottlenecks related to: i) how encompassing and central the emerging issues of the narratives are and if a qualitatively diverse group of stakeholders was involved; and ii) the scalability and universality (i.e. beyond conservation areas borders) of the EVs identified during this process and how to ensure that a bottom-up approach for conservation monitoring can converge to higher level monitoring systems. If conservation areas would be used to contribute to national and international reporting, these aspects need to be properly addressed in the monitoring design stage. Establishing a concrete group of variables that can be commonly assessed across conservation goals and across protected areas allows monitoring systems to contribute directly to national and international monitoring efforts.

At the national level, replying to and supporting international agreements and conservation goals has also to rely on the conservation efforts from protected areas and on a strong conservation policy that allow the positive effects of these areas to be spread beyond their borders. In order to achieve this, local conservation goals have to be placed in a multi-scale context, from local to global. This implies the involvement of a diverse group of stakeholders and the identification of critical conservation goals and, therefore, essential variables strongly related to these critical conservation goals. The exercise here implemented with the use of the ECOPOTENTIAL Storylines was already a step in this direction but a more comprehensive study is needed to assess the scalability of both conservation goals and system descriptions/variables.

Therefore, another critical issue is related to the process of supporting a bottom-up approach for conservation monitoring that can converge to higher level monitoring systems. Here we focused on giving protected areas the liberty of identifying, describing and collecting their own essential variables. As for any other bottom-up approach, this generated a high diversity of variables considered to be essential by each protected area but a synthesis of this exercise (section 3) already showed that some commonalities can be highlighted. Nevertheless, it also showed that even if different protected areas can contribute to a single essential variable, the scope of their contribution may vary (e.g. for species abundance one protected area can be referring to only bird communities, while another can be referring to reptiles). Without clear guidance on monitoring procedures and transparency, there is the possibility of a complete mismatch between the data collected across protected areas, particularly for biodiversity and ecosystem related data.

At the same time, supported by high level guidance on monitoring schemes, establishing a concrete set of essential variables for a specific conservation goal, ensures conservation managers a transparent and comprehensive description and monitoring of that goal. Also, by implementing a system-based approach coherently across conservation areas/goals, patterns in variable selection will emerge and create the foundations for more broad-scale assessments that go beyond the boundaries of specific protected areas, allowing the benefits generated by a monitoring program to be multiplied across conservation goals, making management and monitoring more effective. This same approach can also allow to identify modelling needs and be a precursor to the development and implementation of "wall-to-wall" modelling frameworks that consider several reporting needs at the same time. This requires interoperable monitoring schemes and design and concrete guidelines established at higher levels (e.g. national scale), but at the same time leaving some degrees of freedom for protected areas to focus on their specific conservation goals.

The process of identifying EVs can illustrate data gaps and thematic, temporal and spatial limitations of the available datasets and could help conservation managers to identify new data needs. If this approach is followed, it is important to assess how these datasets and eventually methodological limitations are shaping current research and conservation management priorities and options. By focusing on the social-ecological system being managed, rather than just on the conservation goals, the EV approach will help to focus managers on empirical evidence and will allow for the conservation priorities to be set solely based on the outcomes of conservation goals, and not merely on whether proposed actions have been implemented. By using a remote sensed based approach (section 4), this approach allows protected area managers to overcome relevant ecosystem and biodiversity data collection and systematization issues and at the same time will move a step further in implementation of a cross-scales and cross-ecosystem monitoring framework.

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Annex

Annex 1 – List of all variables identified by the different storylines including their descriptions.

Theme	ConnectingGEO EV	Hardanger vidda	Peneda-Gerês	Swiss National Park	GPNP	Sierra Nevada Irrigation	Sierra Nevada ES	Northen Limestone	Har Hanegev	Kruger	Montado	Lakes Orhid and Prespa	Camargue	Wadden Sea	Danube Delta	Pelagos	# of Storylines Reporting this EV at least once
Aquatic	ECV: River Discharge											Flux of stream water, runoff and submerged springs feeding the lake					1
Aquatic	ECV: Salinity												Long-term increase or decrease in salinity related to human intervention that affects the flora/fauna of wetland				1
Aquatic	ECV: Water Use					Volume of water used for consumption and irrigation						Uptake of lake water for human use					2
Aquatic	ECV: Water Use					Volume of water diverted from natural pathways and storages (river, soil and aquifer) by human intervention											
Aquatic	EREV: Ocean bathymetry															Measures the depth of water in the ocean	1
Aquatic	WaV: Water Quality							NO3 concentration in goundwater/runoff				Concentration of organic and inorganic toxic elements or compounds					2
Aquatic	WaV: Water Quality											Physical (temperature,					

												turbidity, ...) and chemical (pH, dissolved oxigen, heavy metals, chlorophyll, ...) parameters of lake water					
Carbon	ECV: Carbon Dioxide				CO_2 fluxes from vegetated soil (net flux and respiration)												1
Crop	AEV: Crop Type						Different type of crops						Estimated total area (ha) occupied by different crop types (irrigated and non-irrigated) on a yearly basis				2
Disturbance	EBV: Disturbance Regime	Number of overnight stays, hiking path locations and number of domestic animals.	Burnt areas and time since last fire				Number of livestock	Mapped areas affected by wind throw or bark beetle infestations					1) Loss in quality of reed beds (for nesting birds or harvesting) due to inappropriate water management, salinization or mechanical damage.				5
Disturbance	EBV: Disturbance Regime												2)Estimated total area (ha) of reed beds harvested each year				
Diversity	EBV: Taxonomic Diversity	Alpha diversity/ number of species in 30 x 30 meter plots.	Species diversity: meadows species richness			Abundance, diversity and density of species	Abundance, diversity and density of species	Tree species composition, height, stem diameter	number of key species per unit area (For selected species that provide the most			Estimated number of individuals of each sampled species (including invasive species)		Number of individual per species	Bird and Fish species living in the an area		9

									important ecosystem services)								
Ecosystem composition	EBV: Ecosystem composition by functional type			Horizontal (canopy cover, gaps) and vertical forest structure		Ecosystem delimitation under functional traits criteria		Tree species composition, height, stem diameter									3
Ecosystem extent	EBV: Ecosystem Extent and Fragmentation			Area and spatial distribution of forests and grasslands	Surface area of grasslands, shrublands and forests	Area occupied by different ecosystems	Area occupied by different crops	Mapped forest area (usually > 30% tree canopy cover)			Area occupied by an ecosystem	Surface area of lake bottom covered by macrophyte	Estimated total area (ha) occupied by different wetland ecosystems	Ecosystem Extent Is the coverage and domain of the ecosystem / ecotopes while fragmentation is a metric relating to the continuity or segmentation and isolation of ecotopes.			9
Ecosystem extent	EBV: Ecosystem Extent and Fragmentation					Ecosystem delimitation under functional traits criteria						Phytoplankton Distribution = Position and extention of phytoplancton masses	Estimated total area of submerged macrophytes (= foraging habitat to aquatic birds)				
Evap	EREV: Evaporation and Evapotrasnpiration												the process of transferring moisture from the earth to the atmosphere by evaporation of water and transpiration from plants. The same to the reference evaporation provided				1

													by FAO adjusted for wetlands				
Habitat	EBV: Habitat Structure							Tree species composition, height, stem diameter			Horizontal structure: Canopy cover metrics: percentage canopy cover; frequency distribution of patch sizes. Vertical structure: Cover values of trees, shrubs and herbs in sampling quadrats (i.e., relative cover of vegetation layers); Foliage height diversity (i.e. vertical arrangement of vegetation)	Presence and type of vegetation and algae (coastal and pelagic) and physical characteristics of lake bottom (e.g. presence and dimension of pebble)			Habitat structure is defined as the composition and arrangement of physical matter		4
Land	ECV: Land Cover	Area that is suitable for summer and winter grazing.	Area and extent of woodlands and meadows from Land Cover series (Landsat LCCS classification (EODESM))	Area and spatial distribution of forests and grasslands	Surface area of grasslands, shrublands and forests	Area occupied by different ecosystems			the spatial arrangement of the vegetation either by self-organization or imposed by the abiotic structure or by humans (measured by various landscape indices)	Woody cover (CC) is defined as the percentage area covered by a tree canopy surface for a particular ground surface area (pixel) and is expressed in percent (%)				A classification of the land delineating the type ground cover and plant life occupying this space. Similarly, for the marine environment this related to the sediment composition of the bed, grain sizing, and/or			8

														plant/animal cover			
Land	EREV: Land use, Land Cover, including urbanization, hydrology, grid description			Presence and % cover of plant species, particularly the relative cover of evergreen vs. deciduous tree species	Surface area of grasslands, shrublands and forests	Area occupied by different ecosystems	Spatial distribution of land uses		human made structure that provide human non ecological services installed in a natural matrixes (measured in terms of land cover, infrastructure and its function in terms of energy and materials flows)				Duration, frequency and season during which ecosystems have surface water		Floodplain surface upstream		7
Phenology	EBV: Phenology		Time of maximum productivity at $1km^2$		Beginning, peak and duration of grass growing season												1
Population	EBV: Population Abundance		Distribution and abundance of *Iris boissieri* and *Taxus baccata*		Number of individuals in the population (mountain ungulates) from summer counts	Abundance, diversity and density of species	Abundance, diversity and density of species	Distribution and abundance of plant and animal species			Number of individuals in a population, i.e. population size; for plants, coverage percentage in sampling quadrats may be used as a proxy	Estimated number of individuals of each sampled species (including invasive species)	Trends in abundance of bird species using different wetland types	The number and abundance of species living within certain domains			9
Population	EBV: Population Structure	Number of animals in different age and sex classes every year (live animals and hunting quota).									Tree population (forest) age structure, e.g. frequency distribution of diameter classes						2
Population	EBV: Species Distribution				Position (XY coordinates) of individuals during											The spatial distribution of cetacean species across the MPA	2

					summer counts												
Precip	ECV: Precipitation		Daily precipitation for Process-based Models / Average, max and min precipitation for SDMs at 1km^2		Daily amount of rainfall	How precipitation is distributed throughout space	How precipitation is distributed throughout space	daily amount of precipitation	The number of rainfall events per time. (Measured using rain gauges)		Temporal rainfall distribution (intra annual and inter annual patterns)	Daily amount of rainfall	Monthly amount of precipitation in mm				8
Precip	ECV: Precipitation								Rainfall amount per event (measured using rain gauges)								
Productivity	EBV: NPP	Grams per meter squared per year.	Annual average of NPP per 1km^2	Net primary productivity of forests and grasslands	Seasonal Grass biomass production				total organic energy accumulated by plants per unit area per unit time (measured as biomass accumulation)		Biomass production (total amount of carbon dioxide taken in by plants: gross primary productivity less respiration); NDVI (or similar indexes) could be used as a proxy			The net primary productivity from diatoms, algae, and benthic algae as well. Detailed as a collection of mg/L	Amount of inorganic carbon assimilated by phytoplankton from a volum of water over a given time period		8
Productivity	EBV: NPP														Amount of inorganic carbon assimilated by macrophytes from a volum of water over a given time period		
Productivity	ECV: Above ground biomass	Biomass calculated from Landsat data (Normalized difference lichen index &	Chlorophyll / Nitrogen for species-rich meadows mapping		Seasonal Grass biomass production			Aboveground tree biomass	total organic energy accumulated by plants per unit area per unit time (measured as biomass	Above Ground Woody Biomass (AGB) is the total dry biomass of woody plants							5

		moisture index).							accumulation)	above 0.5m height and is expressed in tonnes per hectare.							
Productivity	ECV: Above ground biomass									Herbaceous biomass is defined as weight of dry grass per unit area (g/m2)							
Productivity	EOV: Chlorophyll		Chlorophyll / Nitrogen for species-rich meadows mapping									Physical (temperature, turbidity, …) and chemical (pH, dissolved oxigen, heavy metals, chlorophyll, …) parameters of lake water				The concentration of this pigment identifies the amount of light absorbed by photosynthetic phytoplankton in the ocean and is a proxy for measuring the net primary productivity of the ecosystem.	2
Radiation	ECV: Surface radiation budget (Atmosphere surface)							Global radiation (above canopy if forested)									1
Snow	ECV: Snow Cover	Depth in millimeters .		Height and duration of snow cover	Daily snow heigth, and snow cover area												3
Soil	ECV: Soil Carbon				Total oganic and total inorganic carbon content of soil at different depths			Amount of soil C per unit area			Inorganic and organic carbon in soil; Fraction of soil organic matter in soil samples (soil organic carbon as						3

											part of soil organic matter is particularly relevant for the Montado example)						
Soil	ECV: Soil Moisture				Water content of soil at different depths		Maximum fraction of the total volume of soil that can be occupied by the water contained in it under saturation conditions	Volumetric soil moisture content			Soil water content at a certain depth						4
Temp	ECV: Sea Surface Temperature											Physical (temperature, turbidity, …) and chemical (pH, dissolved oxigen, heavy metals, chlorophyll, …) parameters of lake water				The water temperature close to the sea surface.	2
Temp	ECV: Temperature	Degrees Celcius.	Daily, max and min temperature for Process-based Models		Daily maximum, minimum and average air temperature (1 m above soil)		How temperature is distributed throughout space	daily air temerature at 2m height						The temperature can be subdivided into Sea Surface Temperature relating to the Degree C of air above the water and actual sea temperature defining the degree C of the water			6
Temp	ECV: Temperature		Average, max and min temperatur		Superficial temperature of soil (from 0 to												

			e for SDMs at $1km^2$		15 cm of depth)												
OTHER	Chlorophyll / Nitrogen for species-rich meadows mapping			Presence and % cover of plant species, particularly the relative cover of evergreen vs. deciduous tree species	Relative number of individuals in each sex/age classes (mountain ungulates) from summer counts												2
					Nitrogen content of soil at different depths			Amount of soil N per unit area				Concentration of nitrogen, phosphorous and carbon compounds of lake water					3
																	1
																	1
				Density of human activity (spatially explicit), including buildings, roads, no. of visitors, hikers, skiers...													1
					Visual description of soil horizon and texture of soil				Soil structure is the diversity of landform elements such as rocks and soils. An important component of geodiversity is pedodiversity (Measured as: rock cover to soil cover ratio, variability of soil depth, soil								2

									quality diversity)								
						The relative ability of an individual to survive, reproduce and propagate genes in its environment											1
							Measure of a soil's ability to transmit water when submitted to a hydraulic gradient										1
										defined as a percentage of the dry matter (%)							1
										defined as the one-sided green leaf area per ground surface area (m2/m2) - unitless							1
		Number of overnight stays, hiking path locations and number of domestic animals.													Number of tourists involved in different activities (fishing, bird watching etc); Number of beds night	It is defined by the number of whale-watching passengers per boat and the revenues generated by it	3
													Action of adding water to an ecosystem to compensate for embankment and/or to improve				1

													productivit y				