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Deliverable 2.1

Review of existing Essential Variables (EVs) relevant to PAs studies

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1. Executive summary

This report corresponds to the deliverable D2.1 ("Review of existing Essential Variables (EVs) relevant to PA studies") that is the final output of Task 2.1, within ECOPOTENTIAL Work Package 2 (WP2, "Conceptual Scientific Framework"). It provides a first review and synthesis of the available information regarding the concept and application of essential variables (EVs) to different thematic areas (e.g. biodiversity, climate, ecosystems). At the same time, ECOPOTENTIAL focuses its activities and pilot actions on a targeted set of internationally recognised Protected Areas in Europe, European Territories and beyond, including mountain, arid and semi-arid, and coastal and marine ecosystems. Having this in consideration, this Deliverable aims to identify a set of essential variables relevant for Protected Areas (PAs).

In order to describe the PAs, within ECOPOTENTIAL, a set of storylines[1] was outlined and associated to the PAs.Using the available storylines as the backbone of the methodological approach, we selected five storylines that cover the three ecosystem types listed above (i.e. mountain, arid and semi-arid, and coastal and marine ecosystems). Due to their diversity, these storylines and corresponding Protected Areas serve as examples for other Protected Areas of the same type and allow defining a diverse set of essential variables to be considered in the scope of ECOPOTENTIAL.

Across three storyline lines, a total of fifty-four (54) Essential Variables were proposed. From these, ten (10) Essential Variables are common across the considered ecosystems: i) species distribution; ii) species abundance; iii) disturbance regimes; iv) precipitation; v) temperature; vi) land cover; vii) phytoplankton biomass; viii) dissolved organic matter; ix) chlorophyll-a; and x) bacteria concentrations.

Identifying Essential Variables with policy-relevance requires a continuous and iterative process that includes decision makers and scientists. The initial efforts taken by ECOPOTENTIAL have created positive exchanges between ECOPOTENTIAL and the protected areas and have helped not only to identify a clear set of essential variables that need to be monitored but also to define a communication path that will allow in the near future to convey relevant information from earth observation systems. The interdependencies among storylines/protected areas, in terms of the identification of Essential Variables, highlight the need for a systematic approach that ultimately will allow producing relevant results for the protected areas in Europe and elsewhere. This will also allow to contribute to the goals of the GEO/GEOSS ecosystem-related activities.

In our efforts to analyse Essential Variables with relevance to ecosystem benefits and Protected Areas, we identified some important issues that will be addressed in the near future, namely:

i) in order to identify the most appropriate Essential Variables supporting Protected Areas, it is important to consider (within the storylines) the requirements and/or conservation goals for each Protected Area;
ii) if Essential Variables are to be important for conservation managers there is a need to establish a stronger relationship between the conservation managers from the Protected Areas and ECOPOTENTIAL (through the storylines) to allow for a more operational use of Essential Variables;
iii) the need to identify when Remote Sensing products provide a better alternative to calculate Essential Variables; and
iv) the absence of direct relations between the identified Essential Variables and their potential to act as significant inputs for ecosystem service modelling.

[1] Within ECOPOTENTIAL, storylines link real-life issues which have broad relevance to many Protected Areas included in the project. The storylines specify the needs for Earth Observation data and in-situ data for ecosystem modelling, ecosystem services, cross-scale topics, demands for future protections, policy and capacity building. Each storyline is focused within at least one Protected Area and it puts the basis for further operational work in the field. Storylines are iterative processes whose flow of activity and practical implementation evolves with the increase of knowledge and the demands *by stakeholders.*

2. Introduction

2.1 Main objectives

Within this deliverable we show how the use of Essential Variables can help the reporting and management requirements of Protected Areas in Europe and beyond. To illustrate this, we focus on a set of protected areas and associated storylines that describe issues of concern to these protected areas. These protected areas and storylines cover a wide range of socio-ecological conditions and geographic extent. Taking into consideration the current development of the different tasks in ECOPOTENTIAL and their current and expected outputs, these storylines are also being enhanced in other WPs (e.g. WP7, WP6), allowing for further deepening the underlying questions ultimately aiming to inform management decisions related to the protected areas conservation goals. As a consequence, the work developed in this Deliverable will continuously evolve during the project duration as an iterative process that will ultimately allow to identify, refine, validate and publish a set of essential variables relevant for protected areas across Europe.

Overall, this Deliverable aims to: (i) review existing concepts on essential variables and to summarize the basic concepts of essential variables and put in evidence their role in environmental monitoring; (ii) to showcase how essential variables can address the needs and requirements of Protected Areas to monitor and assess ecosystem services, ecosystems and biodiversity; and (iii) illustrate how these needs must be incorporated in the selection and future use of Essential Variables. In the wider scope of ECOPOTENTIAL this deliverable intends to serve as an important step to the main discussion regarding the process to identify, validate and progressively monitor essential variables relevant to protected areas.

2.2 The concept of essential variables and its applications

Over the last few centuries, the world's cultural and natural landscapes and seascapes have changed profoundly due to the intensification of impacts of human activities (Thuiller et al. 2008; Darnhofer et al. 2010). Such activities have significantly impacted ecosystems, affecting their functions, processes, services and values to the society (MA 2005; IPCC 2007; EEA 2015). As these problems became more apparent, world leaders have also become more aware of the social, economic and ecological implications resulting from these impacts (Daily and Matson 2008) and the need of effectively monitor the state of the environment. The recently established sustainable development goals (SDGs) are a clear example of society's response to these challenges by establishing development goals that tackle different aspects of the relation between society and nature. At the European level, the 2020 Biodiversity Strategy also argues that *biodiversity and the ecosystem services it provides are protected, valued and appropriately restored for biodiversity's intrinsic value and for their essential contribution to human well-being and economic prosperity, and so that catastrophic changes caused by the loss of biodiversity are avoided*. These encompassing visions intrinsically call for data availability across several themes and scientific disciplines that allow to assess and monitor the pursuit of these environmental goals.

In parallel, over the last years several Earth Observation systems were implemented at the European and global scales to gather data related to different aspects of our environment, e.g. climate, ocean, biodiversity (Skelsey et al. 2003; Nichols and Williams 2006; Morvan et al. 2008; Jones et al. 2011; Drusch et al. 2012; Tallis et al. 2012; Crowther et al. 2015). Despite the significant progress made to promote and implement these systems that allow to identify, collect, process and make available standardized information that meet the needs of a wide range of users (Guralnick et al. 2007), there are still user requirements that are not being met, particularly those linked to nature conservation. On top of that, there is still insufficient consistency in the monitoring and sharing of such information (ConnectinGEO, 2016a) due to a focus on data gathering rather than a consistent crosscutting policy approach.

Over the last five decades, there has been a continuous effort in the refinement of essential climate variables to overcome some of these issues and to have consistent global coverage of climatic data. Meanwhile, for other themes central to the conservation and management of biodiversity (e.g. biodiversity, ecosystem services, land management) existing initiatives are still far from producing a complete and coherent image of the state and trends of important environmental variables. At the global scale, this becomes noticeable if we compare the spatial, temporal and thematic coverage of meteorological data (using WorldClim dataset as an example (Hijmans et al. 2005)) with the distribution of soil profiles (using the ISRIC global soil database as an example (Fischer et al. 2008)) used to calculate a global distribution of climate and soil properties (Figure 2.1). Other examples can be found for different thematic areas, e.g. biodiversity distributions (Global Biodiversity Information Facility), ocean properties (World Ocean Database and World Ocean Atlas Series). Other critical aspects of these datasets include the temporal coverage/quality, thematic consistency, and methodological coherence of the data included in them. Again, while for climate precise daily measures can be obtained for a large amount of the data points, for many other environmental variables needed, precise and reliable measurements are not available with an appropriate temporal frequency and continuity.

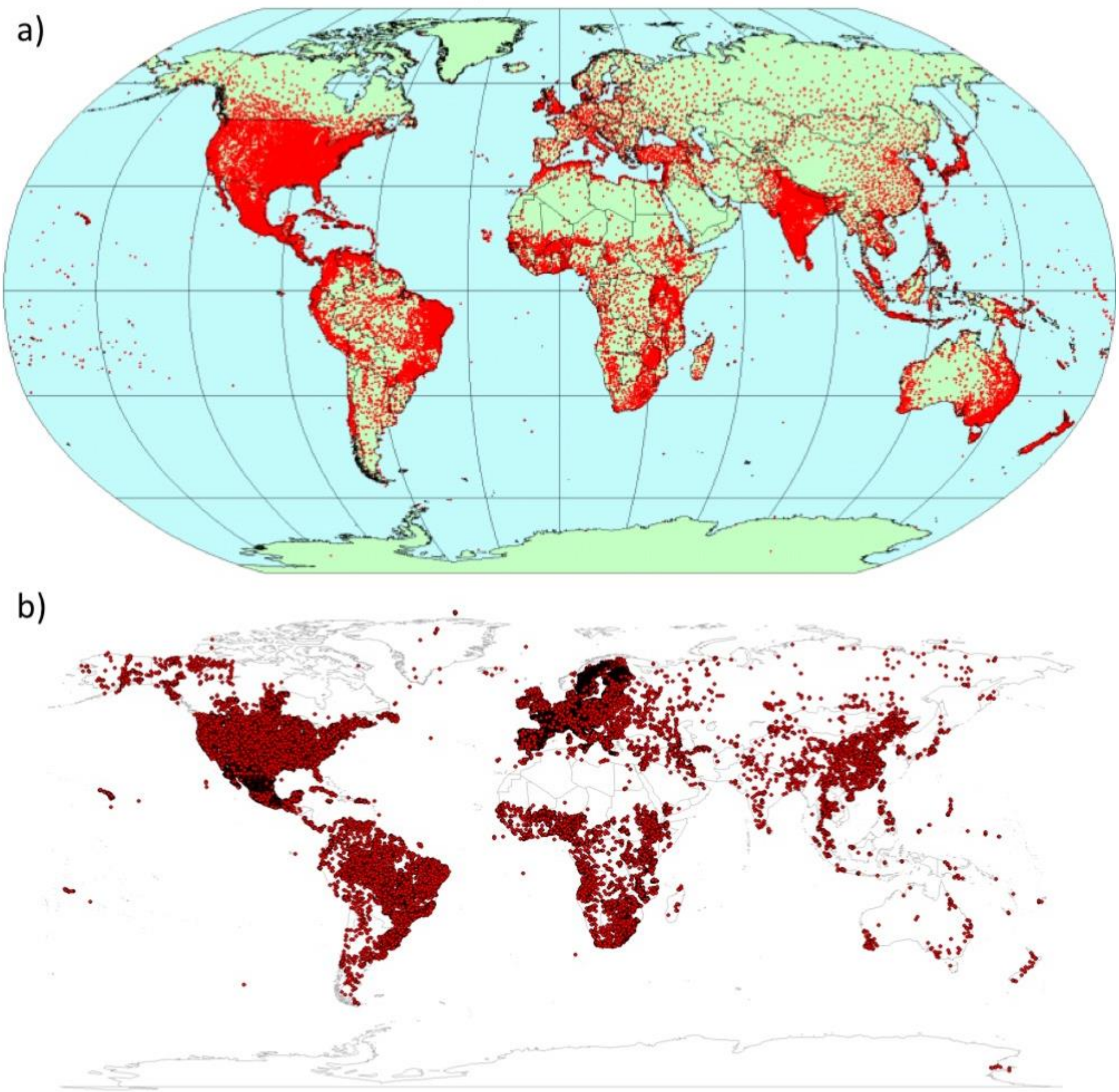

Figure 2.1 Differences between global distribution in climate (a) and soil data (b) used to produce 1km^2 global datasets (although relevant, these maps do not illustrate the temporal and thematic (in)consistencies of the datasets).

All together, these issues are a major constrain to the development of global Essential Variables that are consistent, integrated, and representative of the environmental processes they try to accurately depict. To be able to overcome these constrains, a joint effort has been undertaken by the scientific community to identify Essential Variables (EV) for environmental monitoring across scales and geographic regions. These can be defined as the minimal set of variables that describe the system's state and at the same time are crucial for predicting system developments and allow us to measure and report on the trajectory of the system (CREAF 2016). These can be further specified as fitting one of two potential types: (i) bottleneck variables, related to variables that are critical in the definition of a given ecological, bio-geo-chemical or climatic process (e.g. precipitation is a variable that cannot be overlooked and that is determinant for most hydrologic related studies and models); and (ii) recurrent variables, related to variables that are widely accepted by the technical and scientific communities as critical to explain specific ecological, bio-geo-chemical or climatic processes (e.g. species distribution is a well-recognized Essential Variable to track the effects of climate change on biodiversity). Regardless of the type of Essential Variable and the specific thematic area they highlight (e.g. climate, biodiversity, ecosystem services), there is a set of global requirements that often define Essential Variables:

- The variable is critical for characterizing a specific environmental system or process;
- The variable should be sensitive to detect change at different scales;
- Observing or deriving the variable on a global scale should be technically feasible using proven and scientifically understood methods; and
- Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems, using proven current technology and taking advantage where possible of historical datasets;

Virtually hundreds of variables can fit this definition so the task ahead is to develop and implement a sound process to identify, select, calculate and validate these Essential Variables in the scope of relevant policy and reporting needs. In the context of ECOPOTENTIAL the identification of these Essential Variables is critical to promote a better understanding of the biodiversity and ecosystem services state and trends in the context of Protected Areas and their conservation goals. These will allow to focus and harmonize the protected areas' monitoring efforts across regions and thematic areas. At the same time, the definition of Essential Variables (particularly in the context of ECOPOTENTIAL) takes advantage of current developments in geospatial technology and the ability to collect relevant ecological data from space (Jetz et al. 2016). Altogether, the identification of clear conservation goals, the availability and harmonization of *in situ* data collection, and the strong focus in collecting relevant ecological data from space will allow to identify, calculate and map a set of concrete Essential Variables relevant for Protected Areas.

2.2.1 Types of Essential Variables

The concept of Essential Variables has been put forward by the climate community (GCOS 2010). In face of the unprecedented changes in the global climate system, it was recognized that observation data are crucial to refine our understanding about the climate system and its alterations, to further research and improve modelling and ultimately to guide political decisions (GCOS 2010). In 1992, the Global Climate Observation System (GCOS) was established with the goal of delivering good quality data, collected in a transparent and regular way and freely available to all interested parties. The Essential Climate Variables (ECVs) were developed by the GCOS as an outcome of an iterative process to determine the best variables to monitor the climate system in the long-term (Bojinski et al. 2014). An ECV is *"a physical, chemical, or biological variable or a group of linked variables that critically contributes to the characterization of Earth's climate"* (Bojinski et al. 2014). In order to identify ECVs the following criteria were suggested:

- Relevance: The variable is critical for characterizing the climate system and its changes.
- Feasibility: Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.

- Cost effectiveness: Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

The Global Ocean Observing System (GOOS) has also adopted the EVs concept to develop Essential Ocean Variables (EOVs). EOVs are "those deemed 'essential' for understanding the ocean, having high impact in their contribution to understanding the ocean, and high feasibility to measure whilst addressing key scientific and societal issues" (Grimes 2014). According to this EOVs could then be divided into sub-categories, depending on the aspect of the ocean that they address. Proposed sub-categories are: physical, biogeochemical and ecosystems (GCOS 2010).

Inspired by the ECVs process, and in order to refine our understanding of biodiversity change, the biodiversity community through the Group on Earth Observations Biodiversity Observation Network (GEO BON) is developing the Essential Biodiversity Variables (EBVs). These come from the premise that mass species extinctions are happening (Barnosky et al. 2011; Ceballos et al. 2015) but still there are wide knowledge gaps in the geographic and temporal extent of the available information, and we are far from producing a complete and cohesive picture of the entire process (Pereira et al. 2012; Proença et al. 2016). EBVs can help in the harmonization of biodiversity monitoring data from several sources, by contributing to the identification of how variables should be sampled and measured, so to achieve also better data integration. EBVs can also be used to define the minimum set of essential measurements to capture major dimensions of biodiversity change in a monitoring scheme (Pereira et al. 2013). EBVs have been defined as *"measurements required for studying, reporting, and managing biodiversity change"* (Pereira et al. 2013). In order to guide the process for selecting EBVs, GEOBON has set some criteria (GEOBON 2015):

- EBVs should be state variables: while variables for drivers of biodiversity change and pressures to biodiversity are important they are often not biological entities, hence EBVs should be state variables.
- EBVs should be biological: non-biological variables are important for biodiversity change however EBVs should be biological by definition.
- EBVs should be sensitive to change: whether this is induced by humans or nature (e.g. extreme weather events).
- EBVs should strive to be ecosystem agnostic: this is recognized as a challenge for some cases, however an effort to make EBVs ecosystem agnostic has several advantages, for example, facilitates comparison across disciplines and simplifies aggregation.

According to this, EBVs lie between primary observations and indicators. Primary observations are drawn from in situ monitoring and remote sensing; indicators present an aggregate summary of information as they can require the aggregation of different sources of information, for example EBVs and other ancillary biodiversity attributes (Pereira et al. 2013). By being the intermediate layer between raw data and indicators, EBVs are shielded from changes in policy and EBVs shield indicators from advances in observation technology and science (GEOBON 2015).

Building from ECVs, EOVs and EBV, Essential Variables for Ecosystems are being developed and discussed considering different frameworks and initiatives that are co-occurring in Europe and Globaly. Besides the developments in GEOBON and ECOPOTENTIAL, the EU H2020 project BACI has the goal of supporting latest efforts towards generating "Essential Ecosystem Variables" (EEVs: exploring the intersection of Essential Climate Variables and Essential Biodiversity Variables, http://baci-h2020.eu/index.php/). At the same time, the European Union funded Horizon 2020 project ConnectinGEO, released a report with the current status of EVs for the different GEOSS's societal benefit areas: Agriculture, Biodiversity, Climate (and specifically Atmospheric composition, Carbon Cycle, and Greenhouse Gasses), Disasters, Ecosystems, Energy, Health, Water (and River discharge), and Weather, and the thematic areas Citizen Science, Human Settlements, Oceans (and Marine Ecosystems), and Solid Earth Science (including volcanology). This classification is meant to allow for a more targeted assessment of data needs within different scientific, technical and policy communities but also allows for some superposition (see Table 1 for further reference).

Altogether, following the work developed by ConnectingGEO, it was already possible to identify 93 Essential Variables covering eight different thematic areas (i.e. biodiversity, climate, weather, energy, agriculture, health, water, and oceans). Although other thematic areas are also identified, Essential Variables have been assigned only to these eight themes. The work from ConnectingGEO also allowed to identify a large sum of variables that cover more than one thematic area (34% of the identified Essential Variables) although probably looking at different measured parameters. This means that their essentiality is recognized by more than one community and also that they are significant to more than one process and/or system.

	Themes							
Essential Variable/Class	*Biodiversity*	*Climate*	*Weather*	*Energy*	*Agriculture*	*Health*	*Water*	*Oceans*
Genetic composition	■							
Species populations	■							
Species traits	■							
Community composition	■							
Ecosystem function	■							
Ecosystem structure	■							
Air temperature		■	■	■	(x)			(x)
Wind speed and direction		■	■	■				
Pressure		■						
Precipitation		■		■			■	
Surface radiation budget		■						
Cloud properties		■		■				
Earth radiation budget		■						
Carbon dioxide		■	■					
Methane, and other long-lived greenhouse gases		■	■					
Ozone and Aerosol, supported by their precursors		■	■					
Temperature (sea-surface, sub-surface, deep-sea)		■						■
Salinity		■						■
Sea level		■						■
Sea state		■						■
Sea ice		■						■
Current		■		■			■	■
Ocean colour		■						■
Carbon dioxide partial pressure		■						■
Ocean acidity		■						■
Phytoplankton		■						■
Nutrients		■					■	■
Oxygen		■						■
Tracers		■	■					■
River discharge		■		■			■	
Water use		■					■	
Groundwater		■					■	
Lakes		■					■	
Snow cover		■			(x)		(x)	
Glaciers and ice caps		■						
Ice sheets		■						■
Permafrost		■						
Albedo		■						
Land cover/land use		■		■	(x)			
FAPAR		■						
Leaf Area Index		■						
Above-ground biomass		■						
Soil carbon		■						
Fire disturbance		■						
Soil moisture		■						
Atmospheric pressure			■					
Relative humidity		■	■	■				
All Global Numerical Weather Prediction (NWP) variables and others yet to be determined by WMO/GAW				■				
Aerosols				■				
Bathymetry				■				■

Table 2.1 Table of available Essential Variables [(x) Theme potentially included] (adapted from CMCC (2016))

	Themes							
Essential Variable/Class	*Biodiversity*	*Climate*	*Weather*	*Energy*	*Agriculture*	*Health*	*Water*	*Oceans*
Tidal								
Wave								
Urbanization								
Elevation (Orography)								
Solar Surface Irradiance and its components (global, direct, diffuse)								
Crop area								
Crop type								
Crop condition								
Crop phenology								
Crop yield (current and forecast)								
Crop management and agricultural practices								
Famine early warning								
Short term forecasting of communicable diseases								
Precipitation								
Evaporation and evapotranspiration								
Snow cover								
Soil Moisture/Temperature								
Groundwater								
Runoff/streamflow/river discharge								
Lakes/reservoir levels and aquifer volumetric change								
Glaciers/ice sheets								
Water quality								
Water use/demand								
Sea Level Pressure								
Global Ocean Heat Content								
Macro Nutrients: NO3, PO4, Si, NH4, NO2								
Carbonate System: DIC, Total Alkalinity, pCO2, pH								
Transient Tracers: CFC-12, CFC11, SF6, tritium, 3He, 14C, 39Ar								
Suspended particulates (POC, PON or POM) and PIC ++ laboratory, beam attenuation, backscatter, acidlabile, beam attenuation								
Particulate Matter Export: POC export, CaCO3 export, BSi export								
Nitrous Oxide								
Carbon-13: 13C/12C of dissolved inorganic carbon								
DOM (Dissolved organic matter), DOC, DON, DOP								
Chlorophyll								
Coral Cover								
Mangrove Area								
Harmful Algal Blooms (HABs)								
Zooplankton (biomass/abundance)								
Salt Marsh Area								
Large marine vertebrates: abundance/distribution								
Seagrass Area								
Tags and Tracking of species of value/large marine vertebrates								
Fish stocks								
Bacteria concentration								
Zooplankton (Krill)								

Table 2.1 Table of available Essential Variables [(x) Theme potentially included] (adapted from (CMCC 2016) [cont.])

2.3 Protected Areas: distribution and storylines

ECOPOTENTIAL focuses its activities and pilot actions on a targeted set of internationally recognised protected areas in Europe, European Territories and beyond, including mountain, arid and semi-arid, and coastal and marine ecosystems. Protected areas such as those considered in ECOPOTENTIAL are of high value for the protection of biodiversity and are also sources of ecosystem services provision, but they are also exposed to a variety of pressures, which can change their very nature and lead to a loss of biodiversity and associated ecosystem services.

In this framework, internationally recognized protected areas such as UNESCO Natural Heritage sites, Natura 2000 sites (92/43/EEC) and national parks are "the natural jewels" of Europe and they are ideal sites for pilot actions, as they often include crucial, diverse and endangered ecosystems and play a central role in conservation and management strategies within rapidly changing environments. Moreover, such sites provide long-term ecological, environmental, climatic and socio-economic data, they support continuous field monitoring activities and are commonly active centres of environmental education and citizen awareness raising.

Even though concepts and analytical methods could be developed just for a few sites, the diversity of environmental conditions, protection status and data availability calls for a broader view of ecosystem change, function and services in European protected areas, requiring that a sufficient number of diverse situations are analysed. For this reason, ECOPOTENTIAL considers different ecosystem types and, for each of them, a sufficiently large suite of protected areas in order to identify and avoid singularities and to work out generality across a broad range of biogeographical settings and environmental conditions.

Along these lines, three ecosystem types of crucial interest to Europe will be in focus:

Mountain ecosystems, rich in endemic and endangered species, are directly linked to downstream regions through ecosystem goods and services including benefits to watersheds, slope stability, discharge regulation, food and energy production, recreational services and options for tourism. Mountain ecosystems are "sentinels of change" as they are highly sensitive to the impacts of modifications associated with climate and/or land-use change. In addition, pilot sites in mountains integrate a spectrum of altitudinal zones and ecosystems in one protected area. The role of mountain regions has been acknowledged at the UN Conference Rio+20, and GEO has recently established the Global Network for Observations and information in Mountain Environments (GEO-GNOME). The spatial heterogeneity of mountains exhibits methodological challenges for Earth Observation (EO) (cloudiness, shade, etc.) making these areas excellent training grounds for the development of robust approaches. In Europe, mountainous protected areas of international value exist in all climatic zones and latitudes.

Arid ecosystems and semi-arid, which exhibit unique pathways of ecosystem function and specialized ecosystem services, and host life under extreme conditions. Such water-limited ecosystems can be vulnerable to the current impacts associated with global change. According to climatic projections, large areas in southern Europe are exposed to the risk of facing significantly drier conditions, and collapse of previous ecosystem functioning can occur as a consequence of increased climatic variability (Behnke and Mortimore 2016). Here especially, uncertainties are high about future ecosystem behaviour. In water-limited ecosystems, temporal variability must in particular be addressed by remote sensing and field data. Hence, we see a strong contribution of these sites to improving the monitoring of temporal dynamics in drylands, a biome that is home to some 2.3 billion people worldwide (http://web.undp.org/).

Marine and coastal ecosystems are “an integrated and essential component of the Earth’s ecosystem and are critical to sustaining it” (Rio+20 outcome document *The Future We Want*, 2012). Rio+20 also noted that the health of oceans and marine biodiversity are negatively affected by the impact of human activities, leading to a loss of biodiversity, decreased abundance of species, damage to habitats and loss of ecological functions and ultimately, ecosystem services. Effective management of these ecosystem and their benefits requires sustained monitoring and development of indicators to inform policy and decision makers. Coastal areas are transition zones between ecosystems that are of extreme importance for biodiversity and for the exchange, migration, and refuge of species with complex habitat requirements, being also crucial to people who depend on coastal and near shore ecosystems. In consequence, we see this category of ecosystems and pilot sites as representative for approaches that focus on capturing the mobility of organisms within and between ecosystems.

These three categories of ecosystems characterize the set of internationally recognised Protected Areas selected for inclusion in ECOPOTENTIAL. UNESCO World Heritage Sites and Biosphere Reserves, National Parks, Natura 2000 sites, Large Marine Ecosystems (LMEs) and Long Term Ecological Research (LTER) sites are included. The often transboundary PAs selected in ECOPOTENTIAL span across Europe with crucial additions from European Territories (in the Caribbean Sea) and non-European areas such as the savannah of the Kruger National Park, and are characterized by widely different environmental conditions. The inclusion of the Kruger National Park is crucial as it provides an example of savanna ecosystems, a type of vegetation assemblage which is currently little represented in Europe (an example is a small area in the Montado protected area in Portugal), which could become more widespread in future climate change scenarios.

2.3.1 Methodology adopted for collecting and describing the storylines

Storylines are narratives that “highlight the main features of the considered ecosystems and the relationships between the scenario’s driving forces and its main features” (see e.g. UK NEA, 2011). Within ECOPOTENTIAL, storylines are used to facilitate and practically implement project activities and to link the tasks among the different WPs. Each storyline refers to at least one specific pilot Protected Area in which it will be implemented, ideally in months 6-18 of the project. The storylines will probably be then applied to other protected areas sharing similar characteristics within the project.

Each storyline development started with a scientific research question which was further developed for a given ecosystem type or a given protected area. This was further elaborated through face-to-face or virtual meetings by working groups within the ECOPOTENTIAL community including experts linked to the specific PAs. These working groups jointly aim to identify the key ecosystem services (ESS) linked to the focus areas, the possible drivers of ecosystem change that also affect the specific ESS and to develop a plan to assess the current situation (tourism, raw material supply, water and climate regulation, etc.) of the protected area, taking into account the policy and conservation objectives of each Protected Area.

For each storyline, tables were prepared that summarized all the acquired information. These tables are now available to all project partners and have been used as a starting point for the storyline definition and the discussions between the scientific partners of ECOPOTENTIAL and the Protected Area personnel. In each table, for each Protected Area, a few typical ecosystem types are identified, and for each of them the associated ecosystem services are indicated.

The identification of the key ecosystem services was used as a basis to identify those critical ecosystem functions and processes that support these services and are directly or indirectly impacted by the identified drivers of change. For these functions, drivers, pressures, and most critical components are identified, together with the available *in situ* and remote sensing data that could help characterize current states, could be used in currently available ecosystem and environmental models. A specific storyline template was prepared by the Consortium Coordination Team (CCT) in order to obtain comparable descriptions of the different storylines. The identification of the most important functions/processes, of the drivers/pressures, of the critical elements and of the corresponding indicators, as well as of the available data, was obtained again in close interaction with the PA personnel.

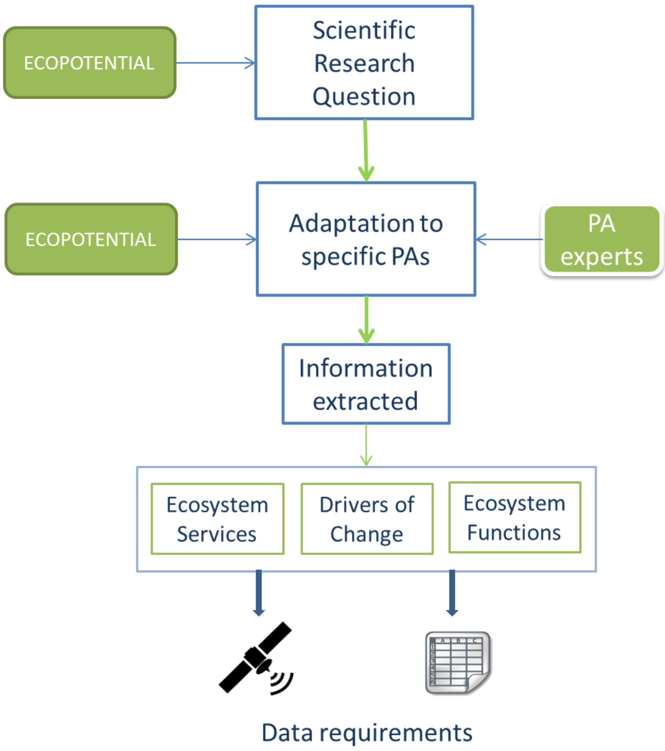

Figure 2.2 General graphical overview of the procedure followed.

Each storyline is required to identify key impact variables from remote-sensing and/or *in situ* data, given the focus of ECOPOTENTIAL on providing data services and products to foster the best use of remote sensing observations in ecosystem studies and PA management and conservation. In some cases, storylines already identify key variables that could service as essential variables.

3. Essential variables extracted from the PAs storylines: identification and classification

In this section, we used some of the storylines developed within ECOPOTENTIAL to extract and distil EVs that are being or can be used within the storylines to assess and quantify the drivers of ecosystem change, the ecosystem components and the impacts of the potential change. The storylines presented in this section are examples of the ongoing work and are all evolving as the project moves forward. A short narrative for each storyline is presented along with the associated research questions (Section 3.1). The storylines presented were built for different ecosystem types: the alpine lakes in Gran Paradiso mountain area and Ohrid and Prespa lakes in the FYR of Macedonia; the Wadden Sea and the Pelagos Sanctuary for marine mammals to represent marine and coastal areas; and the arid and semi-arid systems of Montado and Kruger National Park. The spatial distribution, extent and ecosystem type are shown in Figure 3.1. Indicators that describe the socio-ecological system structure and evolution are defined, as well as essential variables (EVs) that can be used to calculate these indicators (Section 3.2).

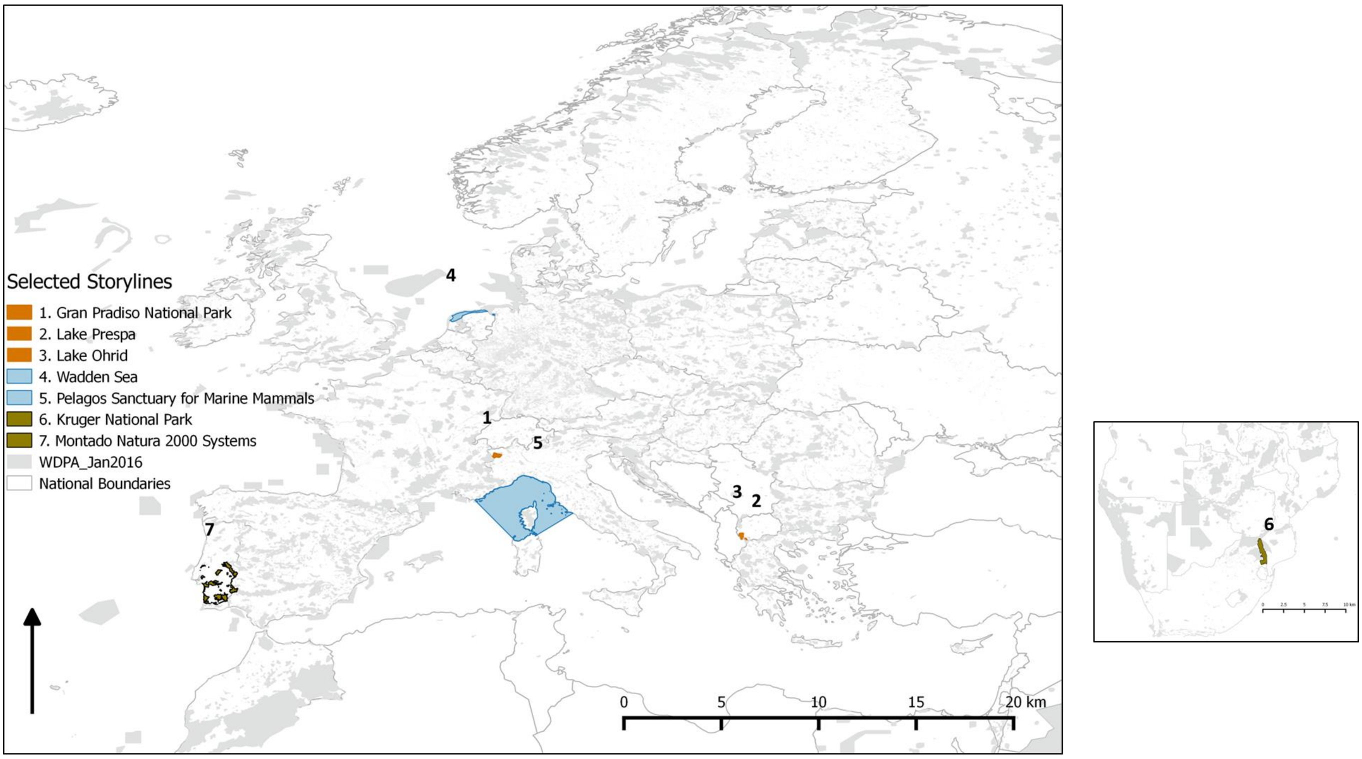

Figure 3.1 Spatial distribution, extent and ecosystem type of the selected storylines.

When looking beyond the Millennium Ecosystem Assessment, a critical information gap has been identified in the common practice of tabulating information sources and the non-explicit relationships between the data sources and the ecosystem functions or essential variables (Carpenter,2009). In the context of WP 7, mind maps were developed as a visualization tool to identify the critical pathways connecting Ecosystem Service components and to highlight relationships within ecosystems using the DIPSR framework (El Serafy, 2016). These mind maps establish a comprehensive way to relate, understand and map ecosystem services to ecosystem functions and measurable variables. Mind maps have been extensively used as a tool that facilitates decision-making (Beel et al. 2009) both to inform environmental management (Burke and Miller 1999; Farmar-Bowers and Lane 2009; Papageorgiou and Kontogianni 2012), but also within other disciplines (D'Antoni et al. 2010). A visual mapping approach was used in the European Project BiodivERsA for the identification of stakeholders and relationships with data sources. It was proven to be very useful as a communication tool and also in identifying critical elements as well as information and data pathways (Durham, 2014). We propose, within WP2, to extend the mind maps to include the identification of Essential Variables within each PA. By applying this exercise across all Protected Areas within ECOPOTENTIAL, commonalities in critical variables identified across the entirety of ECOPOTENTIAL Protected Area sites can be identified and further explored.

3.1 Storylines: narratives and main objectives

3.1.1 Mountain lakes: The Gran Paradiso, Orhid and Prespa lakes

The mountain system we chose to describe is focusing on ***mountain lakes***. Mountain systems are significant for the provision of vital goods and services, mostly freshwater. For that reason, important habitat types within the mountain ecosystems are mountain lakes. Mountain lakes are often oligotrophic and they host specialized ecosystems, which are rich in endemic species. The limited species range, paired with increasing pressures on ecosystems, makes the biodiversity of mountain lakes particularly sensitive to environmental and climate changes. Given that one of the primary species responses to changing conditions is a shift in geographic distribution, the lake watershed isolation may force species adaptation or, ultimately, extinction.

The major threats to the biodiversity of mountain lakes are growth in tourism, rapid urbanization, pollution, land use intensification, water uptake, progressing eutrophication, introduction of alien species and climate change, with different importance in different Protected Areas. Typical phenological responses to changing conditions include shifts in timing, magnitude and duration of phytoplankton blooms, as well as altered community composition (cf. Palmer et al., 2015). The latter can lead to changes in the water quality and a decrease in the overall biodiversity, thus threatening established links across trophic levels and, potentially, implying a loss in ecosystem services. Similarly, the introduction of allochthonous fish (often done for recreation purposes) can lead to the disappearance of larger zooplankton species (such as *Daphnia* spp.) with a change in the overall ecosystem structure and loss of invertebrates and amphibians, as documented in some high-altitude oligotrophic lakes in the Gran Paradiso National Park (GPNP), Italy (Tiberti et al., 2013). For transboundary mountain lakes, such as Prespa and Ohrid lakes (shared between FYR of Macedonia, Greece and Albania), the situation is even more complex. The two lakes are subject to a broad range of management concerns including transnational management, recreation/tourism, water supply and biodiversity protection. Though considerable efforts have been undertaken to reduce pollution and to protect flagship species, Lake Ohrid is facing a “biodiversity crisis” (Albrecht and Wilke, 2008). Given that Lake Ohrid has a surface area of 358 km^2 and 212 known endemic species (e.g. the Ohrid Trout, *Salmo letnica*), probably it is the most diverse lake in the world (Albrecht and Wilke, 2008), and it is clear that efforts must be made to reverse this ongoing "biodiversity crisis".

For most lakes at GPNP as well as for Ohrid and Prespa, many data on the physical, chemical and biological properties of the lake waters are available. In situ data, however, give information only for a point in time and space, thus providing limited information on spatial and temporal changes of environmental parameters across surface waters. Both, endemism and phenology features commonly occur at different spatial scales, ranging from features occurring only in certain watershed parts to features occurring across the whole watershed. The high spatial resolution of satellite images allows for the estimation of water quality and hydrological parameters, such as chlorophyll concentration, Secchi-depth, phenology metrics, surface currents and surface area. Information at catchment scale on land cover, land use, vegetation status and forest fires facilitate the establishment of linkages between catchment scale alterations and lake ecosystem processes. As such, remote sensing data complement and extend traditional lake sampling methods, facilitating understanding of the current state of lake ecosystems and supporting the application of appropriate management strategies.

3.1.2 Marine and coastal areas: The Wadden Sea and the Pelagos Sanctuary for Marine Mammals

For this example, we selected a coastal (Wadden Sea) and an open ocean (Pelagos) ecosystem.

The ***Wadden Sea*** is an international, highly productive estuarine area, and one of the largest coastal wetlands globally. Situated abreast mainland Europe in the south-eastern portion of the North Sea, it borders Germany, the northern portion of the Netherlands, and western Denmark, thereby requiring tri-lateral cooperation in its management and protection. It is a biodiversity hotspot due to its positioning as a convergence point among terrestrial, fresh water, brackish and marine habitats thus supporting a wide breadth of biota. The Wadden Sea is characterized by extensive tidal mud flats, saltmarshes, and deeper tidal creeks between the mainland and chain of islands that denote the outer boundary between the Wadden and North Seas. 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. The Wadden Sea includes: i) a barrier coast with lido, barrier islands, mudflat systems and coastal lagoons, ii) deltaic systems and iii) bar-built and funnel-shaped estuaries.

The area is both UNESCO World Heritage and Natura 2000 site. It is approximately 500 km long with a surface area of around 9,000 km^2, a quarter of which is located within the Netherlands. Almost the entire region is submerged at high tide, and half the area (the mud flats where many birds feed) is exposed during low tide.

The high value ascribed to the Wadden Sea comes from its important regulatory and maintenance functions for the south-eastern coastal portion of the North Sea, its diverse aesthetic values, and the protection it offers against westerly storms to the German, northern Dutch, and western Danish coasts. The Wadden Sea is a nursery area for many fish species as well as a resting and fuelling station for a wide variety of wading birds. More than half of the juvenile plaice, a flatfish, population of the North Sea grow up in the area. Moreover, more than 10 million birds spend varying degrees of time in the region, often on migratory routes between nesting grounds near the North Pole to wintering sites as far south as Africa. This treasured combination of varied species and aesthetics draws a high volume of tourists in many forms, including but not limited to island visitors, game fisherman, boating and mudflat walking excursionists, and commercial operations. Commercial activities include industrial fishing for commercial fish and shellfish; recently aquaculture for shellfish has been introduced. One of the objectives of the application of protected area status to the Wadden Sea is to limit the degree of exploitation by the commercial shellfish industry whose high degree of pressure through mussel extraction has significantly impacted the system's capacity to support the large volume of migratory birds.

The management goals of the Wadden Sea are primarily at the national level, but agreements have been made between all three countries which have stake in a portion of the systems, in order to have the policy and management developed at trilateral level (see http://www.waddensea-secretariat.org/trilateral-cooperation/organisational-structure). Note that this organizational body needs to be taken into account when addressing future management issues of the Wadden Sea. The aim of this storyline is to assess the temporal and spatial dynamics in, and naturalness of, the balance between the functioning of the ecosystem, and the ecosystem services it delivers, under a range of drivers of change and threats, including sustainable use as far potentially is possible given its high protection status.

For the open ocean example, we selected the ***Pelagos*** Sanctuary for marine mammals. Most of cetacean species in the Mediterranean Large Marine Ecosystem (LME) live within areas of significant importance for the biodiversity and fisheries management (MPAs or national parks) (Panigada et al. 2008; Azzellino et al. 2012). One of the most significant areas for these animals in the Mediterranean LME is the Pelagos Sanctuary for marine mammals, a large MPA established in 2002 by a joint declaration between France, Italy and Monaco. The major cetaceans living in that area are fin whales (*Balaenoptera physalus*) and striped dolphins (*Stenella coeruleoalba*). The ACCOBAMS Agreement on the Conservation of Cetaceans of the Black Sea, the Mediterranean Sea and contiguous Atlantic area (www.accobams.org) recognizes that MPAs can aid in ensuring a favourable conservation status of cetaceans within the Agreement area. Despite the establishment of the MPAs, the population of cetaceans in the Mediterranean keeps declining. The major threat towards the population of these cetaceans are human activities and environmental problems (e.g. ship strikes, fixed gear fishing, forage overfishing, acoustic and microplastic pollution) many of which have been well recorded and documented (Coll et al. 2010; Coll et al. 2012). According to recent reports the decline of these 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 goal of this storyline is to assess the spatial distribution of ecosystem services generated by cetacean populations within the Pelagos Sanctuary. In that direction the major drivers of change that affect the ecosystem and ecosystem services distribution within the Pelagos Sanctuary MPA are identified.

3.1.3 Arid and semi-arid areas: The Montado system and Kruger national park

Montado is a High Natural Value wood-pasture system (Habitat type 6310 "Dehesas with evergreen Quercus *spp*", according to the Habitats Directive 92/43/EEC) characteristic of the Mediterranean Basin that generates a broad array of ecosystem services (Pinto-Correia et al. 2011, Bugalho et al. 2011, Plieninger et al. 2015). Among these, provision of cork, charismatic and protected wildlife and habitats, were most selected for their overarching relevance to 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 promoted a growth in cattle density, increasing 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). The shift in precipitation from spring to autumn, and the increase in the frequency of drought and extreme precipitation events results in lower water availability in the growing season, in soil erosion and in water logging during extreme precipitation events (Ramos et al. 2015). As a consequence of multiple interacting factors, trees are becoming more vulnerable to pathogens (Camilo-Alves et al. 2013). In addition, drought events increase the risk of fire, especially in areas of declining tree density and shrub encroachment (Bugalho et al. 2011). Fire impacts include soil degradation, burning of seedlings and saplings and damage or killing of adult trees (especially if it follows cork extraction). The simultaneous increase in tree mortality and decline in recruitment is leading to changes in habitat structure with reduction of tree density, tree cover and fragmentation of the system (Acácio and Holmgren 2014, Almeida et al. 2015). This is expected to lead to a decline in cork production, habitat and landscape quality, and, consequently, a decrease in the abundance and distribution of threatened species.

The sustainability of these wood-pasture systems lies in the balance of management practices. Responses to threats will mostly rely on best practices of ecosystem management, namely the management of soil, grazing and ecosystem structure. The main research questions regarding the degradation of the Montado are intended to lead to a better understanding of its severity and its effect on the delivery of the multiple environmental services provided by this system. The combined use of in-situ data and remote sensing data will be used to assess the effects of structural changes, both of horizontal structure (e.g., tree cover patterns, patch metrics) and vertical structure (e.g., relative cover of vegetation layers), on ecosystem functions and biodiversity at different scales.

The ***Kruger National Park (KNP)*** and surrounding areas 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 KNP are occupied by rural communities who solely rely on natural resources for their daily sustenance or livelihoods – including food and energy security. The location of KNP is well placed in the savannah ecosystems: open canopy forests (about 50% or less tree cover) made of heterogeneous layers of grass and woody plants. As the largest biomes in sub-Saharan Africa, these ecosystems host a large proportion of the African population, generally the poorest communities who rely extensively on ecosystem services, e.g. fuel wood, timber, grazing resources and edible fruits. 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, and water distribution, and more widely on food and energy security. Bush encroachment impacts negatively on available grass resource for herbivores including wildlife and livestock. On the other hand, about 90% of rural community relies on fuelwood as their main source of energy and livestock production as their mainstay for livelihood. To continue conserving biodiversity and ensure that rural people have future access to natural resources, assessment of ecosystem services as outlined above is critical. This storyline uses Earth Observation technologies for spatial and temporal assessments of these natural resources. There is a need of the spatial explicit assessment of ecosystem services within KNP and surrounding areas to be able to understand the state, quality, quantity and extent of the ecosystem function such as vegetation production, nutrient cycling and biodiversity.

The overarching ecosystem service in the KNP is ecotourism, which is linked to vegetation productivity (ecosystem) and animal presence (especially the Big Five). Kruger National park is famous for Ecotourism and generates high economic returns in South Africa. The proposed approach relies on various remote sensing technologies depending on vegetation types. For the grass layer for grazing animals, herbaceous biomass (available grazing resources) and quality (leaf nitrogen) are assessed using high spatial resolution images such as Sentinel – 2 and WorldView-3, with strategically placed red-edge band for assessing vegetation health. For the tree layer, woody biomass and tree cover will be assessed using a combination of state of art Synthetic Aperture Radar (SAR) and LiDAR technology. The estimated vegetation parameters will be further used for modelling ecosystem processes and functions.

3.2 Social-ecological indicators and their relation to essential variables

In this section all the socio-ecological indicators and associated essential variables (as identified within the selected storylines) are presented for the different storylines across all ecosystem types.

3.2.1 Mountain lakes: The Gran Paradiso, Orhid and Prespa lakes

A joint table is presented here for mountain lakes, based on the outputs of the corresponding storyline.

Indicator Variable	Nearest Essential Biodiversity Variable	Nearest Essential Climate Variable	Nearest Essential Ocean Variable
Species and community population dynamics (endemic and invasive species)	Species distribution (Population abundance)		
Nutrient concentration		Ocean sub-surface, Nutrients	
Chlorophyll *a* concentration		Ocean surface, Phytoplankton	Phytoplankton biomass, Chlorophyll a
Macrophytes, phytoplankton/zooplankton and fish dynamics	Species interactions		Fish stocks
Biodiversity indicators	Taxonomic diversity		
Physical-chemical water parameters		Ocean sub-surface, Carbon Ocean sub-surface, Temperature Ocean sub-surface Acidity Ocean sub-surface Oxygen	Nitrous Oxide Dissolved Organics
Industrial and urban discharges	Disturbance regime		
Hydrological indicators		Terrestrial, River discharge Ocean surface, Sea level	
CO_2 and CH_4 fluxes		Carbonate System	
Presence and abundance of invasive species	Population abundance		
Species richness index	Taxonomic diversity		
Habitat modification (land use)		Terrestrial, Land cover	
Nutrients		Ocean sub-surface, Nutrients	

Table 3.1 Relation between the identified indicators and the nearest essential variables (Mountain lakes system).

Indicator Variable	Nearest Essential Biodiversity Variable	Nearest Essential Climate Variable	Nearest Essential Ocean Variable

Chemical (inorganic and organic) compounds		Ocean sub-surface, Carbon	Nitrous Oxide
Temperature profiles		Ocean sub-surface Temperature	
pH, Oxygen and DOC		Ocean sub-surface Acidity Ocean sub-surface Oxygen	Dissolved Organics
Presence of urban waste/discharge	Disturbance regime		
Microbiological indicators (including indicators of urban wastewater)			Bacterial communities
Hydrological lake measurements (input, outputs, level)		Terrestrial, River discharge Ocean surface, Sea level	
Precipitation and temperature		Atmospheric Precipitation Atmospheric Air temperature	
Fish abundance Fishermen Number/licences			Fish stocks
Phytoplankton abundance Nutrients			Ocean sub-surface Phytoplankton Ocean sub-surface, Nutrients
DIC and Eh measurements			Carbonate System
OC measurements in sediments		Terrestrial, Soil carbon	
Macrophytes abundance	Population abundance		
Metal/organic compounds concentration in lakes, streams and groundwater of the watershed	Disturbance regime		
Bacteriological and organic contamination	Bacterial communities		Bacterial communities
Trophic web structure	Species interactions		
Nutrient concentration and Chlorophyll *a* in lakes		Ocean sub-surface Nutrients	Phytoplankton biomass, chl-*a*
Phytoplankton dynamics and phytoplankton species/size distribution	Species abundance		Phytoplankton, pigments and size
Water transparency			Suspended Particulates Bio-Optics
Land cover changes		Terrestrial, Land cover	
Organic carbon			Dissolved Organics
Presence and abundance of invasive species	Species abundance		
Presence of endemic species (invertebrates, amphibians, fish)	Species abundance		
Ice phenology		Ocean surface, Sea ice Terrestrial, Snow cover Atmospheric, Precipitation	
Stratification and mixing regime		Ocean sub-surface Temperature Ocean sub-surface Salinity	
Water level change		Ocean surface, Sea level	
Salinity changes		Ocean sub-surface Salinity	
Species phenology	Phenology		
Lake area, water level change		Terrestrial, Water use Terrestrial Lakes	
Macrophyte cover and diversity; Reed stands; Wetlands	Taxonomic diversity Ecosystem composition by functional type		
Presence and abundance of invasive species and of endemic species through time	Species abundance		
Strength of food web connections	Species interactions		
Changes in keystone species	Species distribution		
Nutrient concentration		Ocean sub-surface, Nutrients	
Physical-chemical water parameters		Ocean surface Sea ice Ocean sub-surface Temperature Ocean sub-surface Salinity Ocean sub-surface Acidity	Nitrous Oxide Carbonate System
Trophic web structure	Species interactions		
(Micro)-Biological and chemical-physical water parameters			Bacterial communities
Hydrological parameters		Terrestrial, River discharge Ocean surface, Sea level	

Table 3.1 Relation between the identified indicators and the nearest essential variables (Mountain lakes system) [cont.].

3.2.2 Marine and coastal areas: The Wadden Sea and the Pelagos Sanctuary for Marine Mammals

A joint table is presented here for the marine and coastal areas, based on the outputs of the storylines developed for the Wadden Sea and the Pelagos Sanctuary for Marine Mammals.

Indicator Variable	**Nearest Essential Biodiversity Variable**	**Nearest Essential Climate Variable**	**Nearest Essential Ocean Variable**
Habitat types & extent		Land Cover	
Spatial heterogeneity and habitat connectivity	Ecosystem structure		
Chlorophyll *a* concentration		Ocean surface, Phytoplankton	Phytoplankton biomass, chl-*a*
Macrophytes, phytoplankton/zooplankton and fish dynamics	Species interactions		Fish stocks
Ratio in presence of successional stages of salt marshes and other habitat types		Land Cover	
Total productivity	Net primary productivity		Net primary productivity
Industrial and urban discharges	Disturbance regime		
Balanced production (consumption vs food chain disturbance)	Species distribution Species abundance	Net primary productivity	
Avian/Seal/Whale abundance and diversity	Species distribution		
Species presence	Species Biomass		
Species nutritional habitat		Nutrient concentration	Bacteria concentration
Presence and abundance of invasive species	Population abundance		
Precipitation		Atmospheric Precipitation	
Shellfish supply	Ecosystem function		
Fish supply			Net primary productivity
Storm surges		Precipitation	
Harbour/Urban expansion			
Wind farms			
Gas exploitation			
Pollution			
Harmful algal blooms			Dissolved Organic Matter Chlorophyll a
Nutrient concentration in streams		Nutrients Chlorophyll a	
Sediment Composition/Texture	Seabed habitat cover		
Aquaculture	-	NPP Nutrient retention	
Connectivity	Habitat structure Ecosystem extent Ecosystem composition by functional type		
Temperature increase		Air Temperature	Sea Surface Temperature Sub-surface and deep-sea temperature
Biodiversity- presence/abundance of key species	Species distribution Population abundance Population structure		
Species presence	Species Biomass		
Species nutritional habitat		Nutrient concentration	Bacteria concentration
Total productivity	Net primary productivity		Net primary productivity
Industrial and urban discharges	Disturbance regime		
Tourism intensity	-	-	-
Species existence value	-	-	-
Species recreational value	-	-	-
Species educational value	-	-	-

Table 3.2 Relation between the identified indicators and the nearest essential variables (Marine and coastal systems).

3.2.3 Arid and semi-arid areas: The Montado system and Kruger National Park

A joint table is presented here for arid and semi-arid systems, based on the outputs of the storylines developed for the Montado system and Kruger National Park. It is worth noticing that, according to the storylines descriptions, several variables are used to assess both the state but also the impact of several drivers of change (or pressures) in the ecosystem, like for instance precipitation.

Indicator Variable	Nearest Essential Biodiversity Variable	Nearest Essential Climate Variable	Nearest Essential Ocean Variable
Stand age structure	Population structure		
Habitat structure	Habitat structure		
Soil moisture		Soil moisture	
Soil organic matter		Soil carbon	
Density of adult oaks	Population structure		
Tree declining symptoms	Physiological traits Primary productivity		
Precipitation regime		Precipitation	
Landscape diversity index		Land cover	
Vegetation productivity - LAI	Primary productivity / LAI	Primary productivity / LAI	
Herbaceous biomass	Primary productivity		
Tree cover/Biomass	Biomass		
Fire regime	Disturbance	Fire regime	
Temperature		Temperature	
Grazing intensity	Grazing intensity		
Bush encroachment	Bush encroachment		
Tree cover change	Tree cover		
Tree mortality (canopy cover change)	Demographic traits		
Cork production	Primary productivity		
Species Distribution and Population abundance of selected species	Sp. Distribution and Population abundance of selected species		

Table 3.3 Relation between the identified indicators and the nearest essential variables (Arid and semi-arid systems).

4. Cross-referencing current EVs with the ones identified in the PAs storylines

4.1 Pool of EVs extracted from the storylines

In the previous section (particularly in subsection 3.2) we extracted 54 variables that were identified and considered essential by the different Storylines. These variables are connected for this deliverable to the available pool of EVs (as identified in Section 2). More importantly they are used to assess the communalities among ecosystem types (i.e. mountain, arid and semi-arid, and coastal and marine) and also to identify a set of variables that are relevant to a given system.

4.1.1 Essential Biodiversity Variables

Starting from the Essential Biodiversity Variables (EBV, Table 4.1) it is interesting to highlight that most of the EBV classes are well covered across the different ecosystem types with exception of "Genetic composition" that is not listed by any of the selected storylines. According to these results, only 14% of the identified EBV (corresponding to 3 variables) are listed within all system types. These cross-cutting variables correspond to "species distribution", "species abundance" (here we merged the different nomenclature that emerged from the storylines description), and "disturbance regime".

Essential Biodiversity Variable Class	Mountain	Arid and Semi-arid	Marine and Coastal
Genetic composition			
Species populations	Population abundance Bacterial communities Species distribution Species abundance	Population abundance of selected species Species distribution	Species distribution Species abundance
Species traits	Phenology	Physiological traits Demographic traits	
Community composition	Taxonomic diversity Ecosystem composition by functional type	Population structure	Ecosystem composition by functional type Population structure
Ecosystem function	Species interactions Disturbance regime	Disturbance Primary productivity	Species interactions Disturbance regime Ecosystem function
Ecosystem structure		Primary productivity Biomass Habitat structure Bush encroachment Tree cover Vegetation productivity - LAI	Net primary productivity Species Biomass Seabed habitat cover Ecosystem and Habitat structure Ecosystem extent

Table 4.1 Relation between the Essential Biodiversity Variables Classes as listed in Section 2 and the ones identified within the storylines according to their type.

Considering now the Essential Variables that are not common between all systems, 55% of them correspond to variables that are unique to each system (14% (3 variables) to Mountain systems; 27% (6 variables) to Arid and Semi-arid systems; 14% (3 variables) to Marine and Coastal systems). This high percentage of uniqueness reflects the different objectives stated by the storylines but also, to some extent, the differences between the systems. This is illustrated in the importance of "phenology" for mountain systems, "bush encroachment" for semi-arid systems or "seabed habitat cover" for marine and coastal systems.

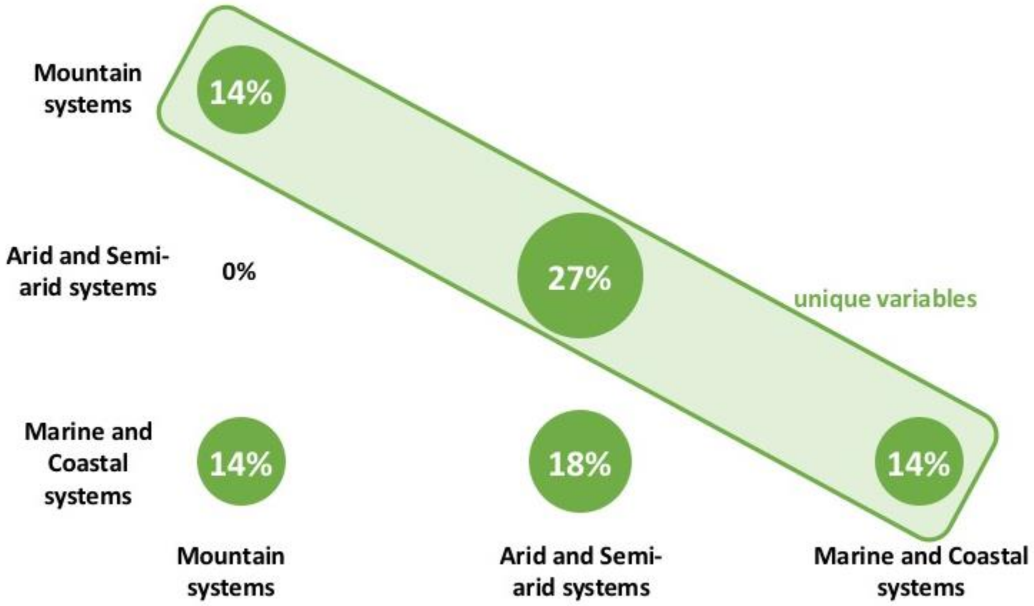

Figure 4.1 Comparison between the commonalities and singularities between EBV according to the different system types (the values illustrated do not consider the variables that are common to all the three systems).

Within the commonalities is noteworthy to see that the storylines describing Marine and Coastal systems share the highest percentage of common variables to other system types (32% of the total pool of variables). These include “primary productivity” and “species biomass” or “species abundance” and “ecosystem composition by functional type”.

4.1.2 Essential Climate Variables

Regarding the Essential Climate Variables (ECV, Table 4.2) it is relevant to underline that only 53% (corresponding to 21 Essential Variables) of the listed essential variables is identified within the Storylines. Of these, 76% (corresponding to 16 variables) are listed to only one of the three systems meaning that only a small portion of the pool of Essential Climate Variables are of significant interest for all systems. Table 4.2 provides an illustration of these relations and the level of communalities between systems.

Essential Climate Variable	Mountain	Arid and Semi-arid	Marine and Coastal
Air temperature	Atmospheric Air temperature	Temperature	Air Temperature
Wind speed and direction			
Pressure			
Precipitation	Atmospheric Precipitation	Precipitation	Atmospheric Precipitation
Surface radiation budget			
Cloud properties			
Earth radiation budget			
Carbon dioxide	Carbon		
Methane, and other long-lived greenhouse gases			
Ozone and Aerosol, supported by their precursors			
Sea-surface temperature	Ocean sub-surface Temperature		Ocean sub-surface Temperature

Table 4.2 Relation between the Essential Climate Variables as listed in Section 2 and the ones identified within the storylines according to their type.

Essential Climate Variable	Mountain	Arid and Semi-arid	Marine and Coastal
Salinity	Salinity		
Sea level	Seal level		
Sea state			
Sea ice	Ice coverage		
Current			
Ocean colour			
Carbon dioxide partial pressure			
Ocean acidity	Water acidity		
Phytoplankton	Phytoplankton		Ocean surface, Phytoplankton
Nutrients	Nutrients		Nutrient concentration Nutrient retention
Oxygen	Ocean sub-surface Oxygen		
Tracers			
River discharge	River discharge		
Water use	Water use		
Groundwater			
Lakes	Lakes		
Snow cover	Snow cover		
Glaciers and ice caps			
Ice sheets			
Permafrost			
Albedo			
Land cover/land use	Land cover	Land cover	Land Cover
FAPAR			
Leaf Area Index		Vegetation productivity - LAI	
Above-ground biomass			Net primary productivity
Soil carbon	Soil carbon	Soil carbon	
Fire disturbance		Fire regime	
Soil moisture		Soil moisture	
Relative humidity			

Table 4.2 Relation between the Essential Climate Variables as listed in Section 2 and the ones identified within the Storylines according to their type [cont.].

From this analysis it is clear that there are three variables that are very significant for all systems, i.e. "temperature", "precipitation", and "land cover". As highlighted in Section 2 the Essential Climate Variables share many of their essential variables with other Themes (e.g. Oceans, Meteorological, etc.). This means that although some variables are only mentioned once here (e.g. fire regime) they relate to other variables that are listed in other Themes (e.g. EBV, disturbance regime) adding to their importance as cross-cutting essential variables. As for the EBV in the case of the ECV the uniqueness of the selection of essential variables also appears to reflect the specificity of the systems (e.g. "lakes" and "snow cover" related to Mountain systems) but also to the modelling expectations of the storylines.

4.1.3 Essential Ocean Variables

In the case of the Essential Ocean Variables (EOV, Table 4.3) the results show that from the 40 EOV only 28% were selected within the storylines. It is also relevant to note that, because of its specificity, this type of variables is not relevant for all systems, at least not according to the selected storylines (e.g. no EOV were selected for Arid and Semi-arid systems). Within those Storylines that found relevant to select EOV, the level of communalities is quite high (46% corresponding to 5 variables), particularly when comparing to the other Essential Variables Themes. Within these, "phytoplankton biomass", "dissolved organic matter", "chlorophyll a", "species abundance", and "bacteria concentrations" are amongst the most relevant. The relevance of these variables for mountain ecosystems is due to our choice of the lake ecosystems storyline.

Essential Climate Variable	Mountain	Arid and Semi-arid	Marine and Coastal
Temperature (sea-surface, sub-surface, deep-sea)			Sea-surface, sub-surface and deep-sea temperature
Salinity			
Sea level			
Sea state			
Sea ice			
Current			
Ocean colour	Bio-Optics		
Carbon dioxide partial pressure			
Ocean acidity			
Phytoplankton	Phytoplankton biomass Phytoplankton pigments and size		Phytoplankton biomass Net primary productivity
Nutrients	Nutrients		
Oxygen			
Tracers			
Ice sheets			
Bathymetry			
Tidal			
Wave			
Sea Level Pressure			
Water temperature			
Global Ocean Heat Content			
Macro Nutrients: NO3, PO4, Si, NH4, NO2	Nitrous Oxide		
Carbonate System: DIC, Total Alkalinity, pCO2, pH	Carbonate System		
Transient Tracers: CFC-12, CFC11, SF6, tritium, 3He, 14C, 39Ar			
Suspended particulates (POC, PON or POM) and PIC ++ laboratory, beam attenuation, backscatter, acidlabile, beam attenuation	Suspended Particulates		
Particulate Matter Export: POC export, CaCO3 export, BSi export			
Nitrous Oxide			
Carbon-13: 13C/12C of dissolved inorganic carbon			
DOM (Dissolved organic matter), DOC, DON, DOP	Dissolved Organics		Dissolved Organic Matter
Chlorophyll	Chlorophyll a		Chlorophyll a
Coral Cover			
Mangrove Area			
Harmful Algal Blooms (HABs)			
Zooplankton (biomass/abundance)			
Salt Marsh Area			
Large marine vertebrates: abundance/distribution			
Seagrass Area			
Tags and Tracking of species of value/large marine vertebrates			
Fish stocks	Fish stocks		Fish stocks
Bacteria concentration	Bacterial communities		Bacteria concentration
Zooplankton (Krill)			

Table 4.3 Relation between the Essential Ocean Variables as listed in Section 2 and the ones identified within the Storylines according to their type.

4.2 Identification of gaps and key essential variables for Protected Areas

After this first description there are still some variables that were not captured within the existing pool of Essential Variables but that were listed by the storylines. An example of this is grazing intensity (listed within the Montado Storyline) that currently falls out of the available pool of essential variables. This particular example opens the way for a deeper discussion on the process to identify, validate and quantify Essential Variables at different scales and considering all thematic levels.

In the scope of ECOPOTENTIAL, although in the case of the EBV the variables were further specified, from the entire pool of Essential variables (as listed in Section 2) only a fraction of these (corresponding to ten variables) was identified across the different systems considered. From these, two can be primarily captured using remote sensing (although there are other four variables that could benefit from the use of remote sensing methodologies) added value products and nine using *in-situ* monitoring approaches (Table 4.4). This does not mean that effort should not be placed in obtaining the other 43 variables that were identified, but it allows to prioritise the resources available and also promotes cooperation between Protected Areas not only to gather data but also, and more importantly, to make sure that the datasets created or compiled are comparable across spatial and thematic boundaries. It also allows to establish bridges between data collection and the calibration data needs for the remote sensing products (WP4) and for the ecological modelling (WP6).

EV type	Key Essential Variable	Remote sensing	*in-situ* monitoring
Biodiversity	**Species distribution**	(x)	X
	Species abundance	(x)	X
	Disturbance regime	X	
Climate	**Temperature**		X
	Precipitation		X
	Land cover	X	
Ocean	**Phytoplankton biomass**	(x)	X
	Dissolved organic matter		X
	Chlorophyll a	(x)	X
	Bacteria concentrations		X

Table 4.3 Illustration of the primary data collection approaches for each key essential variable identified.

Some of these EVs already have methodological/modelling approaches behind them and are associated with specific datasets. The establishment of these EVs at this stage of the project and across protected areas types also provides an important contribution for the standardization of data collection methods, processing algorithms, and modelling approaches.

It is also important to mention here that although the significance of the different ecosystem services generated by the protected areas and the associated ecosystem types is mentioned in most storylines, there are still no social variables listed in the existing pool of EVs. Given the need to capture the value the different ecosystems have to humans in order to better manage the protected areas, a new set of EVs needs to be generated for ecosystem services and social indicators linked to them. Efforts are only starting now from the scientific community within ECOPOTENTIAL but also beyond (e.g. GEOBON Working Group on Ecosystem Services) to work towards this direction.

5. Discussion

This report provides examples on identifying a set of relevant Essential Variables for Protected Areas. To do so, we gathered information from five storylines that partially captured the spectrum of ecosystem types in the context of ECOPOTENTIAL (one mountain lakes, two arid and semi-arid areas, and two coastal and marine areas). This assessment allowed to identify some important issues that should be addressed within the project:

- It is not clear from the obtained data that the identified Essential Variables cover the entire scope of Protected Areas requirements. For example, ecosystem extent was only mentioned in storylines corresponding to two of the considered systems (mountain and coastal and marine areas) while it is a requirement for all Protected Areas under the scope of the Sustainability Development Goals that were ratified by all the countries with partners in ECOPOTENTIAL. This assessment could be overcome by having a clearer reference to the conservation goals of each Protected Area and by clearly state which are covered by the designed storylines.
- In storylines that cover more than one Protected Area (e.g. the Montado storyline) it is important to describe and match the different conservation goals and conservation management requirements to identify the most relevant for the different conservation managers. This relation to the conservation managers is very important in order to make ECOPOTENTIAL viable at the operational level and should be strengthen through the development of the project.
- Also, WP7 is now developing and applying the concept of mind maps to create visual interpretations of the storylines. These developments can and should be used as a complementary way to identify Essential Variables in the future. This will require a close collaboration between WP2 and WP7 and to extend the current set of storylines with mind maps to the complete set of storylines available in ECOPOTENTIAL.
- No specific methods are identified to calculate each Essential Variable across the storylines. This critical piece of information has to be developed within each storyline and associated protected area and then harmonised for the overall ECOPOTENTIAL project in the near future including the differentiation between remote sensing and *in situ* methods.
- Considering the core objectives of ECOPOTENTIAL of establishing more direct links between Earth Observation systems and products and Protected Areas, within the selected storylines there was not a crosscutting option for remote sensing related Essential Variables. This could be overcome by expanding the use of remote sensing products by combining them with *in situ* data (e.g. for calibration purposes) to obtain biodiversity related essential variables. Further work is required in the near future to include the whole set of storylines and Protected Areas as soon as they become available within ECOPOTENTIAL.
- It is also important to highlight the absence of direct links between the identified Essential Variables (c.f. Section 4 for the entire group of identified Essential Variables) and their potential to act as significant inputs for ecosystem service modelling (WP6). This is significantly important to maintain the flow of data and information between Earth Observation and the Protected Areas but also to effectively assess the importance of the identified Essential Variables for conservation management.
- It is required to include the here-defined essential variables as part of the future monitoring programs and as a substantiation of existing ones to enhance the accessibility to relevant information. It is also relevant to consider the spatial and temporal resolution required to describe these essential variables in order to make them relevant to different stakeholders.
- Finally, the lack of a strong reference to indicators or variables accounting for human-nature interactions (only available for the marine storyline), highlights the need for essential variables for ecosystem services to be developed. Efforts should therefore be given to include a new set of EVs for social indicators that are linked to ecosystem services.

Independently of these issues, it was possible to identify eleven variables seen as essential by the set of storylines considered so far. Given the diversity of objectives and environmental characteristics between the related Protected Areas, this set of Essential Variables is presumably relevant for the other storylines and Protected Areas included in ECOPOTENTIAL. This highlights the importance of focussing resources to capture the necessary datasets to calculate them and effectively contribute to strength the flow of data and information to the Protected Areas. In the near future, this same analysis will be repeated on the whole set of available storylines and the Protected Areas they involve.

Although only eleven variables were identified across all the storylines, our results also show important communalities when the different ecosystem types are compared. The storylines describing coastal and marine areas have shown more commonalities with the other two terrestrial systems than among themselves. This is not surprising given the different nature of coastal versus offshore ecosystems and the ecological functions, but also associated ecosystem services of focus (for mountains, we stress that only lake ecosystems were considered in the analysis). This could indicate that it could be possible to produce variables that are relevant and spatially distributed in a terrestrial-marine continuum instead of having variables that only cover one of these systems. Regarding this although some variables were identified as ocean essential variables in mountain systems they are in reality focussed in freshwater ecosystems and consider similar data gathering systems.

As mentioned before, there are some Essential Variables (or groups of variables) that were listed in Section 2 that were not identified within the storylines (e.g. genetic diversity, agricultural essential variables). This is a significant issue as some Protected Areas described in the storylines depend heavily on specific components of the systems like agriculture and forest land management (e.g. related to agricultural essential variables; Arid and semi-arid systems) or on topographic aspects (e.g. related to elevation or bathymetric data; Mountain and Coastal and marine systems). In the near future, the modelling approaches and the conservation goals of the Protected Areas will be better focused, and presumably these essential variables will be more easily identified and highlighted within the storylines.

Overwhelmingly, the positive exchanges between ECOPOTENTIAL and the Protected Areas have contributed to not only identifying a clear set of Essential Variables that need to be monitored, but also to define a communication path that will allow to convey relevant information from Earth Observation systems in the near future. The interdependencies among storylines/protected areas in terms of the definition of Essential Variables highlight the need for a systematic approach that ultimately will allow to produce relevant results for the protected areas in Europe and elsewhere.

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