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Deliverable 2.3

EO-driven Essential Variables and general implications

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Abstract	This report describes and analyses the set of Essential Variables that have been operationally used in the ECOPOTENTIAL

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	research activities and Storylines. The report also suggests a bottom-up approach for determining the Essential Variables that are relevant for the user-driven assessment of ecosystem status, functions, services and expected future conditions.
Keywords	Essential Variables, Protected Areas, Ecosystems, Remote sensing, Scale

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1. Executive summary

Essential Variables are a minimal set of variables that describe a system's condition and trends by providing reliable, traceable, observation-based evidence for addressing specified scientific and/or management questions and applications, including monitoring. They facilitate prioritization and optimization of resources and allow for a transparent and direct way to communicate monitoring needs through different levels of knowledge and decision-making. The challenge ahead is to develop and implement a sound process to identify, select, calculate and validate the Essential Variables to promote a better understanding of the systems conditions and trajectories. This requires to identify the types of primary data currently available and to generate proposals to unify and standardize these data.

In this report, corresponding to the Deliverable D2.3 ("EO-driven Essential Variables and general implications") the project's findings on the identification of Essential Variables to be used for ecosystems conservation are reported. The report represents the final outputs of Task 2.3 of the Work Package 2 ("Conceptual Scientific Framework").

The task's objectives were: 1) to identify and compile outputs and examples of application of locally relevant variables used across ECOPOTENTIAL studies at multiple scales; 2) to assess the diversity of methods and approaches used to calculate locally relevant variables across scales; 3) to layout the process developed during the project for identifying Essential Variables for ecosystem conservation and 4) to suggest a possible set of key Essential Variables relevant for the assessment of the ecosystem status, functions, services, and for studying future dynamics scenarios for user needs for Protected Areas studies and management.

Specifically, we have summarized information from 24 ECOPOTENTIAL case studies and "Storylines" (research threads focussed on specific conservation challenges) which identified and applied Essential Variables at multiple scales, from global level to Protected Areas, and with a diversity of observation methods and targeted systems. The key Essential Variables used in each case study were highlighted by the corresponding authors. In addition, we synthesized information regarding the identification and use of Essential Variables following bottom-up approaches according to the ECOPOTENTIAL Storylines reported in Deliverable 2.2 and the inventory of locally relevant variables considered to be the most essential for Protected Areas, based on surveys with Protected Areas staff working on site, reported in Deliverable 9.1. Though the overlap of locally relevant variables is clearer between Deliverables 2.2 and 9.1, both works have developed frameworks for the monitoring of Protected Areas that are highly representative for Protected Areas in general, whereas the case studies compiled in the present report show a diversity of studies that used and quantified a subset of relevant variables. The guidelines emerging from such bottom-up approaches for monitoring Protected Areas highlight the need of calculating a broad set of relevant variables covering different dimensions of the studied system.

ECOPOTENTIAL case studies have described a wide range of environments across scales, using multiple locally relevant variables and related indicators. While at coarse scales all the case studies made exclusive use of remote sensing observations, most studies at Protected Areas level used both in-situ data and remote sensing products, allowing for long to medium-term monitoring by using archive data and/or very fine scale assessments. Despite the wide use of remote sensing data across case studies, the calculation of locally important variables appears constrained by scale, with only a few – mostly climatic and using land cover products– being calculated or used across multiple scales. This contrasts with a wide diversity of locally relevant variables identified and calculated at finer scales, benefiting from the broader pool of in-situ data not only to calculate the variables themselves but also to validate them.

In the current literature, assessments for ecosystem level features and climatic measurements are available at broad scale. Here, ECOPOTENTIAL has done an important contribution on the assessment of an array of features at the scale of the single Protected Areas, as for example ecosystem structure and functions (e.g., fractional green vegetation cover at global scale), species populations (e.g., European freshwater communities or mountain ungulates), water flow and regulation (e.g., lake/reservoir water level), burned area assessments and prediction, as well as the impacts of changes in ecosystem structure and climate on Protected Areas. At the scale of Protected Areas, thus, important advances were made, either with the use of the latest generation of satellite information (e.g., the use of the EODESM system to enable and monitoring quantitative aspects of ecosystems and environmental conditions) or by expanding the utilization of in-situ data to calibrate temporally explicit models.

Almost 60% of the variables identified and used through ECOPOTENTIAL were already included in the lists of Essential Biodiversity, Climate or Ocean Variables (EBVs, ECVs, and EOVs, respectively) that have been defined so far. This fact highlights the high heterogeneity of the studies at site level, but it also indicates progress towards a unified set of Essential Variables. The EBV classes proposed by GEOBON that received more interest across ECOPOTENTIAL were ecosystem structure, followed by ecosystem function, species populations and community composition. Within those classes, net primary productivity, ecosystem extent, species distribution and species abundance were the EBVs more commonly identified and used. The most used ECV was land cover, followed by atmospheric precipitation, above ground biomass and atmospheric air temperature. Finally, the only two EOVs that were identified or used in ECOPOTENTIAL studies were Chlorophyll-a and phytoplankton biomass. Nonetheless, only a reduced proportion of the studies were developed in the marine realm (Wadden and Mediterranean Seas). A serious effort should thus be made to obtain reliable estimates of these Essential Variables for ecosystem studies and monitoring programs. This will hopefully serve as standard baseline to support the development of locally informed monitoring schemes, which then should be extended with a wider set of locally relevant variables.

The process of identifying Essential Variables is not an exclusion process, but rather a priority setting process, where central elements of monitoring effort are identified to improve the understanding of social-ecological dynamics. To date, however, the process of identifying and prioritizing Essential Variables has largely been based on expert knowledge about globally-relevant measurements. Approaches to identify a set of locally relevant variables (Deliverables 2.2 and 9.1) have illustrated the difficulty of joining a top-down, global-scale definition of Essential Variables with a local, operational-based definition of the most relevant variables needed for specific conservation purposes. We advocate that the top-down approach must be complemented with a bottom-up approach, where conservation managers draw on system-level knowledge and theory to identify locally important variables that meet local or sub-global needs for conservation data and with those, support the implementation of global scale Essential Variables. In the Discussion, we present an approach for defining, in a user-oriented and co-designed way, a set of variables that can be relevant both for local monitoring and for allowing comparison of local results across a network of sites. We describe a scalable framework that builds on system-based narratives and causal diagrams to describe all system components, the variables that represent their state and drivers, the models used to represent them and the data needed.

To conclude, the synthesis of the research studies conducted so far provides a coherent view of how ECOPOTENTIAL is contributing to the definition and implementation of Essential Variables at multiple levels. A small set of relevant variables that have been operationally used across studies and scales has emerged in this project, which moves us towards a more consolidated set of Essential Variables that are relevant across boundaries and/or ecosystems. This list considers variables that have shown to be locally relevant (i.e., variables commonly identified and used at Protected Areas level), but also used across scales (i.e., globally-consistent), namely: **ecosystem structure**; **ecosystem extent**; **ecosystem function**; **species populations**; **species distribution**; **atmospheric air temperature**; and **atmospheric precipitation**.

Ultimately, this report contributes to the definition of monitoring systems that target specific conservation goals and that at the same time provide valuable information to monitor biodiversity and ecosystems across boundaries. The circular flow approach – from end-users to Earth Observation and back to end-users – used in the project has allowed for a significant amount of locally relevant information to be identified and produced using standardized and transferable methods, which can then be used across systems and scales. Because of their global distribution, covering all ecoregions, and current targets, Protected Areas are essential for this approach. With an investment in standards, transparency regarding methods, and on active data mobilisation strategies, countries, Earth Observation networks and the global conservation community would benefit from monitoring programs for Protected Areas. A step forward would be to attach to global conservation targets the global monitoring of these areas and the establishment of a global monitoring backbone. With strong political support and in the face of strong effects of climate and land use change, these areas could be pivotal as early warning systems to signal major regional and global nature shifts.

2. Introduction

2.1 Main objectives

Deliverable 2.3 comes at a final phase of ECOPOTENTIAL where concrete links between in-situ and remote sensing monitoring products have been established in relation to specific conservation goals and/or research questions, in most cases already extensively discussed in the project Storylines, http://www.ecopotential-project.eu/site-studies/storylines.html, and described in other documents. The present Deliverable is devoted to assess, starting from the available existing scientific material and technical reports produced during the project, **what are the common Essential Variables, if any, that emerge from the different research activities and Storylines developed during ECOPOTENTIAL and to layout the process developed during the project for a better assessment and identification essential variables for conservation**. This phase thus provides the possibility to build on the outputs and examples of application of locally relevant variables (defined as variables essential to describe local dynamics) across ECOPOTENTIAL studies at multiple scales and provide a coherent view of how ECOPOTENTIAL has and is contributing to the definition and implementation of multiple Essential Variables. Parallel to this approach, Deliverable 9.1 describes a complementary pathway based on direct interviews with Protected Areas staff, in order to identify what are the main locally relevant variables or otherwise defined indicators that are perceived to be relevant by the personnel working in the field. As addressed in the Discussion, both these two parallel approaches illustrate the difficulty of joining a top-down, global- or continental-scale definition of Essential Variables, which could be limited for local conservation issues, with a local, operational-based definition of the most relevant variables needed for specific conservation purposes (as done in the ECOPOTENTIAL Storylines). Without claiming to have solved this crucial and still open issue, Deliverable D2.3 offers general discussions and insights regarding this subject in its final section.

The synthesis presented here allows us not only to have an overview of the contribution of ECOPOTENTIAL to the Essential Variables discussion but also, since many algorithms and processing chains were established, to illustrate the different approaches that can be used to assess biodiversity, ecosystems and the services they supply. Ultimately, this exercise is meant to provide a contribution to the definition of monitoring systems that target specific conservation goals and that at the same time provide valuable information to monitor biodiversity and ecosystems across boundaries.

Following the description of Essential Variables made in Deliverable 2.1 and the developments made across almost all WPs, this Deliverable’s objectives are to:

i) Identify and compile outputs and examples of application of locally relevant variables across ECOPOTENTIAL studies at multiple scales;

ii) Assess the diversity of methods and approaches used to calculate locally relevant variables across scales; and

iii) Suggest a possible Essential Variables (conceptual) approach, with Essential Variables relevant for the assessment of the ecosystem status, functions, services, and for studying future dynamics scenarios for user needs for Protected Areas studies and management.

Within ECOPOTENTIAL, end-users - mostly from Protected Areas and local managers - play a central role, as the project has developed to support decision-making at multiple scales. In the project, these end-users define the requirements needed to make policy support more effective (examples can again be found in several Deliverables from WP9). With these requirements in mind, a number of Storylines were developed addressing the state and trends of biodiversity, ecosystems and the services by them supplied by Guerra et al. (accepted) (Deliverable 2.2). In parallel, Earth Observations were taken to inform locally important variables that were later used to inform policy relevant indicators according to the requirements pre-established by the end-users.

2.2 Essential Variables and Monitoring

Monitoring programs serve the purpose of collecting systematic information on the state and trends of local/regional biodiversity, ecosystems, as well as climate or water systems to support environmental and conservation policies, decision-making and the assessment of impacts from local to global drivers of change. Each monitoring program is typically designed to address specific policy, management and/or conservation questions. To fully account for progress towards current and new environmental and conservation targets, monitoring systems often try to capture not only information on systems condition, but also knowledge on the dynamics of ecological processes and the related effects on human well-being (DeFries and Nagendra, 2017), as advocated also by the "Long-Term Ecosystem Research in Europe" Infrastructure (eLTER RI), currently in the ESFRI Roadmap (www.lter-europe.net). These, more integrated, data needs require the implementation of innovative monitoring approaches that allow for a wider characterization and quantification of social-ecological systems and the optimization of available operational resources that allow for long-term monitoring (Carpenter et al., 2011; Ostrom, 2009). Even today, with a significant shift to remote sensing approaches, locally collected data serves an important role in obtaining information that otherwise would be missing in such systems (e.g., species identification for many taxa including birds, reptiles, microbes or fungi). In addition, this in-situ data complements environment-related information obtained by remote sensors (e.g., satellites) or it can be used for testing the accuracy of model-based inferences such as those based on distribution models.

Essential Variables are defined as the minimal set of variables that describe the system's condition and trends by providing reliable, traceable, observation-based evidence for a range of applications, including monitoring and predicting system developments. They highlight a specific thematic area (e.g., climate, ocean, biodiversity). For instance, the Essential Climate Variables (ECVs) have been defined as "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). They were developed by the Global Climate Observing System (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). ECVs document change in key parameters such as precipitation, temperature and atmospheric composition, and they are regularly used to support the workings of the Intergovernmental Panel on Climate Change and policy. The Global Ocean Observing System (GOOS) has also adopted the Essential Variables concept, and expanded the coverage of ECVs by identifying biological and ecological Essential Ocean Variables (EOVs) defined as "sustained measurements that are necessary to assess the state and change of marine ecosystems, address scientific and societal questions and needs, and positively impact society by providing data that will help mitigate pressures on ecosystems at local, regional and global scales" (Miloslavich et al., 2018). Also inspired by the ECVs process, and in order to refine our understanding of biodiversity change, the biodiversity community is attempting to identify Essential Biodiversity Variables (EBVs) defined as "measurements required for studying, reporting, and managing biodiversity change" using a framework set up in 2013 by the Group on Earth Observations Biodiversity Observation Network (GEOBON) (Pereira et al., 2013). Currently, 6 broad EBV classes and 21 EBV candidates (EBVs within those classes) have been proposed.

Several variables can potentially fit these definitions of Essential Variables so the task ahead is to develop and implement a sound process to identify, select, calculate and validate the Essential Variables to promote a better understanding of the systems condition and trajectories. This requires to identify the many types of primary data currently available and to generate proposals to unify and standardize these data in the future. Essential Variables lie between primary observations and indicators. Primary observations are drawn from in situ monitoring and remote sensing, whereas indicators present an aggregate summary of information as they can require the aggregation of different sources of information. Essential Variables are therefore intrinsically dependent on both the information collected by the multiple monitoring programs and initiatives across the globe (which must ensure sufficient consistency of collection and sampling methodology) and the level of standardization and systematization. For example, Essential Biodiversity Variables require standard information on specific biodiversity and ecosystem dimensions (e.g., habitat extent; Hansen et al., 2013) that can be systematically measured across systems to allow for comparison and large and cross-scale data mobilization.

At the same time, **monitoring programs**, while operating at different scales and with sometimes different and more specific objectives, would benefit from an Essential Variables approach (Proença et al., 2017; Vihervaara et al., 2017). Monitoring ecosystem conditions and ecosystem services often involves the implementation of costly monitoring programs that seek to combine targeted, hypothesis-driven and/or surveillance monitoring from different sources (Lindenmayer et al., 2018; Navarro et al., 2018). This often leaves monitoring programs with limited financial and logistic resources, hampering their required usefulness and encompassing nature. Since the purpose of monitoring activities, in this context, is to facilitate more effective conservation actions, it is imperative that monitoring systems be as efficient as possible. If they fail to meet this objective, they risk misinforming conservation actions and draining much needed resources for other conservation activities (Legg and Nagy, 2006). Globally consistent Essential Variables should help to improve comprehensiveness, efficiency and usefulness of local and regional monitoring data by contributing to identify gaps (Proença et al., 2017; Vihervaara et al., 2017) and to allocate resources to optimize monitoring outcomes for high priority monitoring programs. Specifically, the Essential Variables framework would allow clarifying the information flows and the dependencies with the monitored systems (e.g., observation from a biodiversity survey in multiple sites through time), the corresponding highly informative variable (e.g., species distribution), and the necessary data analysis to transform it into a relevant indicator (e.g., population changes). Further, shaping specific local and regional monitoring programs around globally consistent Essential Variables would improve the contribution of these specific programs towards tracking global change. For instance, this would help to compare rates of environmental and biodiversity change between regions, countries and continents, and coordinate and harmonize Earth Observations and measurement data across spatial and temporal scales.

Nevertheless, a set of globally-consistent Essential Variables should not be expected to serve all the particular needs and local nuances of individual monitoring programs, but rather create a standard baseline to support the development of locally informed monitoring schemes that will necessarily focus on a wider set of locally relevant variables. A meaningful trade-off should thus be developed between globally-relevant top-down Essential Variables and locally-relevant bottom-up specific variables. We advocate that thinking (also) in Essential Variables terms, especially with a bottom-up approach, would allow practitioners to focus resources and to discuss the value chain of the information that is being measured across each monitoring system.

2.3 From local information to a global asset

Implementing systematic monitoring schemes requires moving from a locally important set of variables to a more consolidated set of Essential Variables that can be realistically measured or modelled at multiple scales across ecosystem types and boundaries and which can capture change at meaningful spatial and temporal scales. This path has to be coupled with transparent ways to aggregate and disaggregate all relevant information. One of the main challenges is that, across scales, monitoring systems often address different purposes, stakeholders and, more significantly, different types of questions or conservation goals (Turak et al., 2017). In terms of data collection efforts, conservation monitoring often focuses on locally relevant variables without a clear concern for data comparability across scales or regions.

In previous research, the criteria for “essentiality” have already been established for the identification of Essential Variables for climate and broad biodiversity classes for global scales (e.g., Schmeller et al., 2017). Here, we approach the problem of “essentiality” from the point of view of the specific needs of sub-global conservation management and **Protected Areas**. Therefore, only a small set of variables can be identified as essential for global conservation monitoring purposes, since for most variables, conservation managers will rely on locally relevant variables and on systems and/or institutions that go beyond their conservation scope (e.g. satellite data sources, national geographic information systems, national statistics institutes). In addition, the locally relevant variables that characterize the social-ecological dynamics of interest to local managers and researchers are potentially only a subset of a wider array of variables needed by users in different regions of the world.

Matching locally relevant variables with globally relevant variables (Essential Variables) is a useful, challenging and still a relatively unexplored exercise that is needed to foster the scalability of the data collected by Protected Areas. For instance, data collection, mobilization, and publishing of data regarding species distribution and population structure can use the standards, methods and tools being developed for Essential Biodiversity Variables (Kissling et al., 2018a). In doing so, automated data flows can be established that feed the development of global datasets critical for biodiversity monitoring and research (Navarro et al., 2018). Such standardization would also allow a more direct contribution to global archives such as those of GEO GEOSS.

In addition, there are consistency and scalability issues even when several conservation areas consider the same locally relevant variables. As an example, different conservation areas can identify "species distribution" as a monitoring variable without the necessary thematic consistency. Addressing such thematic, and eventually temporal, inconsistencies will be critical if considering interoperability across conservation areas. A possible approach would imply developing higher coherence between some of the monitoring activities (e.g., at the national level), allowing information to move across scales and ecosystems, constituting the backbone of a multi-level conservation strategy. A natural candidate case study would be the application of at least a portion of this strategy (for example, defining a few Essential Variables of interest) to the network of Natura2000 sites.

Ultimately, the global selection and update of Essential Variables needs to be informed by and fully incorporate the bottom-up variables selection efforts. Considering the relevance of the information collected by conservation areas, developing global monitoring schemes for Essential Variables needs to draw on those efforts. Therefore, locally important variables that are identified across multiple sub-global regions or Protected Areas are likely to be those most viable to also be monitored at global scale. This happens not only from a practical data availability point of view, but also because variables that are repeatedly identified as key variables to monitor locally are probably also globally important for international conventions and countries. In contrast, locally important variables that are particular only to specific Protected Areas are unlikely to have global relevance.

3. Description of the examples

A number of studies identifying and applying Essential Variables through ECOPOTENTIAL at multiple scales from global to Protected Areas are listed in Table 3.1 and briefly summarized in this section. The key Essential Variables used in each case study were highlighted by the corresponding authors. Further details on such studies are provided in the Annex.

Table 3.1 List of a set studies that have identified and applied Essential Variables through ECOPOTENTIAL. Information of the key Essential Variables used, types of observation method used (RS: Remote sensing observations; IS: In-situ observations), and scale of analysis is provided.

ID	**Essential Variable(s)**	**Observation**	**Scale**	**Title**
1	Ecosystem function	RS	Global	Global vulnerability of soils and belowground biodiversity to erosion
2	Ecosystem function	RS	Global	Ecosystem functional attributes and ecosystem functional types as satellite-derived essential ecosystem functional variables
3	Ecosystem structure	RS	Global	Change vs Stability: are Protected Areas particularly pressured by global land cover change?
4	Ecosystem structure; Community composition	RS	European	Vulnerability of European freshwater systems
5	Ecosystem structure	RS	European	Land cover change for all European PAs
6	Temperature; Precipitation; Radiation; Evapotranspiration	RS	European	Climatic space of the European continent and of the ECOPOTENTIAL PAs
7	Ecosystem structure	RS	European	Ecosystems states and trends across all ECOPOTENTIAL PAs derived from Remote Sensing
8	Habitat extent; Ecosystem structure; Water flow, regulation and retention; Precipitation; Radiation; Wind speed and direction; Evapotranspiration	RS	Regional	Vulnerability of seasonally-flooded wetlands to climate change across the Mediterranean basin
9	Sea surface temperature	RS	Regional	Demonstration of Sea Surface Temperature as EV for the Mediterranean Sea
10	Community composition; Species richness; Ecosystem extent; Ecosystem structure	RS	Protected Area	Remotely sensed indicators and open-access biodiversity data to assess bird diversity patterns in Mediterranean rural landscapes
11	Ecosystem function	RS	Protected Area	Significant understory effects on carbon sequestration in European mountain forests
12	Species distribution; Habitat suitability	RS & IS	Protected Area	Habitat suitability and stability for the iconic plant species *Iris boissieri*, an indicator of cultural ecosystem services in the Peneda-Gerês National Park
13	Population structure	IS	Protected Area	Wild reindeer population dynamics in Hardangervidda National Park
14	Chlorophyll a; Water temperature; Water quality; Water flow; Air temperature; Precipitation	RS & IS	Protected Area	Physical, chemical, and biological conditions of the Lakes Orhid and Prespa

15	Ecosystem extent; Net primary productivity	RS	Protected Area	Grassland extent and productivity in the Gran Paradiso National Park
16	Ecosystem structure; Net primary productivity	RS & IS	Protected Area	Biomass production and carbon storage in the Swiss National Park and Landshaft Davos
17	Ecosystem function	RS	Protected Area	Biomass change in the Kruger National Park
18	Flooding seasonality	RS	Protected Area	Hydroperiod of the temporary ponds in Doñana National Park
19	Net primary productivity	RS & IS	Protected Area	Modelling biomass production in the seasonal wetlands of Doñana National Park
20	Ocean surface; Community composition; Net primary productivity; Chlorophyll a	RS & IS	Protected Area	Water quality and provisioning in the Wadden Sea
21	Crop area	RS & IS	Protected Area	Crop production in Sierra Nevada
22	Ecosystem structure	RS	Protected Area	Land cover change and temporal evolution of ecosystem services in Sierra Nevada
23	Precipitation	IS	Protected Area	Spatial and temporal variability of precipitation and its influence over ecosystem processes and services in Sierra Nevada
24	Air Temperature	IS	Protected Area	Spatial and temporal variability of temperature and its influence over ecosystem processes and services in Sierra Nevada

Case 1	Global vulnerability of soils and belowground biodiversity to erosion
ESSENTIAL VARIABLE(S): Ecosystem function (soil erosion protection)	
SCALE: Global	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: The global vulnerability of soil biodiversity to soil degradation processes is understudied, with current belowground conservation strategies focusing mainly on ecosystem processes without a good representation of how belowground diversity links to ecosystem functioning. The authors develop a dynamic model of the effects of rainfall erosivity and vegetation cover on global soil erosion rates, providing a global and temporally explicit assessment of soil erosion protection for the period between 2001 and 2013.	
LIST OF AUTHORS: Guerra, C.A., Rosa, I.M.D., Eisenhauer, N., Valentini, E., Wolf, F., Filipponi, F., Karger, D.N., Nguyen Xuan, A., Mathieu, J., Lavelle, P., and Pereira, H.M.	
REFERENCES OF THE WORK Guerra, C.A., Rosa, I.M.D., Eisenhauer, N., Valentini, E., Wolf, F., Filipponi, F., Karger, D.N., Nguyen Xuan, A., Mathieu, J., Lavelle, P., and Pereira, H.M. (Submitted). Global vulnerability of soils and belowground biodiversity to erosion. Filipponi, F., Valentini, E., Nguyen Xuan, A., Guerra, C. A., Wolf, F., Andrzejak, M., and Taramelli, A. (2018). Global MODIS Fraction of Green Vegetation Cover for Monitoring Abrupt and Gradual Vegetation Changes. Remote Sensing *10*(653), 1–20.	

Case 2	Ecosystem functional attributes and ecosystem functional types as satellite-derived essential ecosystem functional variables
ESSENTIAL VARIABLE(S): Ecosystem function	
SCALE: Global	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: A better understanding of ecosystem functioning and functional diversity is key to the management of nature and its services, to determine a planetary boundary to promote sustainability and a safe operating space for humanity. The authors identify essential variables to characterize ecosystem functions and ecosystem functional diversity using remote sensing observations (2001-2016; MODIS products).	
LIST OF AUTHORS: Alcaraz-Segura, D., Cazorla, B., Bagnato, C., Berbery, E.H., Epstein, H.E., Jobbágy, E., Cabello, J., Peñas, J., Pacheco, M., Vallejos, M., Fernández, N., and Paruelo, J.M.	
REFERENCES OF THE WORK Bagnato, C., Alcaraz-Segura, D., Berbery, E.H., Paruelo, J.M., Epstein, H.E., and Jobbágy, E. (In preparation) Functional variables to capture ecosystem functioning heterogeneity. Cazorla, B., Meijide, A., Peñas, J., Cabello, J., Vargas, R., and Alcaraz-Segura, D. (In preparation) Ecosystem Functional Types as descriptors of ecosystem functional diversity at regional scale.	

Case 3	Change vs Stability: are Protected Areas particularly pressured by global land cover change?
ESSENTIAL VARIABLE(S): Ecosystem structure (land cover change)	
SCALE: Global	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: Land cover change is a global multi-scale process affecting ecosystems, with potential implications for ecological processes and for the biological communities that support them. This study presents a temporally and spatially explicit estimation of global land cover change within 23 years (1992-2015) underlying the differences between global and regional estimates and the incidence of land cover change within and outside Protected Areas. It also identifies past and current trends of change and stability and understand how these vary over space and time.	
LIST OF AUTHORS: Guerra, C.A., Rosa, I.M.D., and Pereira, H.M.	
REFERENCES OF THE WORK Guerra, C.A., Rosa, I.M.D., and Pereira, H.M. (Submitted). Change vs Stability: are Protected Areas particularly pressured by global land cover change?	

Case 4	Vulnerability of European freshwater systems
ESSENTIAL VARIABLE(S): Ecosystem structure; Community composition	
SCALE: European	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: Climate change is expected to exacerbate the current threats to freshwater ecosystems based on alterations of the variability of the thermal and hydrological attributes, threatening species to the magnitude of extinction risks. Yet, multifaceted studies on the potential impacts of climate change on freshwater biodiversity at scales that inform management planning are lacking. This study develops a novel framework for assessing climate change vulnerability tailored to freshwater ecosystems, including European freshwater species, as well as climatic and hydrological data.	
LIST OF AUTHORS: Markovic, D., Carrizo, S.F., Kärcher, O., Walz, A., and David, J.N.W.	
REFERENCES OF THE WORK Markovic, D., Carrizo, S.F., Kärcher, O., Walz, A., and David, J.N.W. (2017). Vulnerability of European freshwater catchments to climate change. Global Change Biology *23*(9), 3567–3580.	

Case 5	Land cover change for all European Protected Areas
ESSENTIAL VARIABLE(S): Ecosystem structure (land cover change)	
SCALE: European	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: Large-scale monitoring of Protected Areas, including Natura 2000 sites and the numerous nationally designated Protected Areas, has not yet been well established within the EU, although a number of Pan-European datasets could make a start for such a monitoring, such as CORINE land cover	

monitoring. The authors identify large-scale patterns of land cover change in Protected Areas based on CORINE data and the main drivers for land cover change in Protected Areas across Europe.	
LIST OF AUTHORS: Walz, A., and Korup, O.	
REFERENCES OF THE WORK Walz, A., and Korup, O. (2017). CORINE for large-scale monitoring of Protected Areas in Europe. 6th International Symposium for Research in Protected Areas, 02-03. Nov. 2017, Salzburg.	

Case 6	**Climatic space of the European continent and of the ECOPOTENTIAL Protected Areas**
ESSENTIAL VARIABLE(S): Temperature; Precipitation; Radiation; Evapotranspiration	
SCALE: European	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: This study illustrates the representativeness of the ECOPOTENTIAL Protected Areas for the conditions of the European network of Protected Areas and also for the overall climatic conditions and biogeographical regions of Europe. The climatic space of the European continent and of the ECOPOTENTIAL Protected Areas is calculated for Annual Mean Temperature, Annual Precipitation, Solar radiation, Evapotranspiration.	
LIST OF AUTHORS: Beierkuhnlein, C. et al.	

Case 7	**Ecosystems states and trends across all ECOPOTENTIAL Protected Areas derived from Remote Sensing**
ESSENTIAL VARIABLE(S): Ecosystem structure (land cover change)	
SCALE: European	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: The authors focus on the ECOPOTENTIAL Protected Areas and describe a collection of exemplary applications where Earth Observation data is essential. This work illustrates the capabilities of remote sensing and how this technique is being applied in many ways to monitor several different aspects of ecosystems and environmental conditions. Each type of ecosystem (mountain, arid or coastal and marine) presents different challenges that are addressed through different Earth Observation and data analysis approaches.	
LIST OF AUTHORS: Domingo-Marimon, C., and Masó, J.	
REFERENCES OF THE WORK Domingo-Marimon, C., and Masó, J. (2018). Using Earth Observations to Protect Natural Landscapes. E-book available at www.ecopotential-project.eu/images/ecopotential/documents/ecopotential-spaced.pdf	

Case 8	Vulnerability of seasonally-flooded wetlands to climate change across the Mediterranean basin
ESSENTIAL VARIABLE(S): Ecosystem extent; Ecosystem structure; Water flow, regulation and retention (Lakes/reservoir levels); Precipitation; Radiation; Wind speed and direction; Evapotranspiration	
SCALE: Regional (The Mediterranean Basin)	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: How will climate change affect the functionality of seasonally-flooded wetlands in the Mediterranean basin? This study assesses how different climate scenarios would impact the water balance and conditions of wetlands, as well as the water volumes that would be required to maintain them in a healthy state in the future.	
LIST OF AUTHORS: Lefebvre, G., Redmond, L., Germain, C., Palazzi, E., Terzago, S., Willm, L., and Poulin, B.	
REFERENCES OF THE WORK Lefebvre, G., Redmond L., Germain, C., Palazzi, E. Terzago, S. Willm, L., and Poulin, B. Vulnerability of seasonally-flooded wetlands to climate change across the Mediterranean basin (in preparation). Lefebvre G., Redmond L., Germain C., Palazzi E., Terzago S., Poulin B., and Grillas P. (2018). Foreseen impacts of climate changes on wetland hydrology in the Mediterranean area. Society of Wetland Scientists 2018 Annual Meeting. Wetland science: integrating research, practice and policy 29 May – 1 June, Denver, Colorado, USA. Lefebvre G., Redmond L., Germain C., Palazzi E., Terzago S., Willm L., Poulin B., and Grillas P. (2018). Predicting vulnerability of wetlands to climate change across the Mediterranean area. Mediterranean Science Conference for Young Researchers, 16-18 May, Arles, France. Lefebvre G., Redmond L., Germain C., Palazzi E., Terzago S., Willm L., Poulin B., and Grillas P. (2018). Foreseen impacts of climate changes on wetland hydrology in the Mediterranean area. 4th International Conference on Water resources and wetlands, 5-9 September, Tulcea, Romania.	

Case 9	Demonstration of Sea Surface Temperature as Essential Variable for the Mediterranean Sea
ESSENTIAL VARIABLE(S): Sea surface temperature	
SCALE: Regional (The Mediterranean Sea)	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: How marine organisms react to the variations in temperature? The authors evaluate indicators of ecosystem status and change in the Mediterranean Sea and the temporal evolution of some key ecosystem functions, by developing collecting multi-sensor satellite data and developing a time series of Sea Surface Temperature for the period 1982-2016.	
LIST OF AUTHORS: Valentini, E., and Nguyen Xuan, A.	
REFERENCES OF THE WORK Ocean Observation Panel for Climate (2017). "EOV Specification Sheet: Sea surface temperature," Global Ocean Observing System (GOOS) Panel for Physics, EOV-SeaSurfaceTemperature v5.2	

Valentini, E., Filipponi, F., Nguyen Xuan, A., Passarelli, F.M., and Taramelli, A. (2016). Earth Observation for maritime spatial planning: measuring, observing and modeling marine environment to assess potential aquaculture sites. Sustainability 8(6), 519.

Filipponi, F., Valentini, E., Taramelli, A. (2017). Sea Surface Temperature changes analysis, an Essential Climate Variable for Ecosystem Services provisioning. IEE, Multitemp 2017.

Valentini, E., Filipponi, F., Nguyen Xuan, A. and Taramelli, A. (2016). Marine food provision ecosystem services assessment using EO products. Proceedings of "ESA Living Planet Symposium 2016", ESA SP-740 (CD-ROM).

Valentini E., Filipponi F., Nguyen Xuan, A., and Taramelli A. (2014). Demonstration of SST value as EBVs descriptor in the Mediterranean Sea, AGU Fall Meeting, New Orleans (USA) 11-15/12/2017, GC11C-0747: poster.

Case 10	**Remotely sensed indicators and open-access biodiversity data to assess bird diversity patterns in Mediterranean rural landscapes**
ESSENTIAL VARIABLE(S): Community composition; Species richness; Ecosystem extent; Ecosystem structure	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: Changes in ecosystem area have been traditionally used to assess human direct impacts on habitat availability and estimate biodiversity change. However, using area alone as an indicator of habitat change may only partially capture changes in habitat availability for species. The authors use satellite imagery and bird occurrence data to investigate the importance of variables of habitat extent and structure in explaining species richness and community dissimilarity of forest and open-land birds in Mediterranean rural landscapes at the regional scale.	
LIST OF AUTHORS: Ribeiro, I., Proença, V., Serra, P., Palma, J., Domingo-Marimon, C., Pons, X., Domingos, T.	
REFERENCES OF THE WORK Ribeiro I., Proença V., Serra Ruiz, P., Palma, J., Domingo, C., Pons, X., and Domingos, T. (Submitted). Remotely sensed indicators and open-access biodiversity data to assess bird diversity patterns in Mediterranean rural landscapes.	

Case 11	**Significant understory effects on carbon sequestration in European mountain forests**
ESSENTIAL VARIABLE(S): Ecosystem function	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: Forest disturbances weaken the global terrestrial carbon sink, thereby enhancing radiative forcing. This study presents the first landscape-scale study quantifying the effects of tree regeneration and of herb and grass development on forest Net Ecosystem Production in the area of the Kalkalpen National Park (Austria).	

LIST OF AUTHORS: Dirnböck, T., Kraus, D., Grote, R., Klatt, S., Kobler, J., and Kiese, R.	
REFERENCES OF THE WORK Kobler, J., Zehetgruber, B., Dirnböck, T., Jandl, R., Mirtl, M., Schindlbacher, A. (Submitted). Effects of slope aspect and altitude on carbon cycling processes in a temperate mountain forest catchment. Dirnböck, T., Kraus, D., Grote, R., Kiese, R., Klatt, S., Kobler, J., Schindlbacher, A., Seidl, R., Thom, D. (In preparation). Significant understory effects on carbon sequestration in European mountain forests.	

Case 12	**Habitat suitability and stability for the iconic plant species *Iris boissieri*, an indicator of cultural ecosystem services in the Peneda-Gerês National Park**
ESSENTIAL VARIABLE(S): Species distribution; Ecosystem function	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: Remote sensing and in-situ observations	
SUMMARY: The preservation of the narrow endemic and iconic Gerês wild lily (*Iris boissieri*) has particular relevance in Peneda-Gerês National Park. Thus, the availability, stability and temporal trends of suitable habitat areas can be a proxy indicator for this cultural service. This study models the habitat suitability for *Iris boissieri* as an indicator of cultural ecosystem services in Peneda-Gerês.	
LIST OF AUTHORS: Arenas-Castro, S., Carvalho-Santos, C., Gonçalves, J., and Honrado, J.P.	
REFERENCES OF THE WORK Arenas-Castro, S., Gonçalves, J., Alves, P., Alcaraz-Segura, D., Honrado, J.P. (2018). Assessing the multi-scale predictive ability of ecosystem functional attributes for species distribution modelling. PLoS One *13*, 1–31. Arenas-Castro, S., and Regos, A. (2018). A new locality for *Xiphion boissieri* (Henriq.) Rodion in Portugal. Nova Acta Científica Compostelana (Bioloxía) *25*: 1-3. Carvalho-Santos, C., Monteiro, A.T., Arenas-Castro, S., Greifeneder, F., Marcos, B., Portela, A.P., Honrado, J.P. (2018). Ecosystem services in a protected mountain range of Portugal: satellite-based products for state and trend analysis. Remote Sens. *10*(10), 1573. Gonçalves, J., Arenas-Castro, S., Honrado, J.P. (2018). IRIS SDM “Infrastructure for Running, Inspecting and Summarizing Species Distribution Models”, In ECOP VirtualLAB. Available online: https://github.com/joaofgoncalves/ECOP-VLab-SDM	

Case 13	**Wild reindeer population dynamics in Hardangervidda National Park**
ESSENTIAL VARIABLE(S): Population structure	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: In-situ observations	
SUMMARY: Wild reindeer influence ecosystem processes and are considered keystone species of the circumpolar region, but are also important for their economical and recreational value for hunters and landowners in Hardangervidda National Park. The authors model the influence of temperature and	

hunting in the population of wild reindeer on Hardangervidda. This population has been monitored for the last six decades, with counts performed twice annually since 1994.
LIST OF AUTHORS: Bargmann, T., Wheatcroft, E., Imperio, S., and Vetaas, O.R.
REFERENCES OF THE WORK Bargmann, T., Wheatcroft, E., Imperio, S., and Vetaas, O.R. (Submitted). Effects of climate and hunting on wild reindeer population dynamics in Hardangervidda National Park.

Case 14	**Physical, chemical, and biological conditions of the lakes Orhid and Prespa**
ESSENTIAL VARIABLE(S): Chlorophyll a; Lake surface water temperature; Water quality (Phosphorus concentrations); Water flow (stream flow); Air temperature; Precipitation	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: Remote sensing and in-situ observations	
SUMMARY: Lake Ohrid and Lake Prespa are two lakes of high local, regional and international significance because of their geological, cultural and biological uniqueness. The authors investigate the state of physical, chemical, and biological conditions to ensure favourable living conditions for biota, and physical and intellectual interactions with biota, ecosystems, and land-seascapes.	
LIST OF AUTHORS: Tasevska, O., Provenzale, A., Giamberini, M.S., Baneschi, I., Imperio, S., Markovic, D., Hellwig, N., and Zennaro, B.	

Case 15	**Grassland extent and productivity in the Gran Paradiso National Park**
ESSENTIAL VARIABLE(S): Habitat extent; Primary Productivity (above ground biomass)	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: The progressive abandonment of management practices such as mowing and grazing from high-elevation mountain areas causes modifications to grasslands. Grassland productivity has a great importance for grazing and other grassland agricultural production, as well as for the sustenance or wild herbivores. This study explores the Essential Variables for the indicators of grassland extent and, grassland productivity in the Gran Paradiso National Park.	
LIST OF AUTHORS: Viterbi, R., Cerrato, C., Zurlo, M., Rocchia, E., Provenzale, A., Bassano, B., Blonda, P., Adamos, M.P., Tarantino, C.	

Case 16	**Biomass production and carbon storage in the Swiss National Park and Landshaft Davos**
ESSENTIAL VARIABLE(S): Ecosystem structure (carbon sequestration); Primary productivity (above ground biomass)	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: Remote sensing and in-situ observations	
SUMMARY: The production of biomass is a key ecosystem function underlying a set of ecosystem services in the Alps. Due to climate change, the productivity of alpine grasslands is expected to increase.	

At the same time, mountain ecosystems contribute to climate regulation by storing carbon. This study explores the Essential Variables for the indicators of biomass production (2003-2016) and carbon storage in the Swiss National Park and Landshaft Davos.
LIST OF AUTHORS: Stritih, A., Serra, P., Tanase, M., Mermoz, S., Bouvet, A., and Le Toan, T.

Case 17	**Biomass change in the Kruger National Park**
ESSENTIAL VARIABLE(S): Ecosystem function (biomass change)	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: Tree cover and grasslands play a key role in ecosystem functioning. There is a need for spatial explicit assessment of the state, quality, quantity and extent of ecosystem functions such as vegetation production, tree-grass interaction, nutrient cycling, and biodiversity in the Kruger National Park. This study calculates trends in biomass change from 2001 to 2015 within the Kruger National Park.	
LIST OF AUTHORS: Ramoelo, A.	

Case 18	**Hydroperiods of the temporary ponds in Doñana National Park**
ESSENTIAL VARIABLE(S): Hydroperiod	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: The hydroperiod of the temporary ponds is a key ecological parameter determining the composition of plants and waterbirds community that uses these ponds for breeding and completing their life cycle. The authors study the temporal dynamic of the hydroperiod of small waterbodies in Doñana National Park in relation to the protection level and the distance to water abstraction pressures from agriculture and residential areas.	
LIST OF AUTHORS: Bustamante, J., Aragonés, D., and Afán, I.	
REFERENCES OF THE WORK Bustamante, J., Aragonés, D., and Afán, I. (2016). Effect of Protection Level in the Hydroperiod of Water Bodies on Doñana's Aeolian Sands. Remote Sensing *8*(10), 867.	

Case 19	**Modelling biomass production in the seasonal wetlands of Doñana National Park**
ESSENTIAL VARIABLE(S): Primary Productivity (biomass production)	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: Remote sensing and in-situ observations	
SUMMARY: Freshwater wetlands are ideal sites to rear feral cattle. The authors model primary production in relation to water availability via remote sensing in the Doñana National Park. Such models can be used for decision making on the amount and spatial distribution of cattle in the marshes, seeking for the optimal situation taking also into account the conservation of wildlife.	

LIST OF AUTHORS: Lumbierres, M., Méndez, P.F., Bustamante, J., Soriguer, R., and Santamaría, L.
REFERENCES OF THE WORK Lumbierres, M., Méndez, P.F., Bustamante, J., Soriguer, R., and Santamaría, L. (2017). Modeling Biomass Production in Seasonal Wetlands Using MODIS NDVI Land Surface Phenology. Remote Sensing *9*(4), 392.

Case 20	**Water Quality and provisioning in the Wadden Sea**
ESSENTIAL VARIABLE(S): Ocean surface; Community composition (Phytoplankton); Primary Productivity (Phytoplankton biomass); Chlorophyll a	
PHYSICAL OBSERVATIONS USED: Remote sensing and in-situ observations	
SCALE: Local (Protected Area)	
SUMMARY: Phytoplankton blooms in the North Sea sometimes can cause the mortality of mussels and other benthic organisms as well as reducing the water quality levels causing problems for recreational users. The authors use a General Ecological Model construct for calculating nutrient concentrations, and primary production in the Wadden Sea.	
LIST OF AUTHORS: Ziemba, A., El Serafy, G., and Meszaros, L.	

Case 21	**Crop production in Sierra Nevada**
ESSENTIAL VARIABLE(S): Primary Productivity (Crop area)	
PHYSICAL OBSERVATIONS USED: Remote sensing and in-situ observations	
SCALE: Local (Protected Area)	
SUMMARY: In the second half of twentieth century, there was a global abandonment of the traditional and rural human practices. Crop area is one of the Essential Variables of agricultural theme, basic to monitor the temporal evolution of yields, for example. With the aim to know the situation regarding the agricultural production in different time steps in the past in Sierra Nevada, the authors calculate the crops yield statistics based on official statistics and the spatial distribution of land uses.	
LIST OF AUTHORS: Ros-Candeira A., Moreno-Llorca R., Alcaraz-Segura D., Herrero-Lantarón J., Bonet-García F.J., and Millares-Valenzuela A.	
REFERENCES OF THE WORK Moreno-Llorca R., Alcaraz-Segura D., Herrero-Lantarón J., Bonet-García F.J., Millares-Valenzuela A, and Ros-Candeira A. (In preparation). The influence of the ES tool on decision making in Protected Areas. Moreno-Llorca R., Alcaraz-Segura D., Herrero-Lantarón J., Bonet-García F.J., Millares-Valenzuela A., and Ros-Candeira A. (In preparation). Temporal evolution of ecosystem services and trade-offs in Sierra Nevada: implications for PA managers.	

Case 22	**Land cover change and temporal evolution of ecosystem services in Sierra Nevada**
ESSENTIAL VARIABLE(S): Ecosystem structure (change in land cover)	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: Remote sensing	
SUMMARY: Land-use change (deforestation for crops and pastures, reforestation, firewood removal, etc.) constitutes one of the primary drivers of global change, since human activity is to a greater or lesser degree altering the vegetation cover of the planet. The authors use land cover information to get a better understanding of the spatial and temporal distribution of land uses in Sierra Nevada from 1956 to 2007, and to contribute to the modelling of ecosystem services.	
LIST OF AUTHORS: Moreno-Llorca R., Ros-Candeira A., Alcaraz-Segura D., Herrero-Lantarón J., Bonet-García F.J., and Millares-Valenzuela A.	
REFERENCES OF THE WORK Moreno-Llorca R., Alcaraz-Segura D., Herrero-Lantarón J., Bonet-García F.J., Millares-Valenzuela A, Ros-Candeira A. (In preparation). The influence of the ES tool on decision making in Protected Areas. Moreno-Llorca R., Alcaraz-Segura D., Herrero-Lantarón J., Bonet-García F.J., Millares-Valenzuela A. Ros-Candeira A. (In preparation). Temporal evolution of ecosystem services and trade-offs in Sierra Nevada: implications for PA managers.	

Case 23	**Spatial and temporal variability of precipitation and its influence over ecosystem processes and services in Sierra Nevada**
ESSENTIAL VARIABLE(S): Precipitation	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: In-situ observations	
SUMMARY: All processes related to terrestrial ecosystems are conditioned by environmental factors, which inevitably have an impact on the dynamics and intensity with which these processes can manifest themselves. The authors use a fully distributed physically-based hydro-meteorological model to produce daily maps of precipitation in Sierra Nevada, using precipitation data from meteorological stations with records ranging from January 2001 to June 2014.	
LIST OF AUTHORS: Herrero-Lantarón J., Suárez-Muñoz M., Moreno-Llorca R., Ros-Candeira A., Alcaraz-Segura D., Bonet-García F.J., and Millares-Valenzuela A.	
REFERENCES OF THE WORK Millares, A., Moñino, A., Arjona, S., and Baquerizo, A. (2018). Suspended sediment dynamics by event typology and its siltation effects in a semi-arid snowmelt-driven basin. RIVER FLOW 2018, Ninth International Conference on Fluvial Hydraulics, 40-04008. Millares, A., Díez-Minguito, M., and Moñino, A. (2019) Evaluating gullying effects on modeling erosive responses at basin scale. Environmental Modelling and Software *111*, 61-71. Herrero, J., Millares, A., Moreno, R., and Bonet, F. (In preparation). Assessment of the influence of vegetation on ecosystem services related to water through hydrological modelling.	

Case 24	Spatial and temporal variability of temperature and its influence over ecosystem processes and services in Sierra Nevada
ESSENTIAL VARIABLE(S): Air temperature	
SCALE: Local (Protected Area)	
PHYSICAL OBSERVATIONS USED: In-situ observations	
SUMMARY: All processes related to terrestrial ecosystems are conditioned by environmental factors, which inevitably have an impact on the dynamics and intensity with which these processes can manifest themselves. The authors use a fully distributed physically-based hydro-meteorological model to produce daily maps of maximum and minimum temperature in Sierra Nevada, using temperature data from meteorological stations with records ranging from January 2001 to June 2014.	
LIST OF AUTHORS: Herrero-Lantarón J., Suárez-Muñoz M., Moreno-Llorca R., Ros-Candeira A., Alcaraz-Segura D., Bonet-García F.J., and Millares-Valenzuela A.	
REFERENCES OF THE WORK Suárez-Muñoz, M., Bonet-García, F., Hódar, J.A., Herrero, J., Tanase, M., and Torres-Muros, L. (Submitted). INSTAR: an Agent-Based model linking climate and the biological cycle of forest pests in Mediterranean ecosystems. Moreno-Llorca, R., Alcaraz-Segura, D., Herrero-Lantarón, J., Bonet-García, F.J., Millares-Valenzuela, A., and Ros-Candeira, A. (In preparation). The influence of the ES tool on decision making in Protected Areas. Moreno-Llorca, R., Alcaraz-Segura, D., Herrero-Lantarón, J., Bonet-García, F.J., Millares-Valenzuela, A., and Ros-Candeira, A. (In preparation). Temporal evolution of ecosystem services and trade-offs in Sierra Nevada: implications for PA managers.	

4. Discussion

4.1 Overview of current case studies

The current Deliverable gives an overview of the diversity of studies conducted within ECOPOTENTIAL that make use of locally relevant variables (some of them Essential Variables) for the assessment of the ecosystem status, functions, and services. This work focuses on some specific examples of case studies conducted at different scales and systems. This report synthesizes information regarding the identification and use of Essential Variables following bottom-up approaches according to the ECOPOTENTIAL Storylines reported in Deliverable 2.2 (http://www.ecopotential-project.eu/site-studies/storylines.html) and the inventory of locally relevant variables considered to be the most essential for Protected Areas based on surveys with Protected Area staff working on site, reported in Deliverable 9.1.

Across scales, case studies and Storylines, ECOPOTENTIAL studies have described a wide range of environments and ecosystems using multiple locally relevant variables (Table 4.1) and related indicators, and contributing to the development of a set of Essential Variables that have been operationally used in this project. While at coarse scales all the case studies made exclusive use of remote sensing observations, most studies at Protected Areas used both in-situ data and remote sensing products or exclusively remote sensing products (n = 6 studies for each), allowing for long to medium-term monitoring by using archive data and/or very fine scale assessments – making use of newly available satellite information. It is important to note that, although across the different studies there was a strong focus on the use of Remote Sensing products and methods, in-situ data is critical for the development of many Essential Variables (e.g., ecosystem function: soil respiration measures). A smaller number of cases in Protected Areas exclusively used in-situ observations (n = 3 studies). The collection of in-situ data through monitoring schemes must include repeated measurements for targeted systems with standardized protocols either using long-term research sites or making use of large-scale monitoring programmes and citizen science networks, but remains costly and labour intensive (Kissling et al., 2018a). This limitation explains the reduced adoption of approaches in ECOPOTENTIAL studies that exclusively rely on in-situ observations (e.g., temperature or precipitation measurements from meteorological stations). Remote sensing observations are increasingly used because they can extend the geographic and temporal dimensions of in-situ measurements considerably (Pettorelli et al., 2016), though they also face limitations with very high spatial and spectral resolution (Schimel et al., 2013).

4.1.1 Locally relevant variables identified across scales

Despite the wide use of remote sensing data across ECOPOTENTIAL case studies (e.g., for modelling habitat extent and biomass in Gran Paradiso or Kruger National Parks), the calculation of locally important variables appears constrained by scale, with only a few – mostly climatic and using land cover products– being calculated or used across multiple scales (e.g., ecosystem structure, atmospheric air temperature or atmospheric precipitation). This contrasts with a wide diversity of locally relevant variables identified and calculated at finer scales, benefiting from the broader pool of in-situ data not only to calculate the variables themselves but also to validate them.

Broad scale assessments (from regional to global scales) in the current literature are mostly available for ecosystem level features and climatic measurements. Here, ECOPOTENTIAL has done an important contribution on the assessment of ecosystem structure and function (e.g., fractional green vegetation cover at global scale), species populations (e.g., European freshwater communities), water flow and regulation (e.g., lake/reservoir water level), burned area assessments and prediction (Turco et al., 2018), as well as the impacts of changes in ecosystem structure and climate on Protected Areas (e.g., exposure, sensitivity and resilience of wetlands) (Table 4.1).

Table 4.1 Comparison of the locally relevant variables used in the ECOPOTENTIAL case studies compiled in the present report, Essential Variables listed by themes as Essential Biodiversity Variables (EBVs), Essential Climate Variables (ECVs), and Essential Ocean Variables (EOVs), and relevant variables identified in the Deliverable 9.1 (D9.1) and Deliverable 2.2 (D2.2). The numbers in brackets indicate the reference of the study where the variable was used (see Table 3.1). Colour of the relevant variables indicate whether they are of Abiotic (brown) or Biotic (green) nature. The Environmental Variables for Protected Areas (PAs) of 'very high importance' are shown in blue and sub-top variables ('yet still high importance') are shown in green.

Chapter 3 Relevant Variable(s) used	Themes			Nearest Environmental Variables for PAs Surveys (D9.1) n = 26 PAs	PAs Storylines (D2.2)* n = 15 PAs	PAs Cases n = 15	Regional Cases n = 2	European Cases n = 4	Global Cases n = 3
	EBV	ECV	EOV						
Ecosystem function (EF)	Ecosystem function (EF)			All		[11],[12],[17]			[1],[2]
Primary productivity	EF – Net primary productivity	Above-ground biomass		Primary production	S1,2,3,4,7,10,13,14,15	[15],[16],[19]			
Chlorophyll a			Chlorophyll a	Primary production	S2,9	[14],[20]			
Phytoplankton biomass			Phytoplankton biomass	Primary production	S11	[20]			
Seasonality				Primary production	S2				
Secondary productivity	EF - Secondary productivity			Secondary production					
Nutrient retention	EF - Nutrient retention			Element cycling	S4,5,14				
Fire regime	EF - Disturbance regime			Habitat suitability	S2				
Ecosystem structure	Ecosystem structure (ES)	Land Cover		All	S2,3,5,6,7,8,11,13,14,15	[10],[16],[22]	[8]	[4],[5],[7]	[3]
Habitat extent	ES - Ecosystem extent	Land Cover		Habitat suitability	S1,3,4,6,10,12,15	[10],[15]	[8]		
Species distribution	Species distribution			Population dynamics	S3,5,9,12	[12]		[4]	
Species abundance	Species abundance			Population dynamics	S2,4,5,7,10,15				

Chapter 3 Relevant Variable(s) used	Themes			Nearest Environmental Variables for PAs Surveys (D9.1) n = 26 PAs	PAs Storylines (D2.2)* n = 15 PAs	PAs Cases n = 15	Regional Cases n = 2	European Cases n = 4	Global Cases n = 3
	EBV	ECV	EOV						
Population structure	Population structure			Population dynamics	S1,4,15	[13]			
Species richness	Species richness			Biodiversity	S1,10,13	[10]			
Community composition	Community composition (CC)			Biodiversity	S2,3,11	[10],[20]			
Macrophytes	CC - Species interactions			Biodiversity	S11,12				
Genetic diversity	Genetic composition			Gene pool					
Individual fitness				Population dynamics	S6				
Phenology	Species traits - phenology			Biodiversity	S2,4				
Atmospheric air temperature		Atmospheric air temperature		Weather	S1,2,4,7,8	[14],[24]		[6]	
Atmospheric precipitation		Atmospheric precipitation		Weather	S2,4,5,6,7,8, 10,12,13,15	[14],[23]	[8]	[6]	
Surface radiation budget		Surface radiation budget		Weather	S7		[8]	[6]	
Evapotranspiration				Weather	S12		[8]	[6]	
Surface wind speed and direction		Surface wind speed and direction		Weather			[8]		
Carbon dioxide		Carbon dioxide		Weather	S4				
Snow cover		Snow cover		Climate regulation	S1,4				
Water vapour (surface)		Water vapour (surface)		Climate regulation			[8]		
Leaf area index		Leaf area index		Climate regulation	S14				
Soil moisture		Soil moisture		Climate regulation	S4,7,15				
Temperature (near surface)		Temperature (near surface)		Climate regulation			[8]		
Sea Surface Temperature		Sea Surface Temperature		Climate regulation	S9		[9]		

Chapter 3 Relevant Variable(s) used	Themes			Nearest Environmental Variables for PAs Surveys (D9.1) n = 26 PAs	PAs Storylines (D2.2)* n = 15 PAs	PAs Cases n = 15	Regional Cases n = 2	European Cases n = 4	Global Cases n = 3
	EBV	ECV	EOV						
Lake surface water temperature		Lakes		Climate regulation		[14]			
Ocean surface		Ocean surface heat flux		Climate regulation					
Lake water level		Lakes		Hydrodynamics			[8]		
Stream flow		River Discharge		Hydrodynamics	S5,6,12	[14]			
Hydraulic conductivity				Hydrodynamics	S8				
Soil water content				Hydrodynamics	S8				
Water use/demand		Anthropogenic water use		Hydrodynamics	S5, 6				
Geodiversity				Hydrodynamics	S13				
Hydroperiod				Hydrodynamics	S12	[18]			
Wetland evolution				Hydrodynamics	S12				
Soil carbon and nitrogen stock		Soil carbon		Element cycling	S4,7,15				
Water quality				Element cycling	S5	[14]			
Groundwater quality		Groundwater		Element cycling	S7				
Turbidity				Habitat suitability	S10				
Salinity		Salinity		Habitat suitability	S10				
Soil structure				Habitat suitability	S4				
Floodplain distribution				Habitat suitability	S11				
Sediment composition				Habitat suitability	S10				
Crop area				Change in land use	S8	[21]			
Crop type				Change in land use	S8, 12				
Settlements				Changes in land use	S13				
Human disturbance				Disturbance	S1,7,9				
Density of use				Overexploitation	S3,12				
Livestock				Animals of economic use	S8				

Chapter 3 Relevant Variable(s) used	Themes			Nearest Environmental Variables for PAs Surveys (D9.1) n = 26 PAs	PAs Storylines (D2.2)* n = 15 PAs	PAs Cases n = 15	Regional Cases n = 2	European Cases n = 4	Global Cases n = 3
	EBV	ECV	EOV						
Pollution				Pollution	S5				
Mortality				Changes in species	S9				
Number of visitors				Tourism	S9,11				
Revenue				Tourism	S9				

** Storylines names:* S1 Hardangervidda; S2 Peneda-Gerês National Park; S3 Swiss National Park and the Landshaft of Davos; S4 Gran Paradiso National Park; S5 Lakes Ohrid and Prespa; S6 Sierra Nevada (irrigation channels climate change); S7 Northern Limestone National Park; S8 Sierra Nevada (ecosystem services); S9 Pelagos Sanctuary; S10 Wadden Sea; S11 Danube Delta; S12 Camargue Biosphere Reserve; S13 Har Hanegev; S14 Kruger National Park; S15 Montado.

The bulk of ECOPOTENTIAL studies analysed here were developed at local scale, in the ECOPOTENTIAL Protected Areas. Here, important advances were made, either with the use of the latest generation of satellite information (e.g., the use of the EODESM system to enable and monitoring quantitative aspects of ecosystems and environmental conditions) or by expanding the utilization of in-situ data to calibrate temporally explicit models (e.g., counts of reindeer population in Hardangervidda National Park to model population changes and identify predictors of change). In addition, some studies explored and tested the applicability of new Essential Variables to capture relevant changes in ecosystems condition, such as “Sea Surface Temperature” to capture sea warming patterns that could threaten the ecosystem service provision of marine systems. Covering the complexities and local nuances of Protected Areas have required both the development of relevant variables of ‘broad spectrum’ that are applied across scales and systems (e.g., habitat extent or precipitation), as well as the use of highly context specific variables (e.g., snow distribution in the Gran Paradiso or the Swiss National Park or hydroperiod in Camargue or Doñana). All these studies contributed to monitor the consequences of changing land cover and climate, determine biodiversity patterns (from phytoplankton to grassland or bird communities), prioritize areas for action and provide a set of operational tools for planning and management of both terrestrial and aquatic systems. This adaptation of the set of Essential Variables must be recognized to guide the production process and to define the set of data and types of observations required.

The most identified and used variables across scales (at least used in two different scales) were **ecosystem structure** (18 studies in total), followed by variables of **precipitation** (14 studies), **habitat extent** (10 studies), **temperature** (8 studies), **species distribution** (6 studies) and **ecosystem function** (5 studies). The associated measurements included estimations of phytoplankton biomass, habitat availability or vegetation cover, air temperature and precipitation. In all cases, the studies covered both terrestrial and aquatic systems. An especially serious effort should be made to obtain reliable estimates of these Essential Variables for ecosystem studies and monitoring programs.

At coarser scales, considering global, European and regional studies altogether, the relevant variables that are used at least in two studies were ecosystem structure, ecosystem function, precipitation, radiation and evapotranspiration. At local scale (Protected Areas), the sample size of studies is rather limited and this exercise should be repeated on many more sites (e.g., the Natura2000 network). Accepting that this limitation might affect the generality of these results, we note that the most used relevant variables are ecosystem function, primary productivity, and ecosystem structure, whose application goes from the development of habitat suitability models of emblematic plant species to the analysis of land cover changes within Protected Areas. Also, Chlorophyll a, habitat extent, community composition, temperature and precipitation variables were used in more than one study.

4.1.2 Essential Biodiversity, Climate and Ocean Variables used in ECOPOTENTIAL case studies

Almost 60% of the variables identified and used through ECOPOTENTIAL were already included in the lists of Essential Biodiversity, Climate or Ocean Variables that have been defined so far (Deliverable 2.1) (Jetz et al., 2019; Kissling et al., 2018a; Muller-Karger et al., 2018; Pereira et al., 2013). This highlights both a high heterogeneity of the studies conducted, as expected with a majority of studies conducted at local scale, but also progress towards a unified set of Essential Variables. Below we detail the Essential Biodiversity, Climate or Ocean Variables that received more interest across ECOPOTENTIAL.

Regarding the candidate Essential Biodiversity Variables proposed by GEOBON, **ecosystem structure** was the most used EBV (23 studies: 9 case studies and 14 storylines), followed by **ecosystem function** (18 studies: 8 case studies and 10 storylines), **species populations** (15 studies: 4 case studies and 11 storylines)

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and **community composition** (6 studies: 2 case studies and 4 storylines). Moreover ecosystem structure (including land cover) is present in the existing lists of both EBVs and ECVs, which makes it a critical Essential Variable for monitoring the condition and trajectory of the studied systems. Within those EBV classes, Net Primary Productivity (11 studies), Ecosystem extent (10 studies), species distribution (6 studies) and species abundance (6 studies) were the EBVs more commonly identified and used in ECOPOTENTIAL. EBVs of species traits (morphology, phenology, reproduction, physiology and movement) and genetic composition are barely or not included at all in ECOPOTENTIAL studies. However, these EBVs have also received less attention in the wider research community (Kissling et al., 2018b).

Regarding Essential Climate Variables (ECVs), **land cover** was the most used ECV (23 studies), followed by **atmospheric precipitation** (14 studies), **above ground biomass** (12 studies) and **atmospheric air temperature** (8 studies). Other ECV variables that were at least identified or used in one study are: river discharge (4 studies), surface radiation budget (3 studies), soil moisture and carbon (3 studies each), sea surface temperature, snow cover and anthropogenic water use (2 studies each), and surface wind speed and direction, carbon dioxide, water vapour, leaf area index, temperature near surface, lakes, groundwater and salinity (only 1 study). Among the ECVs that were not identified nor used in ECOPOTENTIAL studies there were variables such as pressure, cloud properties, other greenhouse gases than carbon dioxide, or albedo.

Regarding Essential Ocean Variables (EOVs), the only two EOVs that were identified or used in ECOPOTENTIAL studies were **Chlorophyll a** (4 studies: 2 case studies and 2 storylines) and **Phytoplankton biomass** (2 studies: 1 case study and 1 storyline). Nonetheless, only a reduced proportion of the studies were developed in the marine realm (Wadden and Mediterranean Seas). An important effort to include more EOVs in the monitoring systems of those areas (e.g., Zooplankton biomass and diversity that would also serve as an EBV of secondary productivity) is encouraged to monitor the status and trends of the ocean and marine life and to inform policy and management.

Among the 23 variables that were not listed as EBVs, ECVs, and EOVs, there are **locally relevant variables** (e.g., livestock, number of visitors, crop area and type) that might be considered in future iterations of the lists of Essential Variables by themes and their examination may help with the standardisation of measurement types and methodologies. In particular, some of them (e.g., evapotranspiration, hydroperiod, soil water content) are under the water theme, and might become in the future part of a list of Essential Water Variables.

4.1.3 Variables identified and used across ECOPOTENTIAL

To draw comparisons between all the relevant variables identified and used in ECOPOTENTIAL, we included in Table 4.1: 1) those Essential Variables used and calculated in ECOPOTENTIAL case studies; 2) the Essential Environmental Variables perceived as highly important by Protected Area managers, rangers and ECOPOTENTIAL scientists (Deliverable 9.1); and 3) the Essential Variables identified in the frameworks of the Storylines (Deliverable 2.2). From this table, one easily sees that most of the studies adopted **different sets of locally relevant variables**. The studies that aimed at responding a specific research question or goal (i.e., case studies compiled for the present project) often used a reduced set of variables. At the scale of Protected Areas, this implies that authors are describing a specific detailed part of the full Storylines, i.e., they narrow down the number of candidate Essential Variables and reduced the number of parameters depending on the objective (e.g., only Sea Surface Temperature or reindeer population). Nonetheless, the guidelines emerging from bottom-up approaches for monitoring Protected Areas highlight the need of calculating a broad set of relevant variables covering different dimensions of the studied system. Some questions thus arise on the current diffusion use of the Essential Variable concepts in operational practice.

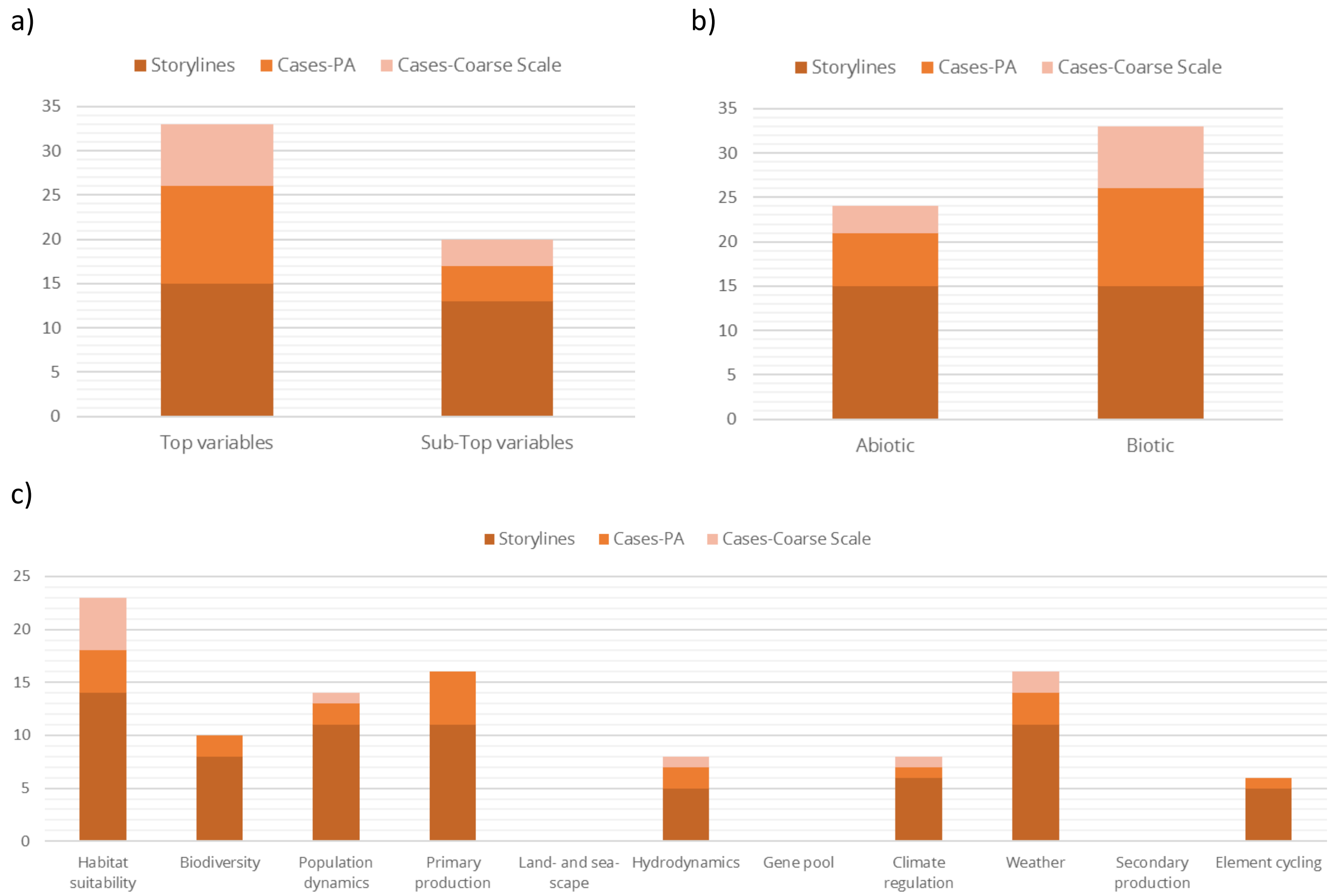

Figure 4.1 Number of storylines and case studies at Protected Areas (Cases-PA) and Coarser scales (regional to global) using: a) the identified “top” or “sub-top” Essential Environmental Variables for Protected Areas of the Deliverable 9.1; b) Essential Variables of Abiotic or Biotic nature; and c) individually for each of the 11 Environmental Variables of Ecosystem Structure and Function for Protected Areas identified in the Deliverable 9.1.

The 11 Environmental Variables selected for Ecosystem Functions and Structure in the Deliverable 9.1 (Table 4.1, Figure 4.1) are categorized regarding their importance as perceived by Protected Area managers into ‘**top**’ (within at least 75 % of the surveyed Protected Areas) and ‘**sub-top**’ (with a high score in at least 50 to 75 % of the Protected Areas) variables. In line with this prioritization, the present compilation of case studies for Protected Areas indicate a higher use of top variables (11 cases) than of sub-top variables (4 cases) (Figure 4.1a), i.e., the variables perceived as highly relevant by Protected Areas staff are also the most commonly picked up in research studies at local scales.

The locally relevant variables used in the collected studies were classified into **variables of Biotic or Abiotic nature** as categorized by the Deliverable 9.1 (only those that were within top and sub-top variables). According to this Deliverable, for Ecosystem Function and Structure, abiotic variables were judged to be of lower importance, except for habitat suitability and land- and sea-scape, hydrodynamics. Consistent with this perception, the number of cases in Protected Areas using Variables of Biotic nature was higher (11 cases) than the number of studies using Variables of Abiotic nature (6 studies). However, the set of variables selected for the description of Storylines always included a mix of Variables of Biotic and Abiotic nature (all 15 storylines).

The highly important Environmental Variables for Protected Areas of the Deliverable 9.1 were substantially covered by the case studies compiled in the present report for Protected Areas and also for other scales (Table 4.1, Figure 4.1c). A similar overlap is found with the candidate Essential Variables inform the Storylines. Variables of Habitat suitability, Biodiversity, Population dynamics, Primary production, Hydrodynamics and Weather conditions were used in at least one case study at local scale. Variables of Habitat suitability were highly used at coarse scales. Although no case studies covered Land- and sea-scape variables, some of the variables within Habitat suitability might be also considered as land and sea-scape variables depending on the context.

The only **variables that are not used** neither in the case studies nor in the Storylines are the gene pool (i.e., genetic diversity) and the secondary production. This highlights an important gap between the perceived importance of the **gene pool** by Protected Area managers and ECOPOTENTIAL scientists and the use of this Essential Variable, which should be addressed in future studies. This gap is consistent with previous studies emphasizing that progress is needed in the implementation of coordinated genetic monitoring systems (Mimura et al., 2017; Navarro et al., 2017). Obstacles for using the gene pool as a key Essential Variable maybe be associated with the need for higher resources and long-term studies for calculating variables that inform on genetic diversity of populations, structure and inbreeding over time. For instance, there are not remote sensing indicators that can be used for quantifying genetic diversity, so these measurements fully rely on in-situ observations. On the other side, the lack of studies using **secondary production** or including it in storylines, might be explained by other variables such as population or species abundance.

Though the overlap of locally relevant variables is clearer between Deliverables 2.2 and 9.1, both works have developed frameworks for the monitoring of Protected Areas that are highly representative and of direct use for Protected Areas in general, whereas the cases compiled in the present report show a diversity of studies that used and quantified a subset of relevant variables. Thus, it becomes clear the need of encouraging and facilitating the use and calculation of Essential Variables in conservation areas by increasing knowledge transfer mechanisms and facilitating the use of pre-prepared remote sensing products (e.g., for the assessment of ecosystem functions).

4.1.4 The set of common Essential Variables that emerge from the different research activities and Storylines developed during ECOPOTENTIAL

As a result of the present overview, a small set of relevant variables that have been operationally used across studies and scales has emerged in this project, which moves us towards a more consolidated set of Essential Variables that are relevant across boundaries, scales and/or ecosystems. Table 4.2 lists the variables that have shown to be locally relevant (i.e., variables commonly identified and used at Protected Areas), but also used across scales (i.e., globally relevant). Some of those variables are actually Essential Variable Classes, as for those classes the authors commonly did not provide further details on the physical Essential Variable that has been monitored to describe the structure or the function of the ecosystem. Building upon this (limited) set of studies, we can conclude that particular attention should thus be given to the estimate of that list of Essential Variables. This will hopefully serve as standard baseline to support the development of locally informed monitoring schemes, which then should be extended with a wider set of locally relevant variables.

Table 4.2. Essential Variables that are both included in the list of selected Environmental Variables from Deliverable 9.1 and at least in one case study of those compiled for the present report, and that have been used at least at two different scales. Finally, if the variable is included in lists of Essential Variables of Biodiversity (EBV), Climate (ECV), and Ocean (EOV) this information is also provided. Upper case letters indicate Essential Variables classes.

Essential Variable(s)	Number of cases Protected Areas	Number of cases Coarse scale	Number of storylines D2.2	EBV, ECV or EOV
ECOSYSTEM STRUCTURE	4	5	14	EBV class
Ecosystem extent	2	1	7	EBV
ECOSYSTEM FUNCTION	6	2	10	EBV class
SPECIES POPULATIONS	3	1	11	EBV class
Species distribution	1	1	4	EBV
Air temperature	2	1	5	ECV
Precipitation	2	2	10	ECV

4.2 An approach to support the use of Essential Variables in local monitoring

The results reported above, albeit for a limited ensemble of study cases, indicate a large spread of the types of Essential Variables used in the different studies. This makes it difficult to extract larger-scale information and coherent pictures from a plethora of local studies. In the following, we illustrate one possible approach to defining, in a user-oriented and co-designed way, a set of variables that can be relevant both for local monitoring and for allowing comparison of local results across a network of sites.

First, we recall that the process of identifying Essential Variables is not an exclusion process, but rather a priority setting process, where central elements of monitoring effort are identified to improve the understanding of social-ecological dynamics. It facilitates the prioritization and optimization of resources and allows for a transparent and direct way to communicate monitoring needs through different levels of knowledge and decision-making. To date, however, the process of identifying and prioritizing Essential Variables has largely been based on expert knowledge about globally relevant measurements (Pereira et al., 2013). While necessary, this approach has not yet been systematically driven or informed by users' needs at the regional, national, or local scales. At the same time, there is a need to make environmental and conservation data more relevant for a range of users (e.g., CBD, IPBES, national and local authorities, NGOs; Geijzendorffer et al., 2017), and strengthen connections with data providers to ensure data quality and comparability across scales. This would lead to the development of a complementary bottom-up approach to formulating a consistent set of Essential Variables globally by considering context-specific user needs across a range of applications at sub-global scales (e.g., Turak et al., 2017).

Here, in line with the previous considerations, the work developed in Deliverable 2.2 and the results obtained in the ECOPOTENTIAL project, we advocate that the top-down approach must be complemented with a bottom-up approach, where conservation managers draw on system-level knowledge and theory (Liu et al., 2015) to identify locally important variables that meet local or sub-global needs for conservation data and with those, support the implementation of global scale Essential Variables (Turak et al., 2017; Figure 4.2). A parallel approach, based on direct interviews with Protected Area staff working in the field, is reported in Deliverable 9.1 to which we refer for more details.

The proposed framework proceeds in four sequential steps as indicated below (this approach is largely based on the Storyline concept developed by ECOPOTENTIAL as a whole):

Step 1. Narratives are used to describe the complexity of ecological and social interactions that influence a specific conservation or management goal. These narratives should be harnessed to identify the major system components, functions and processes, and the underlying causal relationships that affect them. Using existing ecological knowledge, ecosystems supporting similar communities and processes, or facing comparable anthropogenic pressures can be grouped and systematically described (Turak et al., 2017). These elements collectively summarize the monitoring needs to assess a given conservation goal. By examining the causal relations that link the social-ecological system, it is also possible to represent the focal system elements that are conditioned or condition the entire social-ecological system.

Step 2. To quantitatively address these system elements and their changes through time, models that describe the spatial and temporal interactions are often necessary. These models seek to describe critical ecosystem dynamics and can only be operationalized contingent upon the availability of interpretable information and technical capacity to implement them. Some of these models only use static variables, describing the state of a given system component (e.g., topography), but others rely on dynamic variables (e.g., species abundance) that can be analysed to evaluate trends and make scenarios of future conservation trajectories.

Step 3. Independent of the type of information used, modelling approaches rely on a set of variables that condense and summarize observations. These strongly depend on source datasets, making their identification a critical step to operationalize the models and create the foundation for the design and implementation of monitoring systems. Within these, conservation and land managers are able to identify concrete groups of locally important variables that together describe the social-ecological system, matching them – when possible – with current global information needs.

Step 4. Observations constitute the source datasets that are the basic building blocks of any given monitoring system and of which the variables are derived. These are usually dynamic measures that require the consideration of both in situ and remote (e.g., satellite data) monitoring activities (Vihervaara et al., 2017), but can also include information with smaller temporal variability that is still critical to understand system dynamics (e.g., soil type). Conservation managers must prioritize which observations must be collected in situ based on their own needs. Other data requirements can be met through the establishment of institutional collaborations that allows to maintain a constant flow of information, recognizing the fact that many important ecological processes and drivers of change are occurring at scales beyond the extent of the Protected Area in question.

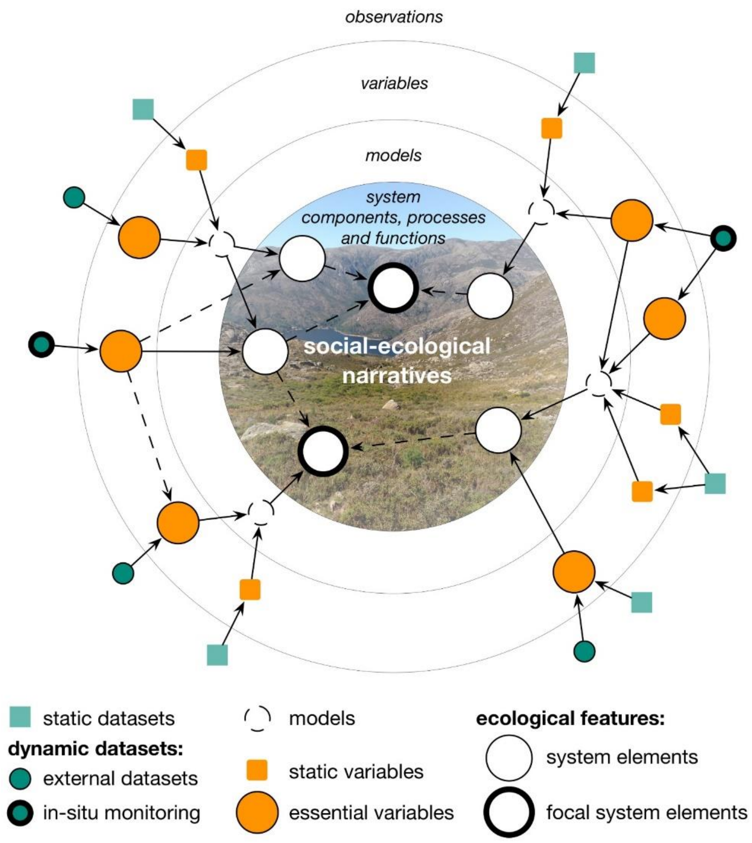

Figure 4.2 Conceptual representation of a system approach to identify essential variables and monitoring priorities in conservation areas. The arrows in the Figure differentiate between direct data dependencies (full lines) and the expected causal relations between system components and essential variables (dashed lines).

The approach to identify Essential Variables discussed here is based on causal diagrams constructed from system narratives and it identifies two types of flows (Figure 4.2): i) a causal flow that is represented by the directional links between the variables of the system; and ii) an information flow that is organized into concentric layers from raw data to system components, functions, and processes. The causal flow makes it explicit how different variables and data sources are combined to model system components. It also declares expectations and knowledge about relationships between the different variables which are important to understand the social-ecological system dynamics. The information flow identifies the variables that can be observed, and what monitoring schemes, observations, and data sources are needed to inform them.

In this context, the use of narratives can contribute to the identification of monitoring priorities targeting specific system elements that are fundamental to understand a social-ecological system. Such narratives have been widely used to facilitate communication between stakeholders engaged in biodiversity conservation and beyond (Hayes et al., 2015). The development of narratives should be an open and iterative process, fostering the inclusion of contributions not only from conservation managers but also from a wider set of stakeholders including resource users, researchers and local knowledge holders (Spruijt et al., 2014).

Narratives support the development of causal diagrams that pinpoint the social-ecological variables that represent the state and drivers of the different components, and their relationships. These also contribute to effectively describe the main aspects and causal relations within the social-ecological system being managed, often including their related threats and drivers, as well as the biodiversity and ecosystem elements and functions that are critical to meet the conservation goals that have been set (Lindenmayer and Likens, 2010).

Conservation monitoring often focuses on locally important variables without a clear concern for data comparability across scales or regions. One of the main challenges is that, across scales, monitoring systems often address different purposes, stakeholders and, more significantly, different types of questions or conservation goals (Turak et al. 2016). On the other hand, matching locally important variables with global essential variables is needed to foster the scalability of the data collected by Protected Areas. For instance, collection, mobilization, and publishing of data regarding species distribution and population structure can use the standards, methods and tools being developed for essential biodiversity variables (Kissling et al., 2018a). In doing so, automated data flows can be established and feed the development of global datasets critical for biodiversity monitoring and research (Navarro et al., 2017).

Still, there are consistency and scalability issues when several conservation areas consider the same essential variable. As an example, different conservation areas can identify species distribution as a monitoring variable without the necessary thematic consistency. Addressing such thematic, and eventually temporal, inconsistencies will be critical when considering interoperability across conservation areas. A solution would imply direct coordination of monitoring activities (e.g. at the national level) that allows information to move across scales and ecosystems, as part of a multi-level conservation strategy.

4.3 Moving forward on using Essential Variables for and from Protected Areas

As mentioned before, national monitoring systems rely on a key set of policy, management and conservation options/questions to define their monitoring priorities. These have to be designed to provide relevant information for decision-making. Once these priorities are set, indicators and modelling frameworks can be identified and described to produce effective monitoring systems that allow for data mobilization across scales. At the same time, countries have internal and external development goals (e.g., the Sustainable Development Goals [SDGs]) that they have to meet according to the agreements made and signed by their representatives. In order to do this, standards are needed not only at the level of monitoring protocols (e.g., how and what to monitor) but also at the level of data mobilization facilities (e.g., the tools and infrastructure provided by the Global Biodiversity Information Facility [GBIF]). At the European level, with the establishment of several Directives on biodiversity, water and risk assessments, a number of digital infrastructures were created to accumulate information on multiple environmental dimensions. As an example, the Water Framework Directive, has allowed the establishment of the Water Information System for Europe that allows Member States to report specific information on the state, change and condition of water ecosystems and biodiversity. Unfortunately, this level of standardization does not apply to other scopes and even for this community there is a lack of inter-comparison with other communities (e.g., biodiversity, climate, etc.).

This being said, while countries collaborate to mobilize data to inform Essential Variables, international institutions (e.g., GEOSS , GEO BON, IPCC, IPBES) contribute to the national efforts by providing guidance and support for the development of monitoring systems and data standards. This approach would mobilize local knowledge, placing it in a broader context, by focusing on the relationships between variables to understand information needs under specific management and conservation contexts (Figure 4.3). By promoting a global infrastructure for monitoring based on multiple nodes, it would also allow data to be quickly mobilized and standardized across scales, while empowering local and national organizations to develop their own monitoring schemes.

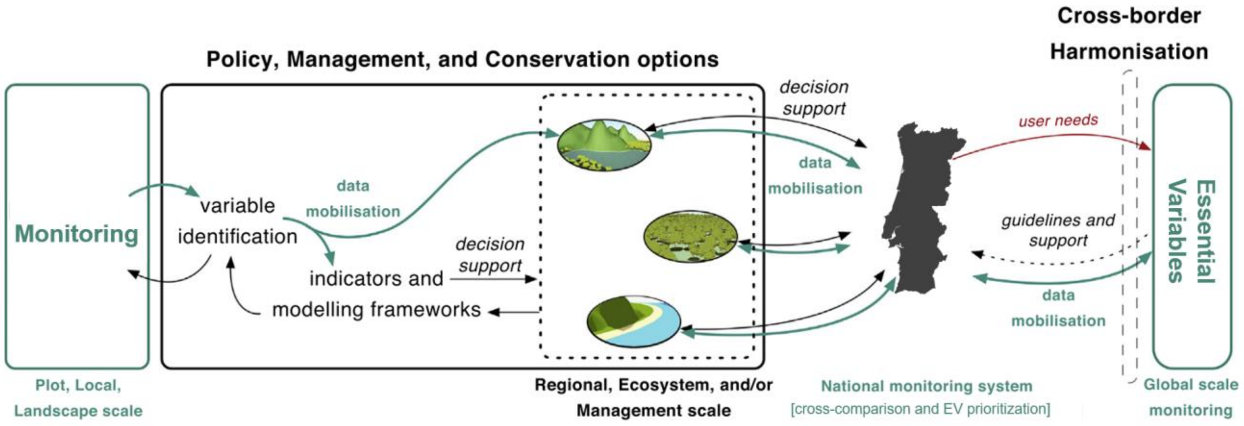

Figure 4.3 A cross-scale approach for global monitoring and definition of Essential Variables. Green arrows indicate data mobilization flows, black arrows indicate decision support flows, and finally red arrows indicate the identification of user needs (based on Navarro et al., 2017).

Moving forward, it is necessary to strike an effective balance between ensuring that individual monitoring programs collect observations relating to locally relevant variables, while at the same time safeguarding that a subset of these variables map directly to, or can be readily translated or generalised into Essential Variables. Achieving this means linking the outcomes of different programs to increase their combined benefits of monitoring programs to that the benefits achieved through multiple programs from local to global scales are greater than the sum of the benefits from individual programs (Turak et al., 2017). In this context, national (or jurisdictional) frameworks have a critical role to play as they must find the balance between the generality of global requirements and specificity of local monitoring programs.

Protected Areas have the potential to be the backbone of global monitoring through the Essential Variable based approach used in ECOPOTENTIAL (Figure 4.4). In ECOPOTENTIAL we used a circular flow approach – from end-users to Earth Observation and back to end-users – to allow for a significant amount of locally relevant information to be identified and produced using standardized and transferable methods, which can then be used across systems and scales. Because of their global distribution, covering all ecoregions (Dinerstein et al. 2017), and current targets (e.g., Aichi target 11), Protected Areas are essential for this approach. With an investment in standards, transparency regarding methods, and on active data mobilisation strategies (Navarro et al. 2018), countries, Earth Observation networks and the global conservation community would benefit from monitoring programs for Protected Areas. Even considering that only a fraction of these globally distributed areas would be able or willing to participate in such initiative, still thousands of sites would be able to report data. A step forward would be to attach to global conservation targets the global monitoring of these areas and the establishment of a global monitoring backbone. With strong political support and in the face of strong effects of climate and land use change, these areas could be pivotal as early warning systems to signal major regional and global nature shifts.

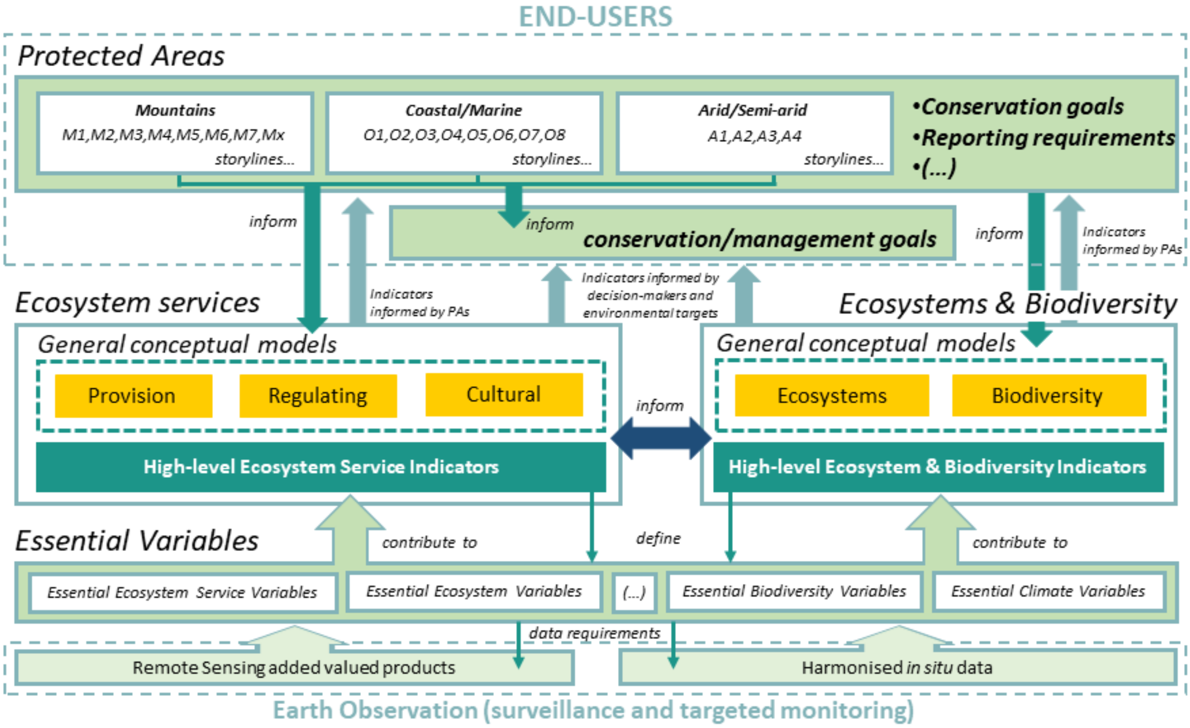

Figure 4.4 General scheme of the approach from Earth Observations to end users across scales.

In the case of Europe, using available legal instruments (e.g., Natura2000) it should be possible to make the current reporting system standard enough that data mobilization based on primary data (i.e., actual observations and not processed data products, such as Atlas data or equivalent) could be made a reality. In this way, the role of Protected Areas would be strength not only as a mean to promote nature conservation, but also as a provider of qualified information on the state and trends of biodiversity and ecosystems. Also, using these sites as a baseline for natural conditions across Europe – as they cover all environmental conditions and ecosystems present in Europe (see example in case study number [5]) –, an effective measurement of human impact could be actually created to support impact assessments across Europe. In this context, the use of Essential Variables to collect and report on the state and trends of ecosystems would be fundamental, as they would allow for common, cross-border, indicators that could be updated and owned by countries or even independently by individual Protected Areas.

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