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Roadmap for current and future novel PAs

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Abstract	ECOPOTENTIAL aims to blend Earth Observations (EO) from remote sensing and field measurements, data analyses and modelling of current and future ecosystem conditions and services. The project focuses its activities on a targeted set of internationally recognized Protected Areas (PA) in Europe, the majority being mountainous, semi-

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	arid, and coastal areas, marked as a UNESCO World Natural Heritage Site, Biosphere Reserve, National Park and/or Natura 2000 site. The aim of WP9 was to deliver a range of practical tools to describe the quality status of Protected Areas (PA) through the development and application of a combination of environmental as well as socio-economic status descriptors, in order to obtain insight in the requirements of current and future novel PA and the possible impacts in response to drivers of change. Thereby, helping to optimize the process to eventually reach a higher level protected status, to underpin changes to be made in future in existing PA, to define modifications in PA boundaries and extent, to prevent potential obstacles, or to initiate remedial action. This supported the assessment and estimates of current and future ecosystem services, which can set (changes in) the management strategies and policy options for current and (the identification of) novel PA, taking into account potential impacts of drivers of changes and the social and economic needs of ecosystem services beneficiaries. The outcomes of WP9 will ease the political decision making on the future protection of new areas by supporting Coastal Zone Management, the Alpine Convention, and other policies with concrete tools for steering the process towards further protection on the one hand and safeguarding socio-economic services on the other side. The following deliverable focused on providing a roadmap to the above-mentioned objectives. This roadmap proposes a six-step approach. 1. Building a strong foundation; 2. Assessing the current status of PAs; 3. Assessing the ecological embedding beyond the individual PAs; 4. Designing management measures; 5. Implementing management measures; and 6. Monitoring, evaluating and adjusting the proposed measures. Additionally, at the end of this deliverable, a toolbox is provided describing different tools, models, and methods developed and how they have been applied in the framework of ECOPOTENTIAL. All tools were analysed and their applicability to future PAs evaluated.
Keywords	Roadmap, Protected Areas, Ecosystem Services, Ecosystem Functions, Habitat, Threats, Essential Variables, Ecosystem Management

Executive Summary

ECOPOTENTIAL aims to blend Earth Observations (EO) from remote sensing and field measurements, data analyses and modelling of current and future ecosystem conditions and services. The project focuses its activities on a targeted set of internationally recognized Protected Areas (PA) in Europe, the majority being mountainous, semi-arid, and coastal areas, marked as a UNESCO World Natural Heritage Site, Biosphere Reserve, National Park and/or Natura 2000 site.

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Abbreviations

CoP	Community of Practice
COP21	21st Conference of the Parties
EEV	Essential Environmental Variables
EF	Ecosystem Function
EN	Endangered
EO	Earth Observation
ES	Ecosystem Service
ESV	Essential Socio-Economic Variables
EV	Essential Variable
GHG	Greenhouse Gas
HNPA	Har HaNegev Protected Area
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
MA	Millennium Assessment
NT	Near Threatened
NDVI	Normalized Difference Vegetation Index
PA	Protected Area
RCM	Regional Climate Model
SAC	Special Areas of Conservation
SPA	Special Protection Area
UNFCCC	United Nations Framework Convention on Climate Change
WeMOI	Western Mediterranean Oscillation Index

1 Introduction

The ECOPOTENTIAL project focuses on blending various Earth Observations such as remote sensing, in-situ measurements, modelling results and data of present and future ecosystem services and conditions. Internationally recognised Protected Areas (PAs) in and outside of Europe, including three different types of interest (i.e. coastal/marine, mountain, and arid and semi-arid ecosystems) are targeted. Often, they are endangered and diverse ecosystems and play an important role in management and conservation strategies. Additionally, World Heritage Sites and Biosphere Reserves, National Parks, Natura 2000 sites, and LTER sites are included in these PAs. Conserving these PAs is the key to conserve nature. All countries have PAs, and globally, they are now covering 15% of land and 8% of coastal waters (Juffe-Bignoli, et al., 2014). Despite this considerable progress towards the global target of having 17% of terrestrial areas and 10% of the world's oceans protected, biodiversity continues to decline (Aichi Target 11) (Coad, et al., 2015).

Figure 1: Protected Areas Around the World (2016)

The diversity of environmental conditions and protection status of the PAs calls for a broad view on the Ecological Functioning and Structure (EF and ES) of the ecosystems, on the ecosystem services (ES) provided by the European PAs, and on the pressures and changes (Threats) imposed on them. For this reason, ECOPOTENTIAL considers for the three different domains a sufficiently large suite of PAs to avoid singularities and to identify commonalities across a broad range of biogeographical settings and environmental conditions. In order to adequately describe and analyse the current and future EF of the PA, the ES they deliver, and the development of pressures imposed on them, an agreed set of indicators of the underlying variables has to be available.

In the past decades, PAs have come under enormous pressure as human populations, income, and leisure time had increased. More people and more different purposes now need to be satisfied, which were often not envisioned when PAs were first established. These anthropogenic pressures vary greatly depending on the country and the type of PA. But in general, the role of PA managers has changed in the sense that they are now not only caretakers but rather assertive advocates who have to manage their areas to provide benefits to local, regional, and national economies as well as to minimise the impacts of threats to the biodiversity and ecosystem integrity of the PA. Rapid growth in visitors and changes in the mix of recreational uses such as hunting, hiking, camping, skiing, and air tours, infrastructure development, and legal resource extraction (e.g. logging, livestock grazing, farming, and energy development), contribute to unintended and environmentally destructive trends, such as spread of invasive species, illegal timber harvesting and poaching as well as air, water, and soil pollution (Prato & Fagre, 2005; Nolte, et al., 2010). Some threats like infrastructure development are external threats, whereas increased invasive species are internal threats. Generally speaking, external threats to PAs are usually more difficult to resolve than internal threats as PA managers often have limited legal authority and/or unwilling to control events external to their PA (Prato & Fagre, 2014). Additionally, PA managers usually have the scientific support to manage ecological challenges but are less equipped to deal with social, political and economic challenges originating outside of their administrative responsibilities.

In recent years, the effects and impacts of climate change on ecosystems have gained more attention. In December 2015, during the 21st Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC) the Paris Agreement was adopted to take collective global action on climate change. In the agreement, climate change is documented as an “urgent and potentially irreversible threat to human societies and the planet” and all sectors and countries are called to act immediately. The importance of ecosystem-based approaches to achieve climate adaptation, including hazards reduction and the role of PAs as a part of national responses to climate change was recognised as a key outcome from the COP21 (IUCN, 2016).

PA managers have an increasingly challenging task of incorporating climate change into their management strategies as well as meeting the demands of the steadily increasing diversity of stakeholders (Worboys, Francis, & Lockwood, 2010). There are already many reviews, policies, and advocacy publications on climate change available. However, practical guidance such as roadmaps for PA managers is lacking. Therefore, this deliverable aims to meet this need. It not only describes the roadmap, but also connects the findings from D9.1 to D9.3 as well as other related work packages (e.g. WP 6, 7, 8).

2 Description of Essential Protection Descriptors

A description of the requirements and of PAs has been based on a bottom-up inventory of the most important Essential Variables (EVs) for the EF, ESs and threats in PAs as perceived by more than 120 PA managers, rangers and scientists of 26 PAs (a full description of the selection process and factual EVs is given in Deliverable 9.1 and 9.2 , (Hummel, et al., 2018; Hummel, et al., 2019) and a summary below).

Based on these EVs, the quality of the PAs was judged to be average to good in general. It was shown that higher data availability correlated to a higher perceived PA quality. This suggests the need for high data availability.

In the ECOPOTENTIAL surveys among PAs the following requirements were recommended to be taken into account to ensure the environmental quality, and to allow for proper management of current PAs and for new PAs to be established in future:

- To assess the full range of 30 EVs (EVs; *ibid.* Ch. 3.5), including:
    - “Ecosystem Functions and Structure” variables on Habitat suitability, Biodiversity, Population dynamics, Primary production, Land- and sea-scape, Hydrodynamics, Gene pool, Climate regulation, Weather, Element cycling, and Secondary production
    - “Ecosystem Services” variables on Leisure activities, Education and research, Habitat for feeding and breeding, Charismatic landscape, Biodiversity conservation, Charismatic species, Spiritual significance, Animals of economic use, and Climate regulation
    - “Threats” variables on Overexploitation, Disturbance, Tourism, Change in species, Climate change, Bad management, Exotic species, Habitat loss, Change in land use, (Illegal) human activities
- Acquire a high data availability for the EVs, because a higher data availability coincides with a better perception of PA quality;
- Because of the general lack of attention to socio-economic EVs in academic studies, these variables should get more attention in further studies;
- Emphasise (and lobby for) rules, tools, and support embedded in directives and legislation at National, European or global levels;
- Acquire a single integrated management authority and a high degree of autonomy for PA management;
- Assess the political support and will to protect a specific area;
- Acquire insight into the role and influence of the different stakeholders in the area.

On the basis of surveys among more than 120 PA managers, rangers and scientists of 26 PAs, of which 22 were European, one Israeli, three near/in Africa, in the years 2015 to 2018 an inventory and analysis of the most important EV for PAs was made. The EVs were then divided into two categories: Essential Environmental Variables (EEV) and Essential Socio-Economic Variables (ESV). In total, 396 variables were suggested as being important in PAs, together with 768 indicator-metrics combinations to measure these variables. After a thorough analysis of the EVs, a total of 67 harmonised variables remained. The importance level of these variables as perceived by the PA managers and scientists, was calculated. In this bottom-up process, 30 Essential Variables were judged by a selection of experts familiar with the topic to be (the most) important for indicating the status and development of the EF, ESs, and pressures (Threats) of/on the PA. The following EVs (incl. EEVs and ESVs) were recognised (within each group in order of priority) (Table 1).

Table 1: Identified EEVs and ESVs for Ecosystem Functions, Ecosystem Services and Threats in PAs

	Ecosystem Functions and Structures	Ecosystem Services	Threats
Essential Environmental Variables	• Habitat suitability • Biodiversity • Population dynamics • Primary production • Land- and sea-scape • Hydrodynamics • Gene pool • Climate regulation • Weather • Element cycling • Secondary production	• Habitat for feeding and breeding • Charismatic landscape • Biodiversity conservation • Charismatic species • Climate regulation	• Change in species • Climate change • Exotic species • Habitat loss
Essential Socio-Economic Variables		• Leisure activities • Education and research • Spiritual significance Animals of economic significance	• Overexploitation • Disturbance • Tourism • Poor management • Changes in land use • (Illegal) human activities

Due to the relatively large number of PAs investigated, the many managers, rangers and scientists queried, the standardised methods used, the firm consistency of the outcomes irrespective the studied domains (Transitional Waters, Semi-Arid, and Mountainous areas), and the strong consensus among PA managers and scientists on the final results regarding the most important ES, EF and Threats to indicate the status and development of PAs (chapter 5.2), the outcomes of the surveys were judged highly representative, and may form the preferable basis for further studies and comparisons on the current and future status and changes in the quality and requirements of PAs. The following three paragraphs showcase these findings in three selected PAs.

2.1 Mountains – Samaria PA

Samaria (White Mountains) National Park is located on the West part of the island of Crete (Figure 2). It was declared as a National Park via a Royal Decree in 1962. It is a multi-designated area and specifically a National Park, Landscape of Outstanding Beauty, Natura 2000 site coded GR4340008 (SAC - Special Areas of Conservation) and GR4340014 (SPA - Special Protection Area) and Biosphere Reserve in the framework of the “Man and Biosphere” Programme of UNESCO. It is a hotspot for biodiversity and a place with a strong and important anthropogenic influence (history, special songs, traditions) (Trigas, Panitsa, & Tsiftsis, 2013). It contains one of the largest gorges in the Balkans, Samaria Gorge, with a total length of 13 km while nine main gorges are located within the area of the White Mountains.

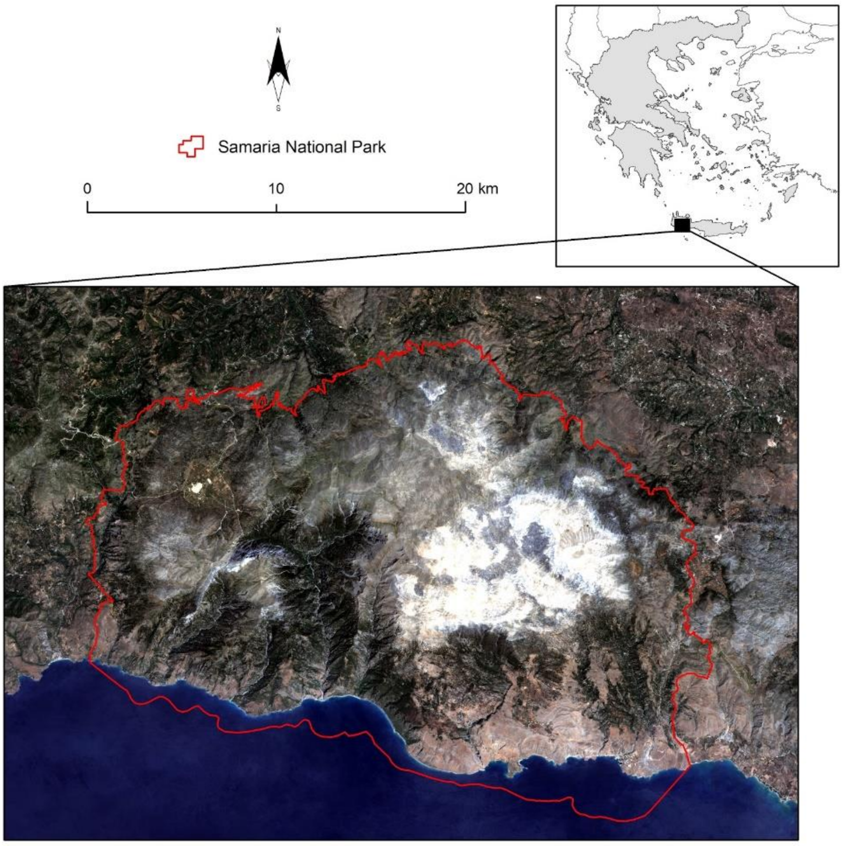


Figure 2: Copernicus Sentinel-2 median reflectance composite, for the period March-October 2018, featuring the boundaries of the Samaria National Park. Contains modified Copernicus Sentinel data (2018) /processed by Dimitris Poursanidis/FORTH.

These specific landscape configuration schemes sustain unique abiotic and biotic environmental characteristics because of the site's wilderness and difficult-to-access areas for direct scientific field work. The area has unique characteristics that are described by the following descriptors: 58.454 ha, altitude ranging from 0 - 2.454 m, more than 50 summits higher than 2000 m a.s.l., 14 different types of habitats, approximately 40% of the entire extent of the county of Chania (Natura 2000 Standard Data Form). Mean Annual Rainfall is between 600 mm to 2000 mm depending on the elevation. The entire area comprises one of the two main environmental lungs of Crete and a regulator leading to the current meteorological and hydrological conditions set in the western part of the island.

The Samaria National Park includes villages that continue their traditional activities while also accommodating a large number of tourists, as the gorge is ranked among the top 10 destinations to visit in Greece and one of the three to visit in Crete. A large proportion of the park is inaccessible by car. Thus, the visitors are concentrated at specific places. To the east the can visit Sfakia area and go uphill till Agios Ioannis, the last village of the area where residents still live, in the central part tourists are concentrated in the downstream portions of the gorge and to the west, some tourists are visiting the borders of the park close to Sougia.

Among the emblematic species that occur in the Protected Area are the wild goat *Capra aegagrus cretica*, (Schinz, 1838), the Bearded vulture *Gypaetus barbatus* (Linnaeus, 1758) and the endemic Cretan lizard *Podarcis cretensis* (Wettstein, 1952). The bearded vulture is a Near Threatened (NT) bird (BirdLife International 2017, 2019) while the Cretan lizard is an Endangered (EN) reptile (Lymberakis, n.d.).

Figure 3: A large population of the Cretan Podarcis cretensis lives within the limits of the National Park (mainly found in West Crete). Dimitris Poursanidis/FORTH

For the latter, within the ECOPOTENTIAL project, the use of Earth Observation data in the framework of Species Distribution Modelling took place in order to provide insights into the spatial distribution of the lizard within the park (Poursanidis, Lymberakis, Spaneli, & Chrysoulakis, 2017), the identification of hot spots of occurrence that are in conflict with activities such as tourism and agropastoral activities, the use of the modelling results in connectivity analysis and finally as the ultimate goal, the use of the results in the conservation and management planning of the Management Body of Samaria National Park.

Table 2: Identified EEVs and ESVs for Ecosystem Functions, Ecosystem Services and Threats in the Samaria PA

	Ecosystem Functions and Structures	**Ecosystem Services**	**Threats (high or very high importance)**
Essential Environmental Variables	• Habitat suitability • Biodiversity • Population dynamics • Landscape and seascape • Gene pool • Climate regulation • Weather	• Biodiversity conservation • Charismatic landscape • Climate regulation • Habitats for animals & plants including rare and endemics • Hydrological regulation	• Climate change • Habitat loss • Tourism • Pastoral activities
Essential Socio-Economic Variables		• Animals of economical use • Education and research • Flood regulation • Agrotourism activity • Leisure activities • Spiritual significance	• Climate change • Landuse change • Distrurbance of rare/endemic species

2.2 Coastal/Marine – Curonian Lagoon PA

The Curonian Lagoon – the largest European lagoon – is a shallow water body (total area 1584 km^2, mean depth 3.8 m) situated in the southern part of the Baltic Sea. The lagoon receives water from the River Nemunas, the third-largest contributor (after the Vistula and Oder) of total nitrogen and phosphorus to the Baltic Sea. The salinity of the water in the northern part of the lagoon fluctuates between 0.1 and 7 PSU; marine, brackish and freshwater species inhabit the lagoon. The most important ecosystem services in the region of the Curonian lagoon, according to the Millennium Assessment (MA), are provisioning services such as fishery and agriculture, maintenance services for fish and birds, regulation of water quality, and cultural services such as recreation.

The northern part of the lagoon is in Lithuania, while ⅔ of its area (in the southern part) belongs to Russia. The Lithuanian part of the Curonian lagoon is designated NATURA 2000 area (both habitat and bird directive protected territories). The Curonian spit along with the adjusting portions of the lagoon is designated as a national park both in Lithuania and the Russian Federation. In 2000, the Curonian Spit cultural landscape was added to the UNESCO World Heritage List. The Curonian Spit landscape is being created not only by natural processes but also by human activities and represents the combined impact of nature and that of human activity. It illustrates the evolution of fishermen society and settlements over time. Until now, the Curonian Spit presents a continuous cultural landscape, which retains an active social role in contemporary society associated with the traditional way of life and in which the evolutionary process is still in progress. At the same time, it exhibits significant material evidence of its evolution over time, the latter integrally related to both natural forces and human activity. As the Curonian lagoon area is under the protection of the national and regional parks, Natura 2000, and UNESCO, it attracts many tourists seeking for various recreational activities. Mostly summer tourists come for sandy beaches, dunes, forests, and settlements in the Curonian Spit National Park where tourism infrastructure is developed and already raising the environmental problems. In winter, many tourists go ice fishing on the frozen Curonian Lagoon (Figure 4).

Figure 4: Recreational fishermen on the frozen Curonian Lagoon

The eastern part of the lagoon in Lithuania is designated as Regional Nemunas Delta Park with several reserves inside with strict conservation guidelines. The Regional Park was established in 1992 in order to safeguard the delta's wildlife and facilitate research. All the territory is considered globally significant and is protected as Ramsar site and “Natura 2000”. However, the area could be characterised by low level of tourism, even though the area has a unique landscape in the Delta, river floods, and the importance for wildlife especially migratory birds. The most important types of tourism types in the territory are recreational fishing (angling, ice-fishing), birdwatching, and water tourism. Present landscape of the Nemunas river Delta has been formed mainly by natural properties and a minimal role by anthropogenic processes. Human settlement mostly affected marshy alder forest and the flooded meadows on the riversides, which were almost entirely converted into polders and experienced extensive anthropogenic transformation. Nowadays, the Nemunas Delta is recognized as a completely cultural landscape. This system of coastal wetlands is one of the most important stopover sites for numerous species of waterbirds, suchas Whooper Swan, Bewick's Swan, White-fronted Goose and Pochard in Europe, in early spring they are clearly dominated by White-fronted Goose. The known redistribution of the key wintering sites of White-fronted geese from Central Europe to the Netherlands and North Rhine-Westphalia region of Germany resulted in the formation of their new migration route, stretching along the Eastern Baltic coast and the floodplains of the Nemunas River Delta.

All identified ecosystem functions and structures with provided ESs and threats (Table 1) are actual for the region of the Curonian lagoon. Original reasons to establish the Curonian Spit National Park were to maintain the diversity of ecosystems, species, genetic varieties, and ecological processes, to protect landscapes reflecting the history of human interaction with the environment and provide scientific, educational, recreational and spiritual needs of societies. Nowadays managers of the PA identify the main threats as changes in species, habitats, land use and hydrology, climate change and harmful algae blooms in order to protect at least the most important structures and functions as habitat suitability, biodiversity, energy transfer through a food web, population dynamics, primary production, hydrodynamics, gene pool, climate regulations.

The original reasons to establish the Nemunas Delta Regional Park were different from the ones for the Curonian Spit National Park due to the reasons were designed to safeguard outstanding areas of living richness, natural beauty and protect landscapes reflecting the history of human interaction with the environment. Present threats identified by managers of the PA are related to changes in conditions for biota and habitats, while various human activities were recognised as a multiple threat too (Table below.

Considering the opinion of PA managers, both PAs maintain a range of ecosystem functions and structures which provide both ecologically and economically important ESs. The most important of them (with a very high level of significance) are provided in Table 2.

Table 3: Identified EEVs and ESVs for Ecosystem Functions, Ecosystem Services and Threats in two PA of the Curonian lagoon

	Ecosystem Functions and Structures	**Ecosystem Services**	**Threats (high or very high importance)**
	Nemunas Delta Regional Park		
Essential Environmental Variables	Habitat suitability, Biodiversity, Energy transfer through a food web, Population dynamics, Primary production, Hydrodynamics, Gene pool, Climate regulation	• Biodiversity conservation • Charismatic landscape • Climate regulation, • Flood provision for animals • Habitats for feeding and breeding/ spawning animals • Hydrological regulation	• Change in species • Climate change • Habitat loss • Agriculture

Essential Socio-Economic Variables		• Animals of economical use • Education and research • Flood and coastal protection	• Change in land use and hydrology • Harmful algae blooms
	Curonian Spit National Park		
Essential Environmental Variables	• Habitat suitability • Biodiversity • Energy transfer through a food web • Population dynamics • Hydrodynamics • Land- and sea- scape • Sedimentation	• Biodiversity conservation • Charismatic landscape • Fire protection • Habitats for feeding and breeding/ spawning animals	• Change in species • Climate change • Habitat loss • Agriculture • Change in sedimentation • Exotic species • Fire • Extreme weather
Essential Socio-Economic Variables		• Flood and coastal protection • Leisure activities • Spiritual significance • Transport facilitation	• Disturbance • Change in land use and hydrology • Harmful algae blooms • Tourism • Eutrophication, harmful algae • Fisheries • Increased salinization • Overexploitation

2.3 Arid/Semi-arid – Har Ha Negev PA

The Negev Highland (Har HaNegev, HN) is an arid environment limited by water and nutrient availability and covers an area of about 1107 km^2. It has a mean annual rainfall of 80-100 mm and a mean annual temperature of 18°C (-4°C – 40°C) (IMS, 2011). Patterns of precipitation and redistribution of rainfall by runoff water drive ecosystem structure and functions, including primary and secondary productivity, decomposition and biodiversity. The system is characterized by high topographic, geologic, geomorphic, and pedologic diversity (geodiversity). The geodiversity further interacts with the biodiversity to create unique Hydro-Geo-Eco-Systems. HN has impressive biodiversity with many unique and endemic species. The high abiotic (geologic) and biotic diversity of the system provide diverse ESs that have attracted human settlement in HN since early times. In the HN Protected Area (HNPA), the priority ecosystem services are habitat services for unique dryland species and the existence value of biodiversity, regulating services, such as those that control the distribution and abundance of soil moisture, nitrogen and soil, and also supports a broad array of cultural services, including educational activities, research, recreation, and tourism.

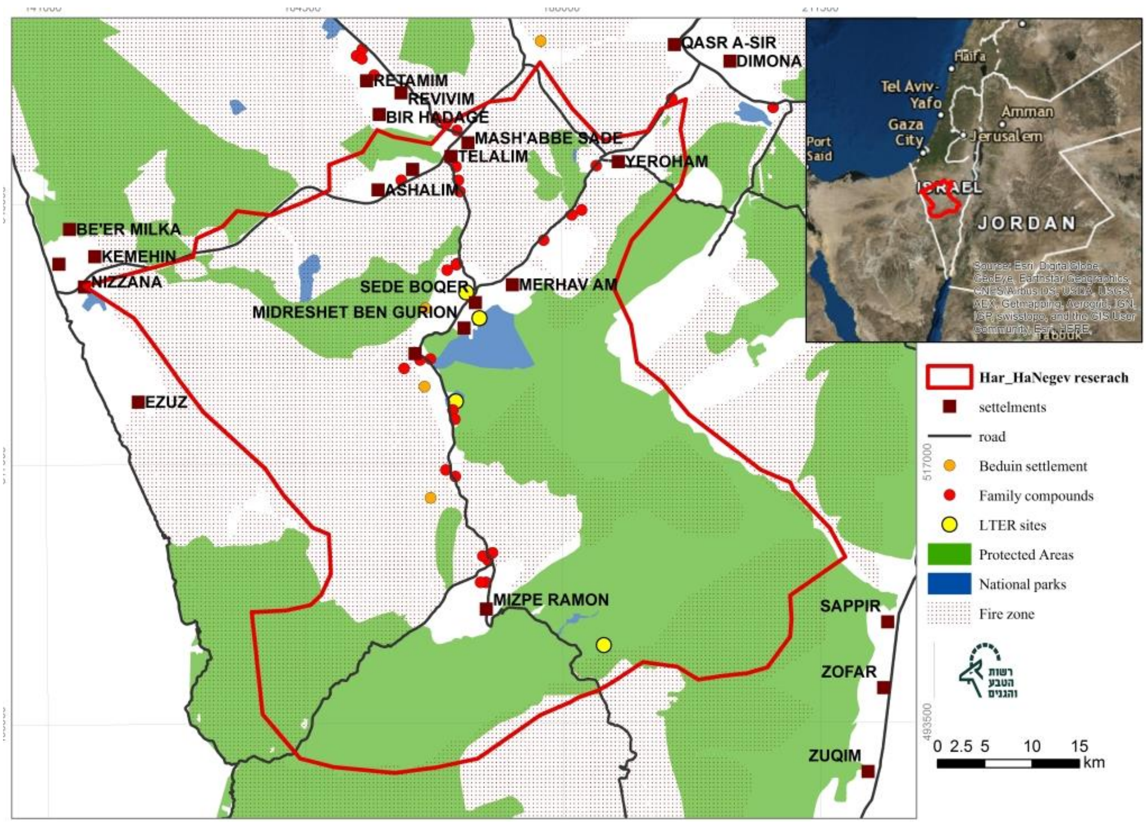


Figure 5: Har Ha Negev Protected Area

Within the HNPA are three small towns, 13 rural communities, and about 30 homesteads. The homesteads make a living from small scale farming, wineries, grazing, and tourism (Orenstein D. , et al., 2009). The Negev is also home for semi-pastoral Bedouins. In HNPA, the Bedouin live in small family communities, and their economic activities include sheep, goat and camel herding, manual jobs and tourism. While all these types of settlements have a considerable effect on the biodiversity and the ecological integrity of the HNPA, these effects and ways to mitigate them are not well understood (Orenstein D. , et al., 2009; Rueff, Parizot, Israel, & Schwartz, 2008; Ginguld, Perevolotsky, & Ungar, 1997; Degen & El-Meccawi, 2009; Kressel, Ben-David, Rabi'a, & Bedouin, 1991).

Human settlement in the Negev – ranging from urbanized, to rural, to nomadic and semi-nomadic – goes back at least 4000 years and has been a fairly consistent feature on the landscape throughout that history. As such, the extensive impact of domesticated grazing and terraced agriculture, make HN and its associated ecosystem structure as we find it today an excellent example of a socio-ecological landscape produced through the long-term interaction of natural and anthropogenic forces (Evenari, Shanan, & Tador, 1971; Bruins, 1990).

The two major drivers of risk for this region are anthropogenic climate change and land use/land cover change. Climate change which is hypothesized to lead greater interannual variation in precipitation, which along with topography and pedology, is the main determinant of soil moisture and thus primary productivity in arid systems (see HN storyline). Land use/land cover change in this region is driven by demographic growth at the national scale, as well as local population growth. In particular, residential development is considered to be one of the major stressors on the HN ecosystem. Such development, along with the various infrastructures to support it (water, sewage, electricity, road networks) has the potential to impact biodiversity directly, via habitat destruction or competition with invasive species, or indirectly, through their modification of ecosystem flows of water, soil and nutrients. This has been the major focus of ECOPOTENTIAL research in HN, including the impact of residential development on vegetation cover (Ohana-Levi et al. 2019) and on aesthetic preferences (Orenstein et al. 2018), and the potential for integrating runoff-harvesting systems into natural ecosystem function (Paz-Kagan et al. 2017). In contrast to other PA drivers of risk, nutrient enrichment and fire risk are less relevant for this dryland system (in fact, nutrient leakage from the system one challenge for dryland systems).

Figure 6: Negev homestead opposite an undeveloped wadi (photo by Haim Singer)

Figure 7: The Onager (Equus hemionus), a reintroduced species to the Negev Highlands (photo credit: Gideon Pisanty, Wikipedia Commons)

Table 4: Identified EEVs and ESVs for Ecosystem Functions, Ecosystem Services and Threats in the Har Ha Negev PA

	Ecosystem Functions and Structures	**Ecosystem Services**	**Threats (high or very high importance)**
Essential Environmental Variables	• Hydrology (precipitation, evaporation, runoff, infiltration) • Pedology (soil formation, distribution) • Energy flow (primary productivity, food webs)	• Soil moisture (for primary and secondary biological productivity) • Forage for grazing animals (wild and domestic) • Microclimate • Soil quality (depth, nutrient content)	• Land use/land cover change (infrastructures, settlement, agriculture) • Anthropogenic direct and indirect desertification (overgrazing, runoff diversion, development) • Global climate change
Essential Socio-Economic Variables	• Demography (population size and distribution) • Economic wellbeing • Tourism activity • Agricultural/Pastoral activities	• Soil productivity for agricultural and grazing • Tourism potential • Education and research	• Social/economic inequality • Political conflict • Loss/absence of economic opportunities • Loss of primary production/soil fertility

3 Projected Impacts of Drivers of Change

In D9.3 (De Wit, et al., 2019) a comparative analysis of drivers of change was done in order to identify threats and drivers for existing PAs. These drivers could be grouped into six different categories: 1) **Climate change** and 2) **Change of Land use** cover the majority of the reported drivers/pressures, with others represented by 3) **Pollution and nutrient over-enrichment**, 4) **Population growth/ tourism & recreation,** 5) **Invasive species and/or Pest species** and 6) **Fire risk.** These drivers and pressures have a huge influence on the delivery of ESs which are explained in more detail below focusing on the first two as these are the major drivers. Additionally, the policy context was important to explore and was therefore added as well.

3.1 Climate Change Effects on ES Delivery

Climate change is expected to have profound effects on aquatic ecosystems related to the changes in temperature, salinity and hydraulic circulation. In the Nemunas delta - Curonian Lagoon protected territories area according to the BBN assessment using downscaled climate change scenarios RCM[1] 4.5 and RCM 8.5 (SHYFEM hydraulic circulation model), we expect limited positive effect on commercial fish stock populations and negative impact on recreational fishery (mostly because of the total loss of ice cover and, subsequently, ice fishing as a service), degradation of water quality and decrease in nitrogen retention by the lagoon.

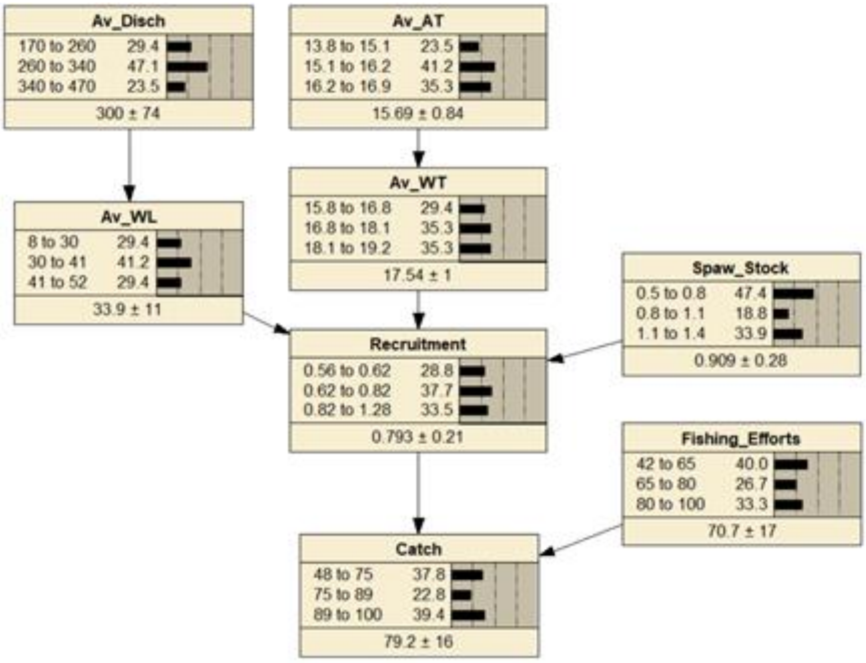


Figure 8: Compiled BBN for pikeperch commercial catches in the Curonian lagoon showing median and standard deviation (from Ivanauskas et al., submitted)

Furthermore, Lorenzo Mari et al. showed (D8.5, Chapter 3.3) how connectivity between populations in the marine environment is highly sensitive to climate variability, and hence vulnerable to climate change. The spatiotemporal development of the ecological connectivity of *Posidonia oceanica* over the past 30 years shows statistically significant negative trends, in particular for the top 100 connectivity hotspots across the Mediterranean LME. These trends are highly correlated to Mediterranean Oscillation Indexes, which

[1] Regional Climate Model

capture climate variability across the Mediterranean Sea. A healthy meta-population of *Posedonia oceanica*, however, is essential to ensure future supply of a number of ecosystem services with local (e.g. purification of waters) and global relevance (e.g. climate regulation by sequestration of Carbon).

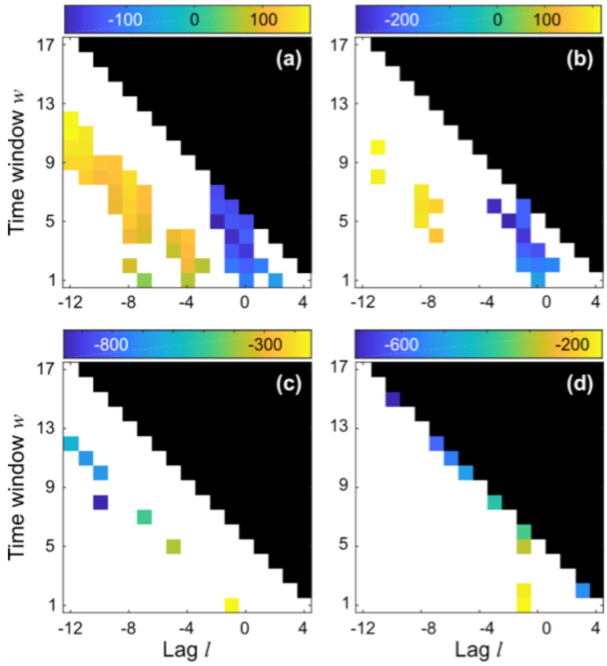


Figure 9: Interplay between climate variability and s-connectivity patterns averaged over the whole Mediterranean Sea. (a) Linear regression of self-retention vs. average WeMOI[2] for the period 1987–2016. (b) In/outdegree vs. WeMOI. (c) Self-retention vs. MOI1. (d)

3.2 Change of Land and Water Use Effects on ES Delivery

The second groups of drivers as identified in D9.3 is change of land use. Changes in agricultural practices within the PA or immediate surroundings and traditional ecosystem uses within the PAs were systematically affiliated to “Change of Land Use”. In addition, planning infrastructure for renewable energy production, exploitation of fossil resources (i.e. gas winning in the Waddenzee) and mining activities within the PAs have also been included in the “Change of Land Use” category. Additionally, another sub-category was added to this chapter: inland open water presence. Knowing how much water is available will help to determine the effects on the delivery of ES.

Land Use

Due to the combined effects of climate change and shifts in land use, the distribution and structure of the vegetation of the Sierra Nevada has been undergoing rapid change, which in turn affects the associated ecosystem services. The cover of tree formations in Sierra Nevada has expanded from 15% to 51.23% over the last 60 years, while the areas of scattered tree cover and natural forests have densified, and the area of cultivated fields has declined (from 17.8% to 4.72%) (Zamora et al. 2016). Therefore, it is important to ascertain future land-use change, as well as its effects on vegetation and ecosystem services.

The main purpose of this study was to facilitate the land-use management of PAs based on ES. A BBN is being designed to develop future land-use scenarios for the Sierra Nevada under different environmental

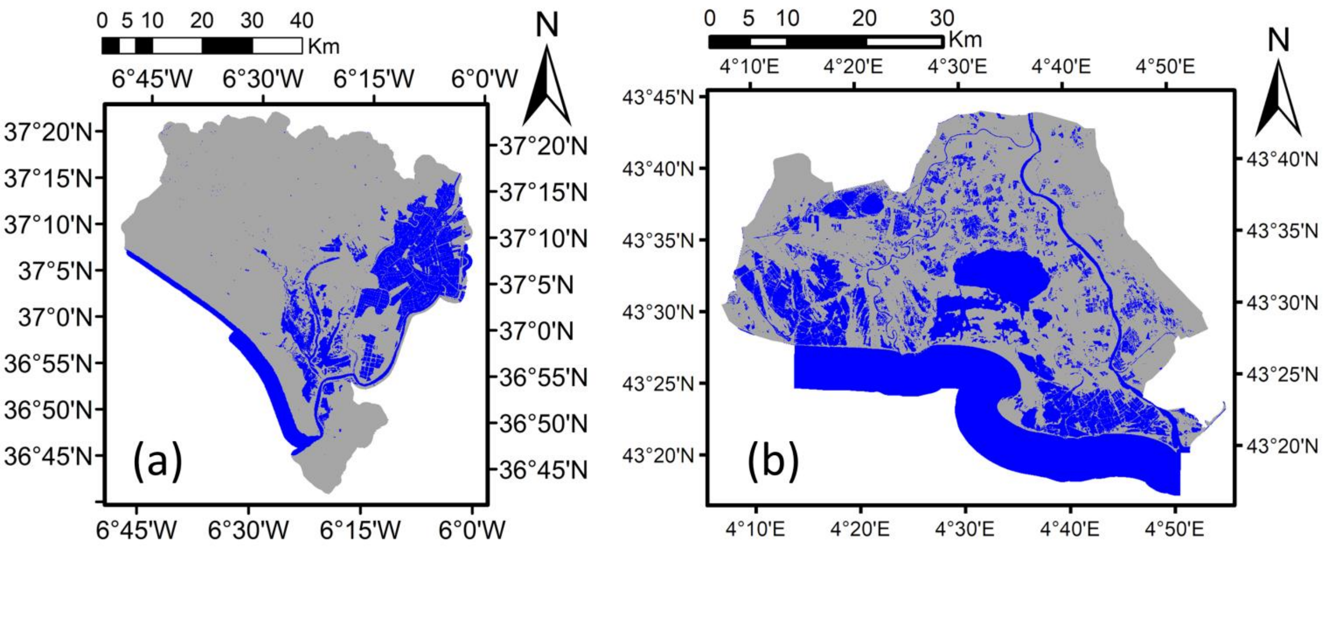
[2] Western Mediterranean Oscillation Index

and management conditions. Afterwards, we will implement these scenarios in other ES assessment models. The analysis of ES trade-offs in several scenarios will help managers to predict the state of ES and their relations in the future.

In the Negev, water management systems analogous to those of ancient dryland farmers can effectively raise the uptake of moisture in the system, while leaving biological community structure largely intact (Paz-Kagan et al., 2017). The more intensive residential development in the Negev has a positive impact of vegetation productivity in close proximity to the settlement, but a significant negative impact outside of a threshold different from the settlement (Ohana-Levi et al., 2019). Here, land use change, per se, does not negatively affect biodiversity and ecosystem integrity – rather, the affect is highly dependent on the type and intensity of land use change.

Inland Open Water and Sparse Emergent Vegetation Presence

Satellite data offer the opportunity to frequently derive the extent of inland surface water with high accuracy; hence, allowing for hydroperiod estimation based on time-series of satellite-based water masks. Within ECOPOTENTIAL, the WaterMasks module, developed by the CERTH team and integrated in the Virtual Laboratory of CNR, may provide a solution for generating water masks (see Figure 10) from radiometrically corrected Sentinel-2 data for future PAs. The methodology behind the WaterMasks module is based on the work presented in (Kordelas, Manakos, Aragonés, Díaz-Delgado, & Bustamante, 2018). The module has been validated for its high performance using numerous Sentinel-2 images for three consequent years at Doñana Biosphere Reserve wetland area. After examining cases where water covers only a very small part in a Sentinel-2 scene (i.e., <2%), it was found that the methodology was reliable for a wide range of water cover extent in a scene (i.e., >2%) and applicable in many cases even for very low water cover extent (i.e., <2%). At the present time, the transferability of the module approach for additional wetland areas, such as Camargue, is examined. Initial results indicate good performance and fine tuning possibility. Latter is currently pursued and iteratively tested in both sites with improving accuracy. A relevant paper is under submission. Regarding future use at PAs, users can rely on the high performance, if the biome and biogeographical conditions are similar or evaluate the water masks generated via the WaterMasks module before using it. These water masks may be provided as input to the Hydromap module.



Co-funded by the European Union

Figure 10: Water masks of (a) Doñana on 01.06.2017, and (b) Camargue on 12.06.2017, estimated relying on the WaterMasks module.

Within ECOPOTENTIAL, the Hydromap module was developed by the CERTH team and it was integrated into the Virtual Laboratory of CNR. This module generates the hydroperiod for a desired time period from series of satellite-based water masks falling within this period, by applying the following interpolation approach. For two dates separated by n days, the occurrence of water is compared. If a pixel is inundated on both dates, then it is assumed inundated for the whole duration of n-days. If a pixel is not inundated on both dates, then it is assumed inundated for n/2 days. The total number of days of inundation per pixel in the hydroperiod map (see Figure 11) is determined by accumulating the water masks throughout the desired time period.

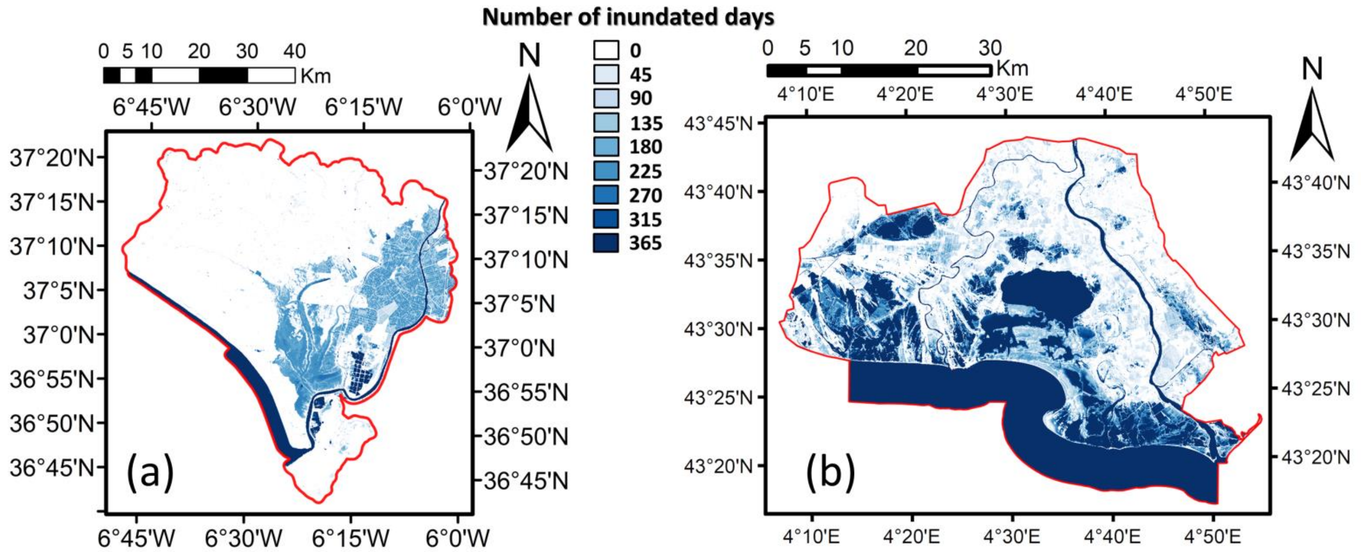


Figure 11: Hydroperiod maps of (a) Doñana from 01.09.2016 to 31.08.2017, and (b) Camargue from 01.06.2017 to 31.05.2018; estimated relying on the Hydromap module.

3.3 Policy Context

The ES concept can be applied as a framework for designing transboundary policies for protection and management of ES across borders (López-Hoffman, Varady, Flessa, & Balvanera, 2009). Although studies have shown that individuals and societies across borders use unique packages of ES, even when they share the same ecosystem (Orenstein & Groner, 2014), the concept of ES could frame cross-border negotiations over natural resources in terms of mutual interests between countries because the notion of societal interest is inherent in the concept. If conservation efforts focus on the protection of shared ecosystem services, the discussion could be transformed into one organized around protecting the mutual interests of the countries. If the interests of two countries do not naturally align, the ES concept can be used to identify innovative approaches, such as cross-border payments for ESs, to overcome differences and find common ground. In the Curonian Lagoon case, the main challenge arises from the fact that the ESs concept exists mostly as an expert opinion only in the Russian Federation, which is not an EU member state. The joint efforts are largely sectorial (e.g. joint Lithuanian-Russian fishery commission take care of the fish resources only), where clear common interest exists or ones bind by high-level international agreements like Ramsar convention. The cooperation mostly exists as bilateral efforts between administrations of protected territories across borders, which naturally align and sometimes are treated as a single entity by international authorities (e.g. Curonian Spit national park by UNESCO). In view of the present political relationship between Lithuania and the Russian Federation, when even the exchange of environmental data is a challenge, the value of EO as a tool for the cross-border ESs assessment became invaluable. According to our modelling results, the most promising direction to enhance the delivery of ESs in the Nemunas Delta and Curonian lagoon area would be jointly orchestrated efforts for the hydraulic management of small rivers entering the delta and the lagoon. This would ultimately provide a substantial positive impact on a range of ES including fishery (both commercial and recreational), tourism, flood protection and regulatory services. Following the results produced by the BN models that placed the fishery practice as the most prominent factor in sustaining fish stocks even preceding the climatic factors in a sequence of importance. Hence, the common and science-based fishery policy is necessary to maintain the stocks of pikeperch, which is the focus for both commercial and recreational fishery in both countries. Moreover, as Nemunas delta is also serving as a migratory route for fish species, the present problem of silting in some of the branches of the Nemunas river could be approached only by joint actions.

From D9.3 the following recommendations could be extracted:

1. While 1) **Climate change** and 2) **Change of Land use** cover the majority of direct drivers of change/pressures on ecosystems, it is important to consider additional categories as these two main categories are not capable of capturing all the direct drivers and pressures correctly. The additional categories proposed in this analysis include: 3) **Pollution and nutrient over-enrichment**, 4) **Population growth/ tourism & recreation,** 5) **Invasive species and/or Pest species** and 6) **Fire risk.**
2. The whole continuum ranging from the Primary driving forces *sensu* European Environment Agency (1999), to direct drivers of change should be clarified in a multidisciplinary debate. This is particularly important to better link the socio-economic, historical and political ecology disciplines to the research on PAs, which is particularly important when working on future developments in PAs and future conservation planning. Traditionally, the study of the driver **Climate change** has been efficiently linked to climate research (see IPCC) and **Change of land use** to geography, while the linkages to other disciplines (e.g. socio-economic, history and political ecology disciplines) need to be developed more strongly in the future to get better information on drivers of change in human societies that have a strong impact on PAs.
3. The subject of multiple designations for PAs and the role of different PAs and surrounding landscapes should pay particular attention to the nested organization of PA's designations and issues of spatial planning. A nested organization with multiple PA designations may have advantages for spatial planning, for example, by allowing inclusion of conservation planning in larger scale regional levels? In practice this leads to a polycentric organization, which may have an advantage in terms of power balance, while it may also suffer from inadequate cooperation among the different management structures. The latter may be exacerbated by the different historical traditions of the different PA designations (e.g. National Parks IUCN category 2 versus Regional Parks and Biosphere Reserves (often IUCN category 5). Therefore, it is recommended to facilitate exchanges and collaboration among the different PA managers in different management bodies responsible for different PA designations in an area and to provide training on governance issues (i.e. coping with multiple designations) and identifying which are the major drivers of change related to the threats experienced by the PA managers to achieve a consensus of major issues among these different management structures.
4. Standardized coherent and homogeneous frameworks for linking drivers to ecosystem changes and use of Essential Variables should be accompanied by bottom-up approaches based on the free expression (i.e. using open questions) by PA managers, which will allow checking of whether the main drivers and variables identified in the International frameworks capture all the concerns of the PA managers of threats on the ecosystems. At the moment, the major part of threats and

pressures mentioned by PA managers is not captured by drivers of Change mentioned by scientists.

5. It is essential to integrate and harmonise Drivers of Change and related threats and pressures that (can) act on/in PAs, in due consultation between PA managers and scientists, e.g. by means of a Community of Practice (CoP), in order to recognise which changes/threats/pressures can be acted on. This will be of practical use to the PA managers to select what measures can be taken to mitigate for the impacts. It has to be taken into account that the recognized Drivers and pressures can be managed or mitigated in the PAs to a strong degree (**Change of Land use, Population growth/ tourism & recreation**, (illegal) Human activities, Disturbance, Fisheries, Overexploitation), or to a lesser degree (**Pollution and nutrient overenrichment**, **Invasive species and/or Pest species, Fire risk**, Increased salinization, Landscape disturbance, Predation, Sediment dynamics changes), or some likely not at all because of their wide spatial and temporal occurrence (**Climate change**, Extreme weather).

4 Relating Environmental and Socio-Economic Descriptors, and Impacts of Drivers of Change

Concerning the monitoring of natural and human drivers of change in PA, the scientific modelling and GIS community is strongly focused on the drivers belonging to the categories **Climate change** and **Change of land use**, and this major focus is also strongly supported by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) recommendations (D 9.3). At present, it appears that this approach captures the majority of the natural and many of the important human drivers of impacts, but not all threats and pressures are captured by these two categories. It is particularly important to consider phenomena that are subject to large-scale transportation processes as these will not be captured correctly if the Change of Land use analysis does not cover the sources of the problem. Hence D9.3 recommended to explicitly consider **pollution and nutrient-over enrichment** (the pollutants and nutrients can be transported over long scales by surface and ground-water flows and through air) and **Population growth/ tourism and recreation**. For the latter it is important to perform an assessment of the links between the demography in the major population centers and the flow of ESs from the PAs to these areas and how this is predicted to change in the future. Hence detailed analyses are needed in large areas that include PAs of the transfer of ESs from ES-provisioning hotspots to ES consumption areas (Palomo, Martín-López, Potschin, Haines-Young, & Montes, 2013). Such an analysis may also be used to implement novel PAs at ES-provisioning hotspots. Monitoring the number of visitors and the touristic recreational activities is also of increasing importance for the PA management. **Fire risk** and **Invasive species and or pest species** are important, albeit difficult issues as they may represent multiple facets. Some ecosystems are naturally adapted to fire and/or pest species, by showing recovery after the perturbations they cause, which can even contribute to increasing biodiversity in these systems (e.g., see intermediate disturbance hypothesis). Unfortunately, these natural perturbations can interact with other factors of change and synergistically cause great damage. For example in Réunion island, fires interact with alien species and changing land use to synergistically create a great threat to the endemic flora and fauna, as the alien species are more competitive in recolonising the burnt areas. At present it is difficult to predict which natural factors will interact with human drivers, and scientists and PA managers need to be alert in the future.

An important part of the human impacts on PA is related to the administrative and governance issues of the PA themselves linked to spatial planning issues, that have been analysed in D9.3. During a historical process, PA designations have been implemented at international, European, national, regional and local scales (D 9.3). This has resulted in overlapping designations and often in a nested structure whereby parts of the territory with stricter regulations (e.g., national parks IUCN category II, strict nature reserves IUCN category 1a and habitat species management areas IUCN category IV) are embedded within larger areas that can be considered as large socioecosystems (IUCN categories V and VI). While overlapping designations can be cumbersome and create difficulties for management in some cases, a nested structure with the strict reserves nested within overarching larger PAs can be very useful. Such a nested organisation may correspond to the social-ecological approach for PA in the Anthropocene (Paloma et al., 2014). Particularly, the larger UNESCO Biosphere reserves (MAB) and Unesco World Heritage Sites have been instrumental to overcome administrative difficulties, i.e. by creating transboundary PAs both at international level as e.g., Danube delta (Romania, Ukrania) and Curonion spit (Lithuania, Russia) or within a country across administrative boundaries as e.g. Camargue (Occitanie and PACA regions). These designations have also strongly contributed to implement more modern approaches to PA management (e.g. 1- pursuing sustainable development goals in larger areas allowing local populations to benefit from the ESs of the PAs, 2-reinforce environmental protection measures in larger areas creating large buffer zones and ecological corridors among , 4- strongly linking the natural and cultural heritages as in Réunion island, Curonian spit and 3- combine marine PA (MPA) with coastal wetlands and terrestrial PA across the aquatic continuum on the coast as e.g. in Camargue. It is expected that, because of their large-scale and the modern and evolving vision on the links between humans and nature, these UNESCO structures can play an important role in the future for adapting PAs to future conditions. Hence, the large territory they represent will allow to adapt the localisation of the reserves with stricter reservations within them to the changes induced within their land and seascapes by climate change (on the coast particularly sea level rise).

5 Guidelines to Come to Future PAs

5.1 Organising and Optimising Current and Future PAs

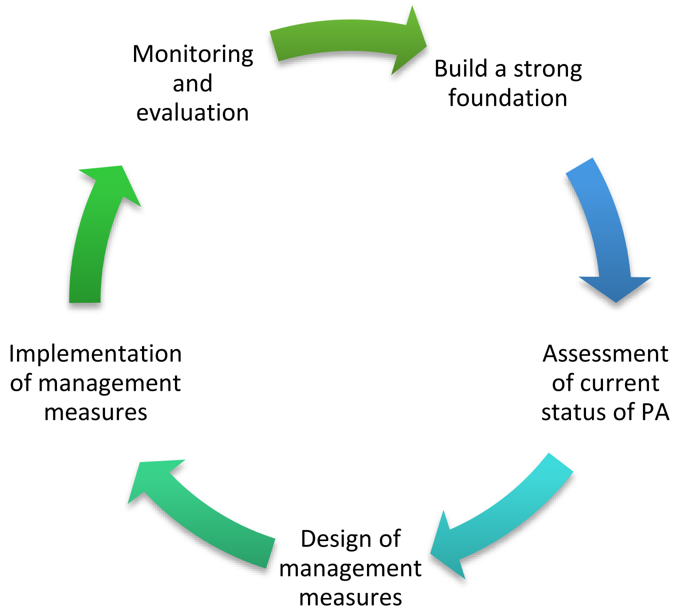


Figure 12: Roadmap

Natural habitats are facing many challenges such as invasive species, poaching, exploitation of resources, developments and most recently, climate change. In recent years, more and more PAs were established to conserve these natural habitats. As identified in D9.1-9.3, climate change is one of the major threats and drivers on the ecosystems and therefore the PAs. However, these PAs could provide "natural solutions" to climate change and its associated effects. Within PAs, the ecosystems are relatively intact and therefore contribute to benefits and effective solutions across many sectors of human society. Not only human society benefits from these intact ecosystems, but they allow many species to adapt to a rapidly changing climate by providing refugial habitat. Climate change will ultimately challenge the way PAs are currently managed. Some changes can already be seen due to a rapidly changing climate such as rising sea level and temperatures, more frequent and more prolonged droughts, increased acidification, changes in the intensity and timing of storms and seasons, as well as large-scale melting of snow and ice. In response to that, some flora and fauna are already shifting. Especially in polar, alpine, coral and forest ecosystems, entire ecological regions are quickly changing. These climate-driven changes often interact with many other environmental pressures like habitat fragmentation and loss, pollution, the spread of invasive species, or overharvest. The impact of many of these pressures are cumulative (IUCN, 2016).

Managing cumulative effects and impacts of climate change and other pressures on PAs is a big challenge. PA managers play a vital role in increasing the awareness of these issues and therefore achieve an effective societal response. Climate change response by PA managers can be divided into two categories: i. mitigation[3], and ii. adaptation[4]. PA managers must do everything in their power to enhance the ability of the natural system in order to capture and store carbon as well as to reduce emissions from PA operations. Mitigation and adaptation are both important and can often not be separated entirely when managing PAs; however, the focus of these guidelines is on adaptation.

As mentioned in the previous paragraphs, PA managers have to tackle climate change by two different approaches: mitigation and adaptation. In the context of PA management, *mitigation* usually means taking certain actions to reduce negative impacts or to remove a threat especially caused by humans to protected ecosystems and resources. In terms of climate change, mitigation means to take direct actions that reduce greenhouse gas (GHG) emissions from operators and/or to increase the capacity of PA ecosystems to remove these gases from the atmosphere and then store them in soils and biomass. These actions include

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[3] Actions that reduce the amount of carbon dioxide and other heat-trapping gases in the atmosphere
[4] An adjustment by human or natural systems to the changing climate

but are not limited to maintaining peatlands and other carbon-dense communities as well as forest integrity and managing fires (Campbell, Miles, Lysenko, Hughes, & Gibbs, 2008). On the other hand, *adaptation* can be seen as adjusting to change by humans or natural systems. There are many different definitions available on this term. For the purpose of this deliverable and the overall of ECOPOTENTIAL adaptation refers to a process that seeks to comprehend the vulnerability of biological systems and how these systems can be supported to minimise negative impacts and enhance the ecosystems' products and services.

Recently, PAs have become an increasingly important component of many national and international climate change adaptation strategies, and also the need for adaptation within PAs themselves has become evident also in pan-European assessments within the ECOPOTENTIAL project (D8.4, Chapter 3.1). The guidelines presented in this deliverable focus on essential elements for adaptation planning and implementation. Additionally, information is given that PA managers can use and apply straight away.

Step 1: Build a strong foundation which includes collecting information and available knowledge on the specific sites, communicating with stakeholders and PA managers, developing a long-term planning, determining milestones.

Step 2-A: Assessment of the current status of PA using a qualitative and quantitative assessment is to be done to determine which species, ecosystem and other values are most vulnerable to climate change/changing conditions.

Step 2-B: Assessment of the ecological embedding beyond the individual PA by the means of a qualitative and quantitative assessment, including (1) the characteristics of neighbouring PAs and connectivity the relevant neighbouring PAs, (2) the conservation value of the individual PA within a large-scale perspective.

Step 3: Design of management measures is based on the assessment done in the previous step, together with stakeholders and PA managers.

Step 4: Implementation of management measures is where the PA takes action based on all of the previous analysis and design.

Step 5: Monitoring, evaluation, and adjustment the PA managers and staff have to measure their indicators of failure and success and then use this information to evaluate and recalibrate their initial decisions.

Step 1: Build a strong foundation

A key component of this first step is to communicate with stakeholders and PA managers. The discussion around climate change should be brought to their attention and included in their day-to-day operations. Sharing ideas and experiences are at the core. Collaboration, leadership, and open-mindedness are the key to help PA managers and staff and other organisations to prepare for a rapidly changing and novel future condition.

PA managers and their staff actively need to seek information from various sources such as internet sites, databases, reports, and toolkits to build capacity and be up to date with the latest progress and status on how PA should be managed taking climate change into account. This knowledge should be collected and added to a repository/library, so the newly obtained information is available to other stakeholders and PA managers. On the other hand, many conservation groups, scientists, partners, as well as traditional knowledge from locals can help PA managers to understand climate change and what impacts it could have on their area. The communication between these groups should be sustained and used as a tool to share knowledge and skills. Additional skills in ecosystem restoration, vulnerability assessment, monitoring of change, climate change interpretation, and connectivity conservation, among other important skills can be developed through online training courses. The obtained skills will support decision makers and those who interact with the public.

PA managers along with stakeholders need to develop a long-term planning for their PA. Questions like *what are the key management aims, what are the key threats to the PA, and what are the most important biodiversity values of the PA, and conservation targets requiring protection* should be answered by the PA managers. For a sample questionnaire see Appendix 1.

Step 2-A: Assessment of the current status of PA

The step 2-A goes deeper into the actual assessment of the present status of the PA. Different kinds of measurements are taken (i.e. in-situ, remote sensing, models) (Figure 13). Not only an ecological/environmental status is determined, but rather the PA and its management as a whole (Dudley, et al., 2005):

- Gap analysis for completing an ecologically representative protected areas system;
- Status of up-to-date management plans;
- Major threats to protected areas;
- Options for restoration;
- Economic and socio-cultural impacts on indigenous and local communities;
- Policies concerning governance and new governance models;
- National and legislative policy frameworks;
- Hidden and non-hidden economic and social benefits of protected areas;
- Capacity needs;
- Review of existing knowledge and experience;
- National-level financial analysis of needs and gaps;
- Needs for specific tools for protected area planning and management;
- Scientific and technical cooperation needs;
- Protected area standards (e.g. planning, management, etc.) currently in use.

Figure 13: Various measuring methods for PAs in Sierra Nevada (left), the Dutch Wadden Sea (middle), and Doñana (right)

Step 2-B: Assessment of the ecological embedding beyond the individual PA

The step 2-B goes beyond the area of the individual PA and incorporates its conservation value from a larger-scale perspective because the performance of conservation depends strongly also on the large-scale configuration in space.

The **connectivity to relevant neighbouring PAs** is one important focus to ensure the genetic exchange and a long-term perspective of the population within and beyond the PA.

All PAs have a strong degree of uniqueness, but to what respect they are exactly valuable in a large-scale conservation strategy remains blurred. Understanding the **type of large-scale conservation value** of individual PAs helps to understand the large-scale conservation value, and what role an individual PA has within this larger context. In D8.2 Chapter 2.3, S. Hoffmann and C. Beierkuhnlein suggest assessing different conservation values, namely inventory diversity, differentiation diversity, species rarity and the species-area relationship, to guide a large-scale strategy of conservation across PAs.

Step 3: Design of management measures

The actions and steps taken during the design process of the management measure will be useful to every subsequent step of the PAs' development and evolution. By implementing adaptive management and systematic conservation strategies, periodic evaluation measures may suggest an amendment to the management plan or even a redesign of the site (e.g. expansion of boundaries). As such, it is critical to dedicate some time in the beginning to create a thoughtful design and accompanying process customised to addressing the needs of a unique site. The most experienced managers working on a large scale agree that a periodic re-evaluation and a redesign of their site will be required. Measures beyond the boundaries of the individual PA might be essential to reflect for the management plan, for instance, measures to ensure, enhance or (re-)establish ecosystem connectivity to relevant neighbouring PAs.

Step 4: Implementation of management measures

After all actions and strategies have been determined and agreed on, the actual implementation plan needs to be executed. As with all steps in the roadmap cycle, implementing any action is not a one-time decision but rather a continuous process. For example, some actions need to be implemented straight away, whereas others can address long-term goals which will take more time and/or resources to put in place. When dealing with climate change implementing decisions and some aspects of planning can be particularly challenging. It usually takes a long time to detect climate changes which can make it difficult to get the required attention and commitment needed for effective management. PA often have to deal with short-term issues that it may be very difficult to justify activities that support long-term planning (i.e. 2-5 years). Furthermore, predicting plausible climate futures and effects is another challenge. Therefore, it is important to adapt to these changes, keeping the management structure flexible and adaptive.

Step 5: Monitoring, evaluation, and adjustment

The final step of the roadmap is to monitor, evaluate and adjust, if necessary, the status of the PA. These are all essential elements of the roadmap. The "learning by doing" approach is vital when climate change affects the management decisions of PAs. In order to adapt to climate change, certain adaptation-specific indicators in existing monitoring practices.

Routine monitoring, evaluation and reporting are required for all PAs in order to create a good foundation for management strategies and frameworks. When dealing with climate change these need to be adapted and incorporated into existing monitoring strategies. In case there are no frameworks in place, monitoring of climate adaptations should be included from the beginning. When monitoring and evaluation plans which are designed to contribute to learning and which also facilitate the exploration of emerging issues (e.g. climate change) will likely enhance the overall understanding and knowledge of the PA and improve adaptation practices.

One challenge during this step is to consider and monitor the PA over both short and long-term timeframes. A lot of climate adaptation activities can take decades before any outcomes are known. Therefore, keeping the long-term change in mind is vital even when only looking for short-term indicators to adjust or improve the present approach. Additionally, other indicators such as management effectiveness, resource stewardship, operations sustainability, mitigation, restoration, and ecosystem services must be considered when monitoring ecosystem change. Even when strategies and goals do not change, sometimes changes in monitoring may be necessary in order to address shifts in species ranges, phenology, and community structure or composition.

5.2 Evidence-based Management

In a series of WP9 surveys during 2017 along a set of internationally recognised PAs, including ecosystems in three domains of crucial interest to Europe, i.e. mountainous, semi-arid, and transitional water systems, the factors on which PA managers can manage the quality of the ecosystems and its biodiversity were assessed (Deliverables 9.1, 9.2).

The PAs spanned all of Europe and beyond, are characterized by widely different environmental conditions, and play a central role for conservation and management strategies in rapidly changing environments. The type of protection of the PAs includes primarily UNESCO World Heritage Sites and Biosphere Reserves, National Parks, Natura 2000 sites, and LTER sites (Table 5).

Table 5 PAs surveyed in the EcoPotential WP9 studies including country and Protection status. Surveys S1 to S4 presented in Hummel et al. 2018 (deliverable 9.1), Survey S5 presented in Hummel et al. 2019 (deliverable 9.2).

	Country	Scientists			Managers			Protection status
		2015	2018	2018	2015	2017	2018	
		S1	S4	S5	S2	S3	S5	
Camargue	F	+			+	+		UBR, N2k
Curonian Lagoon	LT	+			+	+	+	NP, N2k, UWH
Danube Delta	RO	+	+	+		+		UBR, N2k, UWH
Doñana	E	+	+	+	+	+		NP, N2k, UBR, UWH
Eastern Scheldt*	NL	+	+	+		+		NP, N2k

Nemunas Delta	LT				+	+		N2k
Palavasiens	F					+		N2k
Wadden Sea	NL	+	+	+	+	+	+	NP, N2k, UBR, UWH
Western Scheldt*	NL	+		+				N2k
Samaria	GR	+	+	+	+	+		NP, N2k, UBR
Har Ha Negev	Isr					+		NP, UWH
Montado	P		+	+		+		N2k
Kruger	SA		+	+		+		NP, UBR
Appia Antica	I		+	+		+		RP**
Bavarian Forest	D					+		NP, N2k
Castelli Romani	I		+			+		N2k
Gran Paradiso	I	+			+	+	+	NP, N2k
Hardangervidda	N	+			+	+		NP
High Tatra	PL	+			+			NP, N2k, UBR
La Palma	E				+	+	+	NP, N2k, UBR
Kalkalpen	A	+	+	+	+	+	+	NP, N2k, UWH
Lake Ohrid	Mac		+	+		+		NP, N2k, UWH
Lake Prespa	Mac		+			+	+	SNR***
Peneda-Gerês	P	+		+	+	+		NP, N2k, UBR
Pieniny NP	SK		+	+		+	+	NP, N2k
Reunion	F					+		NP, UWH
Sierra Nevada	E	+	+			+		NP, N2k, UBR
Swiss NP	CH		+	+	+	+		NP, UBR

S1 to S5 = ECOPOTENTIAL WP9 Surveys nr 1 to 5; NP= National Park, UBR= UNESCO Biosphere Reserve, N2k= Natura 2000 site, UWH= UNESCO World Heritage; *The Western and Eastern Scheldt though separate water bodies are both part of the area called Dutch Delta; **Appia Antica is a Regional Park (RP); *** Lake Prespa is in Greece and Albania a National Park, in Macedonia a Strict Nature Reserve (SNR).

The selected variables characterise the EF, the ES, and the pressures (Threats) acting on the PAs. The underlying measurements include a blend of Earth Observation data, both remote sensing and in situ field measurements.

After a long (3 years) and strong consultation process with 120 PA managers, rangers and scientists of 26 PAs) a set of commonly agreed, strongly harmonised and standardised variables and indicators has been reached for the most important EF, ES, and Threats. Only those factors were taken into consideration that complied with the demand to be applicable and useful in more than 50 % of the surveyed PAs and having all over a perceived importance as an EV of 4 or more at a scale of 5.

This resulted in 30 EVs that due to the relatively high number of PAs investigated (26), the many practitioners and scientists queried (120), the standardised methods used, the consistency of the outcomes, the applicability in all domains (Transitional Waters, Semi-Arid, and Mountainous areas), and the strong consensus among PA managers and scientists can evidently reflect the status and development of PAs. These EVs are thus highly representative and may form the preferred basis for further studies and comparisons on the current and future status and changes in the quality and requirements of PAs.

5.3 Toolbox Description and Application to Future PAs

The development of EVs and the increasing availability of Earth Observation provide a growing amount of data that can inform the management of current and future PAs. However, in order to support decisions, this data needs to be translated into information that is useful and credible for local actors and decision-makers, by connecting it to their knowledge about the socio-ecological systems they manage (Voinov, et al., 2016). In ECOPOTENTIAL, efforts have been made to make EO data more accessible to PA managers, e.g. through the Virtual Laboratory platform. At the same time, methods have been developed to create a common understanding of the managed systems between scientists and managers (e.g. through Mind-Mapping) and to address issues relevant to managers through modelling. The different approaches, methodologies and tools are summarised in this chapter and an overview of what has been done in the ECOPOTENTIAL framework can be found below.

Table 6: Tools, services, and methodologies developed in the framework of ECOPOTENTIAL

Deliverable	Title	Tools, services, and methodologies
D6.3	Online monitoring data services for ecosystem indicators	Varying per model and module implementation
D7.3	Ecosystem service mapping with Bayesian Networks – a manual	Bayesian Networks
D7.4	Final Report on Prototype Products	Highlighted results of prototype products and various types of Bayesian Networks applied to PAs and management strategies

In T6.4, a series of online monitoring data services (documented in the D6.3) were developed and deployed to the Virtual Laboratory Platform (https://vlab.geodab.eu/) in order to address the needs of the users' community for ecosystem indicators to facilitate decision-making. These easy-to-initiate-and-use operational services are based either on models (applied in T6.2 and T6.3), able to assimilate EO data, or on workflows (developed in WP4) for the derivation of map and land cover feature products from EO data. Latter are intended for use (i) either as stand-alone services or (ii) as workflow components to generate input for models. Each service was related or applied to serve a unique ECOPOTENTIAL storyline and applied to one or more ECOPOTENTIAL PAs, with the view to be used for future PAs as an example or applicable service as well.

Data Services Based on Models

The **INSTAR** service, developed by the Universidad de Granada, aims to aid environmental decision making in pine plantations affected by *Thaumetopoea pityocampa* forest pest. More specifically, it provides a deeper understanding of its population dynamics and forecasts the probability of occurrence and intensity of the pest outbreaks at a landscape scale, given various climate and land use scenarios. As an output, it generates a table where state variables are described, covering the number of pine processionary moths, at each stage for each day of the simulation, as well as the percentage of infected pines and average biomass of the pines. A demo execution with defined datasets is provided to the VLAB, so as the potential user becomes familiar with the inputs required and generated outputs.

Applied to: **Sierra Nevada (Spain)**

Applicability to future PAs: The service may be applied to the same site in a different period and/or to other sites, where pine plantations exist, given that input datasets are available, and parameterization and calibration are performed.

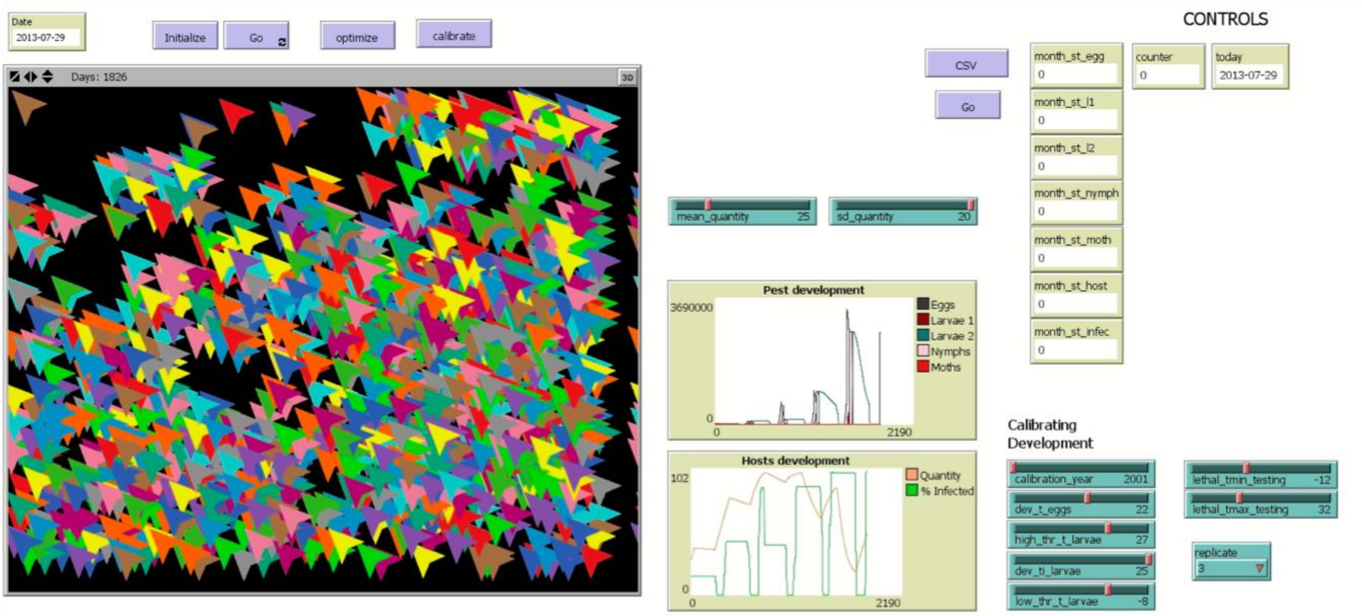

Figure 14: INSTAR execution screen in a simulation of the Thaumetopoea pityocampa forest pest cycle

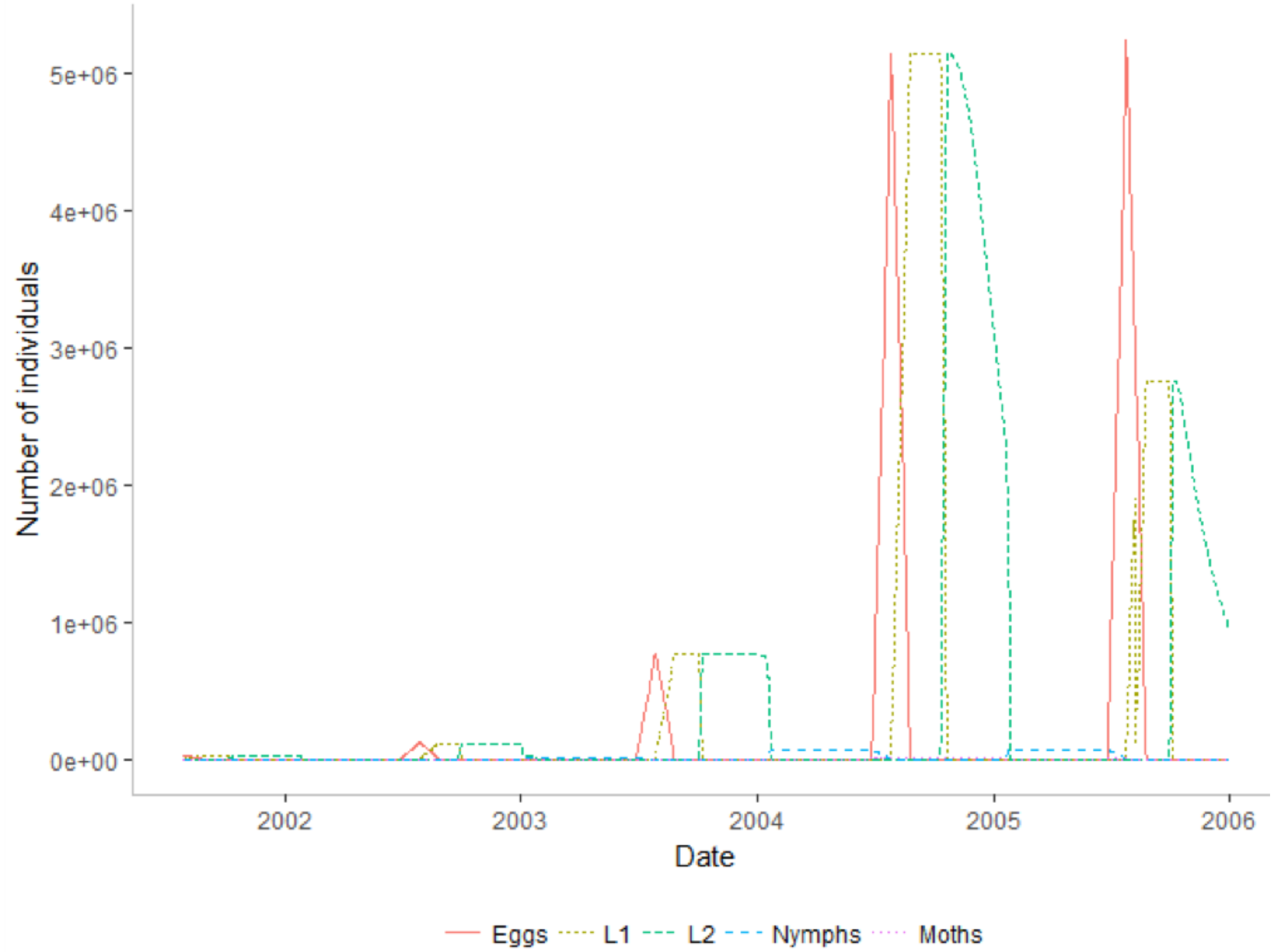

Figure 15: An example INSTAR´s results regarding the different phases of Thaumetopoea pityocampa over a time series

The **WiMMED** service (developed by Universidad de Córdoba) is based on the hydrological WiMMed model, which simulates the whole water cycle. The service provided to the VLAB has the objective to generate maps for two ecosystem services related to hydrology, i.e. the aquifer recharge, which is water provisioning related ecosystem service and the surface runoff, which is a water regulation related service. A demo execution for the whole Sierra Nevada area is provided to the VLAB for the period 2007-2008.

Applied to: **Sierra Nevada (Spain)**

Applicability to future PAs: The assessment of the different ecosystem services related to water and sediment relies on hydrological modelling, since there is no data to evaluate some of these services in the past, nor even in the future. Sierra Nevada is an alpine mountain range that reaches 3500 m asl at a latitude of 37ºN. Its hydrology is dominated by the snow-related processes modified by a Mediterranean climate. This causes a high heterogeneity in all physical properties of the basin due to the topographical influence. To handle this variability from a hydrological point of view, we simulate water and sediment cycles with a distributed and physically-based model called WiMMed (www.ugr.es/local/herrero/wimmed) capable of dealing, to a certain extent, with this variability. So, WiMMED can be applied to assess ecosystem services related to water and sediment in others PAs in Mediterranean mountains environments. Furthermore, it can be used to simulate ecosystem services supply in the future in Sierra Nevada or other Mediterranean mountains protected areas, based on land-use and climate scenarios.

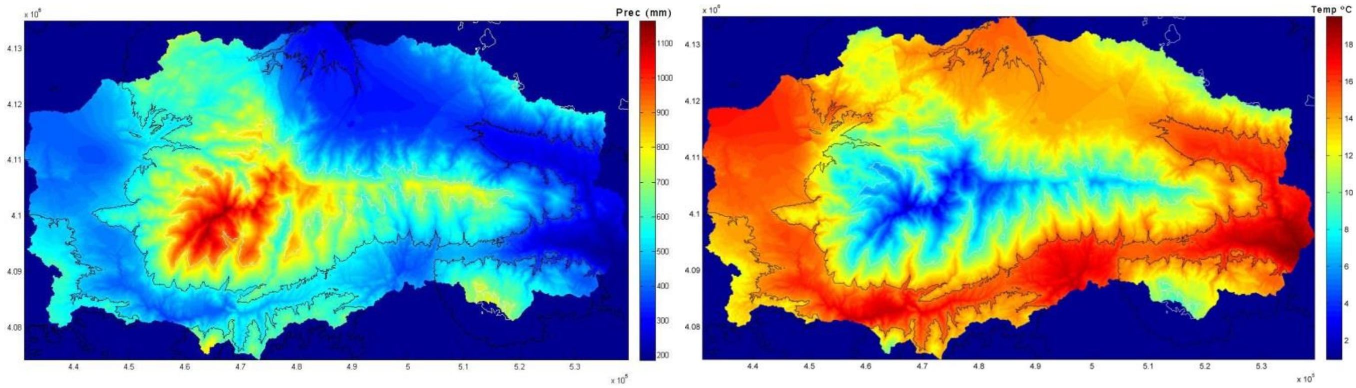

Figure 16: Mean annual precipitation (top) and temperature (bottom) for Sierra Nevada and surrounding area at 90x90 m resolution. Meteorological interpolation was made using WiMMed with all the available data from weather stations for 2000 to 2015. They were prod

The **MountainMetapop** service (developed by the Ecole Polytechnique Federale de Lausanne) provides insight into a potential user about the impact of landscape topography on species distribution. In detail, this service simulates the average presence of a species with certain traits in a landscape, based on spatial patch occupancy model (SPOM). The model consists of local colonization and extinction events that randomly occur in space and time. The probability of occurrence of these events on a particular grid cell depends on the global species occupancy, on the particular extinction and colonization rates, on the species dispersion coefficient, and on the fitness of the species to the local landscape features. In this case the fitness is characterized by two parameters: the optimal elevation for the species and the niche width. A demo case for the Gran Paradiso National Park is implemented in the VLab.

Applied to: **Gran Paradiso National Park (Italy)**

Applicability to future PAs: the model can be applied to different PAs by changing the input file related to the topography. Long time series of species presence/absence data and more complex fitness functions describing the species habitat are required to calibrate the model to real occupancy patterns and this calibration process is not included in this VLab service.

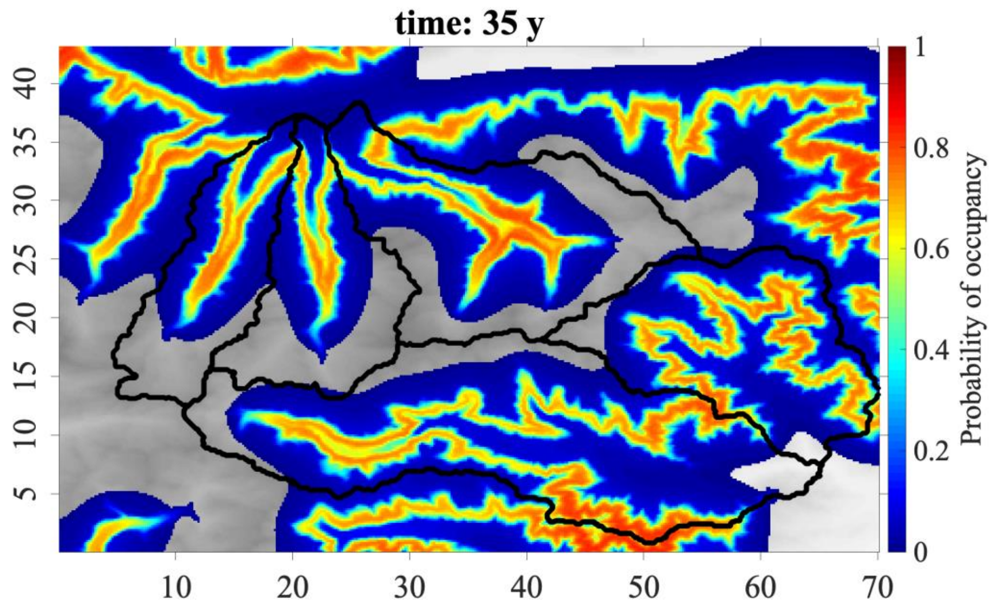

Figure 17 Example of occupancy for a virtual species in the Gran Paradiso National Park after a 35 years-long simulation

Another service, also related to species distribution modelling, is the **EO-SDM** (from Helmholtz Centre for Environmental Research), standing for 'Ensemble modelling of species distributions using Earth observation data'. This service is based on a modelling framework that makes use of various established species' distribution modelling algorithms and tests their applicability in combination with remote sensing data. Generated outputs include maps of species-specific habitat suitability and model uncertainty. A demo execution is provided to the VLAB applied for rove beetles in the specific PA within the periods 2006 and 2007.

<u>Applied to:</u> **Gran Paradiso National Park (Italy)**

<u>Applicability to future PAs:</u> The service may in principle be applied for other taxa in the GPNP provided they have similar habitat requirements and data about species occurrences are available. An expert may also use the code to establish species distribution models in other study areas as well. However, the codes from the VLAB are not accessible at the moment and replicating this tool to another potential PA needs to be further investigated.

IRIS-SDM (standing for 'Infrastructure for Running, Inspecting and Summarizing Species Distribution Models') was developed by the ICETA / InBIO - Instituto de Ciências, Tecnologias e Agroambiente team with the objective to predict spatial distribution of suitable habitat conditions for narrowly distributed species based on satellite-derived Ecosystem Functional Attributes (EFA). IRIS-SDM models the species distribution relying on the biomod2 package for multi-algorithm ensemble forecasting and a set of predictors from satellite-derived EFA. Three components are considered, related to carbon gains (Enhanced Vegetation Index-EVI), sensible heat (Land Surface Temperature-LST) and radiative balance (albedo). Generated outputs include predictions for the current distribution of the target species and a summary of model performances for partial and ensemble models as well as an importance ranking for each predictor variable. A demo execution applied for the *Iris boissieri* species is provided to the VLAB.

Applied to: **Peneda-Gerês National Park (Portugal)**

Applicability to future PAs: Despite the specificities of modelling the demo species (*I. boissieri*), with its particular distribution range and ecological requirements, the service is considered capable of providing relevant outputs for other target species, different settings and environmental conditions.

Last model transformed to an online data service for the VLAB is the **COINS** model, standing for the COntrol of INvasive Species. This service was delivered by the Consiglio Nazionale delle Ricerche (CNR-IIA team), and implements a modelling approach for the optimal spatiotemporal control of species in natural protected areas of high conservation value, by searching for optimal effort allocation, which minimizes invasive species density in time & space. A demo execution is applied for the *Ailanthus altissima* plant species present in Murgia Alta PA.

Applied to: **Murgia Alta (Italy)**

Applicability to future PAs: There are no limitations in the transferability of the service to different sites and/or different dates provided that input datasets are available. Further validation procedure is ongoing.

Data Services Based on Workflows

As far as the online data services based on workflows (rather than models) are concerned, the Centre for Research and Technology Hellas (CERTH) developed and uploaded various services to the VLAB.

'WaterMasks - Inland free water surface derivation from Sentinel-2 satellite imagery' integrates an unsupervised local thresholding approach to estimate water extent of an area relying on a single Sentinel-2 radiometrically corrected image. A pre-operational data service **(SpeckleRemoval),** which may be supportive to the WaterMasks (once this integrates Sentinel-1 datasets in the future), since it suppresses speckle in the SAR Sentinel-1 product by using guided image filtering, was also delivered.

Applied to: **Doñana (Spain), Camargue (France)**

Applicability to future PAs: The **WaterMasks** module could be used by future PAs managers by providing input satisfying the following conditions: (i) per date provide six raster bands of Sentinel-2 (Band 2 - Blue, Band 3 - Green, Band 4 - Red, Band 5 - Red Edge Vegetation, Band 7 - Infrared Edge Vegetation, Band 11 - SWIR) inside a folder named after the date, (ii) rasters within a folder should have the same extent and be valid GeoTIFF files (only .tif and .tiff files are supported).

The output comprises of: (i) the WaterMask(s) in GeoTIFF format with distinct values for flooded and dry areas (pixel value '1' for flooded and '0' for dry areas), containing in their filename the date they refer to, (ii) a text file populated with possible critical errors about the input and general information on the configuration used, and (iii) excel files with information for each folder's rasters attributes.

In order to execute the WaterMasks module and find instructions for its execution in the Virtual Laboratory the following steps should be followed: 1. Follow: https://vlab.geodab.eu/, 2. Select "Workflows" tab to show the list of workflows, 3. Select: "Inland free water surface derivation from Sentinel-2 satellite imagery (WaterMasks)" workflow.

Recently, a methodology was published fusing Sentinel-2 based water masks and a time series of Sentinel-1 data for generating water masks (Manakos, Kordelas, & Marini, 2019). The evaluation results indicated that a water mask can be generated for a target Sentinel-1 image with high accuracy, when the furthest mean day difference between the date of the target S1 image and the dates of the Sentinel-2 water masks is below 30 days. Therefore, this methodology could be taken into consideration by future PAs to overcome the difficulty of estimating water masks directly from Sentinel-2 maps during extended periods of cloud coverage, by exploiting efficiently Sentinel-1 data.

'HydroMap - Hydroperiod Estimation' generates a hydroperiod map from a series of water masks falling within the time period between the starting and the ending date of hydroperiod.

Applied to: **Doñana (Spain), Camargue (France)**

Applicability to future PAs: Hydromap module could be used by future PAs managers by providing input satisfying the following conditions: (i) water masks should be valid GeoTIFF files (only .tif and .tiff files are supported), (ii) all water masks should have the same extent and the same pixel size, (iii) each water mask file should be named by the actual date that it depicts, i.e. YYYY_MM_DD (e.g. 2018_03_29.tif), (iv) define within a text file hydroperiod start and end dates, and the values corresponding to inundated and non-inundated pixels within water masks (example values: for flooded "1", for dry "0". Other values are accepted as well, provided that they are integer numbers in the range of 0 to 254).

The output comprises of: (i) the hydroperiod map in GeoTIFF format with the same extent and the same pixel size to the input water masks, (ii) a text file containing possible critical errors about the input and general information on configuration used, and (iii) an excel file with information for the water masks provided.

In order to execute the Hydromap module and find instructions for its execution in the Virtual Laboratory the following steps should be followed: 1. Follow: https://vlab.geodab.eu/, 2. Select "Workflows" tab to show the list of workflows, 3. Select: "Hydroperiod Estimation (Hydromap)" workflow.

'PhenologyMetrics - Estimation of phenology metrics' generates phenology related layers (i.e. the day of the growth period, at which the greenup takes place, the day of the growth period with the highest NDVI value and the day of the growth period, at which senescence takes place) relying on NDVI time series covering a vegetation growth period.

Applied to: **Doñana (Spain)**

Applicability to future PAs: PhenologyMetrics module could be used by future PAs managers by providing input satisfying the following conditions: (i) define the starting and ending date of the vegetation growth period, (ii) provide time series of cloud free normalized difference vegetation index (NDVI) maps in GeoTiff format (only .tif and .tiff files are supported), which should have the same extent and the same pixel size, (iii) provide a text file that contains a list of dates and the filenames of the corresponding NDVI maps.

The output comprises of: (i) a raster file in GeoTIFF format consisting of multiple layers. For each one of the detected NDVI peaks, 3 consecutive layers are recorded sequentially in the raster file, i.e. for the first NDVI peak the first 3 layers, for the next NDVI peak the next 3 layers, and so on. Pixel values denote the distance in days from a user-defined starting date. The three consecutive layers represent: a) Day at which greenup takes place; b) Day at which senescence takes place; c) Day with highest NDVI value. Finally, there is one last layer that denotes per pixel (i.e. pixel value) the total number of the phenological cycles that have been detected within the set date range, (ii) an excel file with information about the input rasters and their compliance to the specifications.

In order to execute the PhenologyMetrics module and find instructions for its execution in the Virtual Laboratory the following steps should be followed: 1. Follow: https://vlab.geodab.eu/, 2. Select "Workflows" tab to show the list of workflows, 3. Select: "Estimation of phenology metrics (PhenologyMetrics)" workflow.

'PhenologyChanges - BFAST detection of changes in NDVI approximated phenological cycles' registers the abrupt trend changes/ breaks in the vegetation phenology cycles throughout numerous annual data series.

Applied to: **Doñana (Spain)**

Applicability to future PAs: PhenologyChanges module could be used by future PAs managers by providing input satisfying the following conditions: (i) provide time series of cloud-free normalized difference vegetation index (NDVI) maps covering a wide range of years, which should be in GeoTiff format (only .tif and .tiff files are supported) and have the same extent and the same pixel size, (ii) provide a text file that contains a list of dates and the filenames of the corresponding NDVI maps.

The output comprises of: (i) a raster file in GeoTIFF format containing for each pixel the single date of the most pronounced abrupt change, (ii) a raster file in GeoTIFF format containing for each pixel the number of changes that occurred during the given years' range, and (iii) an excel file with information about the input rasters and their compliance to specifications.

In order to execute the PhenologyChanges module and find instructions for its execution in the Virtual Laboratory the following steps should be followed: 1. Follow: https://vlab.geodab.eu/, 2. Select "Workflows" tab to show the list of workflows, 3. Select: "BFAST detection of changes in NDVI approximated phenological cycles (PhenologyChanges)" workflow.

'LandMetrics - Landscape fragmentation measures calculation' is a data service calculates a number of landscape measures used as indicators of fragmentation and/or connectivity of land cover or habitat classes in a selected study area.

Applied to: **Sierra Nevada (Spain), Samaria (Greece), Montado (Portugal), Lake Prespa (Macedonia), La Palma (Spain), Curonian Lagoon (Lithuania)**

Applicability to future PAs: LandMetrics module could be used by future PAs managers by providing input satisfying the following conditions: (i) a raster file in GeoTiff format that represents a land cover map or a habitat class map, ii) optionally, a raster in GeoTiff format corresponding to the segmentation map of the above image, which contains objects of pixels belonging to the same class (if not provided it is calculated by the algorithm.), (iii) a text file including the definitions of the images' filenames to be used and the core configuration settings (i.e. cell size and step).

The output comprises of: (i) a raster file in GeoTiff format for each calculated indicator, where the name of the measure is contained in each filename, (ii) an excel file containing the values of the indicators for each object. The file contains also the object ID of the respective object and the class ID where this object belongs to.

In order to execute the LandMetrics module and find instructions for its execution in the Virtual Laboratory the following steps should be followed: 1. Follow: https://vlab.geodab.eu/, 2. Select "Workflows" tab to show the list of workflows, 3. Select: "Landscape fragmentation measures calculation (LandMetrics)" workflow.

Finally, another data service was delivered by the Agencia Estatal Consejo Superior de Investigaciones Cientifica. It is called **'LAST-EBD Flood mask, Water Turbidity and NDVI'**, and generates the series of thematic rasters (i.e. NDVI, water turbidity, and flood mask) utilising a Landsat scene. Aforementioned rasters are generated, following the generation of a normalised image based on pseudo-invariant areas. These products are considered supportive to the users' community, and especially the Protected Areas' managers, who need to be facilitated by advanced EO based tools and knowledge for improved decision-making.

Applied to: **Doñana (Spain)**

Applicability to future PAs: LAST-EBD data services may be transferable to other areas as well , given pseudo-invariant areas for the area are defined and tested while a reference scene for normalization needs is also selected.

Bayesian Networks

One approach to model socio-ecological systems and integrate both quantitative data (e.g. from Earth Observation) and qualitative information (such as stakeholder and expert knowledge) is by using Bayesian Networks (BNs). BNs are probabilistic graphs, where system variables are represented as nodes, and the dependencies between them are directed links (Kjaerulff & Madsen, 2013). The graphical representation of BNs means that the model structure is transparent and easy to communicate (Voinov & Bousquet, 2010). In addition, uncertainties are explicit and propagated through the model (Ropero, Rumi, & Aguilera, 2013). In WP7 of ECOPOTENTIAL, such models have been used to address a variety of questions relevant for management, such as trade-offs between ecosystem services in the Wadden Sea and Danube Delta and scenarios of land-use change under different policy measures in the Sierra Nevada. Since our understanding of ecosystem functions and services is often limited by a high uncertainties and lack of data, a BN model was used to disentangle uncertainties related to the avalanche protection ES in the Swiss Alps and identify knowledge gaps (Stritih, Bebi, & Gret-Regamey, 2019). In Doñana, EBD-CSIC researchers have explored the factors affecting the waterbird community through a collaborative modelling process, which aims to create a common understanding of the system and facilitate communication among experts, managers, and local stakeholders. Actors were selected based on evidence drawn from a long-term social-ecological research program and regional institutional analysis currently carried out by EBD-CSIC's Spatial Ecology Group (Méndez, Amezaga, & Santamaría, 2019).

EBD-CSIC researchers modelled: (a) the social and ecological factors affecting the sustainable provision of Doñana PA's ecosystem services, as included in its storyline; (b) the policy, management and environmental factors that would ensure the long-term sustainability of the wintering and breeding waterbird communities, in terms of the ecosystem services that they provide and as an umbrella model for the rest of services (water purification capacity, cattle/food production); (c) an alpha-level BN including only a first layer of environmental factors affecting the waterbird community based on (b) and on in-house expertise (e.g., outputs from statistical analyses and internal validation), which was then parametrized eliciting expert-judgement from stakeholders. A second layer of environmental, management and policy factors is currently being parametrized by eliciting expert judgement online. Once finished, the final, gamma-level BN will be used (1) to generate management scenarios and model uncertainty based on a wealth of expert opinions from a diversity of stakeholders, and (2) to guide the co-design among researchers, managers, key stakeholders and other potential users, of EO-based dynamic models and decision support tools. High-res image available from here: https://drive.google.com/open?id=1N00T-SjVvJ7nBr9dvjwOY3YXJWLc7S7W

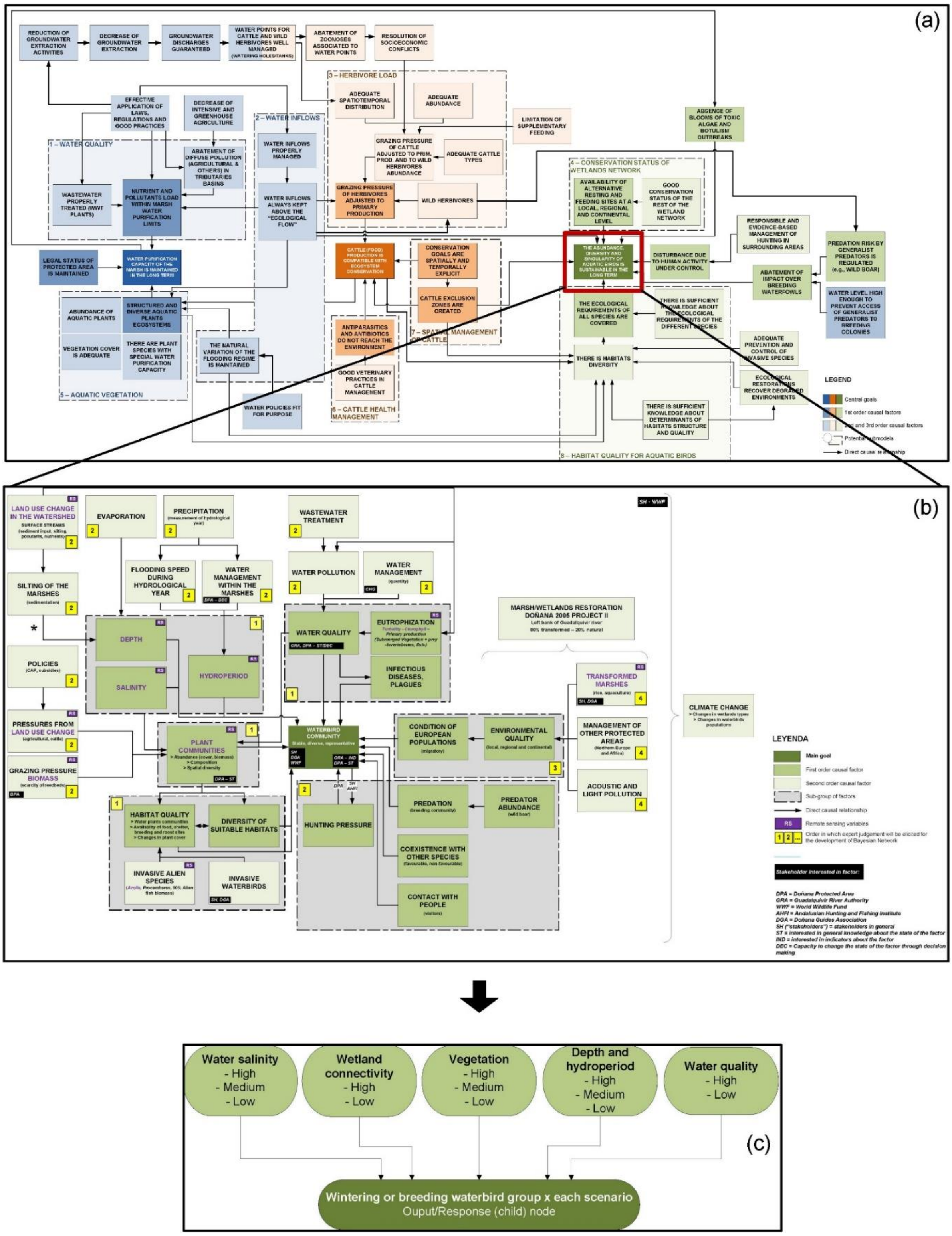

Figure 18: The process was carried out through a series of workshops embedded within an overall adaptive co-management strategy ((Santamaría, Green, Diaz-Delgado, Bravo-Utrera, & Castellanos, 2006; Méndez, Amezaga, Bustamante, Diaz-Delgado, & Santamaria, 2018)

Applied to: **Wadden Sea (The Netherlands), Davos (Switzerland), Danube Delta (Romania), Sierra Nevada (Spain), Curonian Lagoon (Lithuania), Doñana (Spain)**

Applicability to future PAs: To make BN modelling accessible to actors without a strong modelling background (such as PA managers), Deliverable 7.3 provides guidelines on how to develop, quantify, validate, and use BNs. The methodologies applied in the different case studies are presented in detail, so that they can be replicated in other areas. Since the spatial and temporal dimension are often essential in socio-ecological systems, such BN models often need to be run in a spatially explicit way, over multiple time steps. To enable users without programming experience to link their BNs with spatial data, a new online tool with a graphical user interface was developed and is available at gbay.ethz.ch. The platform is accompanied by a Wiki (wiki.gbay.ethz.ch) with instructions on how to use the tool and how to develop a BN, simple examples of BNs for ecosystem services and detailed descriptions of case studies. With the openly available material and simple GUI of the gBay tool, this is an accessible toolbox, where users (including PA managers) can learn to use spatial BNs to address relevant questions in their socio-ecological systems. BNs are able to incorporate different types, sources and quality of data, being especially useful to explicitly identify and represent knowledge gaps and uncertain information, which will surely arise in the future design and planning of future PAs. As a semi-quantitative modelling technique, BNs provide an integrated modelling framework for ecosystem services research, capable to jointly assess poorly documented services (e.g., through expert and stakeholder elicitation) and well-documented ones (e.g., through knowledge provided by statistical and mechanistic models). Developed in a co-design context (e.g., in adaptive co-management settings), they constitute invaluable tools to enhance communication, build consensus, support decision making and increase the trust of non-technical stakeholders in complex scientific models.

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7 Appendix 1: Sample Questionnaire to PA Managers

SAMPLE QUESTIONNAIRE TO MANAGERS OF PROTECTED AREAS

What are the key management aims? ____________________

Does the protected area have a management plan? ☐ Yes up to date ☐ Yes but old ☐ No

What are the key threats to the protected area? ____________________

Are there related social conflicts? ____________________

What are the most important biodiversity values of the protected area, and conservation targets requiring protection? ____________________

What are the options/needs for restoration? ____________________

Do indigenous or traditional peoples occupy or rely on the resources of the PA? ____________________

How are they involved in relevant processes? ____________________

How are local communities involved? ____________________

Does the protected area provide direct economic benefits? Do the benefits come to the people who bear most of the costs?

☐ Environmental services? (erosion, water quality etc)

☐ Tourism?

☐ Sustainable resources?

Is the PA part of a transboundary PA system? ☐ Yes ☐ No

Is a monitoring system in place? ☐ No ☐ Yes but limited ☐ Comprehensive

What are the key needs for capacity to ensure effective management? ____________________

____

What are the current and projected annual funding needs and how to they compare with current available financial resources? ____________________

____

What are the key tools needed to ensure effective management? ____________________

____

What are the key needs for research to ensure effective management? ____________________

____

Figure 19: Sample Questionnaire for PA managers (Dudley, et al., 2005)