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Current state of ecosystems and ecosystem services beyond PAs

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Abstract	European ecosystems and their functioning contribute strongly to the well-being of society. The current state and current of ecosystems are the main controls for the amount of ecosystem services that can be supplied. The crucial role of Protected Areas (PAs) has been recognised in conserving functional ecosystems. We focus on

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	collectives of European PAs and cover three spatial scopes, namely the collective of ECOPOTENTIAL PAs, the collective of all European PAs and finally wall-to-wall Pan-European studies underpinning the relevance for a large-scale perspective on European PAs to support effective biodiversity conservation in the future. In this deliverable, (1) we identify important aspects for systematic evaluation and monitoring of a European-wide network of PAs to stabilise and conserve biodiversity and ecosystem services in Europe, and complement the work of ECOPOTENTIAL in single PAs and storylines; (2) we highlight information needs and technical options to identify and potentially also monitor the current state and trends in European ecosystems and ecosystem services; and finally (3) we provide an overview of the practices to account for diverse uncertainties in the presented studies.
Keywords	Protected Areas, Europe, current state, large-scale assessment, uncertainties

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1. Introduction

By Ariane Walz and Jennifer Schulz

European ecosystems (ES) and ecosystem services (ESS) have been studied intensely for decades, and by following up on Action 5 of the EU Biodiversity Strategy to 2020, the European Commission has strongly supported the mapping and assessing of the state of ecosystems and their services (Maes et al., 2014). Given the continental extent, the diverse climatic zones and small scale setting, ecosystems in Europe are highly diverse, and the latest map of pan-European ecosystem mapping differentiates between 67 ecosystem types, including 21 marine and coastal, 3 freshwater and 43 terrestrial ecosystem types (EEA, 2014). The North-South gradient stretches from the subtropical Mediterranean vegetation zone with strongly seasonal precipitation to subarctic tundra vegetation. Similarly the West-East gradient stretches from very mild seasonality towards strongly continental climate with hot summers and very cold winters. Furthermore, various mountain ranges add vertical gradients in many areas, which creates a variety of micro-climates and different (sometimes extreme) environmental conditions. Due to high population density compared to many other areas in the world, most ecosystems have been modified and managed for agriculture and forestry for many centuries; and different cultural histories, in parts dating back over two millennia, further add to the diversity of European ecosystems (Petroli et al., 2016). Human modification limits the area of natural or semi-natural ecosystems to a minimum across Europe, leaving a steep gradient between strongly modified urban, engineered and degraded ecosystems over heavily managed agricultural and forestry areas, to more or less intact, natural to semi-natural landscapes.

The European ecosystems and their functioning contribute strongly to the well-being of society (Maes et al., 2012; Diaz et al., 2018). They provide crucial ecosystem services, such as the replenishment of clean drinking water for almost 750 Mio. people across Europe; the regulation of water and sediment flows which prevents more frequent and extreme flooding and erosion; the supply of goods and material, such as food, construction wood, or fibres for fabric; and finally also intangible services, such as experiencing nature and enjoyment. The extent and the condition of an ecosystem are the main controls for the amount of ecosystem services that can be supplied (Maes et al., 2018). Within the “Mapping and Assessment of Ecosystems and their Services” of the European Commission, a series of indicator sets has been developed to describe and monitor the state and condition of different European ecosystems (Maes et al., 2018). Where possible, these indicators build on existing pan-European datasets to enable regular monitoring.

The current state of these diverse European ecosystems is characterised by a limited number of large-scale and increasingly more dominant pressures (e.g. Maes et al., 2014), similar as in many other areas of the world (MEA, 2005; Rockström et al., 2009). Summarised according to Erhard et al. (2016), these key pressures include (1) change of habitat through human land take, degradation and fragmentation with vital consequences mainly for wildlife; (2) climate change, i.e. long-term changes in the meteorological conditions like temperature and precipitation, in their seasonality and frequency and magnitude of extreme meteorological events; (3) overexploitation through excess use of natural resources (e.g. by intense crop agriculture, overgrazing or overfishing); (4) invasive alien species, which may act as vectors for diseases, alter ecosystem processes and drive some local native species to extinction; and (5) pollution and nutrient enrichment mainly through sulphur, nitrogen and heavy metals impacting heavily plant health and plant species composition.

The international community, national governments and the European Union are well aware of these processes, and they are in parts directly addressed under the Strategic Goal B in the Aichi Targets within the Strategic Plan of the Convention for Biological Diversity for the current decade (CBD, 2010), and the European Biodiversity Strategy (European Commission 2011). Apart from targets to restore degraded ecosystems and enhancing more sustainable forestry and agriculture, the European Biodiversity Strategy specifically targets the protection of species and habitats in Target 1 (European Commission 2011).

The crucial role of Protected Areas (PAs) has been recognised in reaching this target, as three of the four action items directly relate to the Natura 2000 network (European Commission, 2011). The Natura 2000 network builds on European policies, namely the Bird and the Habitat Directives, and aims for a cohesive network of protected habitats, very strongly targeted at specific umbrella species and vegetation communities. It has been built up since 1992 and currently covers over 27,000 sites, an area of 1.15 Mio km^2, and thus around 18 % of the area of the European Union (Natura 2000 Barometer, 2017). Next to the Natura 2000 sites, additional PAs are designated by national legal frameworks of the EU member states (EEA, 2012). For 2011, the EEA (2012) reports that the overall area of terrestrial PAs added up to 1.1 Mio km^2 and covered around 25 % of the EU-27 at the time, with 70 % of this land being protected by Nature 2000. In some member states, Natura 2000 sites overlap to a great extent with nationally designated areas (e.g. UK, Slovenia and Germany), and in others, Natura 2000 sites are mostly complementary to nationally designated areas (e.g. Finland, Hungary and Spain). The overall number of sites, no matter if Natura 2000 or nationally designated areas, highlights once more the characteristic, either natural or human-induced diversity, and high fragmentation of Europe´s environmental conditions.

Given the crucial role of PAs in achieving effective protection of habitats and species, as aimed for in Target 1 of the European Biodiversity Strategy, we focus on collectives of European PAs and pan-European assessments with implications for the design and coordination of the European network of PAs. Thus, we raise important aspects for systematic evaluation and monitoring of a European-wide network of PAs to stabilise and conserve biodiversity and ecosystem services, and complement the work of ECOPOTENTIAL in single PAs and storylines. Furthermore we highlight information needs and technical options to identify and potentially also monitor the current state and trends in European ecosystems and ecosystem services, and finally we provide an overview of the practices to account for diverse uncertainties in the presented studies.

The assessments cover three spatial scopes, namely (1) the collective of ECOPOTENTIAL PAs, (2) the collective of all European PAs and finally (3) wall-to-wall Pan-European studies underpinning the relevance for a large-scale perspective on European PAs to support effective biodiversity conservation in the future. Given the crucial role of ecosystem functioning, most of the 12 assessments focus mainly on the state of ecosystems, while four explicitly address ecosystem services (Table 1). The assessments cover both terrestrial (including freshwater) and marine ecosystems, and a variety of foci. Several of them directly take up issues of uncertainties, ranging from the variety of purposes for the use of Remote Sensing (RS) across various ECOPOTENTIAL PAs, the choice of indicators or target species, to climate change, and data quality issues. Remote sensing and modelling are the two most prominent techniques across the presented studies. Physical and process-based models are currently slightly underrepresented amongst the modelling studies, despite some nice example (e.g. 3.3 on functional diversity and 3.5 on marine connectivity), which reflects the focus on the current state of ecosystems and ecosystem services and will change drastically when we look at the future states in D8.4.

Table 1: Overview over large-scale assessments including some of the principle qualities of the studies

Chapter	Study Title	ES/ ESS	Spatial scope	Ecosystem Type	Focus	Reference to uncertainty
2.1	Remote Sensing derived ecosystems states across ECOP PAs	ES	ECOP PAs	T+M	Variety of RS demand of indiv. PA	multi-purpose
2.2	State and trends in climate conditions across Europe	ES	ECOP PAs	T	Vulnerability/resilience against CC	multiple sources of gridded climate data
2.3	Uniqueness of PAs for Conservation Strategies in the Europe	ES	European PAs	T	Cross-European coordination of PAs	multi-indicator approach
2.4	Land cover change for all European PAs	ES	European PAs	T	Cross-European monitoring	-
3.1	Pan-European RS analysis for NDVI and LST	ES	Pan-European	T	RS for pan-European monitoring of PAs	-

3.2	SST as an Essential Variables for marine ecosystems	ES	Pan-European	M	Vulnerability/resilience against CC	multiple species
3.3	The potential for functional diversity of forests in Europe	ES	Pan-European	T	Vulnerability/resilience against CC	-
3.4	Vulnerability of European freshwater systems	ES	Pan-European	T-freshwater	Vulnerability/resilience against CC	multiple indicators, species, climate scen.
3.5	Connectivity across LME	ES	Pan-European	M	Coordination of PAs to connect habitats	-
4.1	Examples of ESS assessments for ECOP PAs	ESS	ECOP PAs	T+M	Variety of ESS foci for indiv. PA	
4.2	Carbon stocks as a global ESS across all ECOP PAs	ESS	ECOP PAs	T	Global ESS	
4.3	Marine food provisioning through the Mediterranean Sea	ESS	Pan-European	M	Cross-European coordination of PAs	
Box 1	The global “niche” of PAs		Global PAs	T+M		

Chapter 2 and 3 focus on ecosystem states and trends. Here, **Chapter 2** focuses on analyses of PAs including all ECOPOTENTIAL PAs or all European PAs. This includes on overview across all ECOPOTENTIAL PAs and their interests in RS to deduce ecosystems state (2.1), a study evaluating the efficiency of conservation by different biodiversity indices (2.2), and a study on land cover change as detected from existing pan-European monitoring (2.3). **Chapter 3** comprises assessments beyond PAs, showing the potential to deduce essential indicators for monitoring ecosystem state and trends over large areas (3.1, 3.2 and 3.3) and raise a number of issues to systematically enhance the network of European PAs in face of climate change (3.3, 3.4, 3.5) and threatened connectivity between habitats (3.5). **Chapter 4** contains studies that specifically address ecosystem services supplied by PAs either across all ECOPOTENTIAL PAs, European PAs or beyond PAs. Similar to Chapter 2, also Chapter 4 starts with an overview across the ECOPOTENTIAL PAs (4.1). Then we present an assessment of carbon storage as a global ecosystem service, which can in future be an important asset for PAs if financially rewarded (4.2), and a RS based toolbox to estimate the potential for fish growth as an example for a provisioning ecosystem service (4.3). In addition to the three main chapters we provide some add-on results that open up the scope from the European to a global level and identify the typical “niches” for PAs, including not only biodiversity or bio-physical, but mainly social, political and economic factors (Box 1).

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2. Current state and trends in ecosystems across PAs

By Ariane Walz and Jennifer Schulz

This chapter deals with analyses across PAs, both across all ECOPOTENTIAL PAs and across all European PAs. The first sub-chapter (2.1) provides an exemplary overview across ECOPOTENTIAL PAs over the data they requested to enhance their individual PA management. It demonstrates the diversity of data interests of individual PAs and gives insight in the current opportunities given through RS data as well as the combination of RS data, in-situ data and modelling techniques to derive the demanded information. The second sub-chapter (2.2) investigates the state and trends in climate conditions across all ECOPOTENTIAL PAs based on gridded climate observations, it analyses data of the past 65 years and highlights changes in temperature and precipitation related climate extremes based on a number of indices. The third sub-chapter (2.3) focuses on the uniqueness of PAs concerning their biodiversity, and assesses different indices to measure conservation values of PAs across Europe to evaluate conservation efficiency. The fourth sub-chapter (2.4), finally, investigates CORINE land cover data with pan-European coverage. CORINE land cover change (CLCC) is investigated as primary pan-European monitoring data, which has been available since the 1990s and which is a first entry point towards pan-European monitoring of terrestrial PAs. The study investigates what transitions can be identified for the PAs versus the remaining parts of Europe, how transition rates changed over the observation periods, what IUCN categories compare with each other and what PAs are more inclined to undergo land cover transition processes.

2.1. Ecosystems states and trends across all ECOPOTENTIAL PAs derived from Remote Sensing

Based on C. Domingo-Marimon and J. Masó, 2018: Using Earth Observations to Protect Natural Landscapes. E-book available at www.ecopotential-project.eu/images/ecopotential/documents/ecopotential-spaced.pdf This book completes and extends the photo exhibition "SPACED: Using Earth Observation to Protect Natural Landscapes" prepared by CNR, UNEP, GRIDA-Arendal and CREAF, which illustrated the ECOPOTENTIAL project, that took place from January 8 , 2018 to January 12, 2018 at the European Parliament in Brussel.

INTRODUCTION: Traditionally, protected areas were managed through decisions taken based on local knowledge combined with data collected on the ground and carefully produced by scientific field campaigns carried out on selected plots and along selected transects. However, these in-situ measurements often covered only a tiny portion of the protected area, as a result generating potentially fragmented information. Under these circumstances, protected area experts were forced to empirically extrapolate local information to the whole region in order to design and apply conservation measures to preserve biodiversity, ecological integrity and ecosystem services.

Remote sensing data acquired by Earth observation satellites (such as the new European Sentinel fleet) is a game-changing technology that, for the first time, gives managers a comprehensive bird's-eye view of the geobiophysical variables that are regularly used to assess the status of their protected areas. But the images produced are much more than merely large selfies. Satellites measure the Earth in several ways. Firstly, passive instruments gather reflected sunlight at specific frequencies (called bands) that, for example, are sensitive to the presence of greenhouse gases in the atmosphere or to chlorophyll in plants. Secondly, some active instruments emit radar signals that can penetrate the clouds and measure small changes in topography, and lastly, the same sensor detects the radiation that is backscattered from the target. The major advantage of this technology is that data acquisition can be performed continuously in space and time, allowing for a precise determination of the distribution of the trends in the whole region. The use and application of remote sensing requires new tools and new expertise that have been developed by scientists in recent years. This knowledge is now mature enough to be transferred to protected area managers for its operational usage. Here, we focus on the 24 protected areas that are part of the

ECOPOTENTIAL project and describe a collection of exemplary applications where Earth observation data is essential, accompanied by visual maps covering the whole extension of each protected area.

The main purpose is to illustrate the capabilities of remote sensing and how this technique is being applied in many ways to monitor several different aspects of ecosystems and environmental conditions. Each type of ecosystem (mountain, arid or coastal and marine) presents different challenges that will be addressed through different Earth observation and data analysis approaches, and in Chapter 2.2 provides an overview of the ECOPOTENTIAL PAs, their location, biogeographical setting and protection status. These examples will illustrate the extent to which Earth observation by satellites has become a crucial tool for capturing state and condition of natural ecosystems, as well as for monitoring ongoing changes and supporting knowledge-based conservation and management strategies.

BACKGROUND: In 1946, planet Earth took its first selfie. A camera was mounted on a German rocket in New Mexico, United States and launched 100 km into space before returning with exposed photographic film. Since then, Remote Sensing technology has improved immensely and modern satellites with a range of sensors are orbiting around us while continuously providing new and valuable information on our planet. The unprecedented availability of satellite time series completes field measurements and allows us to understand large-scale changes in our environment and how best to protect it.

Earth observation satellites record electromagnetic energy reflected or emitted by objects on the Earth's surface, capturing not only the part of the electromagnetic spectrum that is visible to the human eye (visible light), but also other wavelengths such as the infrared, including thermal and microwave radiation. This allows us to see reality at an unprecedented detail and distinguish between different surfaces because they reflect solar radiation differently. Existing satellites provide data at a range of different spatial resolutions and temporal intervals that can be selected depending on our needs. Weather forecasting requires frequent data, while monitoring changes in agriculture or natural vegetation generally requires images at a weekly, monthly or yearly basis. Spatial resolutions can vary from less than one meter to a few kilometres, allowing Earth observations to inform us about our planet from local to global scales. Thus, the availability of sensors characterized by a range of spectral, spatial and temporal resolution offers new perspectives in Earth surface monitoring.

Several Earth observing satellites, such as Landsat and many others, are now orbiting the Earth. In particular, the European Sentinel 2A and 2B are twin satellites, which oppose each other in orbit. Their data, freely available, can support the monitoring of land surfaces, providing quantitative information on deforestation, crops condition, glacial or snow melting, as well as emergency response services. These two Sentinels can capture images at spatial resolutions ranging from 10 to 60 meters every 5 days, and ensure continuity to data acquired in the past, such as the optical Landsat data archives. Thus, having access to long-term environmental data records can offer the perspective to detect changes and trends useful to predict new scenarios. Sentinel 3A, on the other hand, focuses on observing weather and oceans, including sea ice, ocean temperature and water quality. It carries a suite of instruments, including a radar altimeter, and will provide continuity to other satellites such as ERS, Envisat and SPOT.

The Sentinel family was created by the European Space Agency for the Copernicus Programme and comprises additional future Sentinel missions to monitor the health of our planet. Specifically, Sentinel-4 and Sentinel-5 will provide data for atmospheric composition monitoring from geostationary and polar orbits, respectively. In addition to optical sensors, radar Sentinel-1 sensors are providing day and night radar images at all weather conditions for land and ocean services.

METHODS AND DATA: as specified in great detail in D4.2

RESULTS: Table 2 shows a series of examples how current states and conditions of ecosystems in 24 of the ECOPOTENTIAL PAs have been monitored by remote sensing data, often in combination with empirical ecosystem data and subsequent modelling. Many of them contain a measure of uncertainty through accuracy assessment or model validation based on field observations, highlighting again the crucial requirement for in-situ observations. All variables listed in Table 2 have been all identified as essential for these specific contexts (see Deliverable 2.1). In all cases the selected ecosystem conditions are crucial for the supply of particular Ecosystem Services within the areas, as indicated also in Table 2, and further elaborated in Deliverable 7.1 based on the storylines of the PAs.

Table 2: Exemplary indicators for ecosystem states and condition from Earth Observation (Máso and Domingo, 2018)

Protected Area	**Indicator for Ecosystem Condition**	**Directly related Ecosystem Services**	**Sensor or EO based Model**
Mountain ecosystems			
Abisko	Tree cover density	Habitat protection Carbon sequestration Erosion prevention	Sentinel 2
Bavarian Forest	Normalised Difference Vegetation Index (NDVI)	Timber Habitat protection Carbon sequestration Erosion prevention	Landsat 8 OLI
Gran Paradiso	Vegetation mapping	Timber Habitat protection Carbon sequestration Erosion prevention	Sentinel 2A
Gran Paradiso	Snow cover duration	Flood prevention Habitat protection	MODIS Terra-Aqua
Hardanger-vidda	Gross Primary Production Vegetation cover Snow cover	Habitat protection Carbon sequestration Flood prevention Wild land meat	MODIS Terra-Aqua, Landsat 8 OLI
High Tatra Mountains	Normalised Difference Vegetation Index (NDVI)	Habitat protection Carbon sequestration Flood prevention Erosion prevention	Sentinel 2A
Kalkalpen National Park	Forest Aboveground Biomass, Vegetation water content	Timber Wild land meat Habitat protection Flood prevention Erosion prevention Carbon sequestration	LiDAR Sentinel 2A
La Palma Island	Decline in Greenness 2016, from forest fire and forest disturbance	Habitat protection Carbon sequestration Erosion prevention Flood prevention	Sentinel 2A Greenness LiDAR Topography
Lake Ohrid and Prespa	Average chlorophyll a concentration	Fishery Habitat protection Water treatment	Envisat MERIS
Peneda- Gerês National Park	Species rich grasslands	Timber Wild land meat Agriculture/meat Habitat protection Flood prevention Erosion prevention Carbon sequestration	Sentinel 2A
Réunion	Volcano activity	Habitat protection Flood prevention Erosion prevention Carbon sequestration	Spot 6
Sierra Nevada National Park	Live green vegetation Snow cover	Fresh water Agriculture/meat Habitat protection Flood prevention Erosion prevention Carbon sequestration	Landsat 5 TM
Swiss National Park	Forest cover changes, Canopy height	Fresh water Timber Wild land meat Habitat protection Flood prevention Erosion prevention Carbon sequestration	LiDAR Canopy height vegetation model
Arid ecosystems			
Har HaNegev National Park	Change in vegetation cover	Agriculture/Meat Habitat Protection Erosion prevention	Landsat 1987-2016
Kruger National Park	Tree biomass	Timber Wild land meat Habitat protection Carbon sequestration Erosion prevention	Sentinel 1

Montados	Tree cover density Leaf area index	Timber Habitat protection Flood prevention Erosion prevention Carbon sequestration	not indicated
Murgia Alta	Landscape dynamics, grassland transformation	Habitat protection Agricultural/crops Agricultural/meat	Sentinel 2 World View 2
Samaria National Park	Lizard habitat suitability	Habitat protection	Model based on EO 3D digital surface model field data
Coastal and marine ecosystems			
Curonian Lagoon	Flood dynamics	Fisheries Habitat protection Carbon sequestration	Sentinel 2 time series
Danube Delta	Normalized Difference Water Index (NDWI) Chlorophyll Turbidity	Fisheries Habitat protection Water treatment Nutrient cycling	Landsat 8 OLI
Doñana National Park	Wetland structure sedimentation flooding	Fisheries Habitat protection Flood regulation	Landsat 8 OLI (time series)
Pelagos Sanctuary	Feeding habitat; individual animals monitoring (fin whales)	Fisheries Farmed seafood Habitat protection	Modelled from chlorophyll levels, high-resolution satellite imagery
Camargue	Flooding stages (salt flats)	Fisheries Wild animals Habitat protection Flood regulation	Sentinel 2A time series
Mediterranean Large Marine Ecosystem	Locally adjusted sea surface temperature	Wild animals (biomass) Animals from in situ Aquaculture (biomass) Habitat protection	Sea Surface Temperature product from Copernicus Marine Environment Monitoring System
Wadden Sea	Modelled birds´food sources	Fisheries Farmed seafood Habitat protection	Sentinel 2m World View 01

DISCUSSION AND CONCLUSIONS: As can be summarized from Table 2 as well as from the methodological details described in Deliverable 4.2, a very diverse spectrum of ecosystems and related indicators has been assessed concerning the current state of ecosystems as well as trends in ecosystem dynamics. Three main approaches for the assessment of ecosystems states and trends can be distinguished and have been applied on a case study basis throughout the ECOPOTENTIAL PAs, namely i) continuous layers based on remote sensing imagery (such as vegetation indices, water indices, etc.); ii) classified or thematic layers based on remote sensing imagery, and iii) modelled spatial representations of indicators based on Remote sensing, field data and eventually further existing environmental information (e.g. feeding habitat at the Pelagos Sanctuary; Lizard habitat suitability at Samaria National Park). With the diversity of approaches developed and tested according to the specifically articulated user needs of the PA managers, and the research questions adapted to the diverse PAs contexts, a large array of methods has been developed and applied to a large number of Earth observation sensors, mainly Sentinel 2A, Landsat 8, LiDAR, MODIS Aqua and Modis Terra and to a lesser extent also Spot and Envisat. Now, the variety of analytical approaches are algorithms “ready-to-use” in other contexts. So far, however, there has not been a consistent comparable approach to report on states and trends across all PAs. Nevertheless, the EODESM system, as multi-modular classification system (see also D4.2) has the potential to mainstream across the different analytical emphasis in ECOPOTENTIAL PAs by using comparable input data for all PAs as well as comparable outputs under the same LCCS2 nomenclature.

OUTLOOK: In addition to new and high-resolution remote sensing data, as Sentinel provides, we also make use of existing time series of lower-resolution remote sensing data. MODIS Terra and MODIS Aqua data are being used for this due to the high temporal repetition and consequently the availability of cloud free image composites for land and sea. This holds the advantages of consistent time series being available over larger areas and over longer time periods. Such time series help to define baselines and detect changes in ecosystems. A subset of the above monitored indicators for ecosystem state and condition will be further analysed across all ECOPOTENTIAL PAs for MODIS time series between 2000/2002-2015/17. These include for all PAs Gross Primary Productivity (GPP) proxies and phenological metrics. Further, for each ecosystem type, either the NDVI, Snow cover duration, Land Surface Temperature for mountain ecosystems; for arid ecosystems NDVI, Albedo, and Land surface temperature; and for marine ecosystems Chlorophyll a, Sea Surface Temperature and Total Suspended Solids/Turbidity (see Table 3 for details) will be assessed.

Table 3: Selection of variables derived from MODIS for all ECOPOTENTIAL PAs

Type of ecosystem	RS variable	Period	Frequency	Spatial resolution	Satellite	Referent expert
Mountains	NDVI	2000-2017	Daily averages	250 m	MODIS TERRA/AQUA	BGU, CREAF
	Snow cover (duration)	2002-2016	yearly	250 m (EURAC) 500 m (MODIS)	MODIS TERRA/AQUA	EURAC, FORTH
	Land surface temperature	2000-2017	Daily averages	1 km	MODIS TERRA/AQUA	FORTH
Arid ecosystems	NDVI	2000-2017	Daily averages	250 m	MODIS TERRA/AQUA	BGU, CREAF
	Albedo	2000-2015	Yearly	500 m	MODIS	FORTH
	Land surface temperature	2000-2017	Daily averages	1 km	MODIS TERRA/AQUA	FORTH
Marine	Chlorophyll a	1998-2015	monthly	4 km	Several	ISPRA
	Sea Surface Temperature	1986-2016	Daily	2 km-4km	Several	ISPRA
	Total suspended solids /Turbidity	From 1984	16 day images (if available and no clouds)	30 m	Landsat /Sentinel 2	EBD-CSIC provides software not product
Common to all PAs - Global	GPP proxy	2002-2016	Yearly	250 m	MODIS	UFZ
	Phenological metrics	2002-2016	Yearly	250 m	MODIS	UFZ

2.2. Current state and trends in climate and climate extremes across all ECOPOTENTIAL PAs

By Elisa Palazzi, Gianna Vivaldo and Antonello Provenzale (CNR)

INTRODUCTION: Protected Areas are subject to long-term modifications associated with climate and environmental changes, enhancing the risk of losing ecosystem processes and services. One of the goals of the present study is to characterize and quantify the changes in climatic conditions across the various ECOPOTENTIAL PAs from the 1960s up to present, particularly focusing on climatic extremes given their substantial environmental and societal importance. Any change in the frequency and/or magnitude of the extremes in climate, in fact, would impact on the environment both at the PA and broader scale and should be considered to plan and support local mitigation and adaptation strategies, which is one of the goals of the ECOPOTENTIAL project.

This analysis was performed using (1) a station-based observational dataset covering the last 60 years providing daily data of temperature and precipitation across Europe and (2) a set of internationally-agreed indices that describe different climatic extremes calculated from daily temperature and precipitation data. The employed data and indices of climatic extremes are presented in the next section. Figure 1 shows the location of all PAs that are analysed in the ECOPOTENTIAL project. In the present study we focused on all of them except the Caribbean and Kruger Park. The analysed PAs - Abisko, Bayerischer Wald (Bavarian Forest), Camargue, Curonian Lagoon, Danube Delta, Doñana, Gran Paradiso National Park, Hardangervidda, Har Negev Reserve, La Palma, Austrian Limestone Alps, Montado, Murgia Alta, Ohrid Lake, Peneda-Gerês, Samaria, Sierra Nevada, Swiss Alps National Park, Tatra Mountains, and Wadden Sea - cover different biogeographic regions and all three kinds of ecosystem which are dealt with in ECOPOTENTIAL, that is, mountain, marine and coastal, arid and semiarid ecosystems. Some PAs are also part of the European-LTER (Long Term Ecological Research) network (www.lter-europe.net/lter-europe/infrastructure/networks). For a detailed description of the characteristics of each PA we refer to the ECOPOTENTIAL web site and documents therein (www.ecopotential-project.eu/site-studies/protected-areas.html).

Figure 1: Biogeographic regions and ECOPOTENTIAL PA

DATA: E-OBS is an observation-based gridded dataset providing daily data of minimum surface air temperature (TN), maximum surface air temperature (TX), mean surface air temperature (TG), total precipitation (RR), pressure (PP) and elevation starting in 1950 and regularly updated, covering European land regions. The dataset builds on daily observations at more than 2000 station locations available through the European Climate Assessment and Dataset portal (ECA&D; http://eca.knmi.nl; Haylock et al., 2008). As described in Haylock et al. (2008), E-OBS was created by first interpolating the monthly precipitation totals and monthly mean temperature using three-dimensional thin-plate splines, then interpolating the daily anomalies using indicator and universal kriging for precipitation and kriging with an external drift for temperature and, third, combining the monthly and daily estimates. A detailed evaluation of the E-OBS uncertainty arising from the interpolation procedures can be found in Hofstra et al. (2009) and in Turco et al. (2013). E-OBS covers a domain extending from 25°N to 75°N and from 40°W to 75°E, encompassing all European land areas. The data files are provided at two different spatial resolutions, namely 0.25 and 0.5 degrees regular latitude-longitude grids. For the purposes of our study we adopted the finest resolution available, i.e. 0.25° latitude-longitude, and we “extracted” for our analysis only the E-OBS grid points encompassing the various PAs.

Though being characterized by uncertainties related to the inhomogeneity and the sparseness of underlying stations and to the assumptions behind their interpolation, we chose the E-OBS dataset since it has the advantage of covering almost all the ECOPOTENTIAL PAs and it is the observation-based dataset that is commonly used as a reference for regional climate model evaluation and validation in Europe in terms of precipitation and temperature and all other quantities/indices that are derived from them. This is particularly important also in view of our future investigation on projected changes in climatic conditions and extremes across the different ECOPOTENTIAL PAs using climate simulations from the state-of-the-art regional climate models.

To gain a perspective on observed changes in climatic extremes, we considered a subset of the 27 indices defined by the joint CCl/WCRP-Clivar/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI; Karl et al., 1999; Peterson et al., 2001) that measure different temperature- and precipitation-related climatic extremes (http://etccdi.pacificclimate.org/list_27_indices.shtml). We “adapted” some of the indices to our purposes, by re-defining them over a different time interval with respect to the “original” definition. Some indices, in fact, were evaluated both over the year (annual indices) and over each of the four seasons (seasonal indices), other indices have a seasonal definition only, still others were defined over specific time spans. Moreover, we added to our analysis a small number of additional indices which are not included in the ETCCDI dataset, such as the HydroClimatic Intensity Index (Giorgi et al., 2011). The full list of extreme indices analysed in the present study are described in the following.

Temperature-based indices

- **Number of frost days (FD):** Annual/seasonal count of days when TN<0°C.
- **Number of summer days (SU)**: Annual/seasonal count of days when TX> 25°C.
- **Number of icing days (ID)**: Annual/seasonal count of days when TX<0°C.
- **Number of tropical nights (TR)**: Annual/seasonal count of days when TN>20°C.
- **Seasonal maximum/minimum value of daily maximum temperature (TXmax; TXmin)**: the maximum/minimum value of the daily maximum temperature in one season.
- **Seasonal maximum/minimum value of daily minimum temperature (TNmax; TNmin):** the maximum/minimum value of the daily minimum temperature in one given season
- **Heating degree days (HDD)**: the sum of daily differences TG-Tth when TG> Tth. In our case, Tth=5°C. Three biological seasons were considered: 1 Jan - 31 May (biological Spring, HDDspring); 1 Jan - 31 Aug

(biological Summer, HDDsummer); 1 Jan - 30 Nov (biological Autumn, HDDautumn). The index should be intended as a measure of the amount of heat stored in the system from the January 1st of a given year till the beginning of each biological season as defined above.
- **Growing Season Length (GSL):** the days between (a) the first occurrence of at least 6 consecutive days whose TG exceeds a threshold value of 5°C and (b) the first occurrence of at least 6 consecutive days with TG < 5°C within the period between August 1st and December 31st.
- **Seasonality index for temperature:** the difference between the value of TG (daily mean temperature) in the warmest month of a year/season and the value of TG in the coldest month of a year/season (hereinafter called Seas_T)

Precipitation-based indices

- **Maximum of consecutive 5-day precipitation (RRmax5d)**: the daily precipitation maximum value established among all the precipitation maximum values, RRmax, computed for each sequence of 5 consecutive days running over a year/season.
- **Simple precipitation intensity index (SDII)**: Computed only on a seasonal basis, is the cumulative daily precipitation evaluated on wet days (the days with RR< 1mm)
- **Seasonal count of days with RR > 10 mm (RR10mm)**: the number of days satisfying the condition RR > 10 mm in each season.
- **Seasonal count of days with RR > 20 mm (RR20mm)**: the number of days satisfying the condition RR > 20 mm in each season.
- **Consecutive dry days (CDD):** Computed only on a seasonal basis, is the maximum number of consecutive days in a season with RR < 1 mm (a measure for the maximum dry spell length).
- **Consecutive wet days (CWD**): Computed only on a seasonal basis, the maximum number of consecutive days in a season with RR > 1 mm (a measure for the maximum wet spell length).
- **Seasonality index for precipitation**: the difference between the value of RR (daily precipitation sum) in the wettest month of a year/season and the value of RR in the driest month of a year/season (hereinafter called Seas_R).
- **Hydroclimatic-Intensity index (HY-INT):** integrates metrics of precipitation intensity and dry spell length. This index is calculated as the product of the mean annual/seasonal precipitation intensity (SDII, intensity during wet days) and the mean annual/seasonal dry spell length (CDD, number of consecutive dry days during each dry spell). Both SDII and CDD are normalized by their mean value for a reference period. An increase in HY-INT would indicate an increase in the occurrence of heavy precipitation events or dry spell length, or a combined increase in both.

METHODS: We first calculated the annual/seasonal change (or difference) between the 30-year climatology of the minimum, mean and maximum temperature (TN_mean, TG_mean, TX_mean), of precipitation (RR_mean) and of all other quantities (e.g., the Diurnal Temperature Range) and indices of extremes (see previous section) derived from these variables between the period 1986-2015 and the period 1956-1985. The statistical significance of these "historical changes" was assessed assuming always a significance level of 95% ($p<0.05$) using a Monte Carlo method based on creating a large number of surrogate series in which the data have been shuffled randomly with respect to time and then calculating again the changes between the two 30-year long climatologies. This significance test was supported by a further method, the Welch's unequal variances t-test (Welch 1947; Zimmerman 2004).

We also calculated the relationship between the various indices and time and used a simple linear regression to calculate the linear trend; we assessed the statistical significance of the trend using the Monte Carlo shuffling method and a non-parametric Mann-Kendall test (Kendall 1938).

Each PA considered in this study is covered by a highly variable number of E-OBS pixels (or grid boxes), ranging from 1 to more than 50, depending on the PA extent. In this study we present the results obtained from the analysis of the E-OBS-derived climate variables and extreme indices averaged over all pixels encompassing each PA.

RESULTS. **Annual indices:** Figure 2 summarizes the results obtained from the analysis of the indices defined on annual basis (as described in section "DATA"). In the figure, the calculated changes (difference between the time average in 1986-2015 and the time average in 1956-1985) are displayed using a 2D-coloured map (hereinafter referred to as "heatmap"), displaying the various PAs (in alphabetical order) on the x-axis and all considered indices on the y-axis. Each cell is coloured according to the value of the change after having standardized it, that is, after rescaling the quantities to have a mean of zero and a standard deviation of one. Standardizing makes it easier and fairer to compare the variables with each other, even if they are measured on different scales. The number inside each cell (+1, -1, or 0), shown in green, is used to indicate the sign and significance of the change without standardization. The number is equal to "1" if the change of a given index in a given PA is positive and statistically significant, equal to "-1" if the change is negative and statistically significant, equal to "0" if the change (either positive or negative) is not statistically significant.

We note a coherent behaviour for a given set of indices whose change has the same sign and significance across all or almost all PAs. We refer, in particular, to the indices describing the change in the mean, minimum and maximum temperature, in the number of summer days (SU) and in the number of tropical nights (TR) which are all significantly positive across the majority of PAs. These quantities have increased in the last ~60 years almost everywhere, in fact, as a consequence of global warming. Analogously, the number of frost days (FD) and, to a lesser extent, the number of icing days (ID) have decreased recently (1986-2015) with respect to the past (1956-1985), which is also coherent with the widespread warming trend of the last decades. Another index showing a positive and significant change in almost all PAs is the Heating Degree Days index, for all three biological seasons we considered. The remaining indices exhibit overall a more scattered behavior across all PAs and their change turns out not to be statistically significant in most cases (the number inside a cell is equal to "0" in these cases).

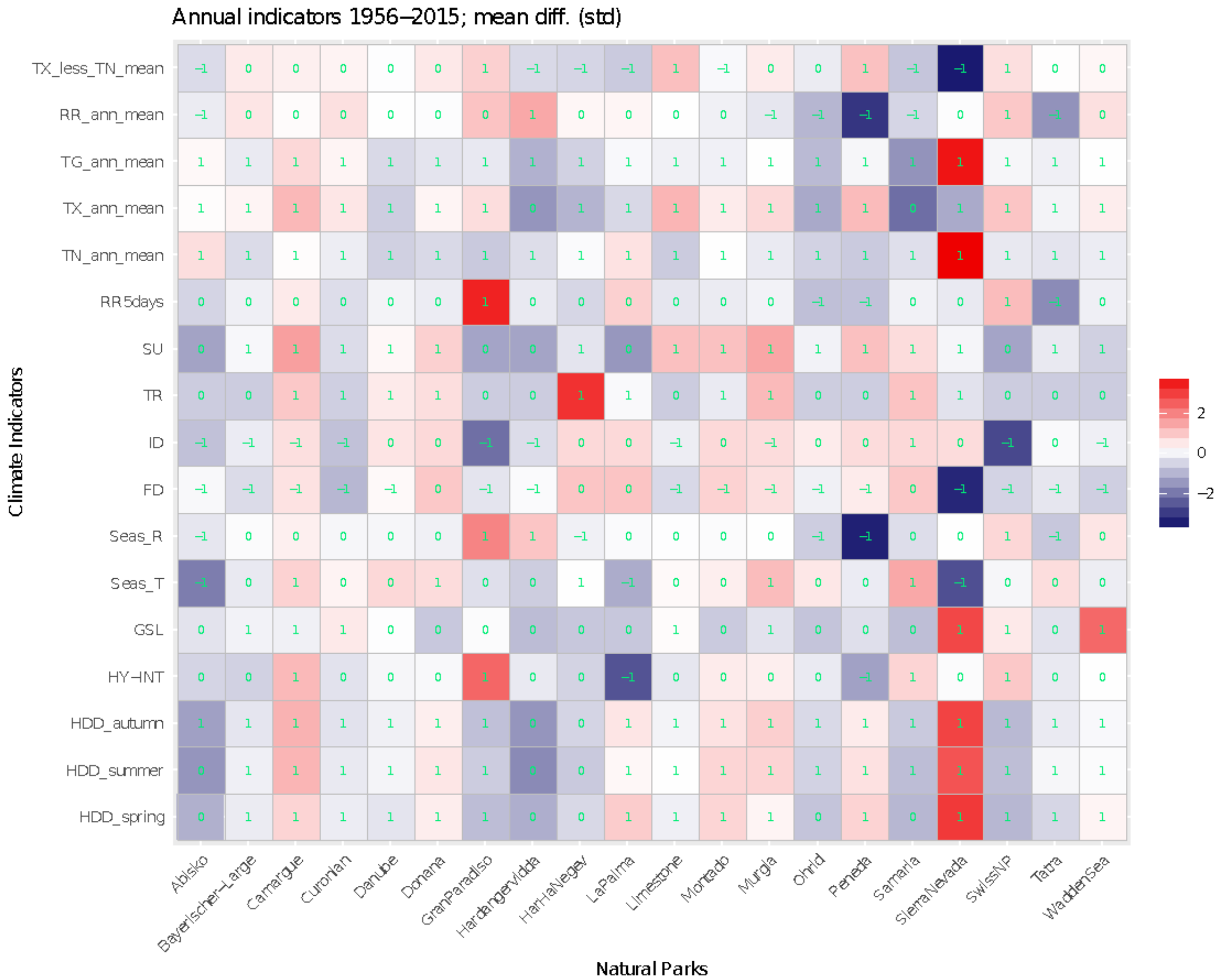

Figure 2: Heatmap of the standardized change between the average in the period 1986-2015 and the average in the period 1956-1985 of each annual climatic indicator displayed in the y-axis. All PAs are represented on the x-axis in alphabetical order. The green figure in each cell indicates the sign and significance of the non-standardized change (see text for details).

In general, the temperature-related indices show a more robust behavior and a more coherent signal across the various PAs than the precipitation-related indices. For example, the averaged change in precipitation (RR_ann_mean in Figure 2) between the two 30-year long periods is not statistically significant, independently of its sign, in the majority of the PAs. Only for 2 (Hardangervidda and the Swiss National Park) out of the 8 PAs that show significant changes we found a precipitation increase, while 6 out of 8 PAs (Abisko, Murgia, Ohrid, Peneda, Samaria and Tatra) underwent a precipitation decrease over the last ~60 years. Similar considerations can be drawn for “RR5days” which decreased significantly in only three areas (Ohrid, Peneda and Tatra mountains) and increased significantly in only 2 ones, the Gran Paradiso and the Swiss National Parks. It is interesting to note that, for the latter two PAs (the Gran Paradiso and Swiss National Parks), almost all climatic indices varied in the same way in the past: both areas experienced positive changes in the hydroclimatic intensity index (HY-INT) and in the seasonality of precipitation (Seas_R), as well as negative changes in the number of icing and frost days (IC, FD). These are both mountain areas and quite close to each other, which may in part explain the various commonalities we found between them. As an example, we show in Figure 3 the time series from 1958 to 2015 of HY-INT and of the two precipitation-related indices (RR5days, Seas_R) in the Gran Paradiso National Park. The red line in the plots was obtained linearly fitting the data and highlights a positive trend of all three indicators (consistently with the changes discussed above in the analysis of the heatmap). It is interesting to note that the trend for all three indices is less intense after the year 2000, and particularly for HY-INT. Another area showing a similar coherent behavior in three precipitation-related indices is Peneda where we found a negative trend over the last ~60 years of total precipitation (RR), HY-INT and RR5ays, as shown in Figure 4.

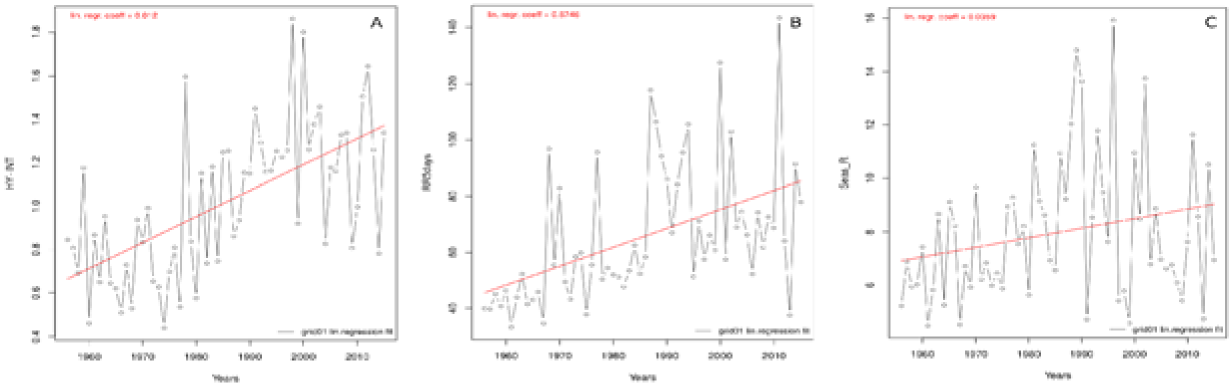

Figure 3: Time series of HY-INT, RR5days and Seas_R indices in the Gran Paradiso National Park PA.

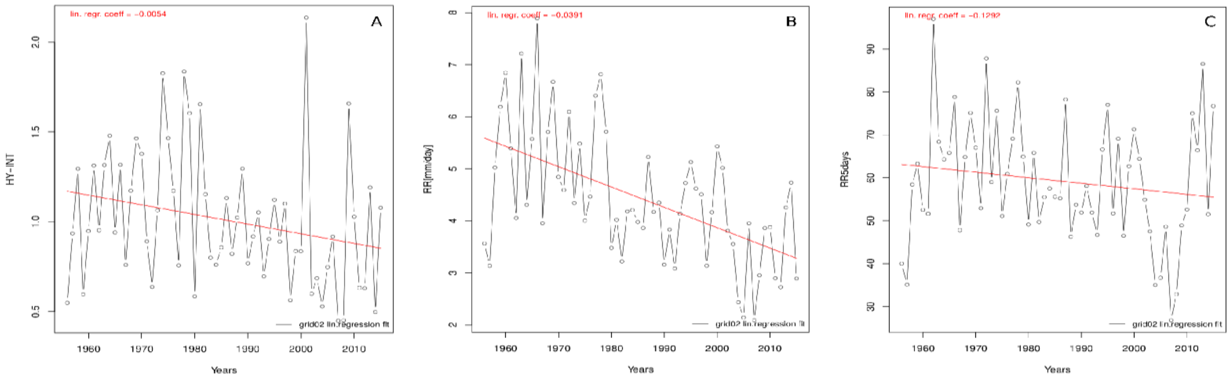

Figure 4: Time series of HY-INT, RR and RR5days in the Peneda PA.

There are some PAs that emerge as those exhibiting the most intense changes in many indices at the same time. One of these areas is the Sierra Nevada PA for which the majority of indices changed in a significant way in the past. Very intense positive changes over the last ~60 years, in particular, were detected in the maximum temperature (TX_ann_mean in Figure 2) as well as in the minimum temperature (TN_ann_mean), in the Growing Season Length (GSL) and in the three heating degree day indices (HDD_autumn, HDD_summer, HDD_spring). Strong negative changes, instead, have occurred in the diurnal temperature range (TX_less_TN_mean in the figure), in the number of frost days (FD) and in the seasonality index for temperature (Seas_T). Another area showing significantly coherent changes in many indices is the Gran Paradiso National Park. In this mountain area we observe positive changes in the mean, minimum and maximum temperature as well as in the diurnal temperature range. Instead, both the number of ice days and frost days decreased from the 1960s up to present. The maximum of consecutive 5-day precipitation and the hydroclimatic intensity index also have increased and the magnitude of their change was large compared to that of other indices. For the Camargue PA almost all the analysed temperature-related indices exhibited a significant change from the 1960s up to present, in line with the generalized warming trend. The hydroclimatic intensity index as well shows a significantly large positive change.

For the sake of completeness, we performed the same analysis shown in Figure 2 using the coefficients obtained by fitting the data with a linear regression (see Figure 5). We calculated the linear fit over the two 30-year long periods already considered for calculating the changes, namely the 1956-1985 (Figure 5A) and 1986-2015 (Figure 5B) intervals, as well as over the entire period, from 1956 to 2015 (Figure 5C). The results referring to the latter (longest) period are in general similar to those shown in Figure 2, referring to the changes of the various indices between the two 30-year long climatologies discussed above. This assures that analysing either the changes between two long-term climatologies or the trends leads to comparable results and that the approach we followed is robust. It is interesting to note that there are similarities between the heatmap referring to the most recent 30 years (1986-2015) and the one obtained for the whole time period (1956-2015), suggesting that trends over the last ~60 years are dominated by the most recent decades. Instead, we observe that many indices whose trend was not significant over the first 30 years (1956-1985) exhibit a significant trend over the last 30 years. This is particularly true for the trend in the mean, minimum and maximum yearly temperature, in the number of summer days and frost days and in the heating degree day indices.

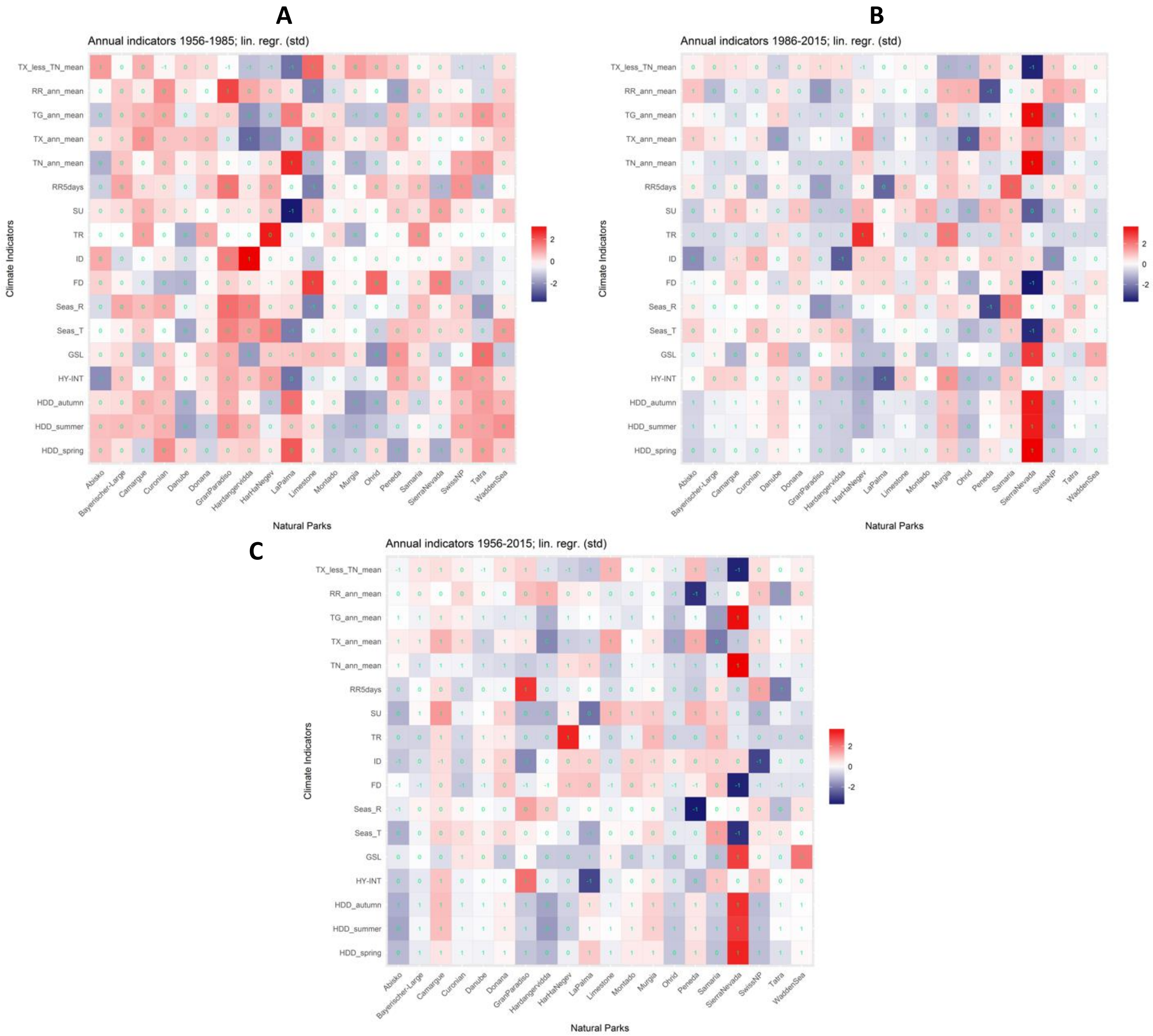

Figure SEQ Figure * ARABIC 5: Coefficients of the Linear regression fit (trend coefficient) calculated over the 1956-1985 (A), the 1986-2015 (B),

RESULTS. Seasonal indices. We repeated the analysis shown in Figure 2 for the seasonally-defined indices. As we described in Section "DATA", some of the seasonal indices have their annual counterpart which has been dealt with in the previous section, while others are strictly defined over the seasons. For them, we used the standard definition of the seasons for the Northern Hemisphere mid-latitudes: winter (December–February, DJF), spring (March–May, MAM), summer (June–August, JJA), and autumn (September– November, SON).

As already observed in the annual indices, we notice that a certain group of temperature-related seasonal indices have a much more coherent behaviour across the different geographical areas than the precipitation-related indices. We refer in particular to the changes in the minimum, mean and maximum temperatures which were positive and statistically significant in almost all PAs and in all 4 seasons (but to a lesser extent in SON) in the last 60 years. On the other hand, the majority of precipitation-related indices exhibit a much less robust signal of change across the different geographical areas and, for many of them, the historical changes were not statistically-significant.

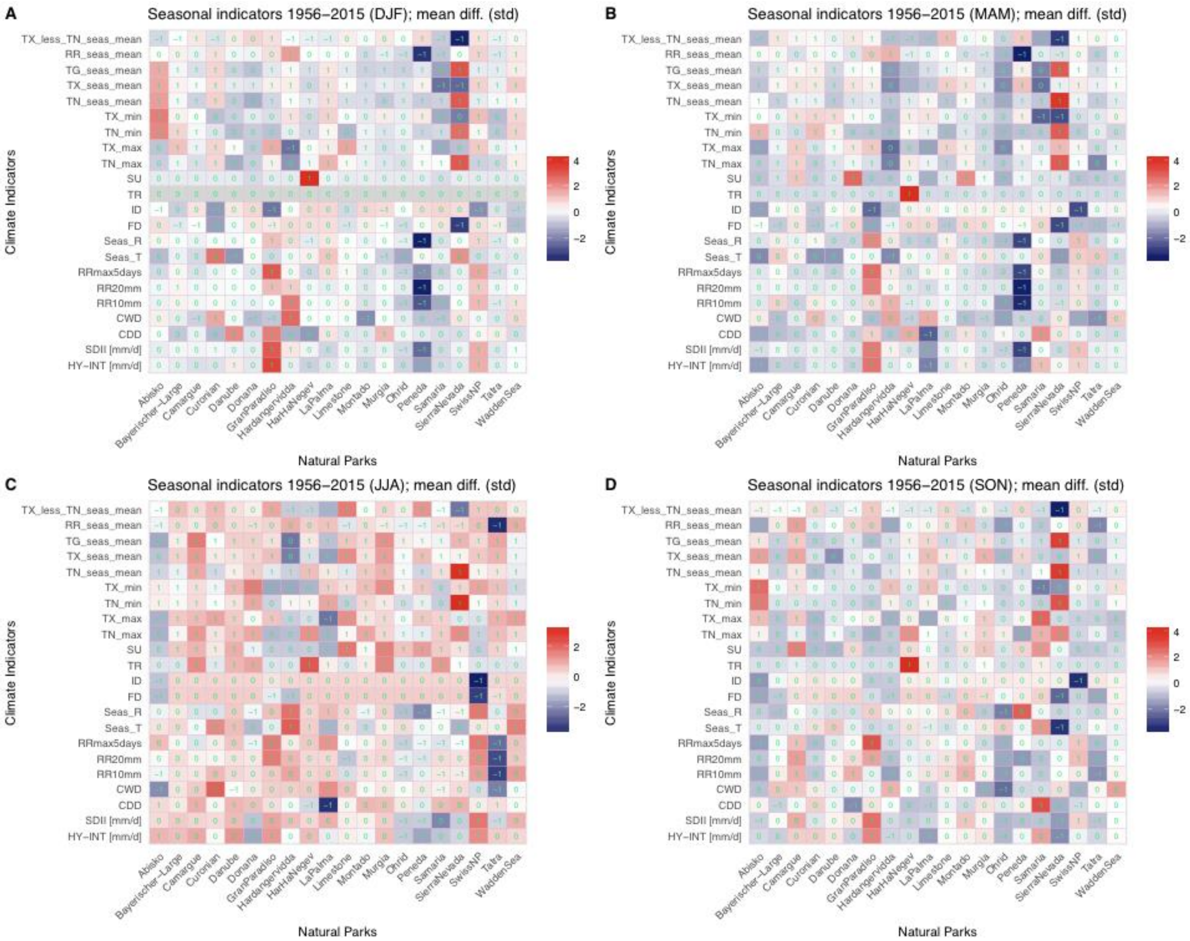

Figure 6: The same as Figure 2, but for the seasonal indices.

One interesting aspect which it is worth focusing on is the pattern of significant changes in HY-INT, SDII, CDD. As already discussed, these indices are related in that HY-INT is obtained as the product of SDII and CDD opportunely normalized (Giorgi et al., 2011) and, therefore, an increase or decrease in HY-INT could arise from an increase or decrease in either SDII or CDD or in both indices. Figure 6 highlights that the change in HY-INT, SDII and CDD varies with the season and with the PA at hand. The Gran Paradiso National Park is the only PA in which significant positive changes occurred in HY-INT, as a consequence of a positive significant change occurred in both SDII and CDD in DJF and in MAM or in SDII only in SON. Another area with a quite robust signal of change in HY-INT in every season except SON is the Swiss National Park. Here, the positive changes in HY-INT were associated with concordant significant changes in SDII. The same kind of robust relationship between the changes in HY-INT and the changes in SDII in all seasons except SON is found for the Peneda PA, though here we observe a decrease of both indices over the last 60 years (as already discussed in the analysis of Figure 4). A similar behaviour was observed at the Ohrid PAs but in JJA and SON seasons only. A further interesting situation is that found in the Abisko PA where we found

HY-INT changes of opposite sign in summer (a positive change driven by the positive CDD change) and in spring (a negative change driven by a negative change of both SDII and CDD).

DISCUSSION AND CONCLUSIONS. Despite the progresses that have been made in recent years, a number of limitations regarding the assessment of temperature and precipitation extremes still exist (Zwiers et al., 2013). These are in part related to the poor quality, consistency and availability of in-situ station observations and to the large uncertainties related to the gridding methods that are commonly used to interpolate point data. Climatic extremes are also inherently difficult to study, because they are particularly sensitive to "scaling issues" in which a mismatch between the spatial representativeness of point-based and gridded values exist. These issues, which are important for the observation-based climate research per se, become certainly very critical when impacts/assessment studies or attribution of climate extremes have to be performed. Our study suffers from both sources of uncertainty, one related to the use of interpolated gridded datasets such as E-OBS (the sparseness of stations and their spatial interpolation) and the other arising from the criticalities/issues in the study of climatic extremes.

Notwithstanding these limitations, there are some aspects that emerge from the study presented above. The majority of temperature-related quantities (not only the indices of extremes, but also the annual/seasonal mean temperature and diurnal temperature range) have changed much more robustly over the last 60 years across most of the analysed PAs than the precipitation-related quantities. The observed temperature-related changes/trends in the various PAs refer to positive changes in the mean, minimum and maximum temperatures, in the number of summer days and tropical nights, and to negative changes in the number of frost and icing days. They are, therefore, in line with warming signals that occurred globally in terms of reduction in the frequency of extreme low temperatures and increases in the frequency of extreme high temperatures. The precipitation-related indices are less robust across the different geographical areas which we analysed than those based on the temperatures, as expected. Precipitation is a less homogeneous variable than temperature and it is more difficult to measure accurately owing to its highly variable behaviour in space and its time intermittency. This makes it even difficult to assess precipitation-related climatic extremes (Zwiers et al., 2013). The quality of precipitation data suitable for "climatic", i.e. long-term, extremes studies are severely limited compared to the datasets available for temperature extremes research. For example, a number of studies have shown differences between different precipitation datasets including their representation of extremes (e.g, Guo et al., 2015).

Despite this, our study also highlighted some interesting results on precipitation-related extremes in specific PAs, such as those belonging to mountain ecosystems and in particular to the Gran Paradiso and Swiss National Parks PAs. These areas have exhibited positive trends/changes in the Hydroclimatic intensity index (HY-INT), related to concordant changes in the average dry spell length and/or in the average precipitation intensity, and thus suggesting a trend toward more episodic and intense precipitation. The HY-INT index (Giorgi et al., 2011) has been found to be an ubiquitous signature of 21st century global warming in several regions of the world, including mountain regions such as the Karakoram-Himalayas (Palazzi et al., 2013).

This study will be extended with an analysis of future changes in climate and climatic extremes over the various ECOPOTENTIAL PAs. We will make use of the simulations performed under the European branch of the Coordinated Regional Downscaling Experiment (CORDEX, Giorgi et al., 2009). The EURO-CORDEX initiative produced a large number of regional projections over Europe of up to ~12 km horizontal resolution (0.11 degrees lon-lat) which is higher than in all previous coordinated experiments of regional modelling (e.g. Jacob et al., 2014)

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2.3. Uniqueness of PAs for conservation strategies in Europe

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INTRODUCTION: Environmental change leads to biodiversity loss at local to global scales. Protected areas are major conservation tools to prevent such loss. But most research on the performance of protected areas focus on local to regional scales (Orlikowska et al. 2016). In addition, the performance of PA networks depends on its large-scale configuration in space (Montesino Pouzols et al. 2014). Therefore, large-scale approaches are urgently needed to identify strengths and weaknesses of PA networks to efficiently protect biodiversity at all scales (Watson et al. 2014, Hermoso et al. 2016).

We suggest assessing the conservation value of PAs in different ways such as in terms of inventory diversity, differentiation diversity, species rarity and the species–area relationship. Consequently, it is possible to identify PAs of high and low uniqueness values to evaluate current conservation efficiency and guide future conservation effort. Thereby, large scale management priorities can be defined.

METHODS: Since distribution data of species are variable in quality and mostly have coarse spatial resolution, we built a probabilistic approach for assigning each reported species to each PA (see also Araújo et al. 2011) by using chain rule probability theory. Based on that, we can estimate the uniqueness of PAs in terms of species rarity and differentiation diversity, and also calculate inventory diversity both directly and accounting for the species–area relationship (SAR). To measure conservation value in these ways, we calculate about seven uniqueness indices as shown in Figure 7 and Figure 8 (reported species richness, area-controlled surplus of reported species, rarity-weighted richness, average rarity, total dissimilarity, turnover dissimilarity, nestedness dissimilarity).

RESULTS: The richness of reported species per grid cell, which ranges from 0 to 189, appears to be low in Poland, the Czech Republic, Romania and Greece, and remarkably high in Bulgaria (Figure 7a). This directly translates into reported species richness per PA (Figure 7b). The other metrics of conservation value (area-controlled surplus of reported species, rarity-weighted richness, average rarity, total dissimilarity balanced dissimilarity and gradient dissimilarity; Figure 8) only partially correlate with reported species richness. Eastern European countries tend to have low values for most of these metrics, but high values of compositional dissimilarity. Macaronesian islands have high values for uniqueness-related metrics. High uniqueness scores are often found for clusters of PAs, especially around the periphery of the EU. In other EU states, also, some PAs have negative Richness SAR_% Surplus, for example on Macaronesian islands, in the Mediterranean Basin, in the United Kingdom, Sweden and Finland (Figure 8a). Scattered across Europe are some PAs with strongly positive Richness_SAR_%Surplus (e.g. in Estonia, Latvia, Germany, Slovakia, Hungary, Austria, Slovenia, Bulgaria and Spain). The values of rarity-weighted richness are heterogeneously distributed across EU member states (Figure 8b). Single PAs with high rarity-weighted richness are found on Macaronesian islands, in the Mediterranean Basin, around the Black Sea, in parts of Central Europe, the Baltic region and in Northern Scandinavia. In most of the rest of Europe, PAs have low rarity-weighted richness. PAs with the highest average rarity tend to occur where rarity-weighted richness is also high (Figure 8c). The range of average rarity values suggests that average reported species rarity is low within the PA network. Total compositional dissimilarity is generally high, but is particularly high in many PAs containing few reported species (Figure 8d).

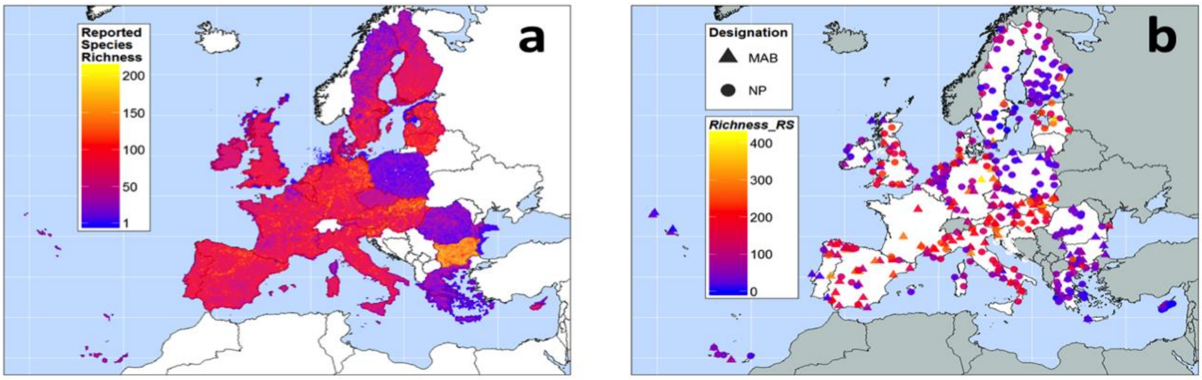

Figure 7: a) Reported richness of the 1654 Annex species of the Birds and Habitats Directive per 10 km x 10 km grid cell in the European Union. The 41 marine species are excluded. b) Reported species richness within 285 national parks (NP) and 147 Man and Biosphere Reserves (MAB) in the European Union. The values estimate the number of Annex species of the Birds and Habitats Directive within these protected areas. For details see Methods section.

Table 4: Ranking of Protected areas in the European Union according to seven metrics of conservation value used in this study, as indicated by the column headers. For each, the three protected areas with the highest and lowest values are shown: name and country (ISO3 code).

	Reported Species Richness		Area-controlled Surplus		Rarity-weighted Richness		Average Rarity		Total Dissimilarity		Balanced Dissimilarity		Gradient Dissimilarity	
TOP	Name	State	Name	State	Name	State	Name	State	Name	State	Name	State	Name	State
1	Flussland schaft Elbe	DEU	Swabian Alb	DEU	Gran Canaria	ESP	Berlengas	PRT	Norra Kvill	SWE	Alonnoisou Voreion Sporadon	GRC	Ängsö	SWE
2	North Vidzeme	LVA	Dalby Söderskog	SWE	Sierra Nevada	ESP (ESP)	Gran Canaria	ESP	Potamos Liopetr	CYP	Berlengas	PRT	Collemellucio-Montedimezzo	ITA
3	Julian Alps	SVN	Ayios Nikandros	CYP	La Gomera	ESP	La Gomera	ESP	Rizoelia	CYP	Axiou	GRC	Julian Alps	SVN
BOTTOM	Name	State	Name	State	Name	State	Name	State	Name	State	Name	State	Name	State
1	Potamos Liopetriou	CYP	Norra Kvill	SWE	Norra Kvill	SWE	De Loonse en Drunense Duinen	NLD	Pfälzerwald	DEU	Julian Alps	SVN	Mesolongiou	GRC
2	Norra Kvill	SWE	Potamos Liopetr	CYP	Ängsö	SWE	De Hoge Veluwe	NLD	Pays de Fontaine	FRA	Slovensky Kras	SVK	Ygrotopon Amvrakikou	GRC
3	Rhizoelia	CYP	Blå Jungfrun	SWE	Blå Jungfrun	SWE	De Groote Peel	NLD	Exmoor	GBR	Flusslandschaft Elbe	DEU	Axiou	GRC

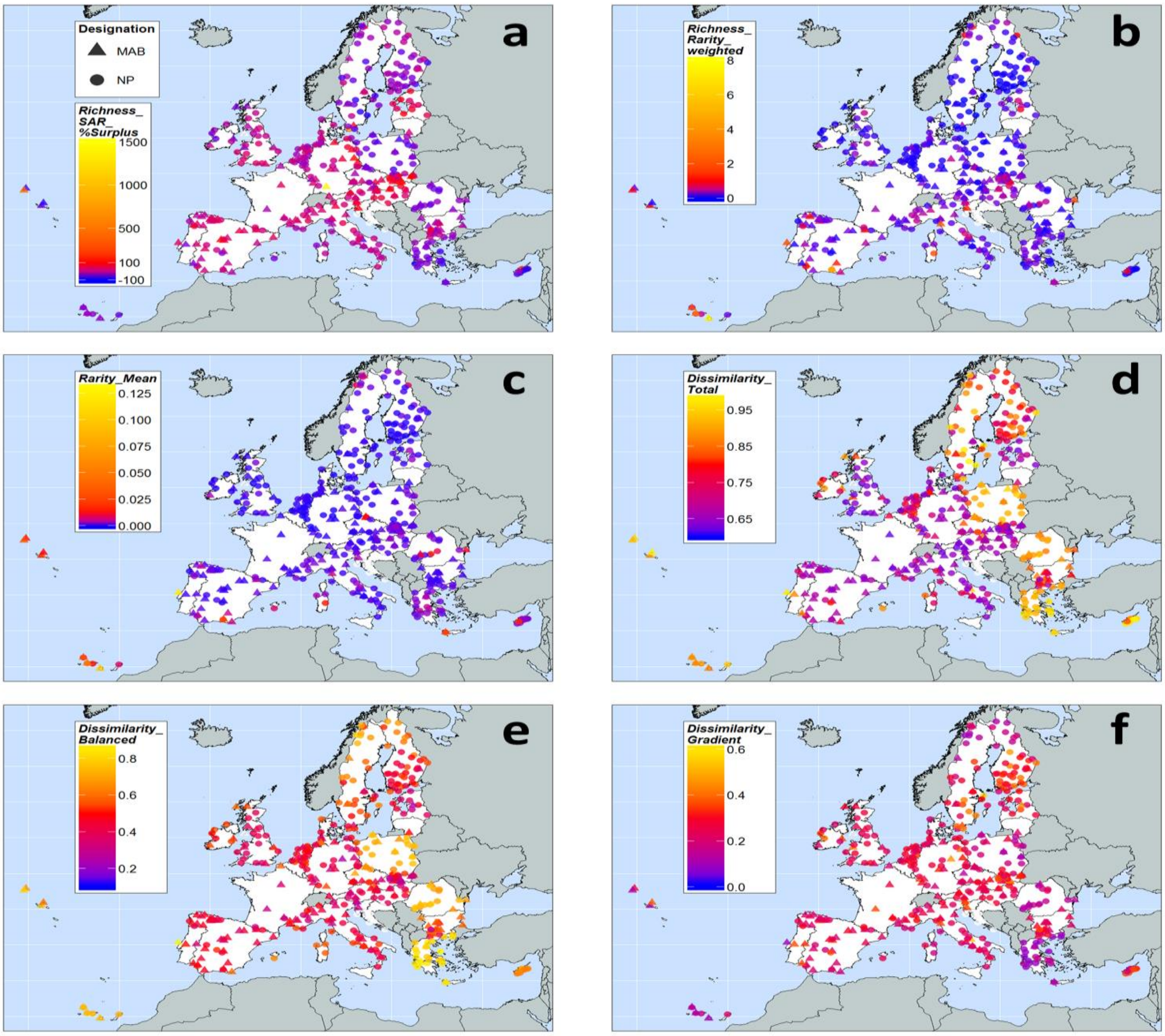

Figure 8: Metrics of conservation value for national parks (NP) and UNESCO Man and Biosphere Reserves (MAB) in the European Union. a) Area-controlled surplus of reported species (Richness_SAR_%Surplus) accounts for the effect of area on reported species richness. It reveals the percentage deviation between observed Richness_RS and predicted Richness_RS, as modelled by the species–area relationship considering observed reported species richness and protected area. b) Rarity-weighted richness (Richness_Rarity_weighted) integrates reported species richness and rarity. It is a measure of the protected area's reported species richness, but weighted by the conservation weights of reported species. c) Average rarity (Rarity_Mean) is calculated by Richness_Rarity_weighted over Richness_RS. It represents the average rarity of reported species within the protected area. d) Total dissimilarity (Dissimilarity_Total) indicates beta diversity between protected areas regarding their species composition. e) Balanced dissimilarity (Dissimilarity_Balanced) and f) gradient dissimilarity (Dissimilarity_Gradient) are the additive components of total dissimilarity.

In Table 4, we list the three PAs with the highest and lowest values for each of the seven conservation-related metrics. These rankings reinforce the geographical patterns described above. Based on the various conservation values, this European wide assessment of PAs shows the sensitivity of scorings through different indicators and suggests systematic evaluation to guide a pan-European conservation strategy (Hoffmann et al. Submitted.).

DISCUSSION AND CONCLUSION: A macroscopic perspective is necessary to guide effective conservation strategies (Araújo et al. 2011, Le Saout et al. 2013, Montesino Pouzols et al. 2014, Maiorano et al. 2015). Research effort has barely aimed to understand the potential of PA networks at international scale (Orlikowska et al. 2016), and most nature conservation funding has not been addressed to high conservation priorities (Hermoso et al. 2016). With our study, we propose a new perspective and simple analytical tools for decision-making and conservation prioritization at large scales. Funding strategies require transparent instruments to set conservation priorities for the spatial distribution of conservation effort (Hochkirch et al. 2013a, b; Maes et al. 2013, Kati et al. 2014, Linnell et al. 2015). Our novel approach allows PAs to be ranked, with respect to biodiversity components of conservation concern, and can be easily adopted for any data and PA type, and for other components of biodiversity.

Our method supports international conservation planning by demonstrating strengths and weaknesses of PA networks. We developed, for the first time, a range of measures of conservation value for PAs that include both richness metrics and dissimilarity values. Compositional dissimilarity is a crucial dimension of conservation performance of PA networks (Chiarucci et al. 2008) that is often neglected (Socolar et al. 2016). It is just another fundamental component of biodiversity that informs about complementarity, and is therefore highly relevant to multi-site considerations, such as to PA networks.

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2.4. Land cover change for all European PAs

By Walz, A. and O. Korup. 2017. CORINE for large-scale monitoring of Protected Areas in Europe. 6th International Symposium for Research in Protected Areas, 02-03. Nov. 2017, Salzburg

INTRODUCTION: Protected Areas (PAs) are recognized to play a crucial role in safeguarding European biodiversity, and are therefore also directly addressed in international conservation obligations through the Convention of Biodiversity, namely the Aichi Targets. Large-scale monitoring of PAs, including not only NATURE2000 sites, but also the numerous nationally designated PAs, has not yet been well established within the EU (EEA, 2012), although a number of Pan-European datasets could make a start for such a monitoring. Land cover change is among the most obvious transitions that ecosystems can go through and that can often indicates the overall state of the ecosystem. CORINE land cover monitoring has been established in the late 1980s and has been iterated three times since then. It covers all Europe, including all PAs. CORINE has not specifically been designed for the monitoring across PAs, and even less so for the monitoring of single PAs. Still, it remains one of the most promising data sets for large-scale land cover monitoring of PAs across Europe over the past almost 30 years, and there is a strong potential to learn from this monitoring for future, possible more adapted monitoring of PAs based on recently more and more available remote sensing data. In this contribution, we aim at identifying (1) large-scale patterns of land cover change in PAs based on CORINE data and (2) main drivers for land cover change in PAs across Europe.

METHODS: CORINE land cover change (LCC) has been published for the four survey periods in 1990, 2000, 2006 and 2012. In addition to the well-known wall-to-wall European land cover data, also CORINE LCC focuses specifically on the monitoring of change. These data cover all 44 CORINE land cover classes, and use a Minimum Mapping Unit of 5 ha with a width of at least 100 m. The technique of mapping changes first has been applied by most countries since 2006, and for previous survey periods the data have been reconstructed. Hence, the land cover change data are available between all survey periods, i.e. for 90-00, 00-06, and 06-12.

To analyse land cover changes, the 44 CORINE land cover classes have been grouped in major land cover flows (LCF) according to Feranec et al. (2010). These LCFs include a total six flows, with LCF4 representing changes towards forest and natural ecosystems and LCF5 representing all changes with loss of forest and natural ecosystems. The Common Database on Designated Areas (CDDA) is the official source of PA information from European countries to World Database of Protected Areas. It contains various types of nationally designated PAs and provides also the IUCN category of each PA. In December 2016, CDDA contains 101,712 PAs, with 97% of them including also spatially explicit information on their extent. Data gaps still exist for Austria, Estonia, Hungary, Ireland, Montenegro, Romania and Turkey. Greenland had to be excluded because of missing CORINE land cover data. After all a total of 97,705 nationally designated PAs covering a total of 276 Mio ha, including 105 Mio ha on land, were included in the analysis. Variables tested to explain observed land cover change in PAs include data on the level of the individual PA, NUTS3, NUTS2, national and higher levels.

All observed CORINE LCC were assigned to one of six LCFs. Then all spatially explicit PAs boundaries of the CDDA were intersected by CORINE LCC. A 1km-buffer was calculated for each PA, and again intersected with the CORINE LCC. Areas of PAs, PA buffers as well as areas of each observed change within PAs were calculated. The annual fraction of change was derived by normalising observed change by PA size and the number of years between surveys. Annual fractions of change for all LCFs are plotted for each change period to identify most important processes. Using Kruskal-Wallis tests, significant differences in annual fractions of change were tested for (1) PAs, buffers around PAs and across European were tested and for (2) different IUCN categories for the last period 06-12. For this first analysis only land cover change was included that was completely contained within a PA, with a consequent reduction of analysed PAs by about 19 % of the PA with observed change.

Quantile regression analysis was used to identify main drivers of CORINE LCC within European PAs. In the analysis we use drivers of different spatial resolution, namely from the level of the individual PA, NUTS3, NUTS2, NUTS1, and pan-European scale.

RESULTS: Out of the almost 95,000 PA available with their geographic boundaries, 3394 were affected by land cover change according to CORINE LCC. Changes within PAs are dominated by LCFs 4 and 5 (gain and loss of "forest and natural vegetation") in all three CORINE LCC periods, although the identified rates of change vary considerably between the three periods (Figure 9).

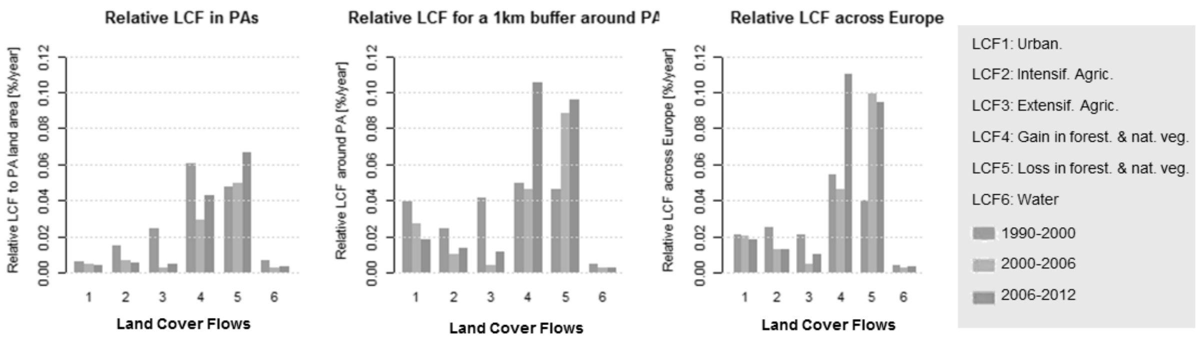

Figure 9: Mean rates of LCC for all six different LCFs within PAs, in a 1km buffer around PAs and across Europe for the periods 90-00, 00-06 and 06-12.

Rates for LCFs 4 and 5 also dominate land cover change outside PAs and across Europe. Across all periods rates of change in close vicinity of PAs and across Europe are similar, with rates being particularly high for the period 06-12. The two dominating LCFs vary considerably between IUCN categories (Figure 10A) with absolute change adding up tremendously in particular for the large extent of areas protected on IUCN level V. Rates of changes normalized by the area covered by different levels of protection, however, are not exceptional for the IUCN categories V and VI, which explicitly allow for human intervention to sustain the region and biodiversity (Figure 10B).

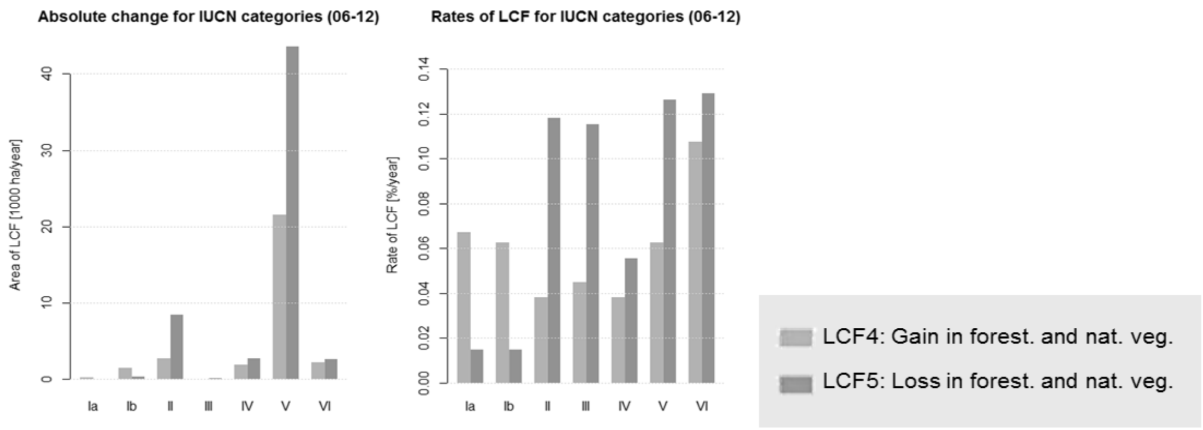

Figure 10: Rates of LCC for LCFs 4 (A) and LCF5 (B) (loss and gain of forest and natural vegetation) across IUCN categories for 06-12

Gain of forest and natural vegetation is more similarly distributed between IUCN categories than loss, which is particularly low for IUCN categories Ia and Ib. Kruskal-Wallis and Dunn´s test confirm significant difference in land cover change between IUCN categories, as well as within and outside PAs.

Median regression models of potential driving factors indicate patterns to explain rates of change for LCF4 and LCF5 (Table 5). Significant contribution to explain both rates of land cover change include the elevation, IUCN categories, population density at NUTS 3 level, the national environmental tax as the share of GDP and latitude position of the PA. Significant explanation, thus, include factors from local, NUTS 3 and national level.

Table 5: Summary of Median Regression Models for LCF5 and LCF4. Significant factors are indicated in bold for each model.

Scale	Variable	LCF4				LCF5			
		Value	Std. Error	t value	Pr(>|t|)	Value	Std. Error	t value	Pr(>|t|)
	(Intercept)	-0,0707	0,3245	-0,2178	0,8276	0,7042	0,3036	2,3193	**0,0204**
PA specific level	Elevation (m)	-0,0004	0,0001	-4,7652	**0,0000**	-0,0003	0,0001	-5,3686	**0,0000**
	Slope (%)	0,0025	0,0018	1,4195	0,1558	0,0051	0,0019	2,6203	**0,0088**
	Marine fraction (%)	0,0146	0,0460	0,3163	0,7518	0,0037	0,0026	1,4165	0,1567
	Land area (ha)	0,0000	0,0030	-0,0161	0,9872	0,0000	0,0001	0,1923	0,8475
	Site area (ha)	0,0000	0,0030	0,0152	0,9879	0,0000	0,0001	-0,2148	0,8299
	Ann. rate of LCF4/5 (%/a)	3,0631	1,2173	2,5163	**0,0119**	1,6652	1,5762	1,0564	0,2908
	IUCNCATIb	-0,6177	0,1232	-5,0155	**0,0000**	-1,0524	0,1165	-9,0300	**0,0000**
	IUCNCATII	-0,8092	0,1007	-8,0364	**0,0000**	-0,5253	0,0913	-5,7540	**0,0000**
	IUCNCATIII	0,0201	0,1527	0,1316	0,8953	0,1984	0,1049	1,8906	0,0588
	IUCNCATIV	-0,0648	0,0649	-0,9979	0,3184	-0,2200	0,0643	-3,4185	**0,0006**
	IUCNCATUA	-0,6183	0,0873	-7,0831	**0,0000**	-0,3581	0,0869	-4,1215	**0,0000**
	IUCNCATV	-0,6959	0,0670	-10,3917	**0,0000**	-0,5242	0,0701	-7,4725	**0,0000**
	IUCNCATVI	-0,1084	0,1714	-0,6327	0,5270	-0,3496	0,1537	-2,2746	**0,0230**
NUTS 3 level	Population density	0,0001	0,0000	2,0814	**0,0375**	0,0003	0,0001	2,1169	**0,0343**
	Migration rate	0,0040	0,0052	0,7739	0,4390	0,0079	0,0033	2,3731	**0,0177**
NUTS 2 level	Population density	0,0002	0,0001	1,1163	0,2644	0,0000	0,0002	-0,0415	0,9669
	Migration rate	-0,0113	0,0066	-1,7152	0,0864	-0,0057	0,0052	-1,0907	0,2755
National level and higher	Environ.. Tax (% GDP)	-0,2761	0,0468	-5,8986	**0,0000**	-0,1578	0,0443	-3,5627	**0,0004**
	Latitude (°)	-0,0231	0,0045	-5,1237	**0,0000**	-0,0463	0,0047	-9,8619	**0,0000**
	Longitude (°)	0,0175	0,0037	4,6827	**0,0000**	0,0049	0,0026	1,8829	0,0598

DISCUSSION AND OUTLOOK: CORINE LCC, as the one available pan-European land cover change monitoring programme, indicates dynamics in land cover within PAs that differ substantially from their direct surrounding and overall Europe. Dominating land cover changes are gains and losses of forest and natural vegetation. The observed changes are mainly from and to “forest and natural vegetation”, and confirm that development and changes in agriculture are minor within PAs. IUCN category and elevation above sea level are significant PA specific factors to explain rates of change, and also regional parameter from the NUTS 3 and national level and higher proved significant. The analysis, hence, shows that drivers for land cover change within European PAs can be identified at different scales.

Following up on these first results, we will assign land cover change to human intervention or natural processes, conduct more systematic testing of individual drivers and use hierarchical modelling for single groups of PAs. For Pan-European land cover monitoring system of PAs, higher temporal and spatial resolution and better indication of natural disturbances and ecosystem degradation would be a powerful asset.

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3. Current states and trends in ecosystems beyond PAs

By Ariane Walz and Jennifer Schulz

This chapter deals with the current state of ecosystems on a European scale beyond PAs. The first sub-chapter (3.1) uses remote sensing data to detect limiting factors for terrestrial ecosystem productivity based vegetation indices and land surface temperature on a pan-European scale. The sub-chapter 3.2 investigates the use of remote sensing based measurements of sea surface temperature (SST) as an Essential Variable for marine ecosystems. Based on an assessment of several water quality variables derived from satellite, such as (SST) and Chlorophyll-a concentration together with other modeled variables like currents, dissolved oxygen (DO), etc., the final result is an integrated toolbox oriented towards the development of an EO downstreaming service to support the planning of maritime uses. Based on the trait-based dynamic vegetation model LPJmL-FIT, the sub-chapter 3.3 investigates the gross primary productivity (GPP) and potential functional diversity of European forests across and beyond ECOPOTENTIAL PAs. The study presented in sub-chapter 3.4 deals with the vulnerability of European freshwater ecosystems to climate change building on about 1,700 species in about 19,000 habitats and including all the three dimensions of climate change vulnerability, namely exposure, sensitivity and resilience. Finally, a pan-Mediterranean assessment of habitat connectivity across the Mediterranean Sea is presented in sub-chapter 3.5, identifying areas of key relevance to maintain this connectivity.

3.1. Pan-European RS analysis for NDVI and LST

By Arnon Karnieli, Dani Varghese, Natalya Panov, Tarin Paz-Kagan.

INTRODUCTION: Among other climatic and physical factors affecting vegetation growth, water and energy are the two primary ones (Churkina and Running 1998; Nemani et al. 2003). Water is required by all living organisms and precipitation is crucial as the main source of water supply. Plants can be stressed by lack of moisture as well as an excess of moisture. Energy, mostly measured by air/soil temperature determines photosynthetic and respiration rates as well as the amount of nutrients available for plant uptake through the influence on litter decomposition rate. In a traditional way, precipitation and air/soil temperature are standard and common variables that are continuously measured in meteorological stations worldwide. However, these are point observations that should be interpolated in order to obtain a spatial map over a large area. The alternative is to use remote sensing data.

In terms of Earth observation, data from both visible to near-infrared (VNIR) and thermal (TIR) spectral regions, have advantages in terms of utility of vegetation growth limited factors. It is thus assumed that the Normalized Difference Vegetation Index (NDVI), based on the VNIR region, can be a good proximity to rainfall and land surface temperature (LST), based on the TIR region, to energy. Since these two variables are standard produces of several spaceborne systems (e.g., MODIS, Sentinel 2 and 3), it is further assumed that by studying the relationship between these two, it would be possible to (1) map the areas governed by water or energy growth-limiting factors; (2) study the change of the relationship between these two variables (NDVI and LST) in different time of the year (e.g., months); (3) study long-term changes (e.g., 2000 – 2017) of the spatial distribution of these variables; (4) to examine the relation between the two variables in specific time, e.g., in wet vs. drought years; and (5) relate the relationship between the variables to the main land-cover classes over Europe (e.g., forests, scrublands, agriculture crops, etc.).

Although LST-based assessments of land surface conditions have shown a better performance over sparse vegetation cover (Friedl and Davis 1994), VNIR-based indices are more reliable at assessing the condition and dynamics of vegetation over intermediate levels of vegetation cover (about 50%, Huete et al. 1985). Therefore, extensive work has been devoted to combining these state variables into a unified climatic indicator, based on the assumption that complementary information in these spectral regions may provide a more robust characterization for different phenomena at the land surface. Studies have revealed a strong negative correlation between NDVI and LST (Gurney et al. 1983; Goward et al. 1985; Hope et al. 1986; Hope 1988; Goward and Hope 1989; Nemani and Running 1989; Price 1990; Smith and Choudhury 1991; Hope and McDowell 1992; Nemani et al. 1993; Prihodko and Goward 1997; Goward et al. 2002), resulting from the cooling effects of canopy transpiration. These early studies were typically limited to relatively small areas and based on a limited number of images. The spatiotemporal variability of the LST-NDVI relationship on continental or global scales has been investigated in several studies (Schultz and Halpert 1995; Lambin and Ehrlich 1996; Churkina and Running 1998; Nemani et al. 2003; Julien et al. 2006; Olthof and Latifovic 2007; Sun and Kafatos 2007; Julien and Sobrino 2009). However, all of these studies used only the yearly or growing season mean values. Despite the general concept of negative correlation between NDVI and LST, the global distribution of the LST and NDVI relations shows negative correlations over drylands and mid-latitudes and positive correlations over the tropics and high latitudes (Schultz and Halpert 1995; Churkina and Running 1998; Nemani et al. 2003; Julien and Sobrino 2009).

Thus the main goal of the project was to explore the spatial and temporal relation between LST and NDVI with respect to climatic growth-limiting factors over the entire European continent. In this regard, it is hypothesized that across the European continent, mainly from south to north, the relation between LST and NDVI change. In the south, we expect to have significant indirect relationship (correlation) between LST and NDVI due to the water-limited environment, while in the north – significant direct relationship, due to the energy limited environment. In the transition area between the south and the north the correlation is expected to be insignificant. Of course, these relationships are expected to be changed in different time of the year.

METHODS: Moderate Resolution Imaging Spectroradiometer (MODIS) version 6 (including Terra and Aqua products) monthly data (MOD11C3, MYD11C3, MOD13C2 and MYD13C2) with a resolution of 5600 m were used to produce the NDVI and LST data for the European domain. Images from 2000 to 2017 were downloaded from the LP DAAC website and categorized on monthly level. Firstly, Terra and Aqua layers were stacked and performed data quality test by using the LST, NDVI layers with its corresponding quality layers. In the second procedure all the quality tested layers were calibrated with scale factors, as mentioned in the data layer characteristics of the product. In the third step, all the calibrated layers (18) were stacked month wise and generated a single layer that carries the information from 2000 to 2017. Finally, these layers were used to produce the scatterplots that exhibits the spatial relationship between NDVI and LST.

RESULTS: The spatial distribution of LST vs. the NDVI over the European domain, established upon long-term average from 2000 to 2017, is presented for May and September in Figure 11. These maps are based on the scatterplots of LST vs. NDVI, shown in the small figures. In each scatterplot, two branches can be observed – one with positive correlation and the other with negative correlation. The feature space within these scatterplots, is translated to geographic locations in the large figures and proves the hypothesis that negative relationships (i.e., water limited factors) are characterize the southern part of the European domain and positive relationships (i.e., energy limited factors), the northern part.

(A)

(B)

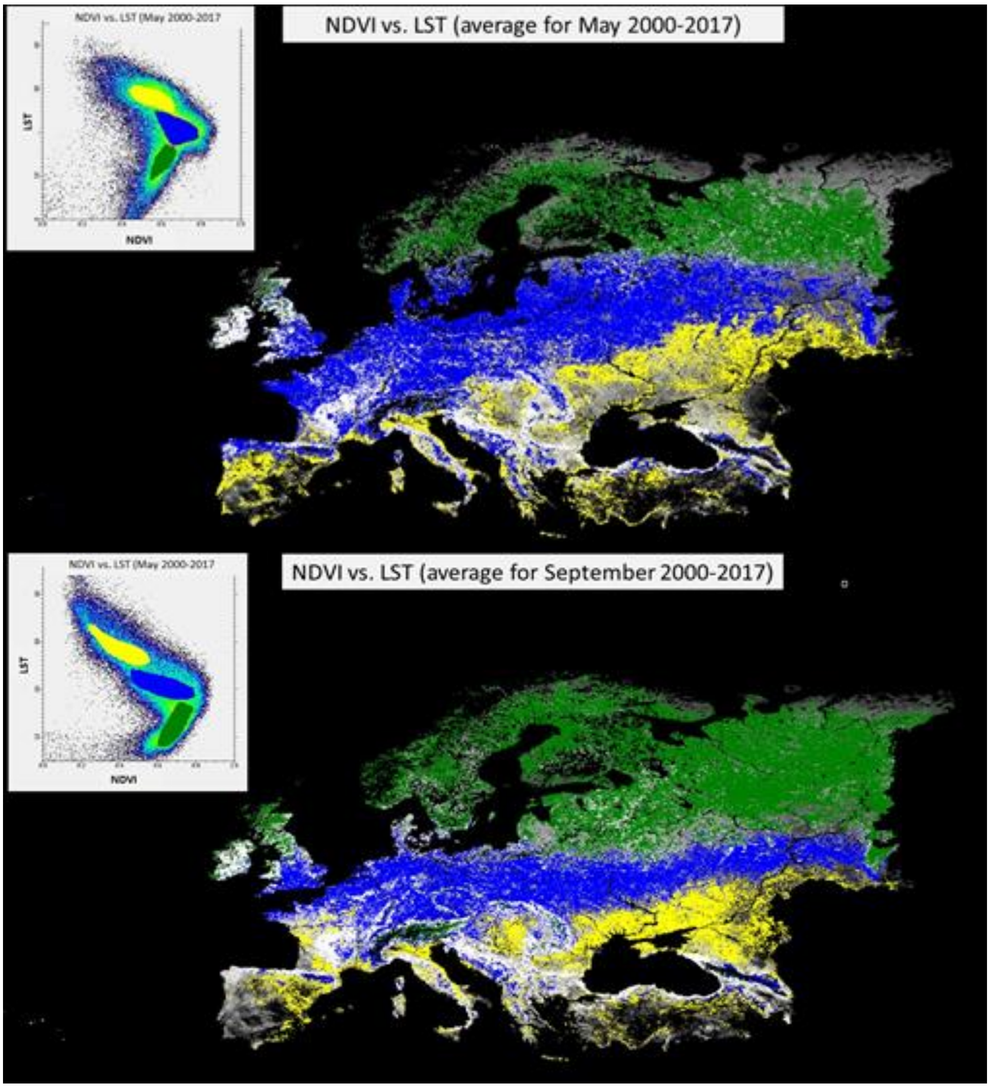

Figure 11: Spatial distribution of Land Surface Temperature (LST) vs. the Normalized Difference Vegetation Index (NDVI) over the European domain in May and September (long term average from 2000 to 2017). Small figures show the scatterplots of LST vs. NDVI. The feature space within these scatterplots, is translated to geographic locations in the large figures.

DISCUSSION AND CONCLUSION: This project explores the spatial and temporal relationship between LST and NDVI over Europe during two representative months (May and September). In contrast to the common perception that LST and NDVI are typically negatively correlated, it is demonstrated that this relationship in fact varies with location, specifically along the latitude. This study revealed that during the beginning and the end of the growing season, solar radiation is the predominant factor driving the correlation between LST and NDVI, whereas other biophysical variables play a lesser role. It was found that when energy is the limiting factor for vegetation growth, as is the case at higher latitudes and elevations in the study area, a positive correlation exists between LST and NDVI. Conversely, when energy is the limiting factor for vegetation growth, as is the case at lower latitudes in the study area the LST-NDVI correlations are generally negative.

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3.2. Sea surface temperature as an Essential Variables for marine ecosystems

Valentini, Emiliana; Filipponi, Federico; Nguyen Xuan, Alessandra; Passarelli, Francescomaria; Taramelli, Andrea, 2016. Marine food provision ecosystem services assessment using EO products. European Space Agency Living Planet Symposium. Prague, Czech Republic from 9-13 May 2016.

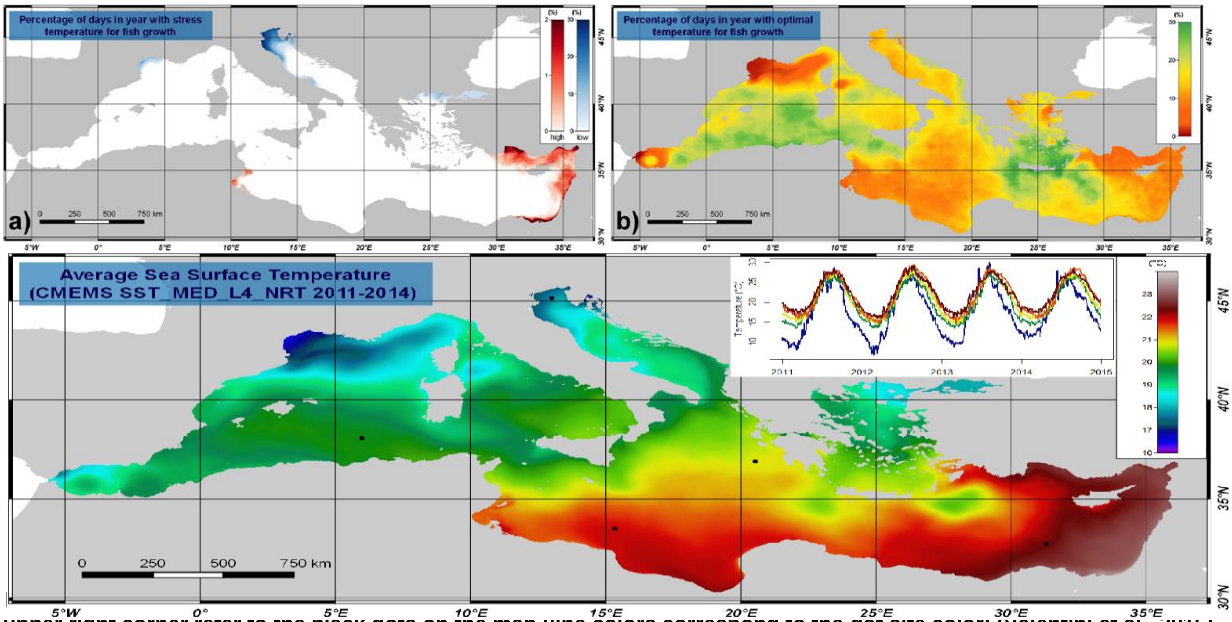
Filipponi Federico, Valentini Emiliana, Taramelli Andrea, 2017. Sea Surface Temperature changes analysis, an Essential Climate Variable for Ecosystem Services provisioning. 9th International Workshop on the Analysis of Multitemporal Remote Sensing Images (MultiTemp), Bruges (Belgium) 27-29 June 2017, IEEE Conference Publications. DOI:10.1109/Multi-Temp.2017.8035255. ISBN: 978-1-5386-3327-4.

Status and evolution of food provision service through sea surface temperature time series analysis using STL and EOF on Mediterranean LME was also presented in D4.5. The existing monitoring schemes from an EO point of view could highly benefit from the availability derived indicators at high spatial resolution and for long periods in order to better foresee future essential variables evolution and as a consequence changes in ecosystem service delivery (D 7.1).

INTRODUCTION: Physical, chemical and biological characteristics of seawaters are primary descriptors to assess the spatial and temporal dimensions of ecological productivity performances in terms of fish vitality, growth and stress. Among these characteristics, temperature can be considered the key descriptor, i.e. the Essential Variable (EV) to characterize fish vitality and thus marine food provision potential, because it influences the variation of many other parameters and as consequence the entire life cycle of marine organisms. Focusing on the thermal habitat of fish species, a fish growth model is used to reveal different scenarios in the potential growth of fish populations under past and current conditions.

METHODS: In this research a time series of sea surface temperature (SST) products from the Copernicus Marine Environment Monitoring Service (CMEMS), namely the CMEMS operational product 'SST_MED_SST_L4_REP_OBSERVATIONS_010_021' reproducing daily gap-free measurements of SST at 4 km horizontal resolution over the Mediterranean Sea was analyzed in order to determine trends of spatial and temporal variability of SST. Therefore, three different analytical methods were used. Firstly, Seasonal Trend Decomposition analysis using Loess (STL), was used to divide the SST time series into the three components, namely the trend, seasonality and remainder. Secondly, Empirical Orthogonal Function (EOF) analysis, consisting of a principal component analysis representing spatial and temporal dimensions to rank spatial patterns of variability, their time variation and the importance of each pattern on the basis of variance (Falcieri et al., 2014), has been adopted in order to reduce the input time series dataset to a smaller set of orthogonal patterns. And thirdly, a series of Self-Organizing Maps (SOM) has been used to reduce data dimensionality of large spatio-temporal datasets adopting a neural network method with an unsupervised training process (Kohonen, 2001). Based on this threefold SST trend analysis, scenarios of potential fish growth rates were generated using an EO based fish growth model developed by Valentini et al., 2016. For the assessment of fish growth conditions based on CMEMS products, the spatial and temporal distribution of water quality variables derived from satellite were considered, such as Sea Surface Temperature (SST) and Chlorophyll-a concentration, together with other modeled variables like currents, dissolved oxygen, etc. With this model, annual fish growth scenarios were generated for the fish species Sea Bass and Sea Bream for the three periods 1984-1987, 2011-2014 and 2038-2041 for the whole Mediterranean Sea.

RESULTS: For the Mediterranean Sea SST values range from a minimum of 3.65°C to a maximum of 34.8°C in the period 2011-2014, the map of average SST is shown in Figure 12 (Valentini et al., 2016).



upper right corner refer to the black dots on the map (line colors correspond to the dot site color).(Valentini et al., 2016)

Figure 13: a) Percentage of days in year with stress temperature for fish growth. b) Percentage of days in year with optimal temperature for fish growth. (Valentini et al. 2016)

Spatial variability of this variable follows a latitudinal gradient and the main basin circulation. The percentage of days in year with stress seawater temperature for fish growth (Figure 13a) reaches up to 30% in the northern Adriatic Sea and up to 15% in the Sea of Marmara and Gulf of Lion. Furthermore, results based on the SST trend analysis indicate that in the past three decades the eastern part of the Mediterranean Sea experienced greater SST increase than the western part, producing different scenarios of fish growth rates across the Mediterranean regions for past and current conditions (see Figure 14 and Figure 15).

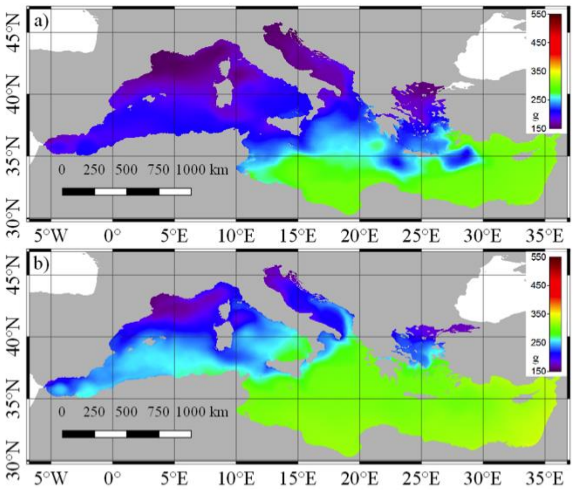


Figure 14: Estimated annual fish growth for Sea bass fish species: (a) scenario for the period 1984-1987; (b) scenario for the period 2011-2014 (Filipponi et al., 2017).

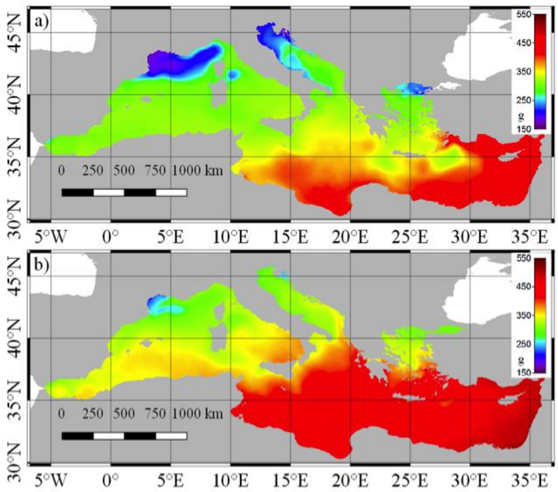


Figure 15: Estimated annual fish growth for Sea bream fish species: (a) scenario for the period 1984-1987; (b) scenario for the period 2011-2014 (Filipponi et al., 2017).

Apart from the specific scenarios derived for two representative fish species, a final research result and output of the ECOPOTENTIAL project is an integrated toolbox oriented towards the development of an EO downstreaming service (see Valentini et al. 2016), that collects the workflows of processing procedures to support the planning of maritime uses.

DISCUSSION AND CONCLUSION: Extended time series of EO products provided by CMEMS provide consistent information to support the valuation of essential variables such as SST as a basis for estimating fish growth potential, which in turn is a proxy for provisioning (food production) ecosystem services (ESS). The Mediterranean Sea large marine ecosystem show a SST rise of 1.4 Celsius degrees on average during the period 1982-2016, with a higher increasing trend in the eastern part of the basin. The used data analytics are capable to extract information from large EO product datasets, demonstrating that the use of extended time series of EO products, and the availability of wide datasets collection in the framework of the Copernicus services, allow the generation of downstreaming services and scenarios for ESS under climate change.

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3.3. The potential for functional diversity of forests in Europe

By Maik Billing, Kirsten Thonicke, Boris Sakschewski, Werner von Bloh und Ariane Walz

INTRODUCTION: A long land use history, intensive management, planting of monocultures and fragmentation has strongly reduced the diversity of European forests. In contrast, scientific research strongly supports that biodiversity, including functional biodiversity, is an important factor for the resilience and the ability of a system to recover after disturbances (Sakschewski et al., 2016; Thompson, Mackey, McNulty, & Mosseler, 2009; Yachi & Loreau, 1999). Therefore, especially in face of climate change, it is crucial to maintain and restore forest diversity in Europe. This study assesses the potential functional diversity of European forests across and beyond ECOPOTENTIAL PAs, as a results of climatic controls mainly, and with no respect to historic and current human intervention. From such pan-European assessment of the functional diversity, we aim to identify regions of high and low functional diversity. We identify areas with high functional diversity but low protection coverage, which could be highly valuable for extended nature conservation efforts.

METHODS: We use the trait-based dynamic vegetation model LPJmL-FIT which is a subversion of the global dynamic vegetation model LPJmL and simulates individual trees with unique plant functional traits including e.g. specific leaf area (SLA), leaf longevity (LL) and wood density (Sakschewski et al., 2015). These individual trees are the stochastic products of different traits combinations which include the associated trade-offs between traits, and do not necessarily specific tree species. With these traits combinations it allows a better representation of the functional diversity and trait adaptability, compared to other vegetation models that are based on plant functional types with fixed traits (Sakschewski et al., 2016). The model and resulting trait combinations are highly sensitive to environmental conditions, mainly climate, and do not include land use and forest management. Within the covered area, LPJmL-FIT simulates two different plant functional types: Boreal needle-leaved trees (NL) and broadleaved trees with a summergreen phenology (SG). Pan-European simulations were run with dataset of the WATCH (Weedon et al., 2011) and WFDEI (Weedon et al., 2014) datasets based on the reanalysis of ERA-Interim data on a 0.5 degree resolution between between 1984 and 2014 after a 500 year spin-up.

We use MODIS data to validate the model for eight different PAs across Europe with near natural forest stands, which cover a broad range of climates, between 1984 and 2014. For the validation of carbon fluxes (GPP), we used

MODIS remote sensing data (MOD17A2H, monthly, 2004-2013) and - where available – flux tower measurements from the Euroflux network. The MODIS data was retrieved from the online Application for Extracting and Exploring Analysis Ready Samples (AppEEARS), courtesy of the NASA EOSDIS Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (Running, 2015). In order to identify the MODIS pixels, which cover nearly natural forests within the PAs, we used information from websites of the protected areas and literature. If no information was available, we cut the MODIS data by the whole extent of the protected area. In addition, only MODIS-pixel were selected, which contain at least 75% of tree canopy cover in year 2000 according to Hansen et al. (2013).

The validation of the distributions of simulated specific leaf area (SLA) and wood density (WD) for both plant functional types builds on the global trait database TRY (Kattge et al., 2011). Here, we compare the observed data to the modelled trait distributions in grid cells that correspond to the location of the original observation.

For a pan-European assessment of the potential functional diversity, we calculated the Shannon Diversity Index (SDI) from the SLA distribution of each cell. For this, the SLA distributions across individual trees from each cell were binned into 100 equally sized intervals covering the entire SLA spectrum. Based on the binned data, the SDI was calculated by applying the formula for the Shannon Diversity Index (Shannon, 1948). High SDI values indicate a broad and even coverage of the SLA spectrum. To overlap the potential functional diversity to conservation efforts, we selected the 500 largest terrestrial protected areas in the CDDA database and compared their spatial distribution to the mean SDI.

RESULTS: The validation with MODIS derived GPP for a set of near-to-natural forests in Europe indicates a tendency for over- or underestimating the annual sums of GPP compared to MODIS, and a good representation of intra- and inter-annual variability in GPP for most sites. The first can be partly explained through the focus on trees in the LPJmL-FIT model, while in reality grasses or shrubs add to the overall GPP as observed from space; and the lack of MODIS to detect the vertical thickness of primary production. The exceptions in the good representation of seasonality include Penedas-Gerês, and Dundo, because these sites partially include broadleaved evergreen trees, which are currently not represented in the model. While the means of the simulated plant functional traits are close to the means derived from observations in the TRY database, the variance of the simulated traits is a lot smaller. The latter can be explained through the absence of trait plasticity in the model. Whereas the model assigns mean trait values to each individual, in reality plant traits can vary greatly even within a single tree (Konôpka, Pajtík, Marušák, Bošeľa, & Lukac, 2016).

Table 6: Error measures of the GPP model output compared to the MODIS data for each site. (ME = Mean Error, NMSE = Normalized Mean Square Error) (Kelley et al., 2013)

Site	GPP			Mean monthly GPP			Annual sum of GPP			Comment
	ME	Corr.	NMSE	ME	Corr.	NMSE	ME	Corr.	NMSE	
Białowieża (POL)	-6.71	0.94	0.12	-6.7	0.986	0.04	-80.5	0.33	4.89	highly correlated GPP and seasonality, underestimation of annual sum
Dundo (HRV)	-8.0	0.79	0.51	-8.0	0.87	0.30	-95.4	0.38	3.88	relatively low correaltion in GPP, overestimated break-in of GPP in summer due to dryness
Hainich (DEU)	-17.0	0.93	0.18	-17.0	0.98	0.09	-204.4	0.48	8.11	highly correlated GPP and seasonality, but strong underestimation of annual sum
Kalkalpen (AUT)	8.5	0.97	0.07	8.5	0.985	0.04	101.7	0.76	2.80	high correlation in every category, overestimation of annual sum
Lägern (CHE)	-0.3	0.97	0.11	-20.3	0.99	0.07	-243.1	0.75	6.51	high correlated GPP and seasonality, but strong underestimation of annual sum
Peneda-Gerês (PRT)	-12.1	0.68	0.67	-12.1	0.72	0.56	-144.7	0.82	2.74	highest correaltion in annual sum, but strong underestimation, low correlation seaonality
Seitseminen (FIN)	1.1	0.93	0.14	1.1	0.99	0.03	13.5	-0.47	2.54	anticorrelated annual GPP, seasonal dynamics well represented

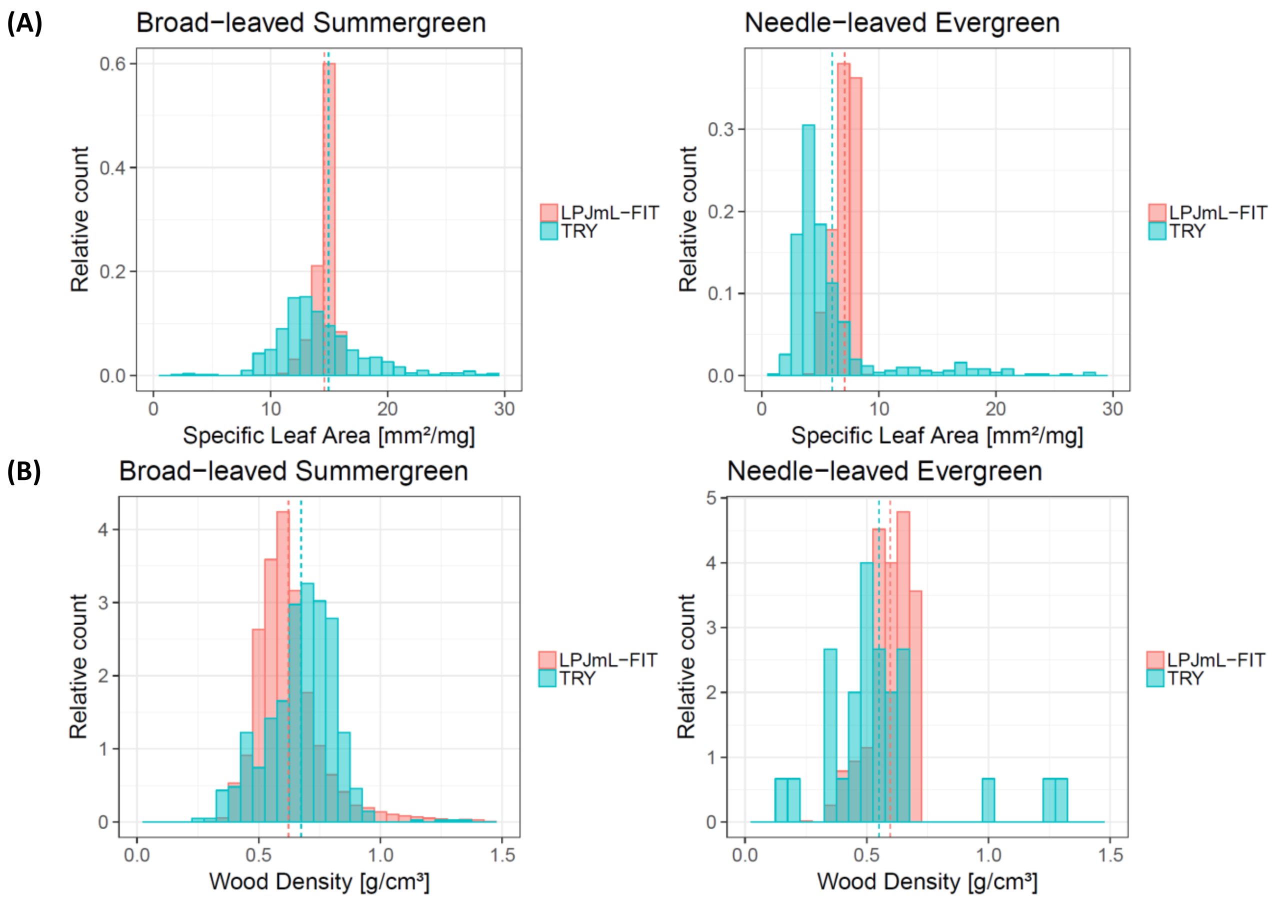

Figure 16: Comparison of SLA (A) and WD (B) between simulated and observed trait distributions from the TRY database, the dotted line indicates means of each dataset.

The model results show a high functional diversity around 57°N in the overlapping zones of needle- and broad-leaved trees and in the Mediterranean region. As illustrated in Figure 17, the coverage of large PA, especially in the Baltic States, Denmark and Turkey, is weak. However, these regions appear highly valuable for extended nature conservation efforts, because they allow protecting a broader spectrum of functionally different tree species at the same time.

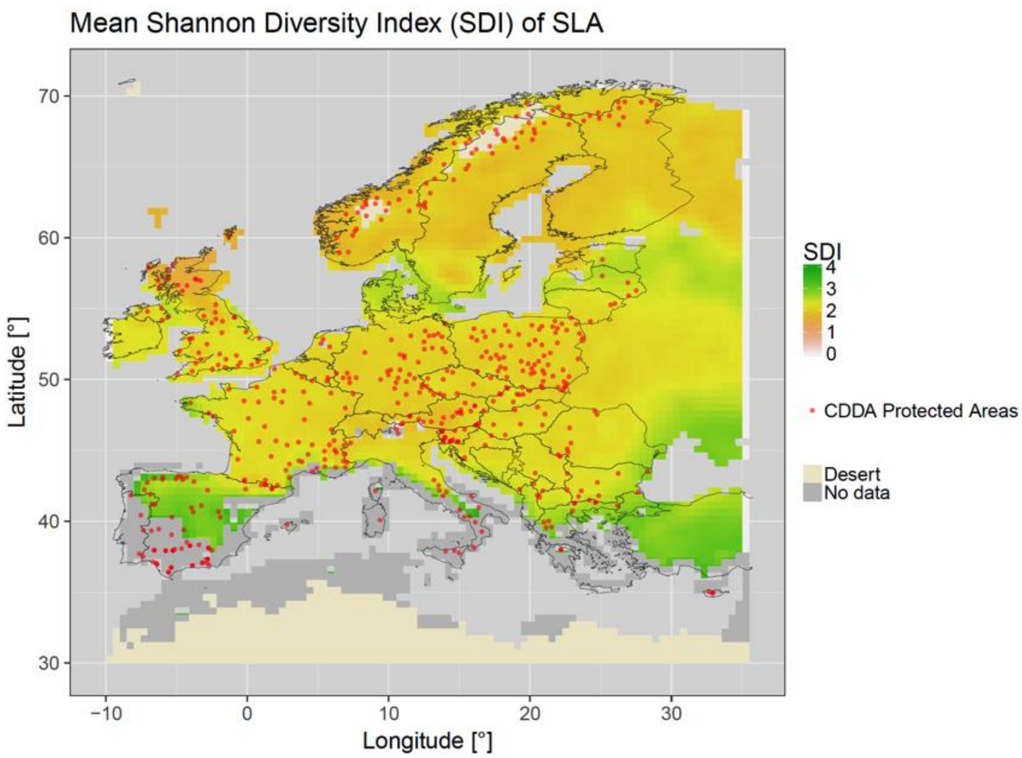

Figure 17: Mean Shannon Diversity Index between 1984 and 2014 of the SLA distribution overlapped with the 500 largest terrestrial protected areas in the CDDA database. Black lines illustrate the countries contributing to the CDDA.

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3.4. Vulnerability of European freshwater systems

By Markovic, D., Carrizo, S.F., Kärcher, O., Walz, A. and David, J.N.W. 2017. Vulnerability of European freshwater catchments to climate change. Global Change Biology 23(9): 3567–3580.

INTRODUCTION: Climate change is expected to exacerbate the current threats to freshwater ecosystems based on alterations of the variability of the thermal and hydrological attributes, threatening species to the magnitude of extinction risks, yet multifaceted studies on the potential impacts of climate change on freshwater biodiversity at scales that inform management planning are lacking. The aim of this study was to fill this void through the development of a novel framework for assessing climate change vulnerability tailored to freshwater ecosystems. The three dimensions of climate change vulnerability are as follows: (i) exposure to climate change, (ii) sensitivity to altered environmental conditions and (iii) resilience potential. Several methodologies were used to combine these dimensions across a variety of future climate change models and scenarios.

METHODS: Our vulnerability framework includes 1685 freshwater species of plants, fishes, molluscs, odonates, amphibians, crayfish and turtles alongside key features within and between catchments, such as topography and connectivity. Distribution maps were obtained for 1685 European freshwater species including 323 plants, 508 fishes, 657 molluscs, 134 odonates, 54 amphibians, five crayfish and four turtles (https://www.iucn.org/theme/species/our-work/freshwaterbiodiversity/what-we-do/biofresh-0). This data includes native portions of species ranges throughout Europe that were compiled by the IUCN Global Species Programme as part of the Red List assessment process. The data were mapped to the HydroBasins level eight resolution catchments (Lehner & Grill, 2013), which delineates European river and lake systems into 18 783 catchments. The HydroBasins dataset is based on high-resolution elevation data obtained from the NASA's Shuttle Radar Topography Mission (SRTM), except for regions above 60 degrees northern latitude, where coarser scale elevation data were used (HYDRO1k, developed by the U.S. Geological Survey). The climatic and hydrological data describing the thermal and hydrological regimes across Europe for the 20th and 21st century were derived from the global gridded 0.5° 9 0.5° WATCH (Water and Global Change) data set. All future projections were based on three general circulation models (GCMs), ECHAM5, CNRM and IPSL, with each following the A2 and B1 emission scenarios. Finally, the climatic data combined with the hydrological data results in 54 distinct sets (3 HMs x 3 GCMs x 2 scenarios x 3 time periods). The protected areas used in this analysis include PAs of IUCN categories I-IV from WDPA (https://www.protectedplanet.net/) and all Nature 2000 sites (www.eea.europa.eu).

The exposure indicators are based on the assumption that ecologically relevant hydrological and thermal regime alterations are best described by changes to the magnitude, frequency, duration, timing and variability of regime attributes. Vulnerability indicators take into account the present of threatened species, species with a restricted range, species confined to a single biogeographic unit, unique catchments, and species with narrow environmental tolerance. And as resilience indicators were included altitudinal range, latitudinal gradient, network density, and network complexity. Within each catchment, each of the three dimensions that make up the vulnerability of freshwater ecosystems to climate change, namely exposure, sensitivity and resilience, was assigned a category of 'low' (≤0.25), 'medium' (>0.25 and ≤0.50), 'high' (>0.5 and ≤0.75) or 'very high' (>0.75). The resulting indices were overlaid to assess the vulnerability of European freshwater ecosystems at the catchment scale using four different vulnerability indicators. This allows to explore the sensitivity of the vulnerability mapping to assumptions about how the three vulnerability dimensions interact. Vulnerability Assessment Method 1 (VAM1) is the most conservative, with the climate change vulnerability calculated as the average of the three vulnerability components and classified as 'low' (≤0.25), 'medium' (>0.25 and ≤0.50), 'high' (>0.5 and ≤0.75) or 'very high' (>0.75). VAM2 is based on the symmetric distribution of scores. VAM3 is based on a positively skewed distribution of scores. VAM4 employs the rule that categories are assigned to score combinations based on the lowest dimension score.

RESULTS: Catchments of high exposure to climate change, characterized by a combination of large predicted changes in both thermal and hydrological regimes, are mainly located in Spain, the Balkan countries and Baltic Sea countries (Fig. 18-1 a, b). The highest vulnerabilities were found in catchments along the Croatian Adriatic Sea coastline, for the Balkan Lakes Ohrid and Prespa and the Duero, Tajo and Guadiana River basins in Spain. Lake Ladoga the only home of the fish species Coregonus ladogae and the West Highlands of Scotland were found to be highly unique with respect to species' composition. Additionally, warm-adapted species in the southernmost parts of Europe appear to be less sensitive to climate warming than species in central and northern Europe (Fig 18-1 c,d). The degree of a catchment's connectivity appears to have a prevailing influence on all resilience components. Owing to numerous dispersal barriers, resilience is low for the majority of catchments (Fig. 18-1e, f). Consequently, the natural potential of the basins' altitudinal range, latitudinal gradient or river network complexity to provide species the opportunity to cope with climate change is considerably low in most parts of Europe.

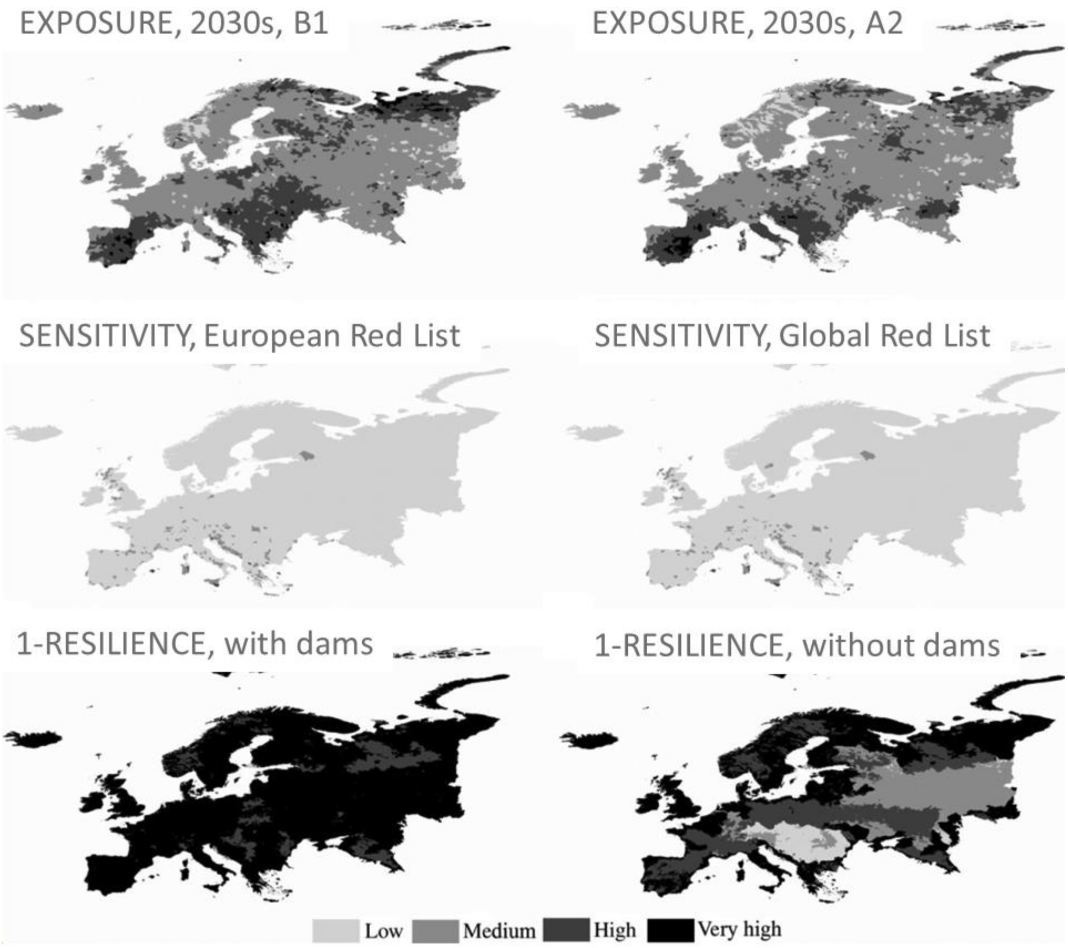

Figure 18-1: Exposure, sensitivity and resilience of freshwater ecosystems across Europe for two climate change scenarios.

Overall, there are considerable variations in the spatial distribution of vulnerability categories and the corresponding summary statistics across different vulnerability methods (Fig. 18-2). As the most conservative method, the main classifications of VAM1 are 'medium' and 'high' vulnerability throughout all scenarios and timelines. These results are nearly consistent with those of VAM2, still having the main classifications 'medium' and 'high', but having a slight shift regarding the 'no dams' situation towards the categorization 'low'. For VAM3, there is a stronger tendency towards the classifications 'low' and 'medium', mainly explained by the positively skewed distribution of scores. As in VAM2, the scenarios with no dams have a remarkably higher number concerning the 'low' vulnerability classification. When considering connectivity disruption by dams, the VAM3 suggests 'medium' vulnerability for about 85% of the total studied catchment's area. For VAM4, irrespective of the scenario and timeline, more than 95% of European river and lake catchments are predicted to be in the 'low' vulnerability category, which are highly unrealistic given predicted shifts in climate and widespread impoundment of rivers. Under consideration of connectivity disruption by dams, vulnerability is generally one category higher than without consideration of dams. The differences between dispersal options are particularly pronounced in the Danube, Neva, Dnieper and the Volga basins (Fig. 18-2).

For the 2030s, there is a consensus among the applied methods that the majority of catchments have ‘low’ to ‘medium’ vulnerability to climate change (>60% of the study area, and with up to 573 lake and river catchments predicted to have ‘high’ to ‘very high’ vulnerability for VAM1 to VAM3. For the 2080s, the consensus between the vulnerability methods is lower than for 2030s, suggesting considerable uncertainty. However, most methods indicate vulnerability increases for the 2080s compared to 2030s across southern Europe (Spain, Italy, Balkan countries) and northern Europe (Scandinavia and northernmost parts of Russia). Lake Ohrid (shared by the Republic of Macedonia and Albania) and Lake Prespa are predicted to have ‘very high’ vulnerability to climate change for VAM1 to VAM3 and all scenarios and timelines. Specifically, ‘very high’ overall vulnerability for the Lake Ohrid and Lake Prespa results from the combination of ‘low’ resilience, ‘very high’ sensitivity and ‘very high’ exposure. Similarly, ‘high’ to ‘very high’ vulnerability to climate change is predicted in Lake Skadar (shared between Albania and Montenegro), Lake Ladoga (Russia), the Greek islands of Rhodes and Lesbos, the Spanish island of Mallorca, the Italian islands of Sardinia and Sicily and for catchments along the Adriatic Sea coast, eastern Spain, southern Greece, western Italy, northern Russia and Finland, Crimea and in the northwest of England and highlands of Scotland. The anthropogenic disruption of hydrological habitat connectivity by dams is the major factor reducing climate change resilience. A gap analysis demonstrated that the current European protected area network covers <25% of the most vulnerable catchments.

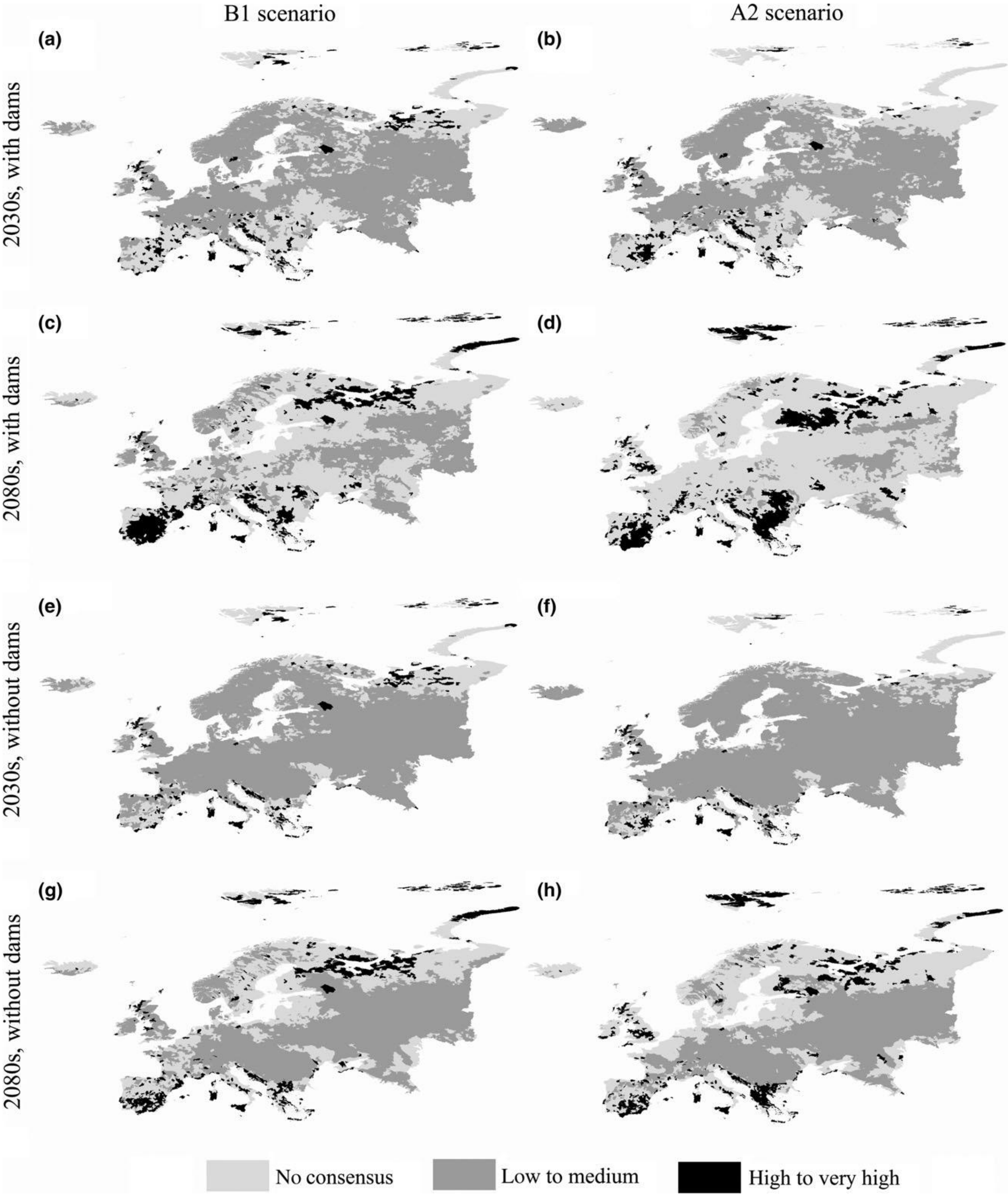

Fig. 18-2. Vulnerability to climate change for European freshwater ecosystems at the catchment scale based on combining the results of the methods VAM1 to VAM3: (a) 2030s exposure, B1 scenario, with dams; (b) 2030s exposure, A2 scenario, with dams; (c) 2080s exposure, B1 scenario, with dams; (d) 2080s exposure, A2 scenario, with dams; (e) 2030s exposure, B1 scenario, without dams; (f) 2030s exposure, A2 scenario, without dams; (g) 2080s exposure, B1 scenario, without dams; (h) 2080s exposure, A2 scenario, without dams. When combining the vulnerability results of the three assessment methods, a catchment was assigned the category 'low to medium' or 'high to very high' only if the same category was assigned for each of the three methods, otherwise it was assigned 'no consensus'.

DISCUSSION AND CONCLUSION: In summary, climate change is expected to amplify existing threats within catchments, alongside causing novel shifts in the hydrological, thermal and biotic components of freshwater ecosystems. The ability of species and communities to adapt to climate change, together with the availability of instream refugia and options for species to move across natural and artificial barriers, will become increasingly important as time progresses. Additionally, an important instrument in dealing with climate change is management actions and mitigation strategies. Specifically, strong cross-sector cooperation among government and industry stakeholders to implement Integrated River Basin Management (IRBM) is required. This should be supported by systematic conservation planning and long-term monitoring schemes that rely on a synergetic use of in situ measurements and earth observation data. Immediate action should include a review of management plans to ensure that freshwater systems are targets for conservation and identification of opportunities to increase catchment resilience, for instance by maintaining and improving connectivity through removal of barriers between habitats. The catchments identified as most vulnerable to climate change provide preliminary targets for development of climate change conservation management and mitigation strategies.

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3.5. Hotspots identification of Posidonia oceanica connectivity within the LME

By Lorenzo Mari and Renato Casagrandi (DEIB, Politecnico di Milano)

INTRODUCTION: To evaluate the state of ecosystems as vast as the Mediterranean Sea (one of the two Large Marine Ecosystems [LMEs] of the *Ecopotential* project) it may be important to select species that play a pivotal role at the community level, either because they are keystone species or because they create favorable conditions for coexistence of many other species in a structured environment (the so called *habitat formers*). One of the most important habitat former in the Mediterranean is the endemic seagrass *Posidonia oceanica* (e.g. Jahnke *et al.* 2017). Despite remaining the most widespread seagrass in the region, *P. oceanica* has faced a very sharp decline in abundance in the last 50 years, estimated to be as high as 34% (Telesca *et al.* 2015). Protecting areas within the sea requires a design that involves multiple scales of intervention. In fact, seascapes are shaped by marine currents: if a Marine Protected Area (MPA) is not enough connected to others, it cannot receive/send propagules (like larvae or seeds), thus the positive effects of protection risk to be vain. Spatial planning of marine protection must thus be conceived as a network design of ecologically connected MPAs rather than a series of parallel and independent best-site selections.

Earth Observations (EOs) can help along different directions in assessing species-specific connectivity within LMEs because from them it is possible to reconstruct marine currents (via oceanic reanalyses) at quite high spatio-temporal resolution. These circulation fields can then be used as drivers of movement for the dispersal agents of species – in this case fruits of *P. oceanica* – released at the right times and places when reproduction occurs. We define quantitative ways to assess connectivity in terms of relative abundance of propagules exchanged from different marine sectors, as well as indicators for identifying *connectivity hotspots* for the studied species, no matter of the current state of site protection. Our modelling experiment is inherently cross-scale along both the spatial and the temporal dimensions. As for the spatial dimension, in fact, we must couple information at the local scale as derived from *in situ* data (suitability mapping) together with large-scale patterns as they emerge from circulation fields reconstructed also using EO data. As for the temporal dimension, the success of reproduction and dispersal events occurring within one specific season must be averaged (in a non-trivial sense) with the same ecological processes occurring in all subsequent seasons and over a climatically relevant period. The evaluation of suitable measures of temporal dispersion also allows to account for the intrinsic temporal variability of the process over different seasons and years, and to identify a limited number of sites within the Mediterranean Sea that are candidate to be protected (e.g. following in the methodological framework outlined in Melià *et al.* 2016), so as to save more with less.

MATERIALS AND METHODS: We estimate basin-wide spatial connectivity for *P. oceanica* using Lagrangian simulations, since the main dispersal agents of species are fruits. Particles are released at marine sites that revealed to be suitable for *P. oceanica* colonies, are transported by currents, and may eventually settle at some *P. oceanica*-suitable sites. The species-specific suitability map used here was produced within the EU-funded MediSeH project (Giannoulaki *et al.* 2013; Telesca *et al.* 2015}: the estimated occurrence probability s_A of *P. oceanica* colonies (a proxy for suitability) at site *A* is given as a high-resolution (1/240°) raster map extending over the whole Mediterranean basin (data available online at http://www.emodnet-seabedhabitats.eu). Circulation fields (daily averages at 1/16° resolution) are obtained from a Mediterranean-wide physical reanalysis assimilating satellite Earth Observations (Lecci *et al.* 2017) produced by INGV (and available online at http://marine.copernicus.eu/).

Model simulations are performed over a climatically consistent time interval (1987-2015). In each year, for each of the n_d = 120 days of the species reproductive season (Jan-Apr), a fixed number of particles (n_p = 15) is released at a depth interval of 0-1 m (*P. oceanica* fruits being free-floating) in random locations of each pixel of the suitability map where $s_A > 0$. A total of about $n_r \approx 5.7\ 10^5$ release sites are identified in this way, so that an excess of $n_t = n_p\ n_d\ n_r \approx 10^9$ Lagrangian particles is tracked every year. The geographical coordinates of each particle are updated by assuming passive transport driven by marine circulation fields, while particle depth is not updated. Numerical integration is performed with a Runge-Kutta fourth-order scheme with adaptive step size. At each time step, three-dimensional trilinear interpolation of the meridional and zonal components of the velocity field is performed. The position of each particle is tracked for a period corresponding to the average duration of the dispersing stage of *P. oceanica* fruits, estimated to be around 28 days.

The strength of *P. oceanica* connectivity between any two suitable sites (say *A* and *B*) in year *y* is assumed to be proportional to the number of particles $n_{AB}(y)$ departed from *A* that successfully reaches *B*. This quantity is primarily driven by the hydrodynamics of passive propagule dispersal by marine currents, but it is also influenced by *P. oceanica*-specific traits, such as timing of fruit release and duration of the dispersing phase. To better account for small-scale heterogeneities in the quality and spatial distribution of *P. oceanica*-suitable sites, we define an ecologically-motivated measure of connectivity in which successful dispersal events are weighted according to the suitability scores of both source and sink sites. Suitability-weighted connectivity (*s*-connectivity, for brevity) between two sites *A* and *B* in year *y* is thus defined as

$$C_{AB}^{S}(y) = s_A\, n_{AB}(y)\, s_B.$$

Analyzing *s*-connectivity at the resolution scale of the suitability map would be very cumbersome. We therefore focus on the marine sectors defined by the coarser resolution of the physical reanalysis of the circulation fields and consider only the marine sectors from where the number of released particles would be higher than 1,000. More than 8,000 marine sectors are identified in this way, covering all the Mediterranean shorelines. Pairwise *s*-connectivity scores between any two sectors *i* and *j* in year *t* are thus defined as

$$C_{ij}^{s}(y) = \Sigma_{(A \in i)}\, \Sigma_{(B \in j)}\, C_{AB}^{S}(y) = \Sigma_{(A \in i)}\, \Sigma_{(B \in j)}\, s_A\, n_{AB}(y)\, s_B\,.$$

With this definition, not only species-specific dispersal patterns but also local suitability conditions are duly taken into consideration, because *s*-connectivity is not normalized by the (spatially heterogeneous) number of fruits released within each marine sector. For this reason, *s*-connectivity can represent an informative tool to evaluate the ecological value (as far as *P. oceanica* dynamics are concerned) of each marine sector within the Mediterranean Sea.

Pairwise *s*-connectivity scores can be suitably organized in a time-varying *s*-connectivity matrix $\mathbf{C}^s(y) = [C_{ij}^s(y)]$, which can be described as a directed weighted network, with nodes and links being, respectively, marine sectors and *s*-connectivity scores. In ecological terms, a first important indicator that can be derived from our *s*-connectivity matrix is represented by its diagonal elements, which indicate *self-retention.* In the context of *P. oceanica* dispersal, each diagonal element of $\mathbf{C}^s(y)$ in fact quantifies how many fruits both are released and settle in a given marine sector (say *i*) in year *y*, with the release (*A*) and settling (*B*) sites being possibly different, but with both *A* and *B* belonging to marine sector *i*. Off-diagonal elements instead quantify inter-sector dispersal events, thus signaling the potential of a sector to function as a *source* or a *sink* for *P. oceanica* dispersing fruits.

To single out the most robust and time-persistent ecological connections for *P. oceanica*, we evaluate for each pair of marine sectors (say *i* and *j*, possibly with $i = j$) the across-year geometric mean μ_{ij} and geometric standard deviation factor σ_{ij} of $C_{ij}^s(y)$. Clearly, large values of μ_{ij} (an indicator of sheer intensity) associated with small values of σ_{ij} (an indicator of temporal variability) are indicative of strong-and-steady connections. In other words, marine sectors characterized by such values can be thought of as *s-connectivity hotspots*.

RESULTS: Lagrangian simulations show that *s*-connectivity scores $C_{ij}^s(y)$ vary conspicuously in different regions of the Mediterranean Sea and fluctuate widely over time in the period 1987-2015, as shown in the movie available at https://youtu.be/jOwSfRga1FU. Despite the apparent spatiotemporal variability of *s*-connectivity patterns, some general features seem to emerge:

- along-coast transport represents a prevailing and persistent means of dispersal for *P. oceanica*;
- crossing of relatively short sea stretches (from West to East: the Alboran, Balearic and Ligurian Seas, the Sea of Sicily, and the Adriatic and Aegean Seas) is quite common, yet fairly erratic;
- large islands and archipelagos (Balearic Islands, Sardinia, Corsica and Sicily in the Western Basin; Crete and Cyprus in the Eastern Basin) may serve as stepping stones to cross larger sea stretches over different reproduction seasons;
- some sea stretches (from West to East: the Sea of Sardinia, i.e. the body of water between the Balearic Islands and Sardinia, and the Tyrrhenian, Ionian and Libyan seas) are rarely (if at all) successfully crossed by dispersing *P. oceanica* fruits;
- the region centered on the Strait of Sicily, i.e. the area comprised between the southern coasts of Sardinia and Sicily, to the North, and the coasts of Tunisia and Western Libya, to the South, is characterized by remarkable *s*-connectivity, with possible implications for the exchange of *P. oceanica* fruits between the Western and the Eastern Basins of the Mediterranean Sea;
- the Aegean Sea forms a relatively disconnected subsystem within the larger Mediterranean system.

As for time-averaged measures, the blue dots in the map of Figure 19A show the *top self-retainer P. oceanica habitats, i.*e. all the marine sectors characterized by having both an exceptionally large across-year geometric mean of self-retained dispersing seeds (in the top 95th percentile of all existing connections) and an exceptionally small corresponding standard deviation factor (in the bottom 5th percentile). Such top self-retainers are geographically concentrated along the Aegean coasts of the Libyan Sea (nearby the Libya-Egypt border) in the East Mediterranean, along the Croatian coasts, the western coasts of Sicily and Sardinia, and the Gulf of Gabés in the Central Mediterranean Sea, and along the Balearic Sea coasts in the West Mediterranean. Yellow lines in Figure 19A mark the most relevant inter-sector connections, i.e. those ending on *top sink* and *top source P. oceanica habitats* according to our model if we use the same thresholds for sheer intensities (top 95th percentile) and temporal variabilities (bottom 5th percentile) used above for identifying top self-retainers. Interestingly, the few long-distance (i.e. larger than hundreds of kilometers) dispersal connections that appear in the list of the top sources and sinks of Figure 19A seem to be concentrated in the Gulf of Gabés, as detailed by the inset shown as panel B in Figure 19.

The hotspots of *s*-connectivity for *P. oceanica* have quite different ecological characteristics with respect to a generic, yet suitable marine sector randomly selected in the Mediterranean Sea. Each gray [or black] dot in Figure 19C represents one of the 8,000x8,000 connections between marine sectors that are suitable for *P. oceanica* in the whole Mediterranean Sea [or between hotspots] in a two-dimensional space, where the temporal geometric mean of sheer intensity μ_{ij} is contrasted to its corresponding geometric standard deviation factor σ_{ij}. This representation makes it clear that hotspots form ecological connections that are order of magnitudes more intense and temporally persistent than generic sites. Therefore, they may play an important ecological role for populations of *P. oceanica* within the LME Not surprisingly, yet deserving a note, the distribution of the relative frequency of *P. oceanica* suitability restricted to the *s*-connectivity hotspots (white histogram in Figure 19D) has a significantly larger mean (<*s*> = 0.57) than the same distribution evaluated over all *P. oceanica*-suitable sites (gray histogram in Figure 19D, <*s*> = 0.26).

DISCUSSION AND CONCLUSIONS: Our biophysical modelling of an important habitat former species for the Mediterranean Large Marine Ecosystem, *Posidonia oceanica*, provides an EO-informed map on locations of hotspots candidate for protection. From a purely ecological perspective, site selection must of course take into account not only the biological capacities of species dispersal but also reproduction abilities and other components of population dynamics. From a socio-economic point of view, though, not all locations are equally suitable to "sacrifice" portions of their seascape to conservation programs. The Mediterranean Sea is an area of interest for a series of activities, ranging from maritime traffic to industrial fishing or tourism, and it is faced by human populations of different nationalities and cultures on the European and the African side. From our simulations it is not evident that cross-continental connections for *P. oceanica* do exist, but it is because we used very strict selection rules (5th – 95th percentiles) and none of the important dispersal events between Europe and Africa is so intense *and* persistent over time to pass the filter we impose. Nevertheless, as revealed by the movie above, very significant (yet more ephemeral) dispersal events may create important ecological and genetic connectivity bridges for *P. oceanica* between the two North-South borders of the Mediterranean Sea, thus going even beyond the EU territories.

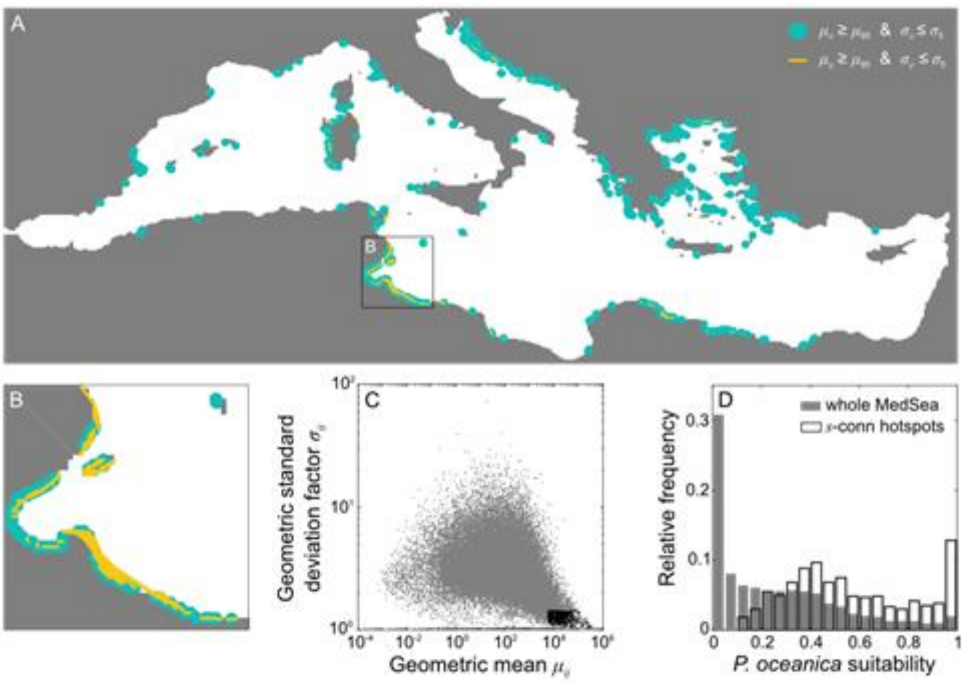

Figure 19: Hotspots of s-connectivity. (A) Sectors i for which the geometric mean μii of the time-varying self-retention scores Ciis(y) is above the 95th percentile of the distribution of all positive μuv's (μ95; μii is the geometric mean of the time-varying s-connectivity scores Cuvs(y) between any two generic marine sectors u and v) and, at the same time, the geometric standard deviation factor σii is below the 5th percentile of the distribution of all finite σuv's (σ5; σuv is the geometric standard deviation factor of Cuvs(y)) are shown as cyan dots. Pairs of sectors i and j for which μij is above μ95 and σij is below σ5 are shown as yellow links. (B) As in panel A, with a focus on the region of the Gulf of Gabés (Tunisia, Central Mediterranean Sea). (C) Two-dimensional plot of average s-connectivity scores (geometric mean vs. geometric standard deviation factors evaluated across years for all possible pairs of marine sectors). Gray dots identify generic, P. oceanica-suitable marine sectors, while black dots identify the hotspots of s-connectivity shown in panel A. (D) Frequency distribution of suitability values for all the P. oceanica-suitable sectors across the Mediterranea Sea LME, compared with the same distribution restricted to the s-connectivity hotspots.

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4. Current state and trends of ecosystem service supply by PAs

By Ariane Walz and Jennifer Schulz

After having focused on ecosystem states and function in the previous chapters, this chapter look at ESS in PAs. We want to emphasise that most of the ECOPOTENTIAL ESS assessments are strongly related to ecological functions, the state of ecosystems and their change. They are evaluated based on continuous data from RS and biophysical/empirical models, unlike many earlier studies based on categorical land cover data and look-up table approaches (e.g. Burkhard et al. 2012, Costanza et al. 2014). These data are continuous in space and time and not classified. Hence they can provide information on gradual change in space and time. Here, we first summarize findings from an early compilation of individual ESS assessments of ECOPOTENTIAL PAs, as presented in D7.1 ("Assessment of the services of protected areas") and discuss their meaning for a large-scale assessment of ESS supply through PAs in Europe (4.1). Then we present results from estimates of carbon stocks as an example for a global ESS across all ECOPOTENTIAL PAs that accounts for both comparability between PAs and variability within specific PAs (4.2). Finally, we present a studies focusing on a potential productive service, namely the productive capacity to produce fish in aquaculture in the Adriatic Sea, namely there (4.3).

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4.1. Examples of ESS assessments for individual ECOPOTENTIAL PAs

By Ariane Walz and Jennifer Schulz

Based on a first compilation of ESS assessments in the ECOPOTENTIAL PAs (D7.1) (Appendix 6.2), the following conclusions can be drawn across the exemplary ESS assessments of seven PAs:

- **Selection of ESS**: The four assessments for terrestrial, mountainous PAs overlap in some ESS of interest. Here the productivity of fodder, either for wild or for domestic animals, was included in all assessments. Water regulation was of high interest in two of these PAs. In contrast, carbon storage was only assessed by one of the PAs. For marine and coastal PAs, fish stocks were an important ESS addressed in two of three PAs.
- **Local Issues**: All assessments focus on highly local issues. This led to different interpretations of the same ESS indicator. For instance, the direct runoff is used for water regulation, positively perceived for Peneda-Gêres, where it allows for irrigation of farmland, whereas in Sierra Nevada direct run-off is considered a threat as it triggers soil erosion there.
- **Indicators of supply of ESS**: Indicators chosen to measure ESS varied between all studies due to their very local nature and data selection/availability. One example is the indicator for fish stocks with "Catch of Commercial Fish kg per Unit Effort" in the Curonian Lagoon, versus the "Potential Fish Harvest in kg" for the Pelagos Sanctuary. For the Curonian Lagoon empirical evidence were used to estimate the ESS indicator, whereas estimates for the Pelagos originate from a large-scale ecosystem model using remotely sensed data from the Copernicus Marine Environment Monitoring Service (CMEMS) with limited empirical validation.
- **Indicators for demand of ESS**: Demand for ESS has been a minor focus in most PAs. Here, proxies include local and national statistics, such as fish landings, livestock numbers, crop harvests, etc. Only Peneda-Gêres explicitly

addressed ESS demand (for irrigation water) beyond the boundaries of the PA itself, and therefore the broader spatial context of ESS supply by the PA.

- **State and trends in ESS**: The state of ESS has been quantified until Nov 2017 for around 15 indicators, which are difficult to set in context without quantitative measures of demand. More meaningful than just the state of ESS are, however, estimates of trends in ESS supply. Here, we see that many ESS have changed over the past 10 to 30 years, including both decline and increase. Most of these changes are not intentional, but whether they are threatening the current value of the PAs for conservation and for their supply of ESS cannot be fully judged. For such an evaluation, more emphasis is needed in the quantification of ESS demand, within the PAs and beyond.
- **Use of remote sensing**: RS data supports the analysis of all assessments. The ecosystem mapping was conducted by the analysis of RS data. Landsat is still the most important sensor to reconstruct changes over the past three decades. Accomplished with Sentinel, these data provide good insights into smaller scale patterns and intra-annual variation and have been used for instance, in Sierra Nevada, Peneda-Gêres, and Camargue. This gives a first indication of the great contribution that Sentinel will most likely be able to provide in the coming years for ecosystem monitoring.

The limited number of local ESS assessments in PAs does not allow for an extrapolation across European PAs. However, it shows that individual PAs have very different focus in ESS assessment. This is closely connected to the variety of ecosystems across Europe and the pressures they face, e.g. human activity, climate change, changes in disturbance regime. So far, PAs are mostly dedicated to conserve local biodiversity and habitats, the capacity of PAs to deliver ESS has not explicitly been a driver for the creation of PAs. Therefore, current management concerns are strongly related to threats to the current local biodiversity and habitats. In several of the ECOPOTENTIAL PAs, this is strongly related to historic cultural landscape with their specific biodiversity. In contrast, only one of the PAs includes Carbon Storage in their ESS assessment, which reflects that globally important ESS aren´t a primary concern for PA managers (different the assessment presented in 4.2). Nevertheless, the PAs total up to over 1.2 Mio km^2 in Europe, and it would be worth checking their overall contribution to European ESS supply within the PAs and beyond their boundaries. Despite the local variations in ecosystems, threats and conservation aims, a pan-European monitoring of PAs and their ESS would require a consistent set of indicators, methods and data for monitoring including quantification of demand for benchmarking and management of PAs.

4.2. Carbon stocks as a global ESS across all ECOPOTIAL PAs

By Frank Weiser and Carl Beierkuhnlein (Biogeography Department, University of Bayreuth)

INTRODUCTION: It has been shown, that protected areas while covering only 12.2% of the land cover, hold 15.2% of terrestrial carbon stocks (Campbell, 2008). In Europe, 13.6% of carbon is stored in protected areas. Quantifying the effect of protection on carbon storage is not easy. Global datasets, such as Ruesch & Gibbs, 2008, often feature such coarse spatial resolutions, that small scale changes can't be detected and only exist for one point in time. Local carbon calculations often need a high investment of time and effort to be completed successfully. This study therefore bridges the gap by using the IPCC Tier 1 methodology combined with the ECOPOTENTIAL land cover classifications created using the EODESM system in the virtual laboratory. The goal is to compare create quick, rough carbon estimates for the protected areas within ECOPOTENTIAL from global dataset with estimates on a much finer spatial scale.

METHODS: As a first step to assess carbon stored in biomass, we extracted carbon values from the CDIAC carbon map for the year 2000 (Ruesch & Gibbs, 2008). By using the IPCC GPG Tier-1 method for estimating vegetation carbon stocks using the globally consistent default values provided for aboveground biomass (IPCC, 2006), the dataset provides a global 1x1km carbon dataset based on a land cover classification. To improve the accuracy of their estimation, we then used the same IPCC Tier 1 method to replicate it with the EODESM land cover classifications with a spatial resolution of 10x10m produced in ECOPOTENTIAL. Every land cover class was assigned a carbon value based on land cover and ecofloristic zone. Then, the mean carbon stored per hectare was calculated for every protected area within ECOPOTENTIAL. Additionally, soil carbon was extracted from the SoilGrids dataset with 250m resolution (Hengl et al., 2017).

RESULTS: The global dataset (Ruesch & Gibbs, 2008) mostly shows similar results as our own dataset calculated from the EODESM land cover classifications (see Figure 20). For three protected areas, the datasets differ strongly: Peneda Gerês, Swiss National Park and Samaria. Peneda Gerês shows the biggest difference with the CDIAC dataset predicting a mean carbon storage of 54.17 tonnes carbon per hectare and a calculated storage of 18.02 tonnes carbon per hectare from our own calculations. Overall, the mountainous protected areas of intermediate longitude on average store most carbon with Bavarian Forest NP storing the highest amount of carbon per hectare. Most soil carbon is stored in ECOPOTENTIAL wetland PAs, such as Curonian Lagoon, Wadden sea delta and Danube Delta (see Figure 21).

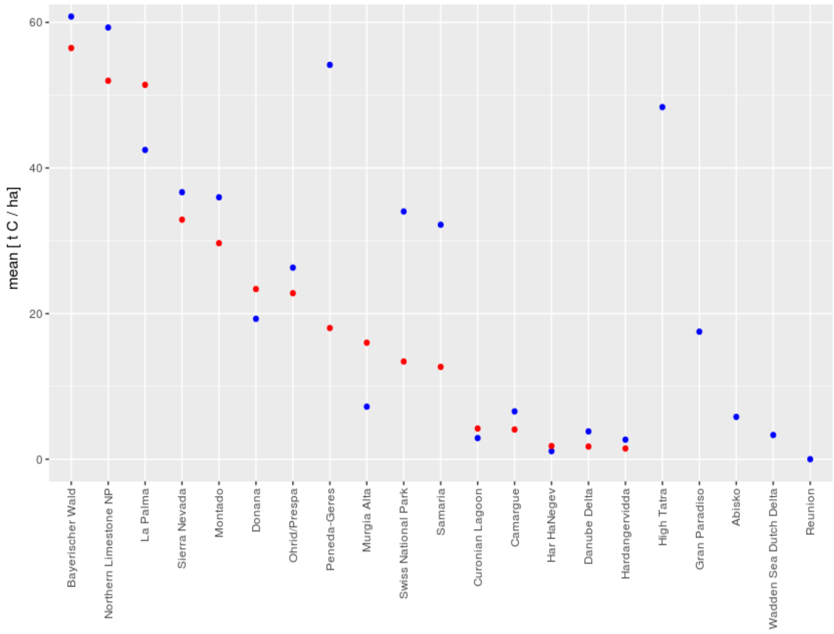

Figure 20: Above and below ground carbon calculated from the EODESM land cover classifications (red) and extracted from the CDIAC dataset (blue) created by Ruesch & Gibbs, 2008. The missing values of some protected areas are caused by missing land cover classifications and will be added as soon as possible.

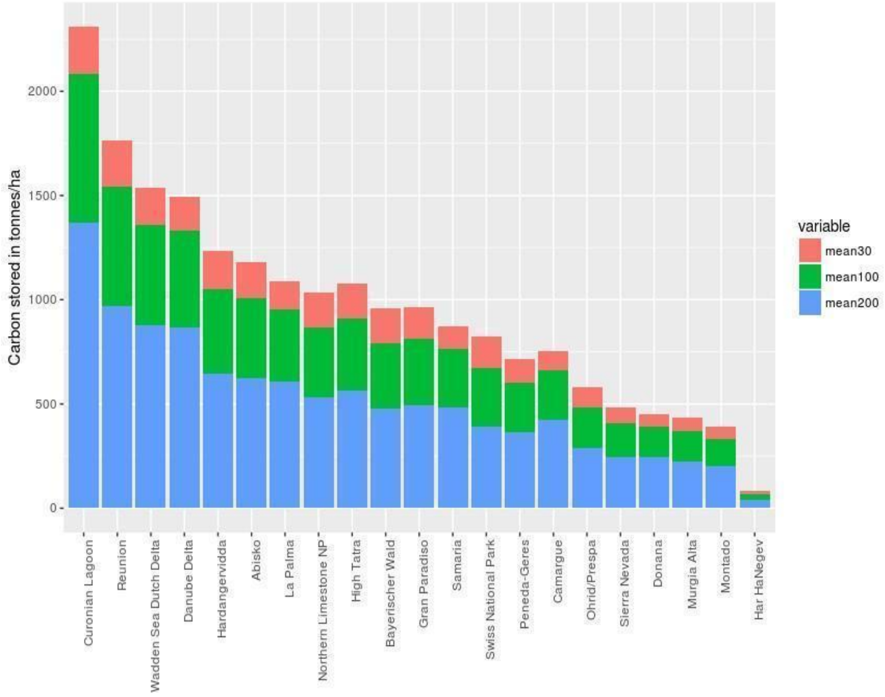

Figure 21: Mean carbon storage in the soil of the protected areas in three different depths, 0-30cm, 30-100cm and 100-200cm. The data was extracted from SoilGrids (Hengl et al., 2017)

DISCUSSION AND CONCLUSIONS: While the values of the global carbon dataset with a 1x1 km resolution (Ruesch & Gibbs, 2008) were similar to our own calculations in many PAs, the difference for Peneda Gerês, Swiss NP and Samaria are substantial. Upon closer examination it was discovered, that forest cover was often overestimated in the 1x1km classification, increasing the estimated carbon stocks substantially. This shows, that even a rough estimate such as the IPCC Tier-1 method profits heavily from a fine spatial resolution when calculating carbon storage at protected area level.

The mean carbon storage per hectare shows that above ground carbon storage is largest in forested PAs in mountainous regions. This proves the importance of protecting forests from deforestation. But it also opens up the same protected areas to criticism. In many protected areas, disturbances are allowed to run their course with little to no management. It has been shown, that disturbances in forests, such as bark beetle outbreaks, wind throw or fire, while beneficial to biodiversity, have negative impacts on many ecosystem services, including carbon storage (Thom & Seidl, 2015). A time series of land cover classifications from the ECOPOTENTIAL Virtual Lab could therefore be useful for calculating the effect of disturbance events or changes in management strategy on carbon storage.

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4.3. Marine food provisioning through the Mediterranean Sea

Valentini, Emiliana, Filipponi, Federico, Nguyen Xuan, Alessandra, Passarelli, Francesco Maria, & Taramelli, Andrea (2016). Earth Observation for Maritime Spatial Planning: Measuring, Observing and Modeling Marine Environment to Assess Potential Aquaculture Sites. Sustainability, 8(6), 519

Status and evolution of food provision service through sea surface temperature time series analysis using STL and EOF on Mediterranean LME was presented also in D4.5. The existing monitoring schemes from an EO point of view could highly benefit from the availability derived indicators at high spatial resolution and for long periods in order to better foresee future essential variables evolution and as a consequence changes in ecosystem service delivery (D 7.1).

INTRODUCTION: Physical, chemical and biological characteristics of seawaters are primary descriptors for understanding environmental patterns and improving maritime spatial planning for potential aquaculture uses. By analyzing these descriptors in spatial and temporal dimensions, it is possible to characterize the potential productivity performances of different locations for specific aquaculture species, namely for sea bass and sea bream. This information is highly valuable for decision-makers to identify sites with conditions feasible for aquaculture fish growth, and assess their different productivity performances in terms of potential fish harvest.

METHODS: The toolbox aims to first identify sites with conditions feasible for aquaculture fish growth (feasibility scenario); and then assess their different productivity performances in terms of potential fish harvest (suitability scenario). The workflow starts with the evaluation of actual competing uses of the maritime space. It further uses a number of in-situ measurements, e.g. seawater temperature at different depths, and RS data, e.g. sea surface temperature, to extract areas that fulfil environmental pre-condition for aquaculture of sea brass and sea bream.

It combines in-situ measurements, e.g. seawater temperature at different depths, and RS data, e.g. sea surface temperature and builds on the InVEST FinFish model for aquaculture (Sharp et al., accessed 2016) to estimate fish harvest. The model considers that each pixel (grid cell) of the SST product represents a potential fish farm. The harvest simulation ran for a total of 6 years over all the pixels in the area identified as feasible.

RESULTS: The areas feasible for the aquaculture of sea brass and sea bream have been identified based on spatial planning documents, as well as the evaluation of environmental factors from in situ and RS data. Results suggest that offshore northern Adriatic Sea is a feasible site for fish aquaculture of sea bass and sea bream species, in terms of physical, chemical and biological parameters within the vitality ranges of the two selected fish species. Nearshore coastal areas have been revealed as not feasible for fish aquaculture because of low average current speed, frequent occurrence of high turbid water conditions, and periods of intense river discharge and seafloor sediment resuspension due to the shallower bathymetries. Bora and sirocco wind patterns significantly affect the variability of seawater temperature as well as the concentration of Dissolved Oxygen.

The most evident spatial pattern resulting from InVEST FinFish model for the offshore areas identified as feasible, is the latitudinal gradient that increases moving from north to south, similar to the gradient of Sea Surface Temperature. Within the harvest model, fish growth is mostly dependent on temperature, i.e., warmer locations will enable fish to reach their target weight faster, while the total biomass of each farm depends on how many cycles of outplanting and harvesting are performed in the farm. As a consequence, the suitability shows a decreasing harvest gradient moving from north to south (Figure 22).

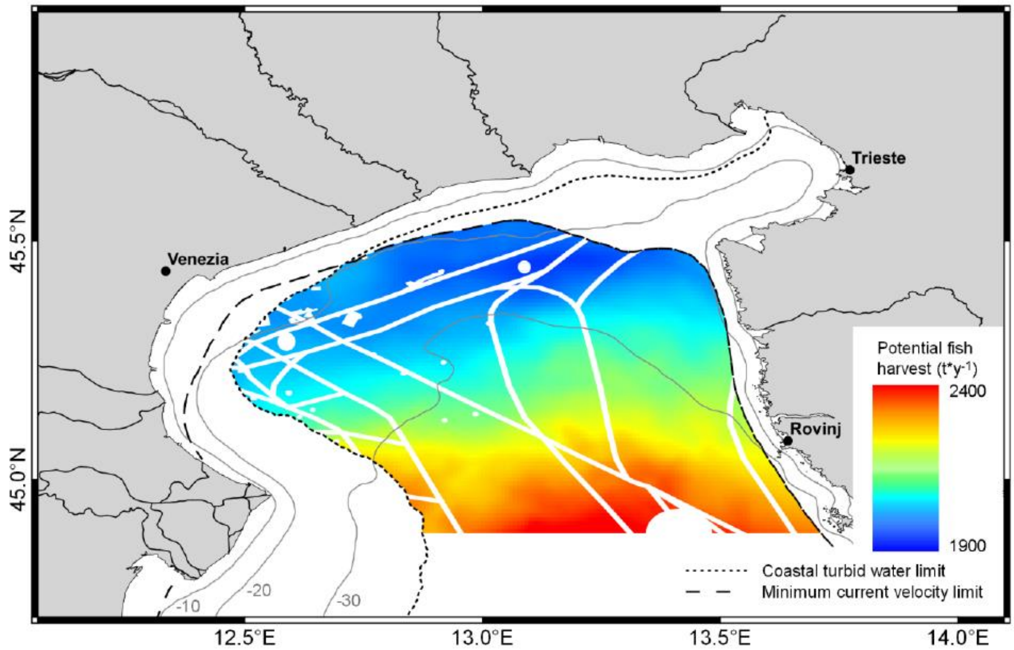

Figure 22: Potential fish harvest estimated within the areas identified as feasible for aquaculture (pixel spatial resolution 300 m).

DISCUSSION AND CONCLUSION: The toolbox makes systematic use in-situ and RS data. It furthermore applies an additional model to estimate fish growth from the environmental factors observed through these data. It thus, provides an indicator that is directly customised to explicit stakeholders´ knowledge needs and can therefore provide relevant information to them.

Considering the definition of sustainability as a multidimensional concept that takes into account environmental, economic and social aspects, this study focuses with environmental issues, mostly related to fish growth. From a fish point of view, the toolbox heads in the right direction. However, when the sustainability definition includes environmental issues like pressures and impacts, or includes social and economic frameworks, our toolbox is lacking. For the environmental issues, it provides an initial state of seawater properties, against which the impacts can be eventually measured (not prevented) by monitoring activities. In this sense, satellite-derived information can support aquaculture farmers and policy makers by issuing warnings on potential water quality threats (e.g. pollution and harmful algal blooms) and monitoring the environmental impact of sea farms.

The toolbox, representing a pre-operational Copernicus downstreaming service that integrates data and products from different sources (in situ, Earth Observation and modelling), is innovative because it is based more on parameters relevant for fish vitality than on those oriented to farm functioning. It has been designed for the Mediterranean, northern Adriatic Sea, but because of its modularity/multi-stage process, it can be easily adapted to other areas, or scaled to larger areas. Stakeholders and farmers involved in maritime spatial planning can use resulting scenarios for decision-making and market-trading processes.

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BOX 1: The global "niche" of PAs
By David Mouillet, CNR Montpellier

Protected areas (PAs) are a core management response to the pervasive and multiple impacts of global changes on habitats, species and ecosystem services. For instance, the biodiversity and abundance of terrestrial and marine vertebrates are notoriously higher within PAs than outside their boundaries although a lack of restrictions or financial capacity can hinder such conservation benefits. To face the rapid expansion of human activities, even towards the last wilderness areas, and the unprecedented rate of biodiversity loss, the global coverage of PAs has markedly increased over the last decades with 15% of the world's terrestrial surface and 7% of the ocean area designated as formally protected in December 2017. Parties to the Convention on Biological Diversity (CBD) recently re-committed to protect at least 17% and 10% of the amount of land and sea by 2020, respectively. Such targets should be reached rapidly owing to the positive dynamic of PA establishment and the accelerating momentum for designating large, even giant (*e.g.* 1.5 million square km for the Papahānaumokuākea marine national monument in Hawaii), PAs under lobbying from some governmental and non-governmental organizations (NGOs).

The downside of this race to protect more land and sea is the heterogeneity of the efforts among countries, levels of economic developments, environments and human densities. So, a global assessment of coverage by PAs may hide many gaps in both environmental and sociological dimensions. We already know that PA establishment rarely coincides with local biodiversity hotspots since being a political process. Instead, PAs tend to be biased toward places that are remote or unpromising for human activities like fisheries or agriculture and toward more developed countries. However, little is known about the influence of conflicts, conservation-oriented NGOs, local human footprint, and primary productivity on PA establishment particularly the most restrictive ones (IUCN category I). Besides the global niche of PAs in their environmental, geographical and human dimensions has never been drawn in comparison to non-protected areas. Here we present the first global quantitative picture of the multidimensional niche of protected areas and the first model accurately predicting the presence of PAs globally and identifying their key determinants.

First, we defined a global grid on both land and sea with cells of 10 by 10 km squares. We then estimated 15 explanatory variables on these cells among which 5 are environmental (temperature, precipitation, productivity, 5 are geographical (distance to the coast, etc…) and 5 are social-economical (Human Development Index, conflicts, presence of non-governmental organizations etc.). We used binomial generalized linear models (GLMs) to explore the relationship between the presence of conservation effort (some coverage by protected areas) in each grid cell islands. We included a quadratic term for each quantitative variable since non-linear effects are expected. We select the most parsimonious model based on the lowest Akaike Information Criteria (AIC) to provide regression statistics and partial plots.

The presence of terrestrial protection is accurately explained by 10 retained variables (Area Under the Curve AUC-value=0.81) with Human Development Index (HDI), the presence of conflicts and temperature having the strongest effects. For marine protection, the most parsimonious model also retains 10 variables and is very accurate (AUC value=0.83) with HDI and fisheries dependency having by far the strongest effects.

We used partial regression plots to visualize the effect of each main factor while controlling for the others. For instance, on terrestrial cells we found that the probability of having some conservation effort is negatively related to the frequency of conflicts (Figure 25a), to the distance to the Sea (Figure 25b) or to the density of population (Figure 25c). This presence of conservation effort has a quadratic (U-shape) relationship with the HDI (Figure 25d).

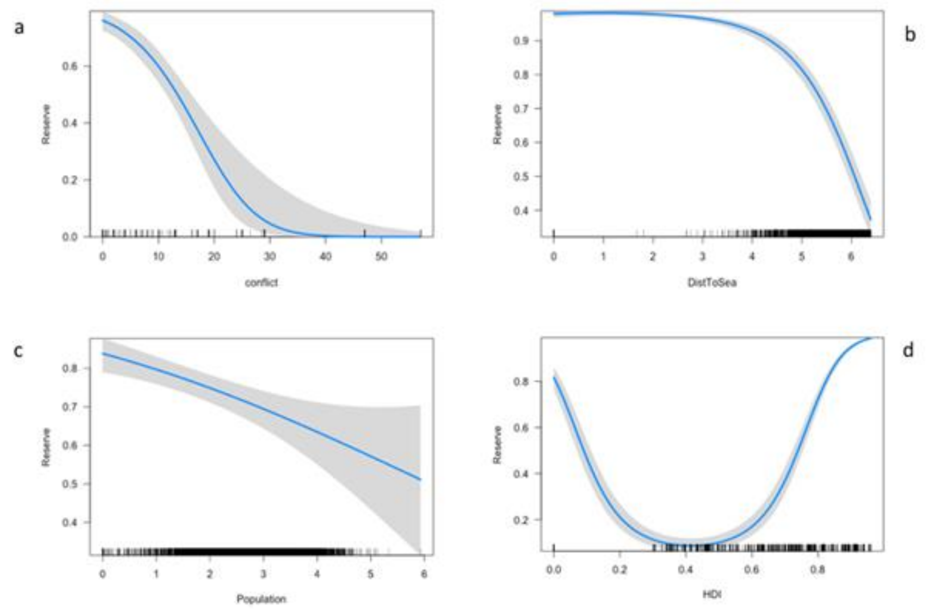

Figure 25: Partial regression plots showing the influence of 4 main explanatory variables on the probability of having some conservation effort (presence of protected area) on terrestrial cells of 10 by 10km with (a) presence of conflict, (b) distance to sea, (c) population and (d) Human Development Index.

For marine cells, we observe some bias in the breadth of environmental conditions covered by protected areas compared to the global envelope of environmental conditions. For instance, marine protected areas are biased towards more productive and colder seawaters (Figure 26).

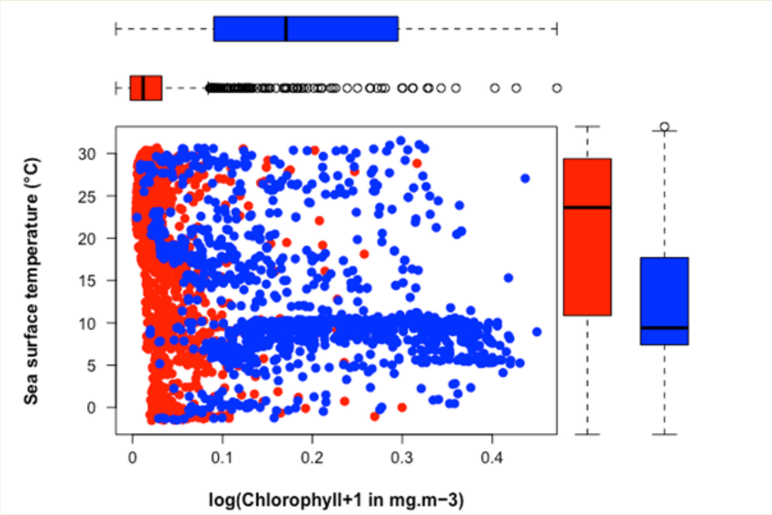

Figure 26: The relative bias in marine conservation efforts toward temperate regions and areas of high chlorophyll concentration. Blue dots represent currently established marine reserves; red dots represent random unprotected sites. Boxplots show the mean variation in chlorophyll concentration (top) and sea surface temperature (SST; right) in protected areas (blue) and in random unprotected sites (red); the thick line inside the boxes represents the mean value. The MPA database was downloaded from the World Database on Protected Areas (www.protectedplanet.net) and filtered to only keep 'marine reserves' corresponding to MPAs satisfying at least one of the following criteria: they are fully no-take zones, they include a no-take zone, or they are classified as strict nature reserves or wilderness areas (i.e. IUCN categories Ia or Ib).

5. Discussion and Conclusions

By Ariane Walz and Jennifer Schulz

The twelve assessments summarised in the above three chapters build a wealth of information to discuss (1) information needs and technical options to identify and potentially also monitor the current state and trends in European ecosystems and ecosystem services, (2) considerations to enhance the existing European network of PAs for the future, and (3) the current practices to account for diverse uncertainties. Here, most of the assessments are able to provide information to several of these topics as indicated in Table 7, and ensure a high diversity in foci in ecosystems and ecosystem services, as well as methodological approaches to reflect these issues.

Table 7: Overview over the twelve studies presented and their main contributions to the three issues to be discussed.

Chapter	Study Title	Assessment and monitoring of ES/ESS state and trends	Considerations to enhance PA network for the future	Reference / analysis of uncertainty
2.1	Remote Sensing derived ecosystems states across ECOP PAs	High diversity in knowledge needs Potential to cover this diversity	Target conservation goals of individual PA Potential role within PA network	*Discussed: Data uncertainty (Spatial, temporal, them. resol.)* *Model uncertainty*
2.2	State and trends in climate conditions across ECOP PAs	Network of in-situ climate data observations	Vulnerability/resilience to CC	Choice of Indicators *Discussed:* *Data uncert.* *Interpolation uncert.*
2.3	Uniqueness of PAs for Conservation Strategies in the Europe		Enhance pan-European network of PAs	Choice of Indicators *Discussed:* *Data uncert./choice*
2.4	Land cover change for all European PAs	cross-European monitoring	-	-
3.1	Pan-European RS analysis for NDVI and LST	pan-European RS by MODIS	Potential shifts in bioclimatic limitations to ecosystems	-
3.2	SST as an Essential Variables for marine ecosystems	pan-European RS by MODIS	Vulnerability/resilience to CC	Multiple indicator species
3.3	The potential for functional diversity of forests in Europe	-	Vulnerability/resilience to CC	-
3.4	Vulnerability of European freshwater systems	Species	Vulnerability/resilience to CC, connectivity of habitats	Choice of Indicators, Data uncert. (climate scenarios) *Discussed:* *Data uncert./choice of species*
3.5	Connectivity across LME	-	Connectivity of habitats, identification and role of hotspots	-
4.1	Examples of ESS assessments for ECOP PAs	High diversity in knowledge needs	Consideration to manage for ecosystem services supply of individual PA	-
4.2	Carbon stocks as a global ESS across all ECOP PAs	1 km estimates versus 10 m EODESM	Role of Global ESS	Data uncert./resolution
4.3	Marine food provisioning through the Mediterranean Sea	large-scale COPERNICUS RS products	Vulnerability/resilience to CC	
Box 1	The global "niche" of PAs	-	Controls in distribution of PAs	-

5.1. Large-scale assessment and potential monitoring of ES and ESS states and trends

Individual PAs

The two overviews across all ECOPOTENTIAL PAs (Chapter 2.1 and 4.1) show a strong heterogeneity across individual information needs on state and trends of their ecosystems and ecosystem services. This reflects very well the individuality of PAs, in their environmental niche, their land use history and the current pressures they are exposed to, and the needs of local PA managers (see also D11.2 and storylines). Furthermore, it highlights the strong technical and methodological potential to meet many of these very individual information demands and the opportunity for taylormade monitoring of individual PAs. The improved accessibility of remote sensing imagery including data of high temporal and spatial resolution of 5 to 10 m is a big step forward towards this option, but the studies also show still remaining limitations. One of these limitations is the lack of in the past data for time series analysis at a grain of 10 m or smaller. Time series analyses for individual ECOP PAs in Chapter 2.1 and 4.1 are still based on LANDSAT, as Sentinel time series are still too short at this stage. However, they promise high potential for remote sensing based monitoring in PAs for the future.

Technical solutions

In addition to data availability, crucial processing steps remain to establish an individualised monitoring scheme. The three classes of information identified in Chapter 2.1 mirror increasing processing requirements with level (a) continuous layers based on remote sensing imagery (e.g. vegetation indices, water indices), level (b) classified or thematic layers based on remote sensing imagery (e.g. land cover), and level (c) modelled spatial representations of indicators based on Remote sensing, field data and eventually further existing environmental information (e.g. feeding habitat at Pelagos Sanctuary, Lizard habitat suitability at Samaria). All of them are based on existing methods, data and techniques, but their operational use for the monitoring of individual PAs and thus practical PA management are not yet established.

Besides providing a series of prototype examples from the ECOPOTENTIAL PAs, ECOPOTENTIAL also develops technical solutions to meet information needs of individual PAs. Three principle achievements of ECOPOTENTIAL to meet information needs of individual PAs (both under further development) include for the ECOPOTENTIAL sandbox mainly for level (a) information that requires a number of processing and selection steps which follow in principle the same protocol, and the EODESM system for level (b) information requirements based on classified information, and (c) model based indicators using the RS data streams. The ECOPOTENTIAL sandbox offers access to EO data from existing archives and provides technical processing solutions and algorithms which are most suitable to establish a customised monitoring scheme for individual PAs (e.g. https://github.com/ec-ecopotential/dcs-sen2cor). Similarly also the EODESM system, which facilitates combining a large range of RS data sources of different spatial and temporal resolutions to customised classification-based information, can be used to establish such a monitoring scheme, given that the same original remote sensing products are or will be available for different time steps (e.g. 4.2, and more details in D4.2). How models can be used to derive more indicators that are directly relevant for stakeholder, has been nicely demonstrated in the assessment of suitability for aquaculture of fish in the Northern Adriatic Sea (4.3). The ECOPOTENTIAL Virtual Laboratory Platform aims exactly at offering such web-based data services, including open archives, scientific models accessible as web services, semantic assets, and analytics services (for more detail see WP10).

Pan-European Assessment

At the same time the assorted studies presented in Chapter 2, 3 and 4 also provide good examples for pan-European assessments of a number of ecosystem state indicators and their time series. Here, the overlap of indicators is only small with the knowledge needs identified for the management of individual PAs, namely NDVI, GPP, LST, SST and chlorophyll-A. However, these indicators all have been classified essential for the monitoring of ecosystems, biodiversity or climate as an essential driver of ecosystem states (see Deliverable 2.1). Furthermore, they are all integral part of the upcoming assessment of ecosystem state and trends across all PAs which has been laid out in Chapter 2.1.

Remote sensing data (Chapter 3.1, 3.2, 4.2, 4.3), networks of ground based observations (Chapter 3.4) and existing EU monitoring (Chap 2.3) are the three main data sources to assess the current state and trends of ecosystems in the presented studies. Monthly MODIS products with large coverage of terrestrial and marine areas were, for instance, used for these analyses which allow to go back until the year 2000, and thus provide a certain basis for trend analysis. A further advantage of MODIS are the monthly cloud-free composites which can be produced as at least every second day an imagery is provided all around the globe. MODIS builds a good basis for large-scale monitoring of processes across all Europe or all European PAs, but the 250 m resolution and the noise typically associated with lower resolution reduce the relevance of MODIS data for many issues of interest for the management of the individual PAs.

Existing networks of standardised ground-based meteorological stations support the monitoring of climate conditions throughout Europe. The presented study in Chapter 3.4 exemplifies a number of important indicators of the changes occurred in mean climate and in climate extremes since the 1950s, based on long-term daily precipitation and near surface air temperature. It is based on the European Climate Assessment & Dataset project (ECA&D) dataset, which currently contains eleven elements from 10,596 quality-checked meteorological stations throughout Europe and the Mediterranean (https://www.ecad.eu/). Such networks have been improving over the past decades, but still show the potential to improve in their regional coverage for systematic monitoring. The study presented in Chapter 3.4 doesn´t use the observed time series directly, but builds on the E-OBS data set, an interpolated, regularly updated dataset based on these observations. Like all currently available gridded observational data sets, E-OBS is limited to coarse resolutions (~25 km for E-OBS) and is therefore suitable only for studies at scales larger than the single location, and for applications such as the comparison and validation of climate models at regional scales. In fact, though having its limitations from the sparse distribution of underlying in-situ stations in some regions and the employed gridding algorithms, E-OBS is being extensively used to evaluate the performances of state-of-the-art regional climate models over Europe as well as as a reference dataset to correct eventual temperature and precipitation biases in the model outputs, as proved by the extended existing literature on this dataset and its applications.

CORINE, as the most prominent family of environmental monitoring products of the EU, holds a series of four time steps dating back to 1990 at a 100 m resolution with a minimum mapping unit of 25 ha/100 m. A valuable asset for smaller scale applications, such as the analysis of land cover change in PAs across Europe, are the layers of land cover change with a minimum mapping unit of 5 ha available since 2000. Still, building on classified remote sensing data, it only shows post-classification change, and can not indicate gradual change which is of particular relevance for the identification of degradation processes in ecosystems. Furthermore, the number of and the long spacing between the available time steps impede the detection of seasonal or regular variation from trends in most areas.

Combining large-scale and small-scale monitoring needs

Summarising, we clearly see two complementary purposes of PA monitoring at different scales, one on the level of individual PAs and one for monitoring across PAs in Europe. The first shows a need for high spatial resolution and customized thematic focus for onsite management including for instance also the populations of flagship species and their habitat, while the second shows need for more generic variables to evaluate state and trends of the diverse ecosystems across Europe for the purpose of enhancing basic conservation goals including the manifold dimensions of biodiversity and vital ecosystems which can supply ecosystem services to society. We show successful example to derive data for both purposes, and show ways to operationalise these techniques.

Bridging the knowledge needs of individual PAs with the feasibility of large-scale monitoring is not yet solved. First steps towards a meaningful monitoring of PAs include the identification of Essential Protected Areas Variables (EPAV, as described in detail in Deliverable 2.1) and the ongoing assessments of Pan-European MODIS time series analysis for a set of variables as described in Chapter 2.1. Within this set of variables two variables are being analysed for all PAs (GPP and phenological metrics). Additional variables for terrestrial ecosystems include NDVI and Land Surface Temperature, and Snow Cover Duration and Albedo for mountain and arid ecosystems respectively, and for marine ecosystems Chlorophyll-a, Sea Surface Temperature and Total Suspended Solids. This selection of variables builds a first start for large-scale monitoring, and has also been mentioned as a knowledge need by several of the PAs. However, higher resolution would require accounting for local variability which is highly relevant for the management of an individual PA and the conservation of habitat and biodiversity. Strategically and technically strong advances are being currently made towards such large-scale monitoring by various initiatives including GEOSS (https://www.earthobservations.org/geoss.php), GEOBON (http://geobon.org/) and EUROGEOSS (http://www.eurogeoss.eu).

Besides these quickly developing initiatives and existing data products, Chapter 4.2 shows a strong potential to use also innovative techniques, such as the EODESM system mentioned above, for instance, to enhance the resolution of estimates of ecosystem states and to bridge some of the scaling issues. In the study described in Chapter 2.1, carbon storage as a global ecosystem service for climate regulation has been estimated and compared from a 1km-resolution dataset and 10m-resolution dataset derived from the EODESM system for all terrestrial ECOPOTENTIAL PAs. This indicates the great potential that the highly adaptive EODESM system holds for setting up consistent monitoring schemes not only within, but also across PAs, given the availability of similar input data across PAs. Similarly, also longer periods can be covered if the data are available. As the platform explicitly combines different data inputs, it might not always be straightforward to assign a specific date to detected change. The classes generated by the EODESM system are detailed and comprehensive, but the validity of each is complex to assess (D4.2). The accuracy assessment of biophysical variables (including inputs to the EODESM system) could contribute to evaluate the accuracy of the components of each class associated with each object, or otherwise field data to validate specific classes within EODESM could be used.

The findings presented in this Deliverable build a basis for the development of guidelines for large-scale monitoring in Deliverable 8.5, where also existing monitoring schemes described in the introduction and current advancements from the GEOSS, GEOBON and EUROGEOSS initiatives will be addressed.

5.2. Considerations to enhance the existing network of PAs

Management of individual PAs

The two chapters summarising the results of individual ECOPOTENTIAL PAs (Chapter 2.1 and 4.1) indicate again the large diversity of ecosystems, which partly builds on human interventions and their individual conservation goals. This individuality is captured in detail, for instance, in D2.1, D4.2 and D11.2, and is consistent with and representative for the overarching goal to maintain biological diversity protected by the European Biodiversity Strategy (http://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm) as well as the cultural diversity unique to Europe targeted in the European Landscape Convention (https://www.coe.int/web/landscape). Besides these context-specific conservation goals of individual PAs, their conservation values could be improved through better consideration of the role within the large-scale collection of PAs to build a systematic network through improved Green Infrastructure (http://ec.europa.eu/environment/nature/ecosystems/strategy/index_en.htm) between PAs.

Conservation Efficiency

Complementary, a macroscopic angle is taken in most of the studies here to emphasise the pan-European perspective and its advantage to guide effective conservation strategies. To enhance the current network of European PAs and identify challenges that should be accounted for the future of this network, we suggest first to systematically evaluate individual conservation values across the existing collection of European PAs. A set of measures for conservation value are proposed in Chapter 2.3, including both richness metrics and dissimilarity indices. These indices are able to reveal strengths and weaknesses of the conservation value for individual European PAs, and show that some critical conservation components are underrepresented (e.g. compositional dissimilarity). This simple set of analytical indices allows decision-making and conservation prioritization at large scales, and provides a transparent instrument to set conservation priorities for funding agencies.

Climate change

Climate change has been addressed in several of the presented studies as a crucial challenge for the conservation of biodiversity and intact ecosystems. We already observe trends in meteorological indicators including extreme events over the past 60 years for most of the ECOPOTENTIAL PAs (2.2). Likely impacts on pan-European scales include changes in the limiting factors of primary productivity (3.1) and single species (3.2, 4.3) have been highlighted. A complex vulnerability assessment of freshwater habitats systematically combines the assessment of exposure, sensitivity and resilience of freshwater habitats across Europe for numerous species (3.4). All studies imply the dynamic change in habitats within the existing PAs and across Europe, potentially shifting current habitat distribution. This has implications for the management of the individual PA, as single target species might be threatened locally by climate change, and it changes the role of PAs to mitigate threats on biodiversity and habitats. In the sense of insurance hypothesis, PAs play a critical role to enhance the adaptive capacity of ecosystems through their protection of a diversity of ecosystems and species, usually covering also a great functional diversity. The potential of PAs to be a refuge of high functional diversity is suggested to be an asset in face of climate change (3.3) and should be further recognised as a conservation target. This links also to the set of evaluation indices for conservation measures (2.3), where diversity measures are identified as important conservation measures that are currently underrepresented (see above).

Connectivity

Connectivity is another crucial aspect to maintain an effective network of PAs, although the ensemble of European PAs has not initially been designed to account for it. A systematic analysis of movement of individuals reveals the uneven spatial distribution of corridors and identifies hotspots of connectivity, as shown for the habitat building species *Posidonia oceanica* in Chapter 3.5. This connectivity assessment already gives an important insight into the current state of the Large Marine Ecosystem of the Mediterranean Sea, and also between smaller PAs within the Mediterranean Sea. The identified locations of connectivity hotspot are being proposed as candidate areas for future protection to enhance connectivity between established marine PAs. The EU Green Infrastructure Strategy might be an instrument to foster connectivity between terrestrial PAs across Europe, and the Water Framework Directive already enforces the restoration of connectivity between freshwater systems across national boundaries through the removal of artificial barriers. In the future, connectivity will be even more crucial, as habitats are likely to shift with climate change. Consequently, large-scale corridors need to be promoted to support future range shifts of species (c.f. Theobald et al., 2012). This critical role of habitat connectivity has been demonstrated for freshwater ecosystems, where resilience to climate change of species increases strongly with connectivity to up- and downstream habitats (3.4).

Ecosystem Services as a conservation goal for PAs

The increasing focus on targeting Ecosystem Services in conservation management also within PAs raises the issue on the implications of such a shift in management priorities, as historically PAs have been managed primarily for biodiversity and habitat conservation. Chapter 4.1 shows examples of quantification of Ecosystem Services supply within the ECOPOTENTIAL PAs, and first insights in ESS demand. They demonstrate how PAs supply ecosystem services already without specifically targeting them in their management. They also show that PAs supply ecosystem services not only within the PA, but beyond the PA boundaries, for instance for water regulation in Peneda-Gerês or climate regulation through carbon storage with global demand and beneficiaries (Chapter 4.2). However, in the current literature we find evidence that use of ecosystem services can have adverse effects on conservation goals, for instance, Ziv et al. (2017) reveal a variety of synergies, no-effects and trade-offs between the use of ecosystem services and conservation goals of PAs based on an analysis across about 3,750 Special Protected Areas of the NATURA 2000 network. This has been discussed within the ECOPOTENTIAL community since the first start in June 2015. This result highlights that we need to better understand where and how human intervention will have negative or positive effects on biodiversity and on specific conservation goals. Given the current pressure to evaluate the performance of PAs also from an ecosystem service perspective, this result clearly indicates a need to double-check this strategy.

Global Perspective

European PAs are relevant also for the global network of PAs. The analysis of the occurrence of PAs around the globe (Box 1) reminds us that European PAs are part of this global network. Additionally, it becomes apparent that not necessarily only ecological factors play a key role in the establishment of PAs and networks of PAs. Socio-economic factors, human pressure, and governance issues have been revealed as strong control factors for the occurrence of PAs. Although all the presented analyses focus on the ecological dimensions to enhance the collective of European PAs, this shows the importance of the human factor, and links directly to WP9 on “Future Protected Areas” where a combination of environmental as well as socio-economic status descriptors are investigated for future adaptations or establishment of PAs.

5.3. References to uncertainty

Uncertainty is omnipresent in large-scale assessment. Uncertainties are usually described as related to data (e.g. spatial, temporal and thematic resolution, data gaps), modelling (e.g. prediction performance, choice of processes and parameters, parameter interaction), indicator selection, and with important interaction between these effects. How to deal with uncertainty, in particular model related uncertainties is going to be a primary focus of Deliverable 8.3. Still, we would like to have a glimpse on issues revealed in the presented set of assessments.

Data and model uncertainty in RS

Accuracy assessments are common standard for classification products of RS data and prediction performance for model outputs. Hence, uncertainty measures are available for each classified or model-based products shown in Table 2, such as land cover or habitat suitability maps (see D4.2 and 4.3). Uncertainties increase quickly once multiple data layer with their associated uncertainty are combined. This is the reason why accuracy assessment of the EODESM based classifications as the product of individual input map uncertainties are complex (D4.2). Alternatively, direct comparison with onsite observation can be an option to assess accuracy. Novel ways to assess the accuracy of RS products include pixel-per-pixel based uncertainty maps, as suggested and demonstrated for instance by Khatami et al. (2017).

Indicator choice

The choice of indicator used in an assessment adds to the uncertainty given by underpinning data and models. How sensitive results are to the choice of indicators, has been demonstrated for conservation effectiveness of PAs (2.3), observed climate change (2.2), and vulnerability of habitat to climate change (3.4). Each of these studies uses a range of indicators to gain more robust knowledge on the state and trends of the investigated ecosystems and demonstrates how results vary depending on the choice of indicators.

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6. Appendix

6.1. List of original sources

- Domingo-Marimon Cristina and Joan Masó, 2018: Using Ea rth Observations to Protect Natural Landscapes. Download: www.ecopotential-project.eu/images/ecopotential/documents/ecopotential-spaced.pdf.
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6.2. Summary table across ESS assessments from D7.1

Table A1-1: Summary of a first compilation of ESS assessments in the ECOP PAs (status D7.1 10 Dec 2017).

PA	Ecosystem	Indicator Ecosystem	Data source	Time steps	Trend Ecosystem	ESS	Indicator ESS Supply	Trend ESS Supply	ESS Demand	Indicator ESS Demand	Data source	Trend ESS Demand
Terrestrial												
Peneda-Gêres	Grassland	Total Grassland Cover	EODESM Landsat Sentinel 2	1987 2002 2016	Decline, slow recovery over the past years	Habitat for targeted species		See ecosystem				
			Modelled in WP6	2016	N/A	Grassland species richness		n/a				
						Water Supply	Run-off per 1 km^2 pixel, as precipitation - evapotranspiration	Decline because reduced precipitation	Water supply for irrigation	Irrigated land inside and outside PA	EODESM Landsat Sentinel 2	Decline, and increase since 2002
									Farming	Number of farms inside PA	National statistics	Decline
						Recreation	Flickr 2007-2016	Increase				
SNP	Grassland	NDVI	Landsat	2003-2016		Biomass production Grassland	NDVI	Increase	Fodder for domestic and wild animals	Number of farms		Decline
										Farming area		Constant in and around SNP; Decline in Davos
										Lifestock		Constant
	Forest			2012		Global climate regulation	Carbon storage in forest: Canopy height and biomass measurements	likely to increase				
						Recreation	Flickr 2007-2016	Increase				
GPNP	Grassland	Total Grassland Cover		2012 2016	change (15%)	Fodder for wild and domestic animals	GSIVI (proxy for Gross primary productivity) by NDVI 2002-2016, MODIS	Increase	Wild ungulates	No indicator defined		Stable populations
										Kid/female ratio		Decline
						Recreation	Flickr 2007-2016	Increase	Recreation	No indicator defined		Increase
Sierra Nevada	Cropland					Farming / Food	Harvested yields in kg (national stats per basin: 1956 1977 1984	Decline	Farming			Decline in primary sector

							1999 2007)					
	Irrigated cropland		Decline 1990-2010									
	Non-irrigated cropland		Constant 1990-2010ä			Lifestock keeping	Number of sheep and bees (Nat Stats, by basin)	Decline				
	Natural Vegetation		Increase 1990-2010			Groundwater provision	Modelled aquifer recharge (1956-2007)	Overall decline, but not all valleys				
	Tree density		Still increasing 1990-2010			Water regulation	Direct run-off: Modelled WiMMed 1956-2016	Strong increase in small areas within PA				
	Population		Increase since 2000 after strong decline since 1750			Erosion control	Tn/ha: Modelled WiMMed 1956-2016	Increase over large areas				
						Recreation	Flickr 2007-2016	Increase until 2014				
Lake Ohrid/Prespa												
Har HaNegev						Recreation	Flickr 2007-2016	Increase until 2014				
Krueger NP						Recreation	Flickr 2007-2016	Increase until 2014				
Marine/Coastal												
Curonian Lag						Fish stock supply	Catch Commercial Fish kg per unit effort 2001-2011	Decline until 2008				
							Total landings 2001-2016	Increase until 2005, then constant				
						Recreation	2007-2016	Increase				
Pelagos	Marine Basin					Fish stock	Estimated annual fish growth (for target species) modelled from MODIS	Increase with increasing SST				
						Marine Aquaculture	Potential fish harvest (t/y), modelled from MODIS					
						Recreation	Flickr 2007-2011	Increase until 2014				
Camargue	Reed					Water regulation	Probability of inundation	No trend				
						Habitat	2017,	No trend				

							2016. Reedbed occurance from sentinel 1 and 2 + in situ data					
						Reed Harvest	2016, mapped from sentinel 1 and 2 + in situ data	No trend				
						Recreation	Flickr 2007-2016	Increase				
Wadden Sea						Recreation	Flickr 2007-2016	Increase until 2014				