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Assessment of status and evolution of ecosystem service indicators

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1. Introduction

ES assessments have increased in frequency, though the knowledge generated is often centred on economic valuation and ecological functions (Förster et al., 2015, Abson et al., 2014). Laurans et al. (2013) found that most ES economic valuation studies were not actually put to actual use and utilised by decision makers. Though ES assessments allow benefits and trade-offs to be highlighted (Förster et al., 2015). The first world-wide ES assessment was undertaken as the Millennium Ecosystem Assessment (MA, 2005) followed by an array of assessments on different scales (Ruckelshaus et al., 2015). In recent years EU Member states have committed to mapping and assessing ES as part of Action 5 under the European Biodiversity Strategy to 2020 (European Commission, 2011). The 'assessment' of ES refers to the translation of the ES data into readily understandable information for decision makers (Maes et al., 2016). The development and choice of indicators plays a crucial role here.

PAs cover approximately 15.4% of land worldwide (Juffe-Bignoli et al., 2014), with Aichi Targets aiming to increase this figure to 17% by 2020 (Convention on Biological Diversity (2010). The Ecosystem Services these areas provide are immense, for example it has been estimated 312 billion tons of carbon is stored in indigenous and other protected land globally (Campbell et al., 2008). Whereas traditionally PA design focused on conserving biodiversity, recent shifts have directed the focus to include ecosystem services (Doak et al., 2014, Kareiva and Marvier, 2012, Xu et al., 2017), with research showing the ability of PAs to secure biodiversity, ecosystem services and increase ecosystem resilience (Xu et al., 2017). For example, Viña and Liu (2017) demonstrate how a network of nature reserves designed especially for the conservation of the giant panda (Ailuropoda melanoleuca) in China contribute significantly to carbon sequestration. ES are important for PA managers to consider, and toolkits such as TESSA (Toolkit for Ecosystem Service Site-based Assessment) (Peh et al., 2013) are suggested for use by non-specialists by the IUCN for PA management, with the values and benefits (utilising the ES approach) has been discussed in PA management texts (Worboys et al., 2015).

1.1 Ecosystem service indicators

Ecosystem services indicators are important to measure the trends and state of ecosystem service delivery; with recent years seeing a wide indicator base being developed (Vihervaara et al., 2017). Indicators are powerful tools to inform and improve the knowledge base on ecosystems and ecosystem services, which are useful for decision-makers at any spatial scale for basing their decisions on evidence (Layke, 2009) and also at a higher level to respond to the EU Biodiversity Strategy to 2020 (Maes et al., 2016). Indicators act to simplify information, allowing policy-makers to understand and utilise evidence to make decisions. They have been used in other areas to inform decision makers including education and social well-being and are often a tool which policy-makes utilise (Layke, 2009). Ecosystem service indicators are drawn from diverse sources such as visitation numbers from tourist boards or crop data from agricultural census data. The Millennium Ecosystem Assessment reported that "no widely accepted indicators to measure trends in ecosystem services, much less indicators that measure the effect of changes on human well-being" (MA, 2005).

Much work has taken place on the biodiversity-related measures in relation to biophysical ecosystem services, with limited research (beyond only economic valuation) on ecosystem services and human well-being (Heink, Hauck, Jax, & Sukopp, 2016). A systematic review undertaken by Harrison et al. (2014) found that the relationship between biodiversity attributes and ecosystem services were mostly positive, though to support decision making socio-economic factors also needed to be considered. This being said, it has been found that there is a virtual lack of an ecosystem service indicator-based models in land-use planning (Cowling et al., 2008). With Protected Areas (PAs) historically providing conservation of nature, these areas hold a wealth of ES.

For decision makers to be able to use ecosystem service indicators they first have be developed and utilised. To choose the appropriate indicator, firstly the question of what to measure must be answered, considering the type of assessment, target audience, position on the ecosystem service cascade, data availability and the spatial and temporal scales (Vihervaara et al., 2017). The second question is then how this can be measured, whether it would be direct measurement through field observations/ experiments/ surveys; indirect measurement through earth observation, proxies or socio-economic data; or lastly indirect measurement thought expert based process based or statistical modelling (Vihervaara et al., 2017).

Much guidance is available in the literature for the identification and development of ecosystem service indicators, including Feld, Sousa, Da Silva, & Dawson (2010) who presented an earlier example of an improved ecosystem services indicators using the EEA's Driver-Pressure-State-Impact-Response scheme, and Müller & Burkhard (2012) who discuss how ecosystem service can be seen as impacts in the DPSIR indicator framework.

Several ecosystem services frameworks lead to different indicator selection, but this selection needs to be subject of quality criteria evaluation to have a widely accepted set of indicators (Heink et al., 2016).
There are several ecosystem service classification schemes, including the MA, TEEB, IPBES and CICES (EEA, 2018; Haines-Young, Potschin, & Kienast, 2012). More recently, the MAES framework presented a table with the best indicators for ecosystem services according to the CICES ES classification across different ecosystems (Maes et al., 2016).

Among others, the well-known ES cascade (Haines-Young & Potschin, 2010) presented in the TEEB project has been used in many studies to select indicators that range from the ecological to the socio-economic, from the supply to demand indicators (Van Oudenhoven, Petz, Alkemade, Hein, & de Groot, 2012). CICES has been used as a foundation for the development of ecosystem service indicators (for both supply and demand) (EEA, 2018). Examples include biophysical indicators being used to measure the supply-side of ecosystem services (Castro et al., 2014), and socio-economic valuation indicators that proved to require clear and proper identification of ecosystems services (Kosenius, Haltia, Horne, Kniivilä, & Saastamoinen, 2014). Furthermore, the use of CICES to develop concrete indicators has been discussed by von Haaren et al. (2014) through the introduction of a practice-oriented ecosystem services (PRESET) model for landscape planning. Czúcz et al. (2018) found that from 85 studies utilising ecosystem service indicators, 440 were identified which covered nearly all CICES classes, with cultural and some regulating being the most common. The most common individual classes were global climate regulation, aesthetic beauty, recreation, and bio-remediation, with 20% being economically quantified.

Spatial and temporal scales are important in indicator selection, as ecological process based on biodiversity are highly dependent on both time and space (Vihervaara et al., 2017). Temporal scale can have an impact on measurement of process that are affected by cycles such as day and night. The importance of spatial scales can be seen in pollination services, where pollinators usually work only within a few hundred meters of hives; in contrast carbon storage in tree is seen to work at a global scale (Vihervaara et al., 2017).

In a recent review on the quantification of ES, authors found that ES appear to be poorly quantified in many cases, as often only one side of the cascade is considered (either the ecological or socio-economic side), uncertainty and validation are often not included and there is often an oversimplification of indicators (Boerema, Rebelo, Bodi, Esler, & Meire, 2016). Whether the design of PAs involve consideration of ES or not, they often provide an array of ES. Hence it becomes important to select an appropriate ES indicator to be able to monitor the provision of these ES. Although the indicators explored for the different PAs are only applied for the potential provision and not the actual use of the services, the selection is an effective attempt to develop the first EU wide ecosystem assessment based on existing data.

1.2 Deliverable methodology

A selection of Protected Areas from mountain, coast and marine, and arid ecosystems were used as case study areas to investigate a selection of ecosystem indicators and how they can be used to monitor ecosystem services in PAs. In total twelve Protected Areas participated in this deliverable, five from mountain areas, two from arid/ semi-arid areas and five from coastal/ marine areas. The types of ecosystem service are concurrent with the CICES classification, but the selection of most relevant ESS varies between different PAs. Where possibly, supply, demand and beneficiaries were defined for each of the ESS. Mann-Kendall tests on time series data for selected indicators were calculated. Mind maps developed for ecosystem services as a tool to structure the individual approaches taken by individual PAs were not included in this deliverable, but in Deliverable 7.2. For each individual PA storyline diagrams have been included from Deliverable 2.2, showing the identified essential variables at the storyline level. Individual methodologies utilised for each PA have been explained as appropriate in the Chapter 3.

Recreation was assessed for each of the PAs using images uploaded to the photo sharing site Flickr.com. An estimated 11% of the 2.6 million geo-tagged photos uploaded Flickr (Levin, Kark, & Crandall, 2015), have been found by to correlate with visitation rates within PAs (Wood et al., 2013) and can be seen to be a ‘good indicator’ of PA visitation (van Zanten et al., 2016). Bounding boxes for the shapefiles for the protected areas were calculated using ArcMap 10.3 (ESRI UK Limited, Aylesbury, UK) and the resulting coordinates used in the Flickr API to extract frequency of images uploaded each year between 2007-2016. Mann-Kendall tests were utilised to assess any temporal trends in the data.

2. Importance of ecosystem services in Protected Areas

Twenty-four Protected Areas and their managers are involved in ECOPOTENTIAL. The Protected Areas are distributed across mountain (16), arid/semi-arid (5), and coastal and marine ecosystems (7). The discrepancy in the total is due to Protected Areas representing more than one ecosystem. As part of Deliverable 11.2 information was collected from questionnaires provided to each Protected Area manager or other relevant staff member (see Appendix of D.11.2 for questionnaire). The questionnaire contained an introduction to ECOPOTENTIAL, an explanation to the concept of ecosystem services and explanation of the possibilities of Earth Observation. Three thematic areas were covered by the survey: goals and management of and challenges faced by the Protected Areas, data collection methods and additional known needs and potential collaboration with ECOPOTENTIAL. Nineteen of the Protected Areas participated and responded.

Similarities between the three ecosystem types were clearly noted in D11.2; namely the it was identified that ES concept was relatively unknown and only utilised in a few of the PAs. This was ascribed to a lack of legislative need for the PAs to utilise the ES approach, with the remit of protecting the ecosystems itself coming first, followed by providing recreational and other cultural services. The recreation and aesthetic value were the main benefits that were focused on by the PAs. Cultural services ranked higher than provisioning and regulating services, with recreation, research, aesthetic qualities and education being in the top five services for all three ecosystem types. In the following three sub-chapters on ES indicators in the three different ecosystem types, each PA chose their own indicators; though these do not necessarily relate to the importance of the ES itself. Though the cultural service of recreation has been assessed for all PAs due to its importance as discussed above.

2.1 Mountain areas

Cultural services are found to be the most important in mountainous regions, followed by regulating, then provisioning services (Fig 2.1.1). Of the cultural services recreation was the most important, though this was closely followed by research, aesthetic qualities, and education.

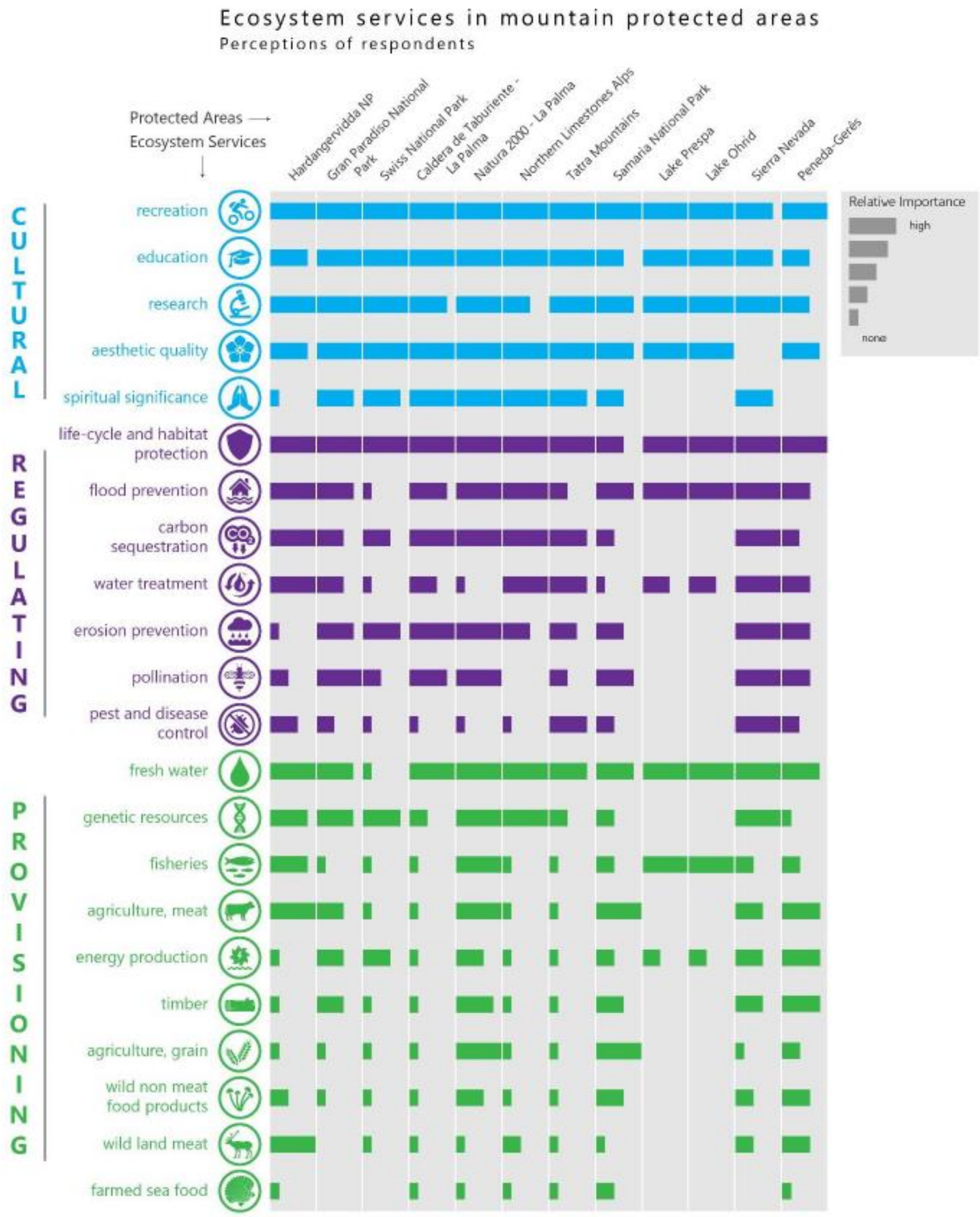

Fig 2.1.1: Importance of ecosystem services in protected mountain areas (Source: Ecopotential D11.2).

2.2 Arid and semi-arid areas

Cultural services can be seen as being the most important for arid and semi-arid areas, followed by regulating and provisioning services (Fig 2.2.1). Of the cultural services recreation/tourism, aesthetics and research and education were the most important.

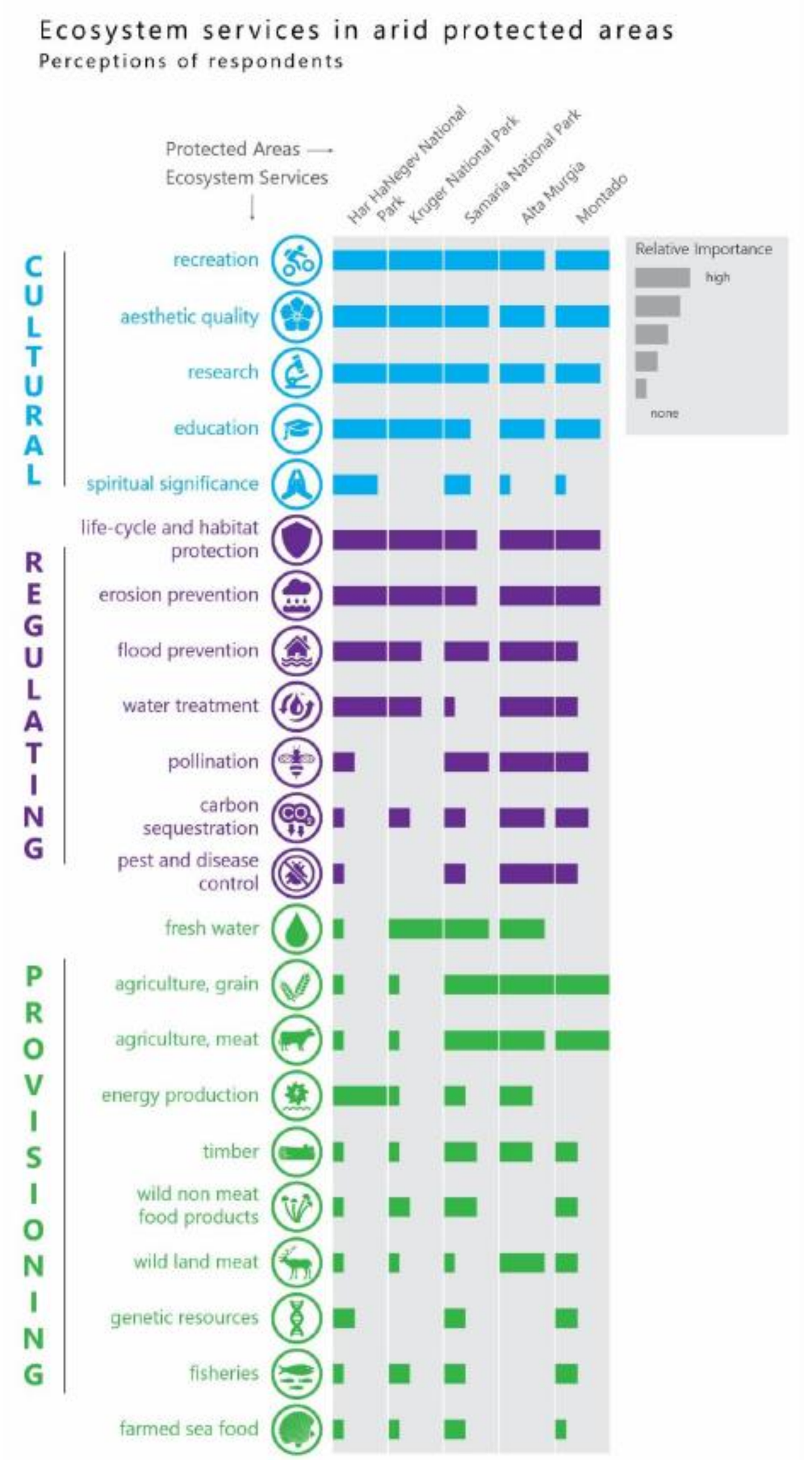

Figure 2.2.1: Importance of ecosystem services in arid protected areas (Source: Ecopotential D11.2).

2.3 Coastal and Marine

The cultural services of recreation and tourism scored the highest for coastal and marine ecosystems (Figure 2.3.1), similarly to mountainous and arid areas. Though the next highest scoring services are fisheries and aesthetic qualities, the education and research, thus 80% of the top five ecosystem services are cultural.

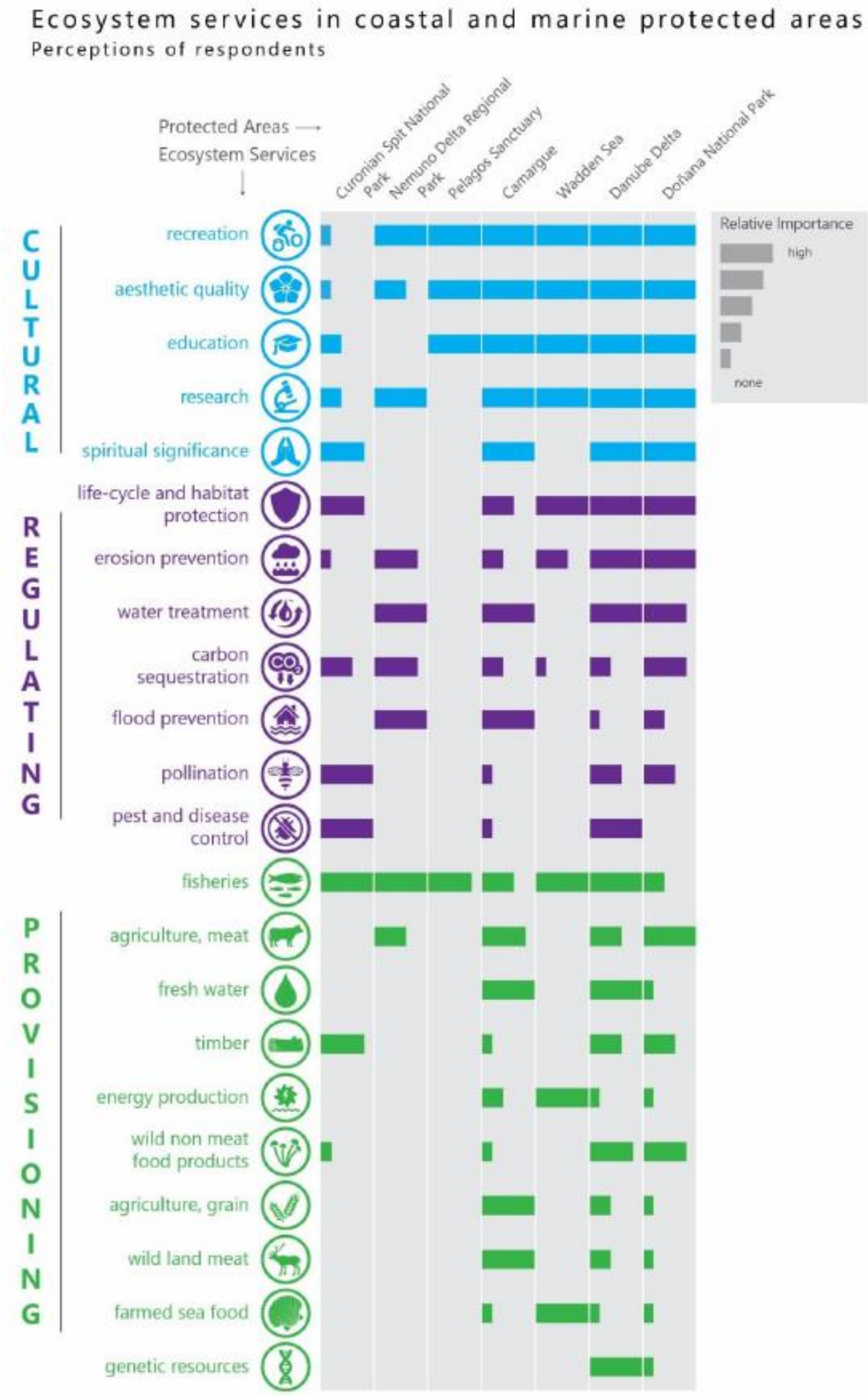

Figure 2.3.1: Importance of ecosystem services in coastal and marine protected areas (Source: Ecopotential D11.2).

3. Ecosystem service indicators in Protected Areas

A wide array of ES indicators was investigated in the following case studies covering twelve PAs. Investigators working with each PA were tasked with choosing appropriate ES indicators that reflected important aspects from their storyline within the Ecopotential project. To facilitate this understanding, the storyline diagrams from Deliverable 2.2 have been included to allow understanding of how the indicator is reflective of an important ES within the PA. These ES indicators are presented here as a first step towards wider and fuller assessment; these indicators are demonstrating how to capture knowledge on individual ES as examples from diverse PAs. A more complete assessment for each individual PA was outside the scope of this study, as taking examples from many PAs is more reflective of the diverse nature of individually important ES across the PAs.

3.1 Mountains

3.1.1 Peneda-Gerês (Portugal)

The Peneda-Gerês National Park covers ca. 70 000 hectares and was founded in 1971. It is located at a climatic transition zone (the climate is Temperate/Atlantic Sub-Mediterranean), with 1-2 dry months in summer. The main ecosystem/land cover types are deciduous oak forests, heathland and scrub, meadows and rock outcrops (in highlands), and forest plantations, scrub, urban areas and agriculture (in lowlands). The current state and temporal evolution of indicators related to supply, demand and beneficiaries of two ecosystem services were evaluated from a larger selection (Figure 3.1.1.1) for Peneda-Gerês National Park; (a) Conservation of grassland habitats (regulation and maintenance), and (b) Water (provisioning).

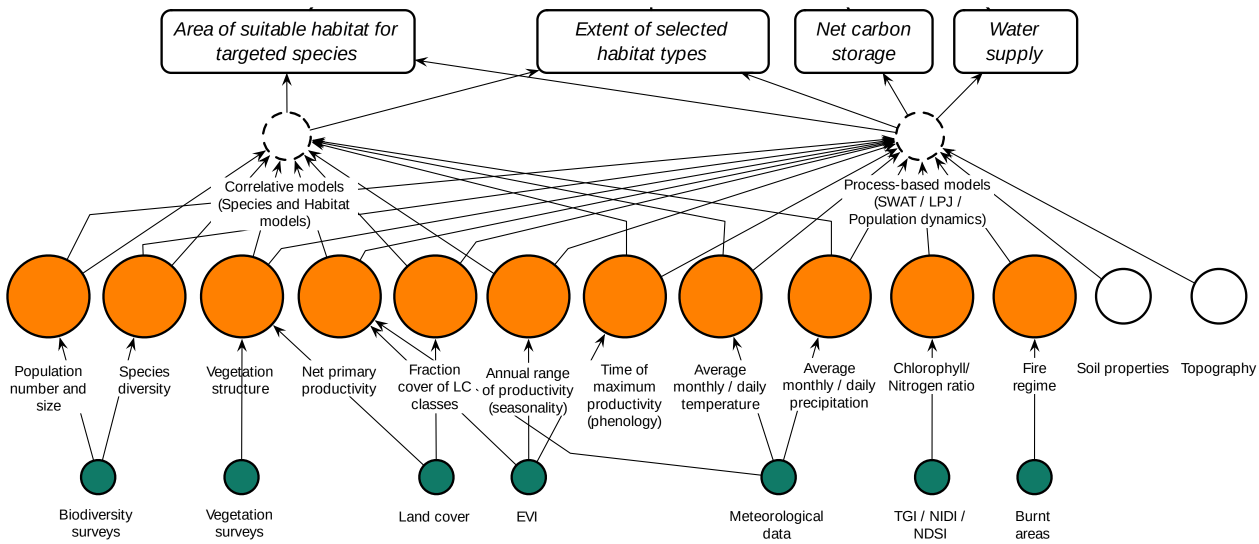

Figure 3.1.1.1: Diagram representing the storyline developed for the Peneda-Gerês National Park, including the identification of essential variables and their links to data sources, models and indicators (Source: Ecopotential Deliverable 2.2).

Conservation of grassland habitats

Supply

Grasslands with high levels of plant species richness are of high importance for nature conservation and also for supply of ecosystem services, in particular for traditional cattle feeding.

Landsat and Sentinel-2 images were used to produce a time-series of grassland habitat maps (1987, 2002, 20016) based on spectral properties of actively managed grasslands. Data on plant diversity collected in the field were used to develop a biodiversity model that assigns a predicted value of plant species richness to each mapped grassland.

This approach allows to discriminate actively (though not intensively) managed, biodiverse grasslands, which are of highest conservation priority in the EU (namely under the 'Habitats' Directive).

The model predicts a fairly wide distribution of grasslands with high levels of species diversity throughout the park, although medium grassland diversity areas prevail. A strong decrease in total grassland area was observed from 1987 to 2002, with a marginal recovery until 2016 (Figure 3.1.1.2). Mann-Kendal test by pixel suggested a negative (loss of grasslands) and significant trend in 5.3% of grassland pixels (from the total Peneda-Gerês area), with $P < 0.05$. The same test indicated a positive (new grasslands) and significant trend in 2.4% of the area with $P < 0.05$.

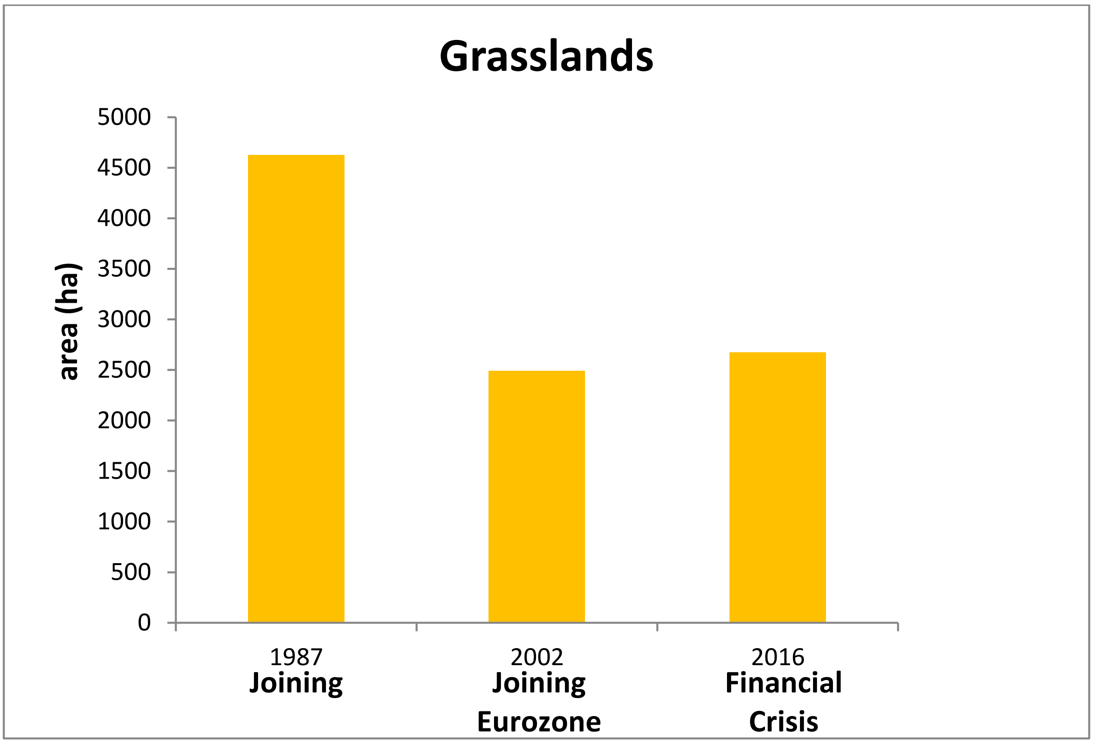

Figure 3.1.1.2: Temporal evolution of total grassland cover in Peneda-Gerês, between 1987 and 2016. Land cover map based on EODESM system applied to Landsat and Sentinel-2 images (WP4).

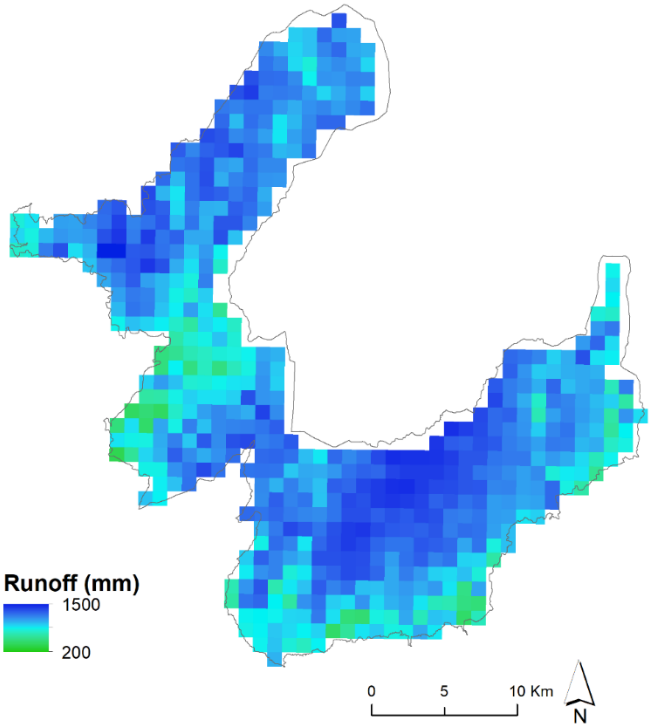

Figure 3.1.1.3: Distribution of Annual Runoff in Peneda-Gerês. Source: Carvalho-Santos et al. (2014).

The grasslands species richness model was only able to predict diversity for 2016, as no field information for the other dates was available. However, it is likely that the decrease in grasslands area since 1987 was followed by a reduction in species diversity and abundance.

Demand and beneficiaries

The conservation of species-rich grasslands is a commitment of the Portuguese government under the EU Habitat Directive. Thus, demand originates from the National authority for nature conservation, which according to EU legislation should report on the areas and status of grassland habitats (annex I of the Habitats Directive). In this regard, the broad European society will benefit from the conservation of grassland habitats in Peneda-Geres. An additional benefit can be related to fodder production for cattle raising. Local farmers are the main beneficiaries and source of demand.

Water

Supply

Peneda-Gerês mountains, where it rains the most in mainland Portugal, are very important suppliers of water. Runoff can be defined as the water that stays in the system after subtracting evapotranspiration from rainfall. This is the simple water balance calculation without considering the differences in water storage (e.g. water in soil). Figure 3.1.1.3 displays the distribution of annual runoff by 1km pixel in Peneda-Gerês, using annual precipitation data (climate normal 1950-2000 from Worldclim) and the average Evapotranspiration product from MODIS (on board of Aqua and Terra satellites). More details on calculation can be found in Carvalho-Santos et al. (2014). Pixels with higher runoff are related with high precipitation inputs and with low evapotranspiration (e.g. bare rock with low vegetation). These are the areas with the highest contribution to the water supply ecosystem service.

Precipitation is the most appropriate variable to characterize the temporal evolution of water resources in a region, and its accurate measurement is essential to understand regional hydrological processes and cycling. It is considered an Essential Climate Variable and, in the ECOPOTENTIAL project, an Essential Water Variable (see Deliverable 2.2). Precipitation for Peneda-Gerês was collected from in-situ data stations (1960-2008). Unfortunately, in the last years precipitation was not monitored properly in the area by in-situ stations. To complement the dataset, the E-OBS gridded dataset for Europe (Haylock et al., 2008) was used and extracted for the Peneda-Gerês region (9 pixel of 25km). Annual values seemed underestimated in E-OBS when compared to in-situ values (Figure 3.1.1.4), probably due to the distance to the main weather stations used in the E-OBS project, which are not representative of the high precipitation conditions of Peneda-Gerês. Nonetheless, the use of E-OBS time-series here is important to evaluate the tendency of precipitation in the last years, for which there are no local data for Peneda-Gerês. Mann-Kendall test suggested a negative, stable and significant trend in both Precipitation time series (In_situ: $S= -542$, $tau = -0.34$, $P < 0.05$ (0.0001); E-OBS: $S= -212$, $tau = -0.25$, $P < 0.05$ (0.017)). This slightly negative trend in annual precipitation amounts have also oscillating between wet and more dry years. However, more important than the tendency of decreasing annual precipitation, is the seasonal tendency of change, i.e. more precipitation in Autumn and Winter and less during Summer.

Evapotranspiration (ET) plays a key role in the hydrological cycle. Figure 3.1.1.5 shows Annual ET for Peneda-Gerês that was taken by MOD–16 evapotranspiration product from MODIS sensor, 250m pixel resolution, MODIS collection 6 (http://modis.gsfc.nasa.gov/). Mann-Kendall test suggested no trend in Evapotranspiration time series ($S= -3$, $tau = -0.033$, $P > 0.05$ (0.91281)).

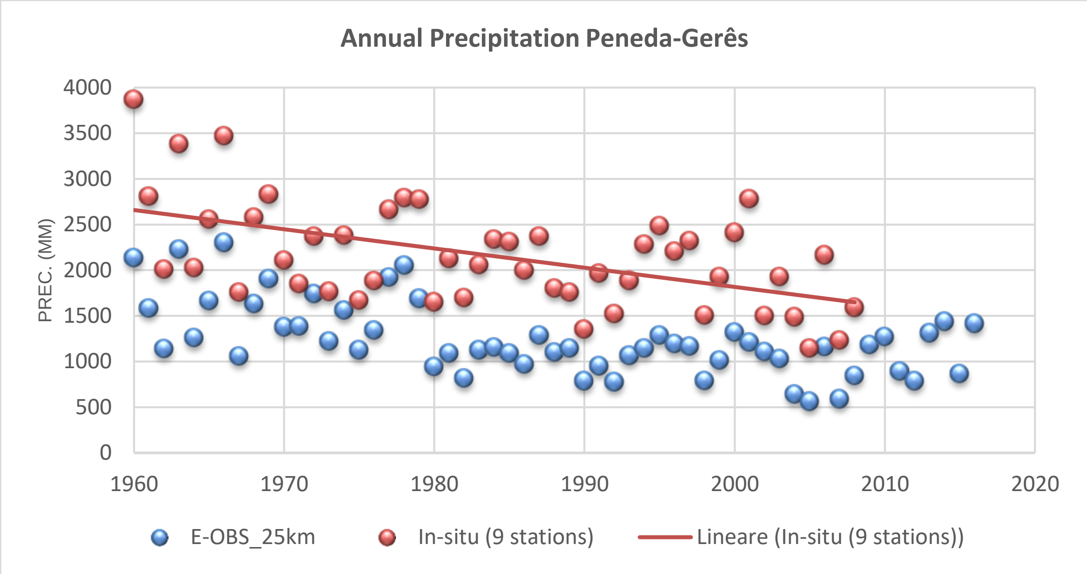

Figure 3.1.1.4: Annual Precipitation in Peneda-Gerês, from in-situ data (9 stations from http://snirh.apambiente.pt/) and E-OBS gridded dataset for Europe (Haylock et al., 2008).

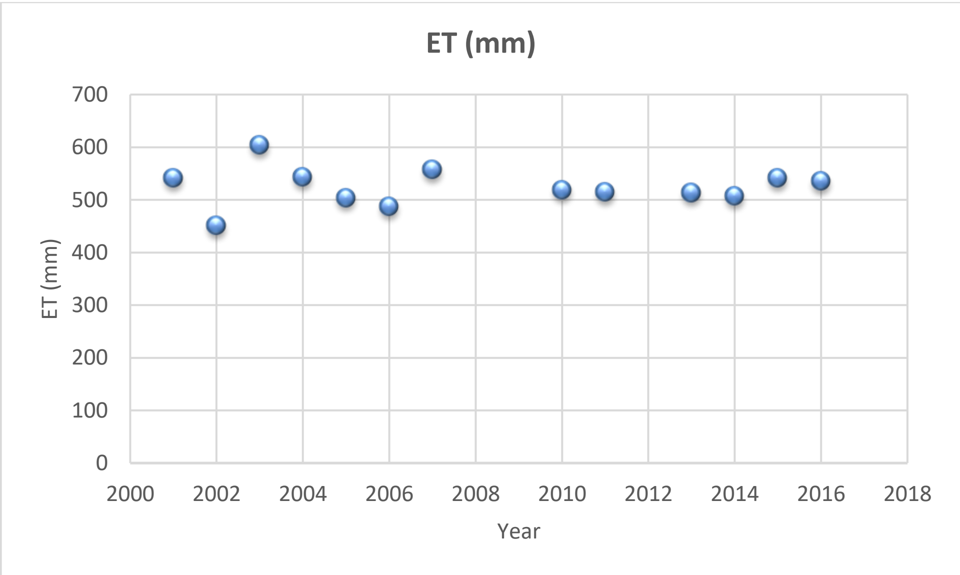

Figure 3.1.1.5: Annual Evapotranspiration in Peneda-Gerês from MODIS sensor on board of Terra and Aqua Satellites (MOD16 product - http://modis.gsfc.nasa.gov/).

Demand

Agricultural irrigation is the activity that uses most water. Irrigated areas were identified in the LULC maps for Peneda-Gerês and surrounding region based on Landsat images for 1987 and 2002, and Sentinel-2 for 2016, using the EODESM platform developed under ECOPOTENTIAL (WP4). Irrigated areas are defined as the ones needing water during Summer months (areas that in April/May appear as bare land, and in July/August appear as green). Irrigated areas, although not occupying a large extent of land cover in the PA, have increased in 2016, after a decline in 2002, comparing to 1987 (Figure 3.1.1.6). This decline in 2002, also visible in the surrounding region (outside the PA) for 2002 and 2016, is probably due to the abandonment of active farming. The growth in 2016, both inside and outside the PA, is probably due to a return to the farming activity following the economic crisis and an increase in financial incentives for new irrigated crops such as berries.

The growth in irrigated areas creates an increase in demand for water and therefore a pressure for the water provision service. A flow of this service can be identified from the PA to downstream areas (Figure 3.1.1.7), suggesting that Peneda-Gerês is important for providing water to regions located downstream in the river catchment, working as water towers that supply water to lowland crop fields.

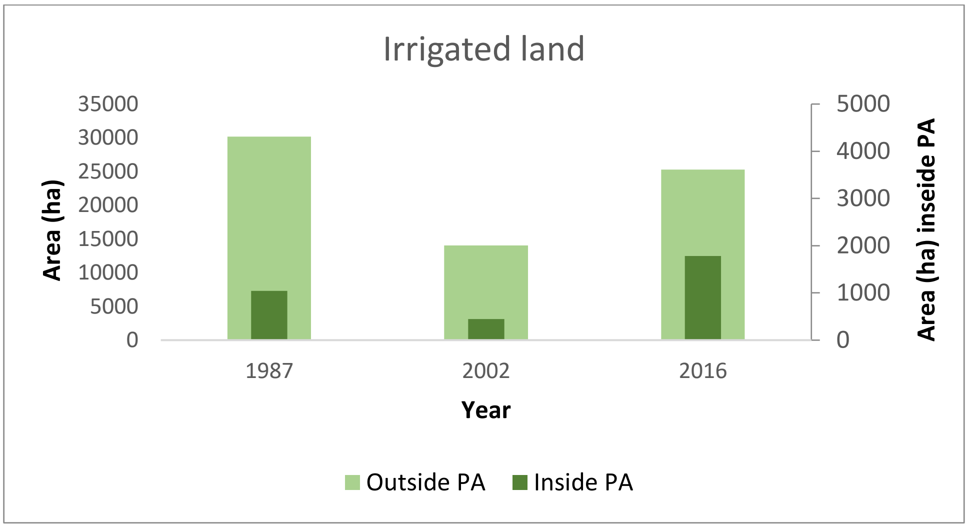

Figure 3.1.1.6: Evolution of Irrigated areas in Peneda-Gerês and surrounding areas between 1987 and 2016. Source: Land cover map based on EODESM system applied to two Sentinel-2 images (WP4).

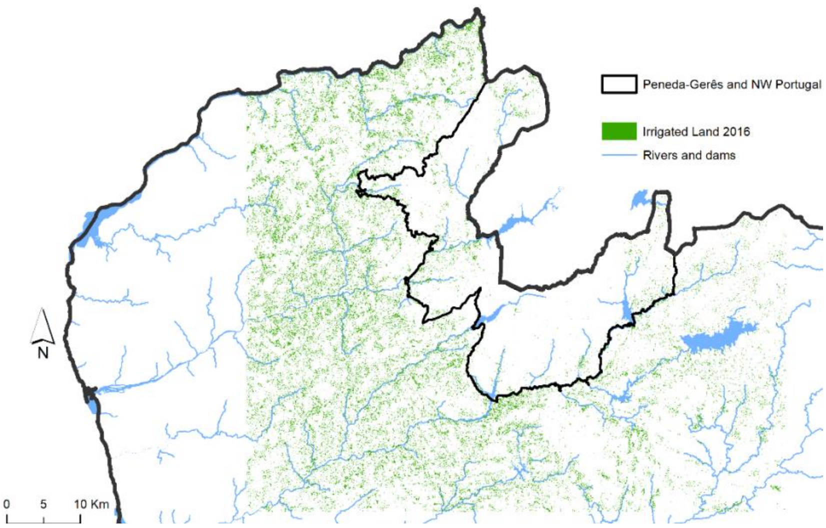

Figure 3.1.1.7: Distribution of Irrigated areas in Peneda-Gerês and surrounding region, in 2016. Source: Land cover map based on EODESM system applied to two Sentinel-2 images (WP4)

Beneficiaries

The direct beneficiaries of water for irrigation are the farmers that depend on water for growing crops (Figure 3.1.1.8). The number of farmers has been drastically decreasing in the last decades in Peneda-Gerês, causing land abandonment, an important driver of ecological change. There is only the exception of one civil parish (Tourém) where the number of farmers has increased since 1989. Since irrigated area (demand) is increasing in Peneda-Gerês, opposing the decline in the number of farmers, this may suggest that agriculture is more concentrated in fewer farmers, with higher economic profit.

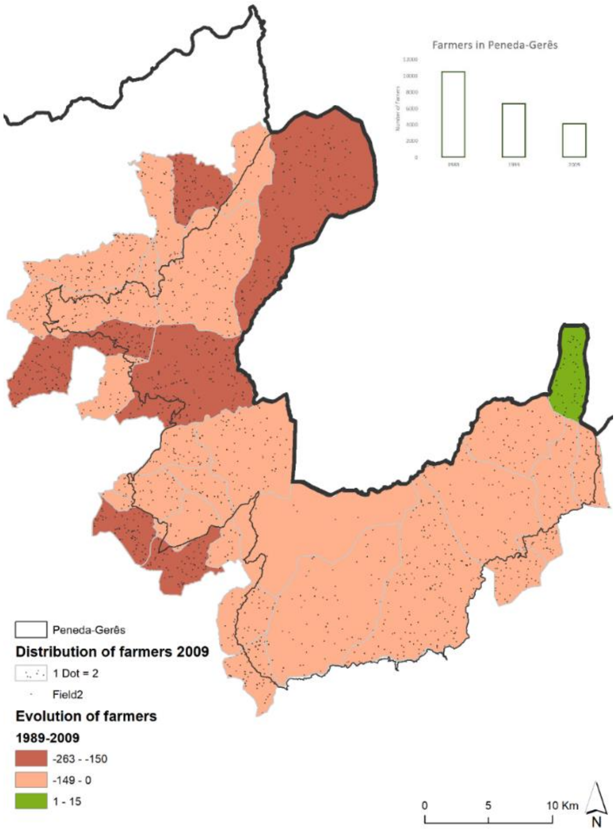

Figure 3.1.1.8: Distribution of farmers in Peneda-Gerês by parish, and temporal evolution (1989-2009). Data source: INE, Statistics Portugal

Recreation

A Flickr analysis shows that photos uploaded per year have fluctuated, with the highest numbers in 2013 and 2016 (Figure 3.1.1.10), a positive trend is suggested by Mann-Kendall test ($S = 25$, $tau = 0.556$, $P < 0.05$).

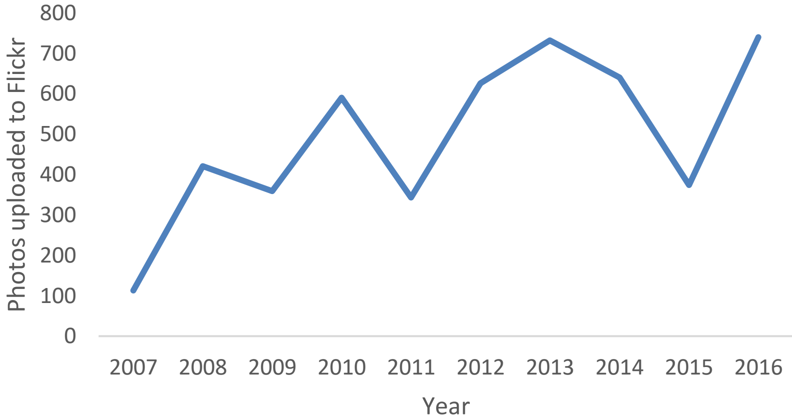

Figure 3.1.1.10: Changes in photos uploaded to Flickr for Peneda-Gerês National Park. Years are filtered by the date the photo was taken.

3.1.2 Swiss National Park and Landschaft Davos (Switzerland)

The mountain landscapes of the inner Alps have a high cultural value due to their scenic beauty and habitats of many charismatic species such as ibex and capercaillie. At the same time, they provide services such as food, timber, recreation, climate regulation and protection from natural hazards (Grêt-Regamey et al. 2008, Huber et al. 2013). They are managed in different ways, from strict reserves such as the Swiss National Park, to more tourism-oriented regions such as Davos. Different management objectives and levels of demand affect the trade-offs between ecosystem services. Land abandonment and increased temperatures have a combined effect on the extent and distribution of ecosystems, with an upward shift in the tree line (Gehrig-Fasel et al. 2007) and densification of previously grazed forests at high elevations (Kulakowski et al. 2011). This change may be beneficial for regulatory services, with an increase in carbon sequestration and protection against natural hazards (Bebi et al. 2012). At the same time landscape heterogeneity is decreasing (Kulakowski et al. 2011), affecting the habitats of many species, as well as the scenic beauty (Grêt-Regamey et al. 2007, Hunziker et al. 2008). Figure 3.1.2.1 shows the identified essential variables, for the Swiss National Park and the Landschaft of Davos the indicators of (a) biomass production (grasslands) and, (b) carbon storage, will be highlighted here.

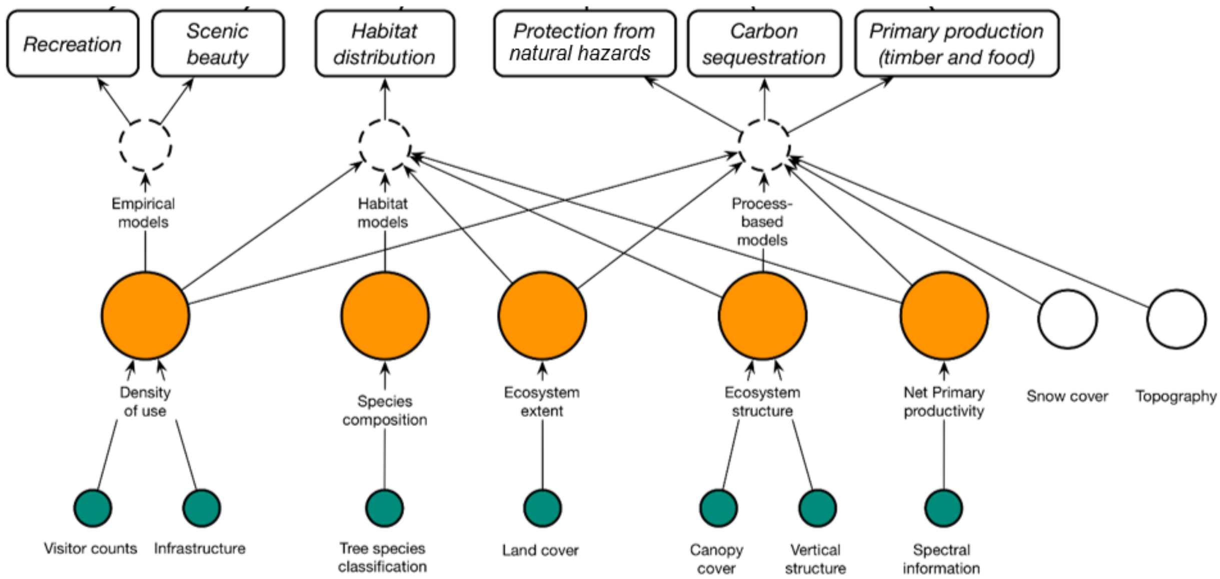

Figure 3.1.2.1: Diagram representing the storyline developed for the Swiss National Park and the Landschaft of Davos, including the identification of essential variables at the storyline level (Source: Ecopotential Deliverable 2.2).

Biomass production (grasslands)

Supply

The production of biomass is a key ecosystem function underlying a set of ecosystem services in the Alps. Due to climate change, the productivity of alpine grasslands is expected to increase (Briner et al. 2012). A commonly used proxy for primary productivity is NDVI, and a time series of the index was produced based on LANDSAT images for 2003-2016 (by UAB). For most of the grassland areas in the SNP and surrounding, the NDVI data confirms the expected positive trend in productivity (Figure 3.1.2.2). This trend is less pronounced in the region of Davos (Figure 3.1.2.3).

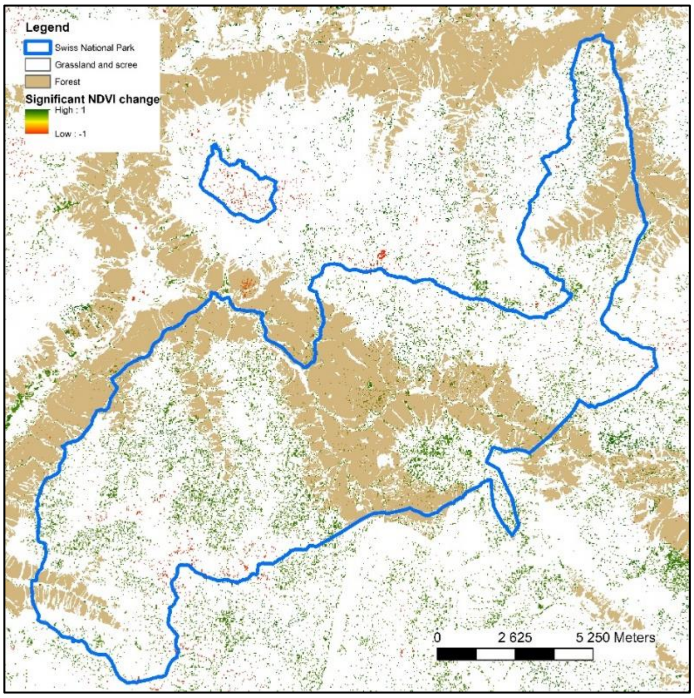

Figure 3.1.2.2: Mann-Kendall trend (tau) values of Landsat NDVI in the SNP (produced by UAB). Only areas with significant ($p < 0.05$) trends are shown. The calculation is based on 7 Landsat images from July and August, 2003-2016.

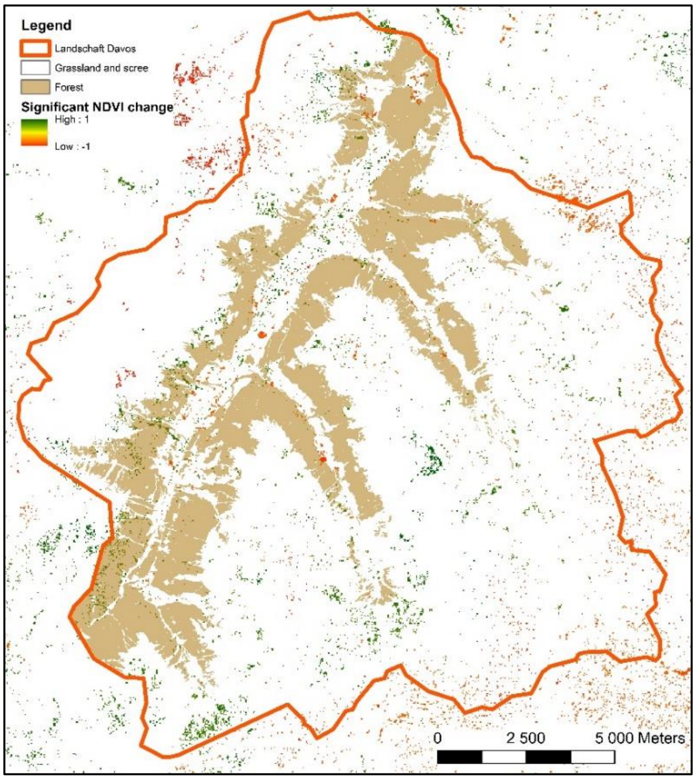

Figure 3.1.2.3: Mann-Kendall trend (tau) values of Landsat NDVI in Davos (produced by UAB). Only areas with significant ($p < 0.05$) trends are shown. The calculation is based on 7 Landsat images from July and August, 2003-2016.

Demand

In the Swiss National Park, biomass produced in alpine grasslands and scree is fodder for wild animals, including charismatic species such as ibex, deer, and chamois (Schweiger et al. 2015). In the areas surrounding the Swiss National Park, the biomass is also used as fodder for domestic animals, mainly for dairy production. Although the number of farms in the region of Davos and in municipalities surrounding the SNP (Zernez, Scuol, Val Mustair) has significantly decreased since the 70s, the number of livestock and area of agricultural land have remained more stable (BFS, 2017), indicating an increase in farm size (Figure 3.1.2.4).

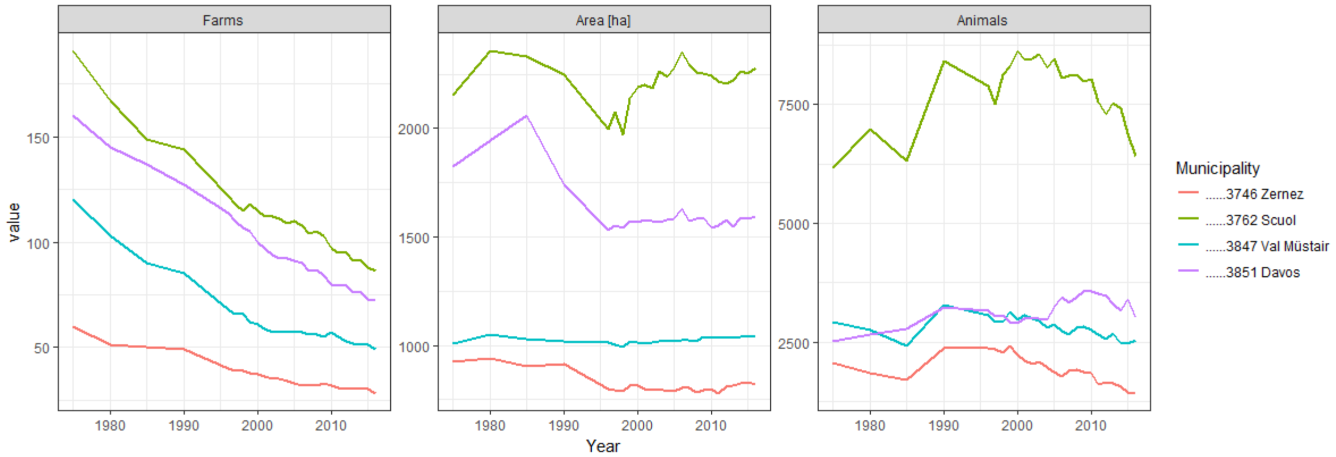

Figure 3.1.2.4: Trends in agriculture in Davos and the areas surrounding the Swiss National Park (Zernez, Scuol, Val Müstair). Although the number of farms has significantly decreased since the '70s ($p < 0.001$), the number of livestock and agricultural area have remained more stable.

Carbon storage

Supply

Mountain ecosystems contribute to climate regulation by storing carbon, and the amount of carbon stored in forests can be estimated based on the amount of aboveground biomass (AGB) (Figures 3.1.2.5 and 3.1.2.6). Within Ecopotential, the AGB was derived (by CESBIO) using an empirical model linking in-situ biomass measurements and a canopy height model derived from high resolution stereo image matching (Leica ADS) from 2012. On average, forests in the SNP contained 208 m3/ha (sd = 96 m3/ha) in 2012, corresponding to around 65 tonnes of carbon per hectare (Thürig and Schmid 2008). Due to the limited availability of consistent canopy height data in the Swiss Alps, an assessment of temporal changes in AGB with remote sensing data is currently not possible. However, due to the ongoing succession from abandoned pastures to forest and the absence of harvesting, the amount of forest biomass and stored carbon is expected to increase (Risch et al. 2009), both within the National Park and in other areas.

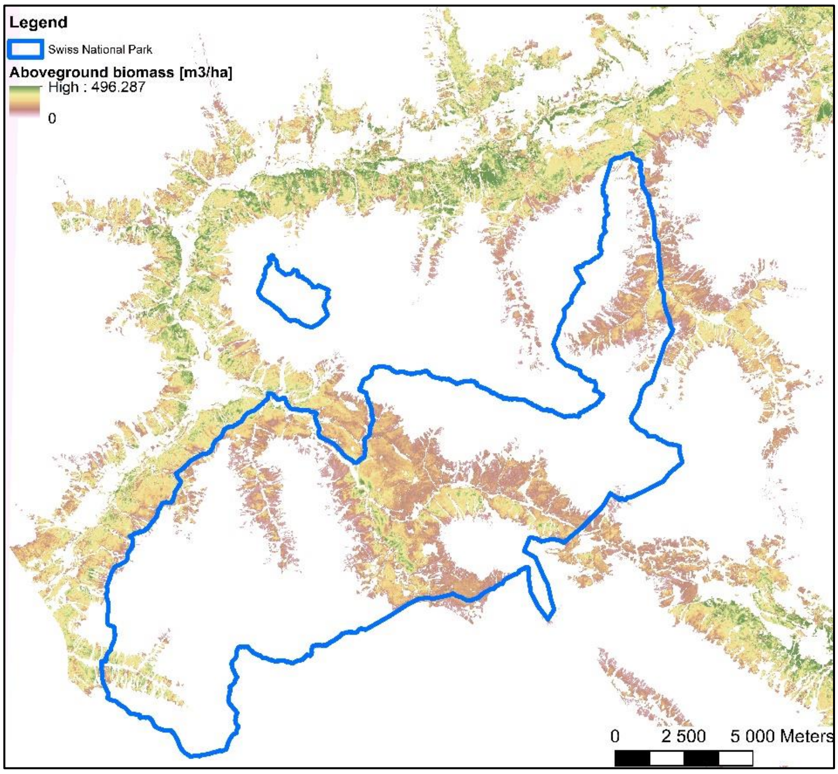

Figure 3.1.2.5: Aboveground biomass in the Swiss National Park in 2012, as calculated based on canopy height (stereo image matching, Leica ADS) and in-situ biomass measurements (Source: By CESBIO for ECOPOTENTIAL).

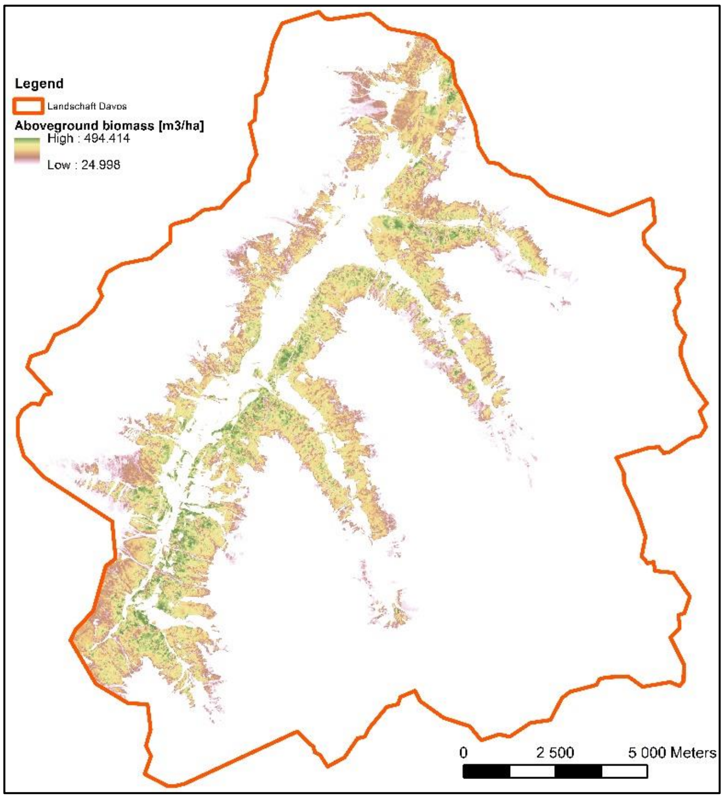

Figure 3.1.2.6: Aboveground biomass in Davos in 2012, as calculated based on canopy height (stereo image matching, Leica ADS) and in-situ biomass measurements (Source: By CESBIO for ECOPOTENTIAL).

Recreation

A Flickr analysis shows that photos uploaded per year declined between 2007 and 2008, then steadily increased until 2015 before dropping in 2016 (Figure 3.1.2.7), a positive trend is suggested by Mann-Kendall test ($S = 23$, $tau = 0.511$, $P < 0.05$).

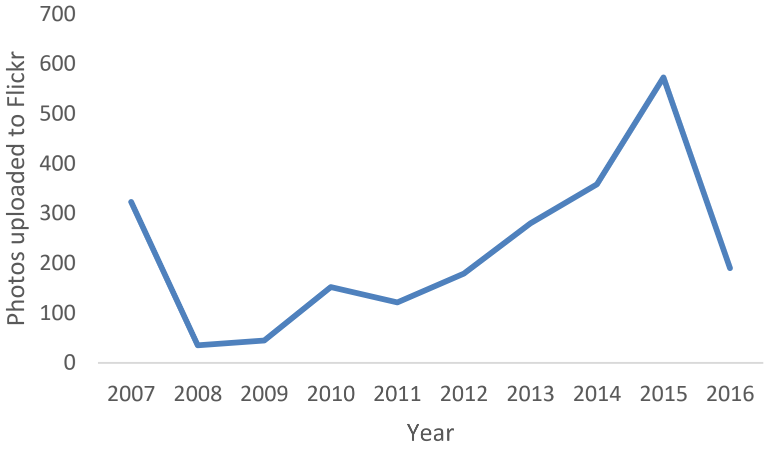

Figure 3.1.2.7: Changes in photos uploaded to Flickr for the Swiss National Park and the Landschaft of Davos. Years are filtered by the date the photo was taken.

3.1.3 Gran Paradiso National Park (Italy)

The Gran Paradiso National Park (GPNP), established in 1922, is the oldest National Park in Italy. It is characterized by the presence of significant glaciers and high-altitude environments, and hosts the original surviving population of Alpine ibex (*Capra ibex*), as well as other mountain ungulates such as Alpine chamois (*Rupicapra rupicapra*). Large mountain ungulates rely on high-elevation meadows to forage during spring-summer (Darmon et al. 2012). Mountain grasslands, however, are semi-natural habitats, whose appearance partly derive from agro/pastoral activities. The progressive abandonment of management practices such as mowing and grazing from high-elevation mountain areas causes modifications to grassland that can affect its forage value for mountain wild herbivores (Parolo et al. 2011) eventually leading to tree encroachment. Abandonment of traditional land management may also affect the net ecosystem CO2 and CH4 exchange (Imer et al., 2013). Climate change is another risk factor for mountain grassland and its role of sustenance for large herbivores. In the next decades, a strong decline (or local extinction) of specialized montane plant species can be expected, particularly if joint effects of climate and land use changes are considered (Dirnböck et al. 2003). Figure 3.1.3.1 shows the identified essential variables, for Gran Paradiso National Park the indicators of (a) grassland extent and, (b) grassland productivity will be explored.

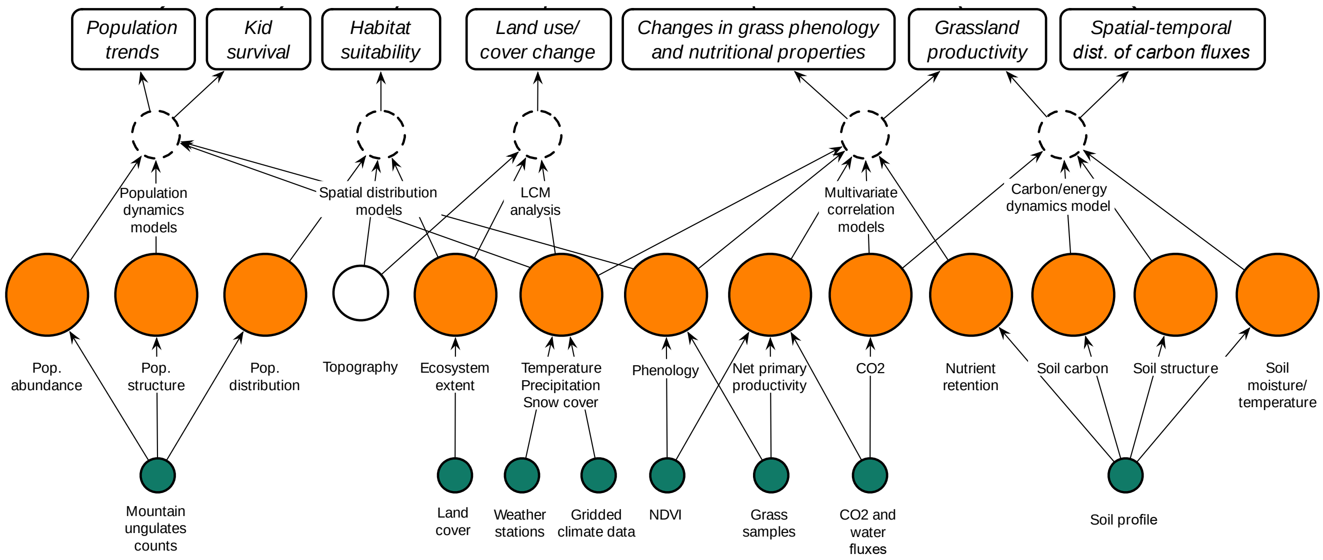

Figure 3.1.3.1: Diagram representing the storyline developed for the Gran Paradiso National Park, including the identification of essential variables at the storyline level (Source: Ecopotential Deliverable 2.2).

Ecosystem extent (grasslands)

Supply – Grasslands, including arid and termophilous grasslands, mountain grasslands, sub-alpine and alpine acidophilous and calcicolous grasslands, constitute more than 30% of the Park area, as calculated from a 2005 habitat map (Fig. 3.1.3.2). Higher percentages of grasslands can be found in the Piedmont valleys (Orco and Soana) and in the elevation interval 1750-2750 m a.s.l. (Fig. 3.1.3.3).

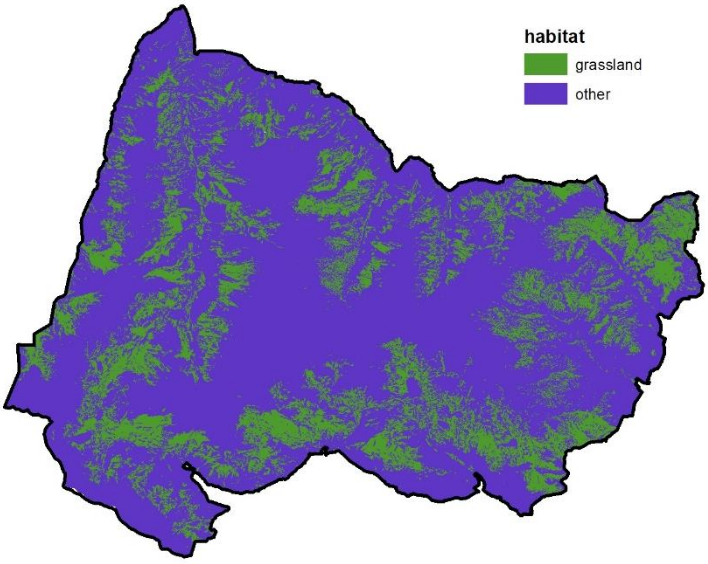

Figure 3.1.3.2: Grassland extent in the Gran Paradiso National Park.

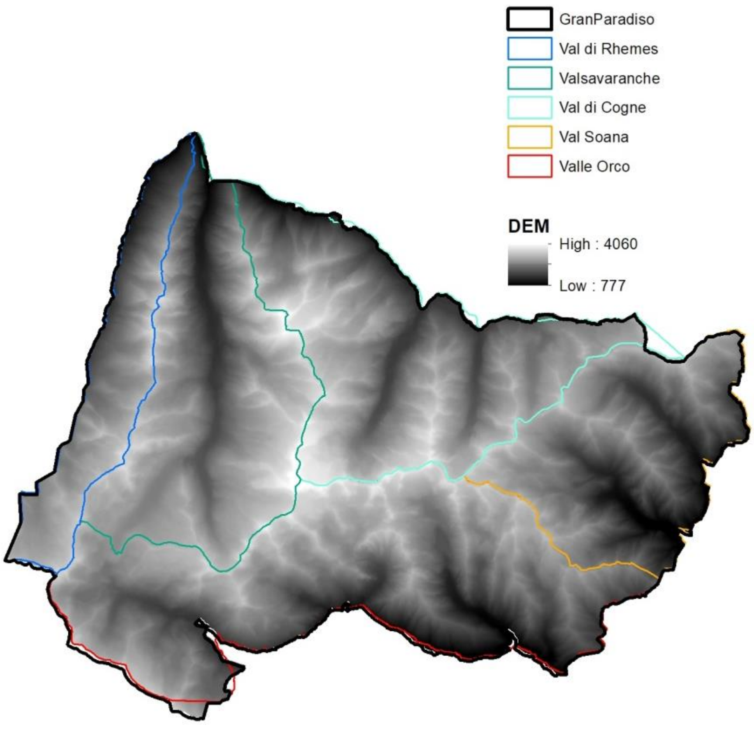

Figure 3.1.3.3: Digital elevation model and valleys of the Gran Paradiso National Park.

IIA-CNR estimated changes (2012-2016) from the class "(semi-) natural grasslands" to "other" land cover considering as time T_1 the layer "(Semi-) Natural Grasslands " from COPERNICUS Service layer dated 2012 at 20 meters spatial resolution (almost 312 km^2) and as time T_2 a Sentinel-2A image dated 13 August 2016, using 9 multispectral bands from Visible, Near and Short Wave Infrared resampled at 20 meters spatial resolution. For the detection of changes, the Cross Correlation Analysis (CCA) algorithm, developed by (Koeln and Bissonette, 2000), which demands a land cover map at time T_1 and only a single multispectral image at time T_2, was considered.

The change map obtained as output was shown below (Fig. 3.1.3.4).

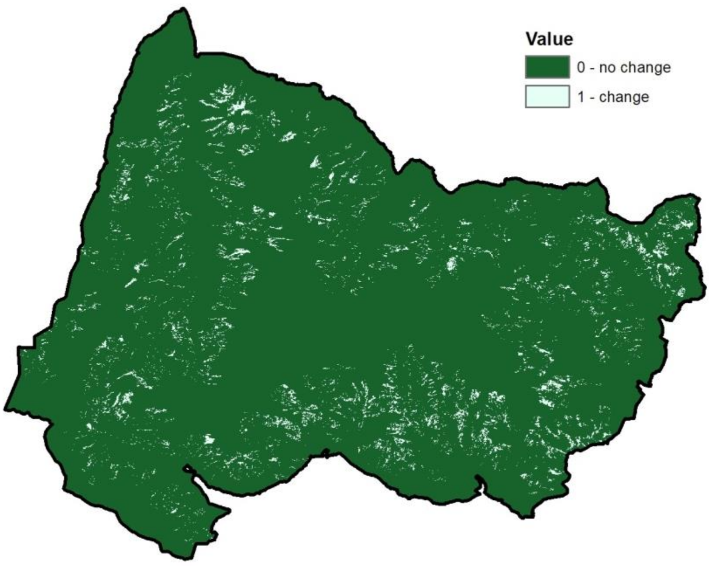

Figure 3.1.3.4: Change map in (semi-) natural grassland extent in the Gran Paradiso National Park in the period 2012-2016, as estimated by the CCA algorithm.

From the quantitative estimation of changes, nearly 25 km^2 of (semi-) natural grasslands result changed corresponding to about 14% of (semi-) natural grasslands occurred at time T_1 in the GPNP area. Most important changes occurred in Piedmont valleys (Tab. 3.1.3.1).

Table 3.1.3.1: Changes in (semi-) natural grassland in Gran Paradiso National Park and relative valleys.

	Changed area (km^2)	%Changed area (referred to grasslands at time T_1)
GPNP	24.66	13.85
Val di Rhemes	1.27	11.93
Valsavarenche	5.04	12.02
Val di Cogne	3.65	10.71
Val Soana	4.85	15.43
Valle Orco	9.90	16.29

The distribution of changes differs at different elevation ranges resulting in a maximum in the range from 2237 to 2737 meters a.s.l., indicating that grasslands between the sub-alpine and alpine zones were the habitats most subject to change. This range is exactly where the actual treeline lies, and where the major changes are expected, due both to climate change (that lead to an upward shift of the treeline) and abandonment of agro-pastoral activities (that lead to the tree-encroachment of high-altitude meadows. Figure 3.1.3.5 shows changes trend versus elevation.

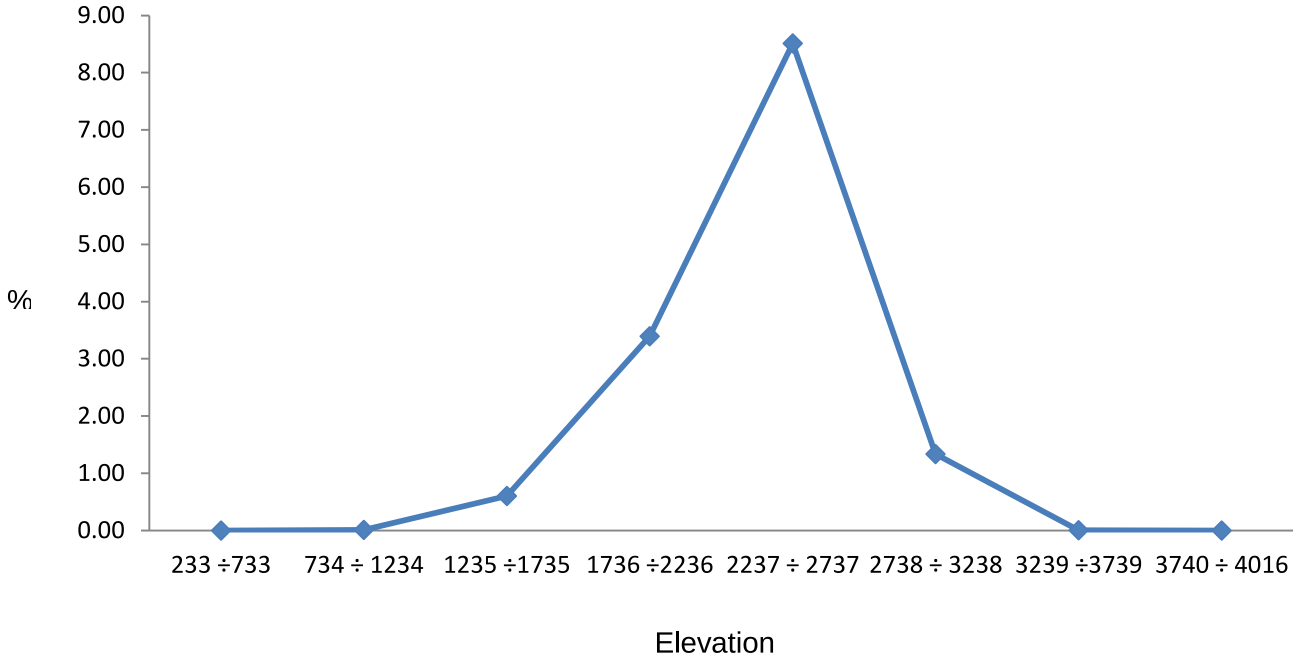

Figure 3.1.3.5. Changes in (semi-) natural grasslands (%), referred to grasslands at time T_1, at different elevation intervals, in the Gran Paradiso National Park.

Some example of meaningful changes due to trees encroachment, mountain trail and outcrop of rocks are shown in Figure 3.1.3.6.

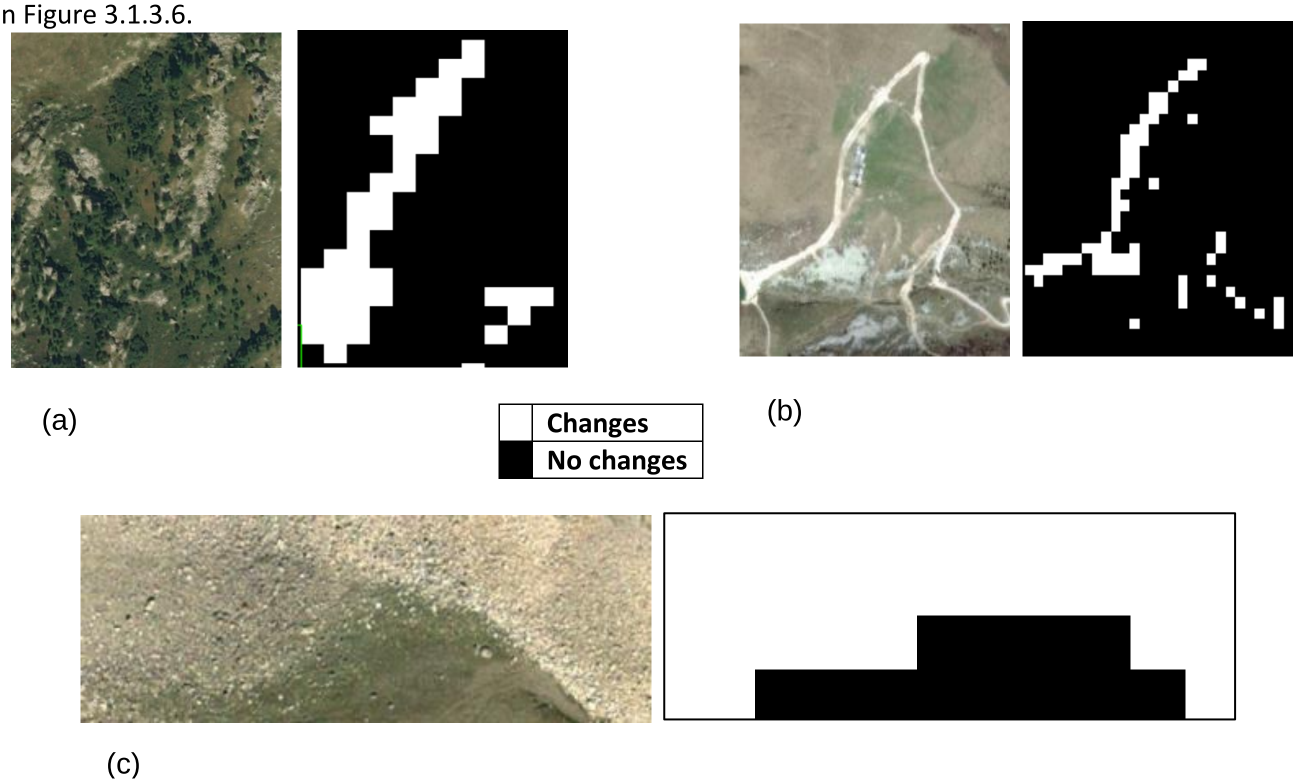

Figure 3.1.3.6. Close-up windows for example of changes in an area totally covered by (semi-) natural grasslands at time T1 to: (a) trees encroachment, (b) a mountain trail and (c) outcrop of rocks.

For each example, on the left a patch from an ortophoto, dated 2016, whereas on the right a patch from the change map was shown.

Demand – Grasslands provide forage for livestock (which decreased in the area in the last years) as well as for wild ungulates. As an example, chamois population in the period 2000-2012 remained fairly stable (Mann-Kendall test, Tau=-0.18, p=0.39). Stability was also found in the individual valleys, except for Rhemes where a significant decrease was detected (Tau=-0.49, p=0.20).

Beneficiaries – While traditional land management is decreasing, sustainable tourism, associated with the presence of populations of wild ungulates and traditional landscape, increased in recent years, as also confirmed by the number of pictures taken in the area (see Recreation).

Grassland productivity

Supply – Grassland productivity has a great importance for grazing and other grassland agricultural production, as well as for the sustenance or wild herbivores. Productivity is regulated by both temperature and the amount and timing of precipitation, as well as by management regime.

A proxy of gross primary production (GSIVI) can be derived from the integral of the vegetation index (NDVI) between start (green-up) and end date (senescence) of the vegetation growing season. UFZ generated the GSIVI values for Gran Paradiso from 2002 to 2016 by use of the R-package "phenex" (https://cran.r-project.org/package=phenex). This product was generated by modelling the phenological curve from MODIS aqua and terra data with two different methods: double logistic function fit and linear. Green-up and senescence days were obtained both with a local and a global threshold. We selected the MODIS terra product calculated through double logistic method with the local treshold (LT=0.65).

Higher GSIVI values are associated to lower elevations in the GPNP, as shown in Figure 3.1.3.6 for the year 2016.

Trend analysis of GSIVI value in the period 2002-2016 revealed that gross primary production mostly increased in recent years (Mann-Kendall test, tau values significant at p<0.05: mean=0.39, SD=0.25). As expected, grassland productivity virtually increased in all significant pixels (Figure 3.1.3.7).

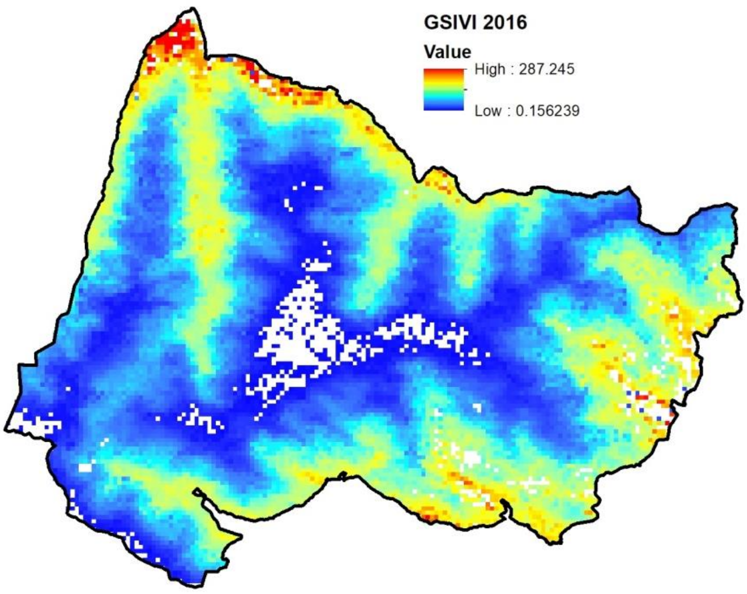

Figure 3.1.3.6: Map of a proxy of gross primary production (GSIVI) in the 2016 vegetative season in the Gran Paradiso National park.

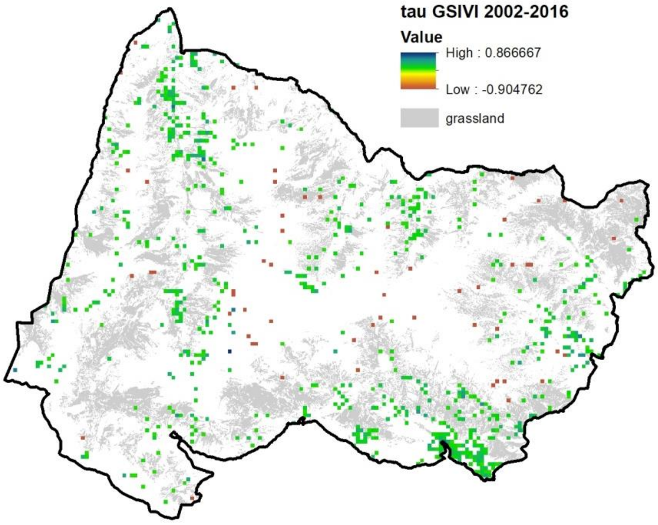

Figure 3.1.3.7: Tau values of trend in GSIVI values in the period 2002-2016 in the Gran Paradiso National park. Only significant values at p<0.05 are shown. Grassland areas are shown in gray.

Demand – A higher grassland biomass could theoretically support a higher number of livestock/wild herbivores in the area, nevertheless a higher content in fiber could lower the quality of forage (see Ranghetti et al. 2016 for an example of estimation of nutritional properties from MODIS data). This can affect in particular ungulate demographic parameters that rely on high-quality forage, such as fertility and juvenile survival. As an example, despite the stability of chamois population in the period 2000-2012 (see above), the weaning success (kid/female ratio) in the same period decreased (Mann-Kendall test, Tau=-0.41, p=0.05).

Recreation

A Flickr analysis shows that photos uploaded per year have increased until 2013, before dropping in 2015, and recovering slightly in 2016 (Figure 3.1.3.8), a positive trend is suggested by Mann-Kendall test (S = 33, tau = 0.733, P < 0.01).

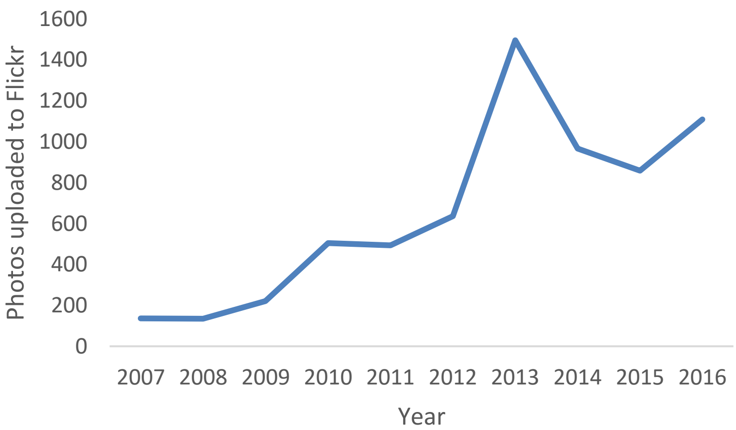

Figure 3.1.3.8: Changes in photos uploaded to Flickr for Gran Paradiso National Park. Years are filtered by the date the photo was taken.

3.1.4 Lakes Orhid and Prespa (Macedonia)

Lake Ohrid and Lake Prespa, located in south-eastern Europe between Albania, Macedonia and Greece are two lakes of high local, regional and international significance because of their geological, cultural and biological uniqueness. Lake Ohrid is one of the few ancient lakes in the world that is continuously providing freshwater habitats for more than one millions years. Lake Ohrid is a habitat for approximately 1 200 known species with more than 200 endemic species and has probably the highest endemic and overall species density in the world (i.e., approx. 1 200 species/358 km²), making it one of the biodiversity centers in the present day Europe (cf. Neubauer *et al.*, 2015). With about 30 endemic species, the endemic biodiversity of Lake Prespa is much lower than that of Lake Ohrid. For this report (a) Maintenance of physical, chemical, biological conditions to ensure favorable living conditions for biota, and (b) Physical and intellectual interactions with biota, ecosystems, and land-seascapes, will be investigated.

Maintenance of physical, chemical, biological conditions

Maintenance of physical, chemical and biological conditions to ensure favorable living conditions for biota is one of the regulatory services provided by freshwater ecosystems. Benefits of biological water purification of lakes range from savings compared to the costs of water treatment facilities, via eutrophication reduction and removal of harmful pathogens to an increased recreation value. Quality of water is mostly described by the chlorophyll-a concentration (Chl-a), total suspended matter (TSM), transparency and nitrogen and phosphorus loading. In particular, being closely related to nutrient availability, Chl-a is commonly used as a phytoplankton proxy within trophic state assessments and studies of algal phenology and blooms.

Maintenance of physical, chemical, biological conditions as regulatory ecosystem service is considered here in a broad sense, i.e. as the capacity of lake ecosystems for the reduction of pollutants, and thus eutrophication control within a given time period (cf. Taguchia and Nakata, 2009; Burkhard *et al.*, 2012). As outlined above, phosphorus is the limiting nutrient and the main cause of eutrophication in Lake Ohrid-Prespa region. Given the dynamics of the phosphorus cycle, the capacity of the lakes to provide eutrophication control depends on the interactions between the lake's physical, chemical and biological conditions. The latter conditions can be either described by the data or the models of the related processes (Figure 3.1.4.1)

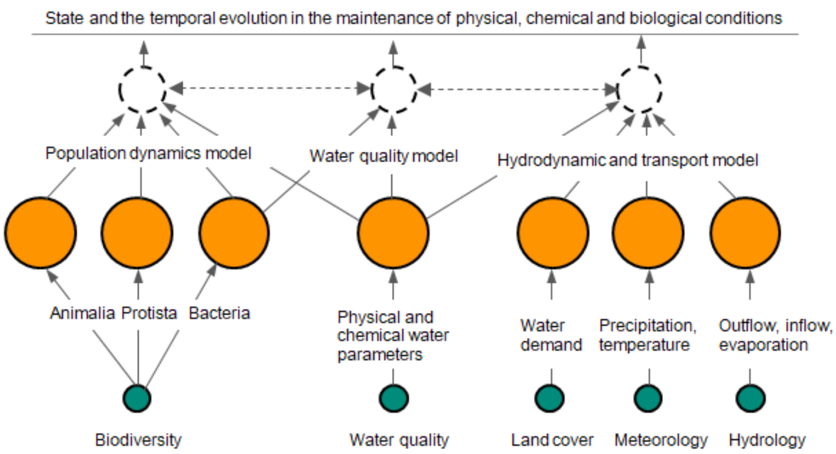

Figure 3.1.4.1: Simplified view of the maintenance of physical, chemical and biological conditions.

Supported with *in-situ* data, multispectral EO-data enable estimation of the water quality parameters and thus the water purification service. In particular, water quality parameters can be derived from sensors like MODIS (Aqua, Terra), Landsat (TM, OLI, ETM), Hyperion and MERIS. Using MODIS-Aqua observations Shi *et al.* (2017) developed and validated an empirical model for estimating Chl-a concentrations in Lake Taihu (China) and quantified responses of cyanobacterial dynamics to nutrient enrichment and climatic conditions. Similarly, Giardino *et al.* (2012) used Hyperion to assess the water quality in Lake Garda (Italy) by means of the Chl-a concentrations and non-algal particles of the suspended matter. In general, studies of the spatio-temporal dynamics of the total suspended matter were mostly based on either MERIS or Landsat data (e.g. Zhang *et al.*, 2014; Zheng *et al.*, 2015).

Here, we combined *in-situ* observations and EO-based data products describing chemical and physical water quality parameters and the hydrological water-balance data. In particular, *in-situ* chemical and physical water quality data for Lake Ohrid consisted of measurements of concentrations of Chl-a (from 2000 to 2011), total phosphorus concentrations and water temperature (from 2000 to 2002, from 2008 to 2010 and from 2013 to 2014). Hydrological water-balance data included annual outflow of the Crni Drim River from 2002-2011, daily air temperature and daily precipitation sums from 2000 to 2002 and from 2008 to 2010. *In-situ* data for the Lake Prespa included measurements of concentrations of Chl-a, total phosphorus concentrations and water temperature for several sampling days from 2013 to 2015. These data were provided by the Hydrobiological Institute Ohrid (HIO). EO-based data products included daily time series at 2-3 days resolution from January 2000 to April 2010 of Lake Ohrid's and Lake Prespa's Chl-a and TSM (provided by the Plymouth Marine Laboratory) and the surface water temperature derived within the Arc-Lake project (publicly available via http://www.laketemp.net/).

Supply: Ecosystem services supply, here, the capacity of lake ecosystems to provide eutrophication control within a given time period, is reflected in the chemical condition of freshwater as estimated by *in-situ* and EO-data within a period from 2000 to 2015 (note, some data were available only within a subset of this period). To assess if there is a monotonic upward or downward trend of the variable of interest over time, the Mann-Kendall test is used as implemented in the R library "Kendall" (McLeod, 2015). The results in the following section follow the diagram shown in Figure 3.1.4.2.

Hydrology: The outflow from the Lake Ohrid was highest in 2010 (33.01 m^3/s), however, no significant trend in the outflow time series was detected by the Mann-Kendall test (p-value of 0.59). No data on outflow or evaporation were available.

Meteorology: Based on the climate station data from 2000 to 2010, the mean annual air temperature is approximately constant (12°C) and manifests pronounced annual cycle with the lowest temperatures in January (about 1.9°C) and highest in August (22.2°C). Between 2000 and 2002, and 2008 and 2010 the annual precipitation sum varied between 538 (2001) and 1145mm (2010). Overall, precipitation is lowest in August and highest in December. Due to insufficient data, Mann-Kendall trend test could not be applied.

Land cover: Based on the Corine Land Cover maps (CLC) from the years 2000, 2006 and 2012 provided by the European Environmental Agency (EEA), we identified the changes within the Ohrid-Prespa region for the following land cover categories: 1) urban, 2) industrial, 3) agriculture, 4) pastures, 5) forest, 6) wetlands and water bodies. To include the effects of the neighboring settlements, Ohrid-Prespa region was defined as the lakes itself and the adjacent hydrological catchments with the total area of 331 387ha.

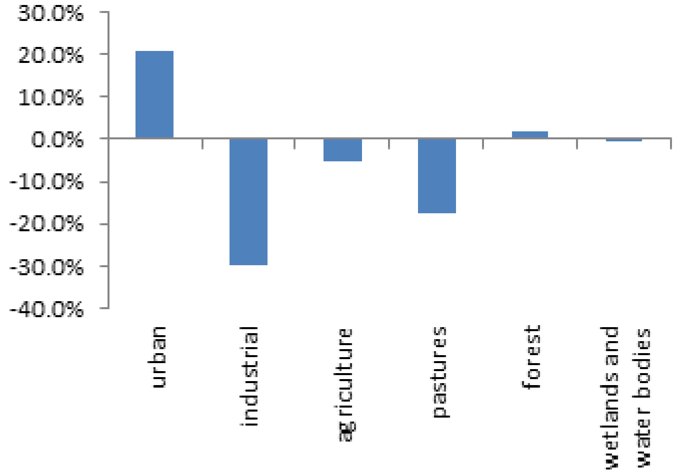

Figure 3.1.4.2: Land cover change from 2000 to 2006.

The most prominent changes from 2000 to 2006 are urbanization, manifested as an increase in the area under urban-related artificial surface by 21%, a decrease in the industrial areas by 30% and a decrease in pastures by 18%. From 2006 to 2012, there were only marginal changes in the land cover, such as the decrease in the area under row crops by 0.1% (i.e., 3 030ha). In summary, the major land cover change in the Ohrid-Prespa region is urbanization.

Water quality-chemical parameters: In summer 2013, the Chl-a concentration in the pelagic zone of Lake Ohrid varied between 0.08 µg/l at 150 m depth and 2.83 µg/l at 20 m depth, while the near surface Chl-a concentrations in the littoral zone were highest at the station Lin on the Albanian side (1.92 µg/l). In contrast to Lake Ohrid, Chl-a concentrations in the surface layer of Lake Prespa are generally higher in autumn than in spring (e.g. at Gollomboc station, Albania, Chl-a concentration in September 2013 was 5.116 µg/l and in April 2014 1.412 µg/l (GIZ, 2015)). The total phosphorus concentrations of Lake Ohrid are generally below 10 µg/l, and between 20 µg/l and 30 µg/l for the Lake Prespa, however, increase in the TP concentrations are observed for both lakes. Due to insufficient length of the annual time series Mann-Kendall test could not be applied to *in-situ* observations of Chl-a and TP.

EO-based data on Chl-a and the total suspended matter were available for some of the lake area pixels. To maximize the gain from the EO-data, we derived pixel mean values of the 2km area around the *in-situ* sampling sites and the mean for all available lake pixels. To account for the seasonal character in the water quality, we focus on the April and August values. As with *in-situ* data, results of the Mann-Kendall test indicate spatial patterns in the water quality parameters. While for most stations/months, the Mann-Kendall test suggested absence of the statistically significant trend, significant increase in the TSM of the Lake Prespa was detected for the station SP 2 Near the Island (p-value 0.032) and for the station Ezerani 2 (p-value 0.032). For Lake Ohrid, only for the station Kalishta, significant TSM increase was detected (p-value 0.035). In contrast, for both, April and August Chl-a values for the Lake Ohrid manifest either negative, or no trend (Figure 3.1.1.3). EO-based Chl-a values for the Lake Prespa suggest no significant trends (Figure 3.1.1.3).

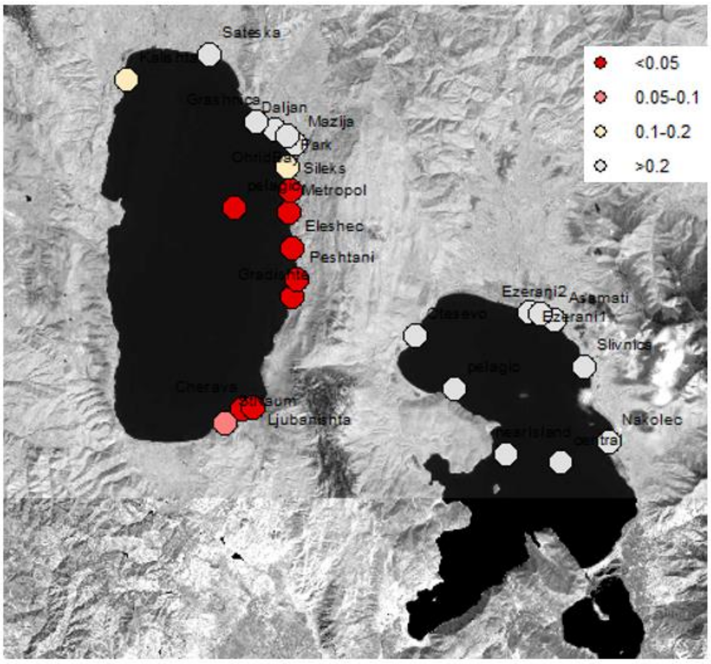

Figure 3.1.1.3: P-values for the Mann-Kendall trend test for EO-based August Chl-a values from 2002 – 2011. All trends with p-values<0.2 were negative.

Water quality -physical parameters: Following the patterns in the air temperatures, mean monthly pelagic surface water temperature of the Lakes Ohrid and Prespa is lowest in January (approx. 7.6°C for Ohrid and 5.8°C for Prespa) and highest in August (approx. 23.4°C for Ohrid and 25.2°C for Prespa). Near lake bottom the temperature of Ohrid Lake is about 6.1°C (at 200m) while the mean monthly temperature of the shallow Lake Prespa varies in the “deep layer” at 30 m between 5.8°C in January and 14.2°C in September. Due to insufficient length of the annual time series Mann-Kendall test could not be applied to *in-situ* observations of water temperature. Satellite based water temperature series were available from 2000 to 2011 for both lakes. Based on the mean annual values, no significant trend over the investigated period was detected by the Mann-Kendall test (p-value for Ohrid 0.11 and for Prespa 0.63).

Biodiversity: Overfishing coupled with species introductions are the major threats to Ohrid’s endemic fish species Ohrid trout (*Salmo letnica*) and belvica (*Salmo ohridana*) (Kostoski et al, 2010). Furthermore, alteration of the unique macrophyte communities of Lake Ohrid due to shoreline manipulations and nutrient enrichment (cf. Schneider *et al.*, 2014; Kostoski et al, 2010) and health impacts of pollution on the endangered Ohrid trout species (cf. Jordanova *et al.*, 2016) are a serious warning signal of the progressing ecosystem degradation.

Based on the results of Schneider *et al.* (2014), the abundance of the benthic alga *Cladophora sp.* over the period from 2009 to 2011 correlated positively with water total phosphorus concentrations, “indicating that P-loading at local scales may be an important driver of *Cladophora* biomass”. Furthermore, the Lake Ohrid study of Schneider *et al.* (2014) suggests “a meso- to slightly eutrophic littoral ecosystem where nutrient supply is incorporated into macrophyte and benthic algae biomass, and transferred through the food web from benthic algae to grazers, and from macrophytes to shredders and gatherers”.

Demand and Beneficiaries: The demand refers here to the direct use/consumption, since no data on the desires were available. Overall, due to increased urbanization and thus, the number of inhabitants, touristic facilities and tourists combined with decreased agriculture and industry (see section Land Cover), the demand for the service “maintenance of physical, chemical, biological conditions” has changed. Among the considered beneficiaries (population, tourists, industry and irrigation), irrigation accounts for the highest demand portion. Specifically, it is estimated that by 2020, 15 205ha of arable land will be irrigated, resulting in approximately 72% of the total demand (124 432 10^3m^3, Table 3.1.4.1; source GIZ, 2015). Given the declining trend in the proportion of agricultural land use (see Section Land use), the key demand "irrigation" will most likely decrease over time. In contrast, following the urbanization trends and the increased awareness for ecosystem pollution, also in context of the EU Water Framework Directive (WFD) with respect to measures of safeguard water quality (Directive 2000/60/EC), the demand between both beneficiary types, inhabitants and tourists is continuously increasing.

Region	Population	Tourists	Industry	Irrigation	Total
Ohrid-Struga	17 837	6 791	5 740	58 480	88 848
Prespa	2 336	924	1 435	30 889	35 584
Total	20 173	7 715	7 175	89 369	124 432

Table 3.1.4.1: Estimated water demand in the Ohrid-Prespa region by 2020 ($10^3 m^3$). The data are based on the values published in the GIZ report (2015).

Physical and intellectual interactions with biota, ecosystems, and land-seascapes

Physical and intellectual interactions with biota, ecosystems, and land-seascapes is one of the cultural services provided by ecosystems. Within the analysis provided here, the focus is on the perception of ecosystems in the scientific domain. In particular, the CICES class "Scientific" is considered here in a broad sense as the capacity of lake ecosystems to stimulate scientific research for a given time period.

Analysis of the CICES class "Scientific" is based here on data from three academic search engines: Web of Science (WoS, http://ipscience.thomsonreuters.com/product/web-of-science/), Google Scholar (GS, https://scholar.google.de/) and Bielefeld Academic Search Engine (Base, https://www.base-search.net/).

Supply: Ecosystem services supply is viewed here as the capacity of Lake Ohrid and Lake Prespa ecosystems to stimulate scientific research. Over the past decade, there is growing scientific interest in the Ohrid-Prespa Region. High biodiversity, in particular high degree of endemism, and poorly studied biogeographical history open numerous questions with regards to the past and the potential future dynamics of hydrological, climatic and ecological changes. For example, as outlined by Albrecht and Wilke (2008), limnologic and biotic history of the actual lake are still insufficiently explored. In addition, some biotic groups such as Diatoms have been well studied; some such as *Rhizopoda* are poorly studied or not studied at all (cf. Albrecht and Wilke, 2008). Multiple factors including habitat destruction, pollution, invasive species, and climate change are threatening the biodiversity of the Lake Ohrid-Prespa region, with increased international attention in course of the WFD implementation and the "Ohrid-Prespa Transboundary Biosphere" declaration in 2014. In view of the above, ecosystem services supply seems to be boundless.

Demand & Beneficiaries: The demand refers here to inquisitiveness, knowledge dissemination, risk reduction, risk prevention or similar. As such, the demand is strongly related to the scientific output in terms of both, published scientific literature and the related citations. The indexed literature counts across all disciplines for the topic "Ohrid" indicate increasing tendency irrespective of the analyzed databases (Figure 3.1.4.4a). The latter is also manifested in the p-value of the Mann-Kendall test that was always below 0.001. Literature and the citation counts within the WoS core selection restricted to science categories listed in Table 3.1.4.2 (i.e., mainly natural and environmental sciences) also indicate increasing tendency (Figure 3.1.4.4b). Referring to the Mann-Kendall test, increasing trend is statistically significant for literature counts (p-value of 0.0004), and marginally significant for citations (p-value of 0.058). We remind here that the articles published in recent years, that is, between 2012 and 2015, have not yet reached the full scope of their dissemination potential, suggesting likely increase in the citation counts in the next years.

The temporal distribution of the beneficiaries was analysed based on the WoS literature counts across the different scientific categories and time periods (2001-05, 2006-10, 2011-15). We remind that the majority of the scientific literature nowadays has interdisciplinary character, with an implication that one research work is commonly classified in several disciplines (WoS uses the term "Science Categories"). Overall, irrespective of the investigated time period, the majority of the indexed literature is a contribution to one of the following science categories: Biology, Ecology, Fisheries, Plant sciences, Limnology or Zoology (Table 3.1.4.2). Among the considered science categories, scientific questions from Biochemistry, Biotechnology, Genetics Hematology, Toxicology appear to be least studied. In addition, with the exception of the latter categories, the scientific interest and thus the beneficiaries' distribution, manifest only slight changes over time.

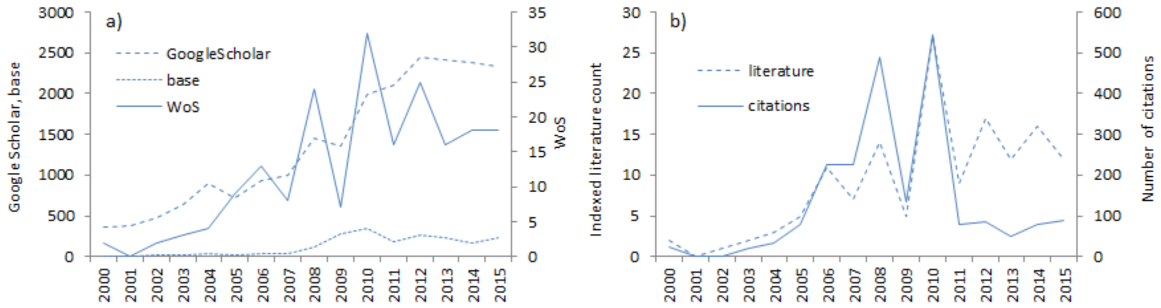

Figure 3.1.4.4: Indexed literature counts: a) Number of indexed literature in the Google Scholar, base and WoS for the topic "Ohrid" between 2000 and 2015; b) number of indexed literature and the related citations in the WoS core collection for the topic "Ohrid" and WoS categories listed in Table 3.1.4.2.

Table 3.1.4.2: The relative and the absolute number indexed literature in the WoS core collection for the topic "Ohrid" per WoS Science Categories and time intervals

WoS Science Categories	2001-2005	2006-2010	2011-2015
Chemistry, Geography, Applied Physics Applied Mathematics	7.1% (1)	4.5% (5)	11.1% (9)
Biochemistry, Biotechnology, Genetics Hematology, Toxicology	21.4% (2)	8.9% (10)	0.0% (0)
Environmental Sciences, Geosciences, Atmospheric Sciences, Water Resources, Multidisciplinary Sciences	14.3% (3)	33.0% (37)	27.2% (22)
Biology, Ecology, Fisheries, Plant sciences, Limnology, Zoology	57.1% (8)	53.6% (60)	61.7% (50)

Recreation

A Flickr analysis shows that photos uploaded per year have generally increased until 2014, before dropping (Figure 3.1.4.5), a positive trend is suggested by Mann-Kendall test (S = 33, tau = 0.733, P < 0.01).

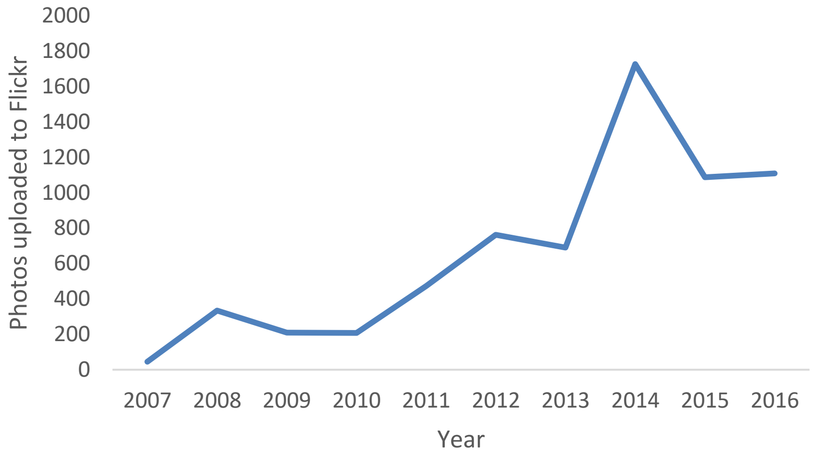

Figure 3.1.4.5: Changes in photos uploaded to Flickr for Lakes Orhid and Prespa. Years are filtered by the date the photo was taken.

3.1.5 Sierra Nevada (Spain)

Sierra Nevada (Andalusia, SE Spain), is a mountainous region covering more than 2000 km^2 with an altitudinal range of between 860 m and 3482 m a.s.l. The climate is Mediterranean, characterized by cold winters and hot summers, with pronounced summer drought (July-August). The annual average temperature decreases in altitude from 12–16°C below 1500 m to 0°C above 3000 m a.s.l., and the annual average precipitation is about 600 mm. The Sierra Nevada mountain range hosts a high number of endemic plant species (c. 80; Lorite et al., 2007) for a total of 2,100 species of vascular plants, being considered one of the most important biodiversity hotspots in the Mediterranean region (Blanca et al., 1998). This mountain area harbours 27 habitat types from the Habitat Directive. Sierra Nevada protected area contains at least 78 animal species and 13 plant species listed in the Annex II and/or in the Annex IV of Habitat Directive or Annex I or Annex II of Bird Directive. It is thus considered one of the most important biodiversity hotspots in the Mediterranean region (Blanca 1996, Blanca et al. 1998, Cañadas et al. 2014).

Figure 3.1.5.1 enables the reconstruction of the time course of a number of socioeconomic variables intimately related to the demand of ecosystem services. Their description and analysis will help improve the way in which the natural resources are managed in a context of global change. From the reforestation undertaken by the Catholic Monarchs in 1571 after the expulsion of the Moors, a sustained reforestation was pursued, reaching a maximum at the end of the 19th century. From this time on, the number of inhabitants were maintained with certain fluctuations until the 1960s. Since then, coinciding with the crisis of the Spanish mountain, the population of Sierra Nevada began a sharp descent. The date of the onset of the demographic decline coincides with the pronounced drop in livestock and beekeeping. This trend has continued to the present. The abandoned fields have been colonized by natural formations of vegetation, with an expansion in the forest surface area from the middle of the 20th century to the present. The above trends are reflected also in economic indicators by sectors: The primary sector was drastically reduced. While the rest of the province underwent this retraction in terms of the secondary and tertiary sectors, in the case of Sierra Nevada it was more related to emigration away from Granada (to northern Spain and abroad).

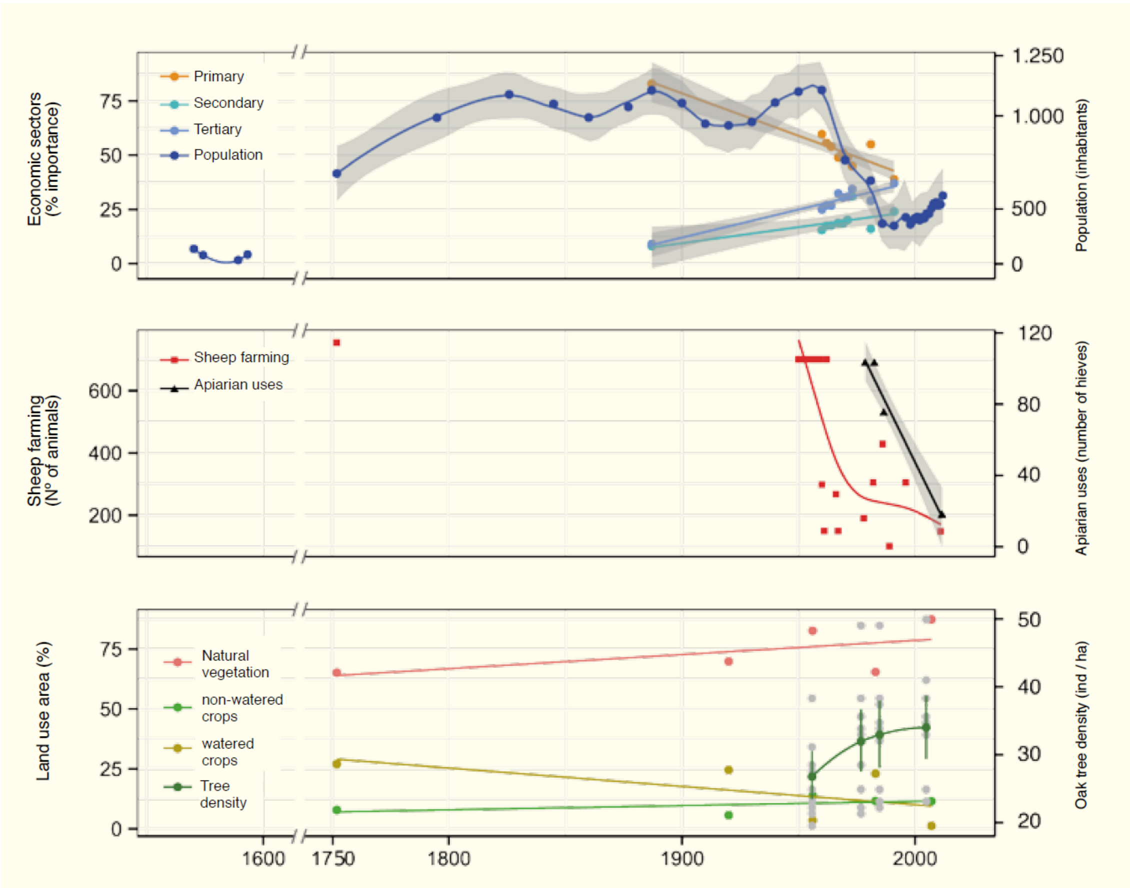

Figure 3.1.5.1: Temporal evolution of socioeconomic variables from 1568 to the present.

Figures 3.1.5.2 and 3.1.5.3 show the identified essential variables for Sierra Nevada, with (a) agriculture and livestock, and (b) hydrology being considered here.

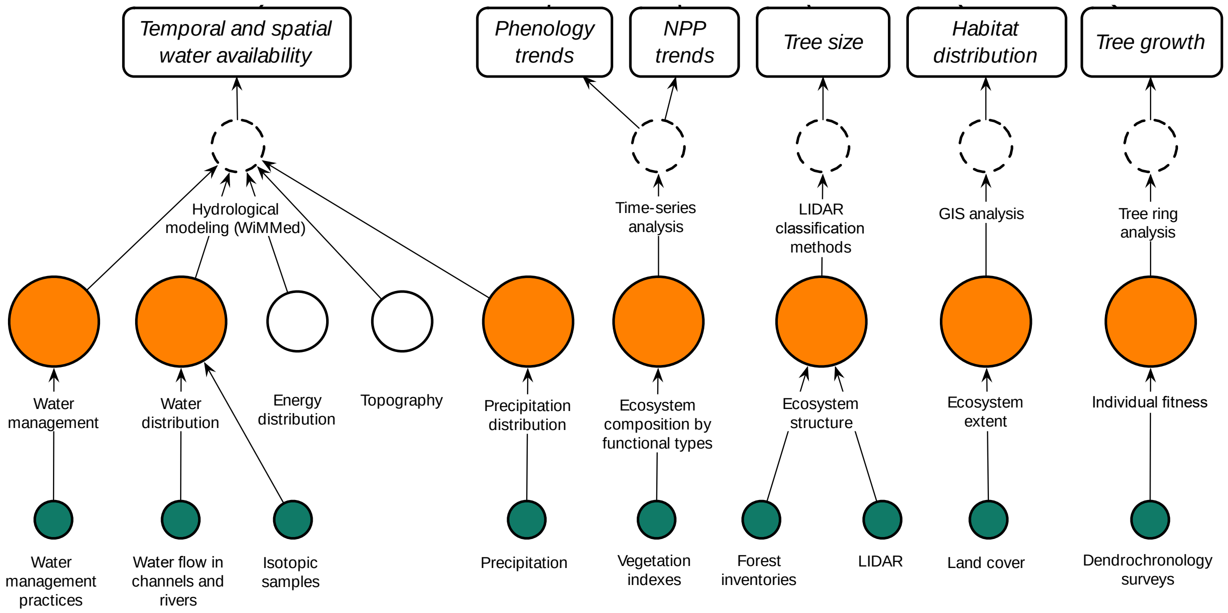

Figure 3.1.5.2: Diagram representing the storyline developed for Sierra Nevada (ancient irrigation channels), including the identification of essential variables at the storyline level (Source: Ecopotential Deliverable 2.2).

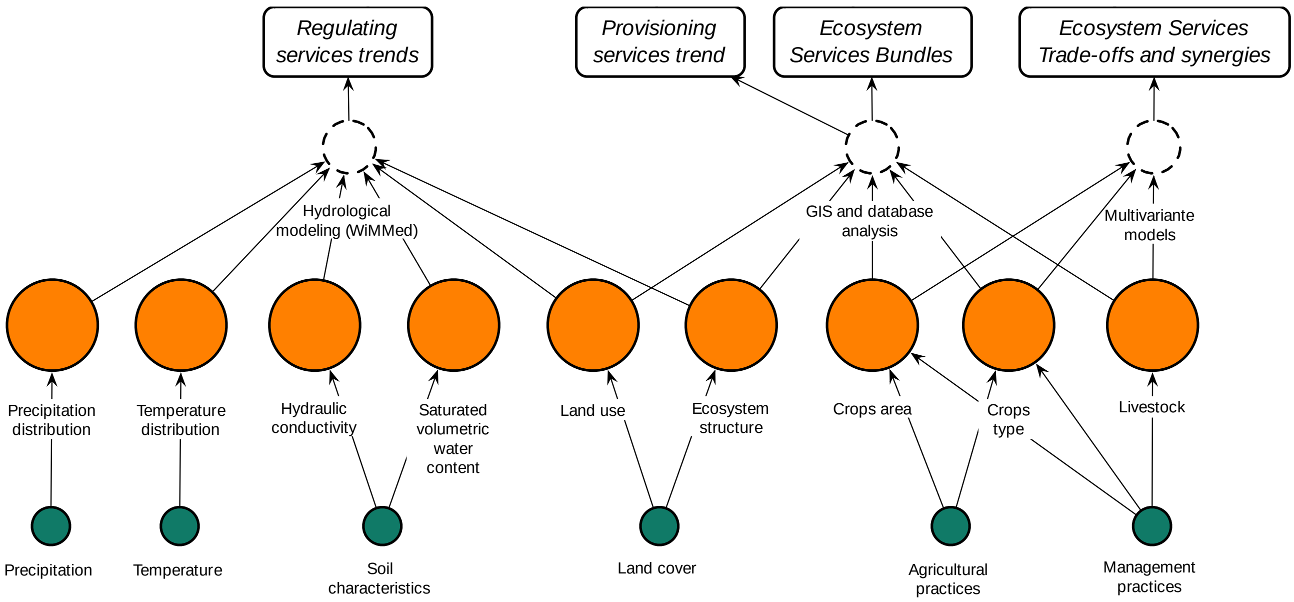

Figure 3.1.5.3: Diagram representing the storyline developed for Sierra Nevada (temporal evolution of ecosystem services), including the identification of essential variables at the storyline level (Source: Ecopotential Deliverable 2.2).

Ecosystem services

The main purpose of this study is to facilitate the management of PAs based on ecosystem services (ES). This requires an of the evolution of ecosystem services in the past. This knowledge will allow as to develop future

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scenarios. Trade-offs analysis will help managers to predict the state of ecosystem services and their relations in the future, based on changes in environmental and management conditions.

Provisioning services have been quantified by the production of agricultural products and livestock in the last decades by the rural economy. Regulating services have been evaluated using WiMMed model (Herrero et al., 2009). WiMMed (Watershed Integrated Model in Mediterranean Environments) is a physically-based, fully distributed hydrological model. Cultural services has been assessed through aesthetic value indicator (Schirpke et al, 2016). The natural spatial unit that we used in the valuation of all ecosystem services were the water basins presented in Sierra Nevada (a total of 30). The main tools used to assess land use scenarios ES Bundles and ES trade-offs are: bayesian belief network, GIS analysis, database queries, regression and multivariate models.

Provisioning services: agriculture and livestock

Supply

For provisioning services, we quantified the production of the variety of agricultural and livestock in the last decades by the rural economy. Furthermore, we assessed the amount of ground water recharged as a proxy of ground water provision. To quantify the agricultural production, we mapped the areas of the different type of crops along time in some milestones (1956, 1977, 1984, 1999, 2007). Then, we obtained from official statistics the harvest yield of the variety of crops in both agricultural systems: rain-fed and irrigated practices. Agricultural production was measured in kilograms of products by basin.

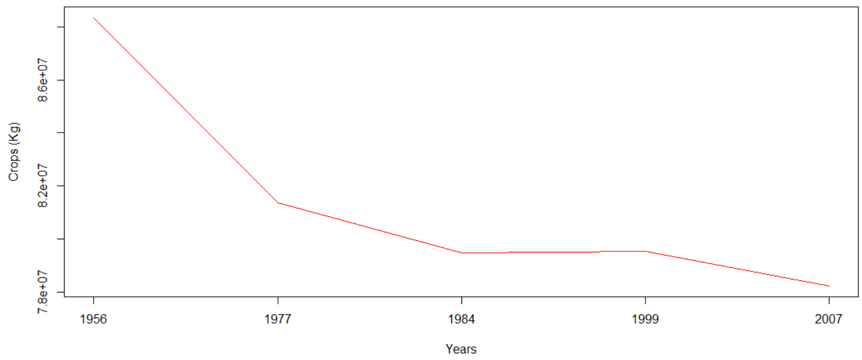

Figure 3.1.5.4: Evolution of cultivated crops (provisioning ES) in Sierra Nevada in the past.

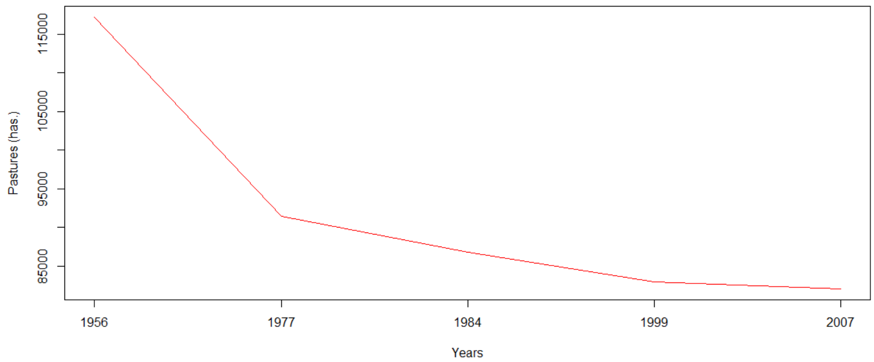

Figure 3.1.5.5: Evolution of pastures in has. (provisioning ES) in Sierra Nevada in the past.

The agricultural production analysis shows that crops have generally decreased until 1956 (Figure 3.1.5.4), a negative trend is suggested by Mann-Kendall test (S = -8, tau = -0.8, 2-sided P = 0.086). In order to estimate

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the potential livestock along the time period, we evaluated the evolution of areas of pastures used by the cattle. The units were hectares (has.) of pastures available for cattle by basin.

The livestock analysis shows that pastures have decreased until 1956 (Figure 3.1.5.5), a negative trend is suggested by Mann-Kendall test (S = -10, tau = -1, 2-sided P = 0.027). The ground water provision in Sierra Nevada is highly related with the available water for drinking and cropping in low-elevation places in summer periods. This service depends on a lot of factors (including the distribution of the ecosystems and the land use changes).

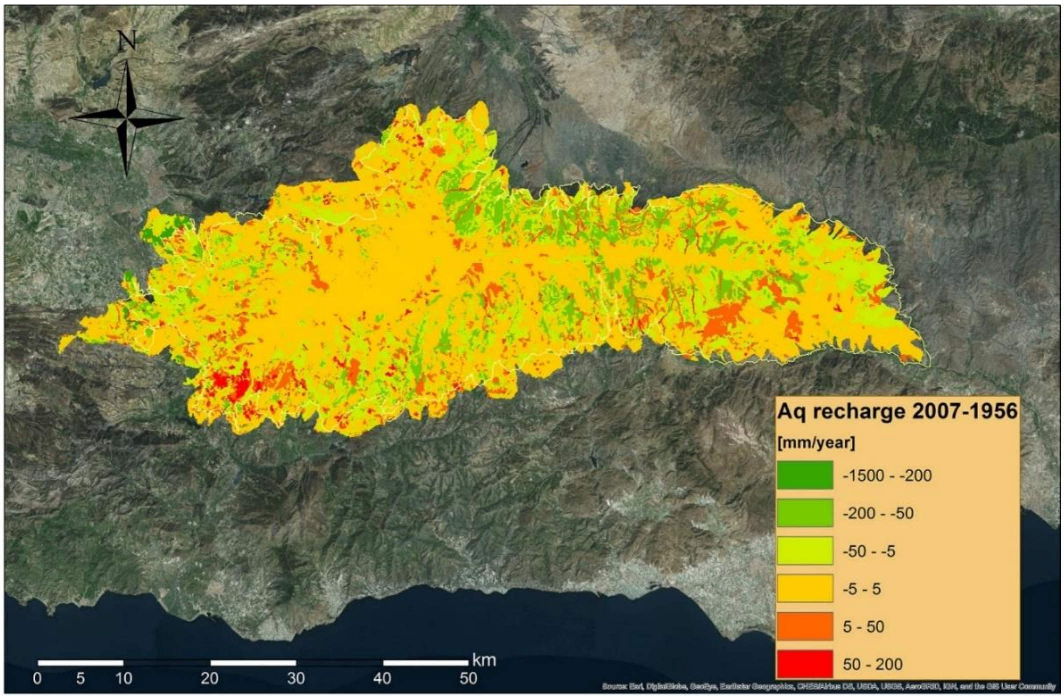

Figure 3.1.5.6: Differences between 2007 and 1956 in aquifers recharge (mm/year) in Sierra Nevada.

Regulating services: Erosion

Supply

Regulation services are being assessed with WiMMed model (Watershed Integrated Model in Mediterranean Environments), that is a physically-based, fully distributed hydrological model. It uses hourly and daily meteorological data, along with certain physical properties of the soil and subsoil to perform the spatial interpolation and temporal distribution of meteorological variables, rainfall interception, snowmelt, infiltration, runoff, surface slope circulation, calculation of the water in aquifers, and basin flow circulation. It thus provides instantaneous value or evolution of the principal flows and state variables, such as water flow volumes, amount of stored water, flooded surfaces, etc. A detailed description of this model is given by Herrero et al. (2009).

WIMMed is already calibrated for Sierra Nevada (Spain) for its present climate using the complete dataset of meteorological data, approximately available since 2000. One of the ecosystem service to evaluate is the capacity of the ecosystems to retain or decrease water runoff. Water infiltration in the soil is the process by which the water goes into the soil pore space, displacing air previously stayed there. WiMMed reproduces infiltration by the physical model of Green and Ampt (1911) along with the exact solution Muñoz-Carpena and Ritter (2005).

WIMMed considers the floor divided into two layers: a surface layer (layer 1) in which dominates the infiltration surface and a lower layer (layer 2) in which occurs the storage and distribution. The infiltration in the surface layer is primarily regulated through the saturated hydraulic conductivity superficial. The lower layer has the effect of delaying the deep infiltration into the saturated zone and keeping the water available for evaporation from the soil. When in the process of infiltration capacity soil water inlet is exceeded, surface puddling occurs and therefore the appearance of surface runoff. We calculated the surface runoff in all basins (mm/year).

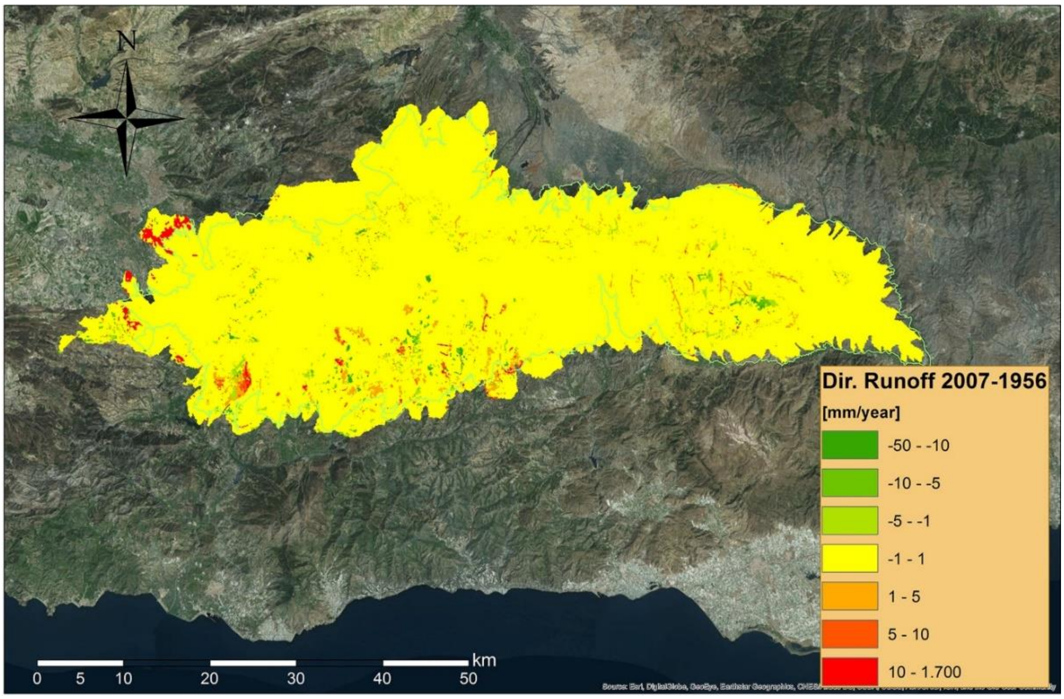

Figure 3.1.5.7: Differences between 2007 and 1956 in runoff (mm/year) in Sierra Nevada.

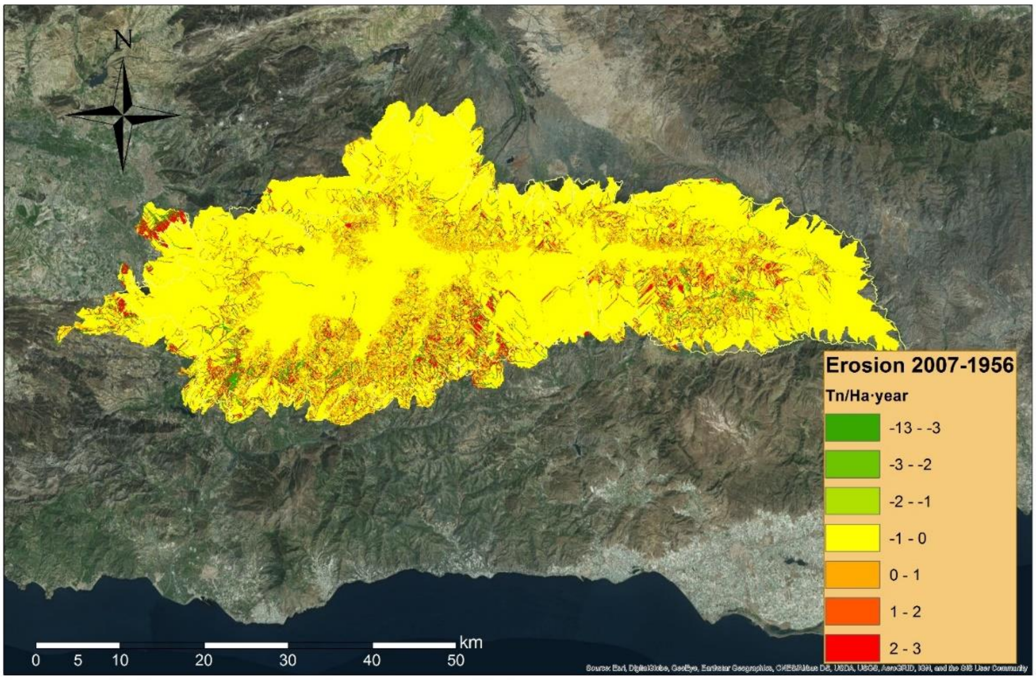

Figure 3.1.5.8: Differences between 2007 and 1956 in erosion (Tn/ha) in Sierra Nevada.

Once developed and implemented in WiMMed the hillslope erosion modeling, the work has been focused on the variation of different parameters which link soil loss with changes in vegetation cover. For this, maps of soil erodibility are being elaborated from the vertical distribution of the root biomass, estimated from the model proposed by Gale and Grigal (1987) and Jackson et al. (1996), and adapted to Mediterranean environments (Martínez-Fernández et al., 1995).

Recreation

A Flickr analysis shows that photos uploaded per year have generally increased until 2014 before dropping in 2016 (Figure 3.1.5.8), a positive trend is suggested by Mann-Kendall test ($S = 29$, $tau = 0.644$, $P < 0.05$).

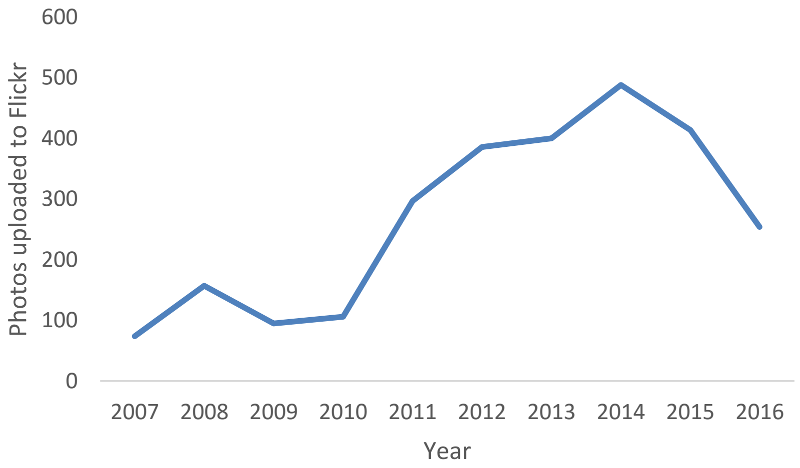

Figure 3.1.5.8: Changes in photos uploaded to Flickr for Sierra Nevada. Years are filtered by the date the photo was taken.

3.2 Arid/semi-arid

3.2.1 Har Hanegev (Israel)

Drylands cover up to a third of the earth's surface and are home to 20% of the world's population (Safriel et al., 2005). While characteristically low in precipitation (Beaumont, 1989; Goudie, 2002), and thus low in primary productivity, they are home to complex ecosystems, unique biodiversity and many ecosystem services (Figure 3.2.1.1). They are also subject to increasing ecological degradation as population growth and increasing demands for food production push larger amounts of human development deeper into arid environments (Beaumont, 1989; Reynolds et al., 2007).

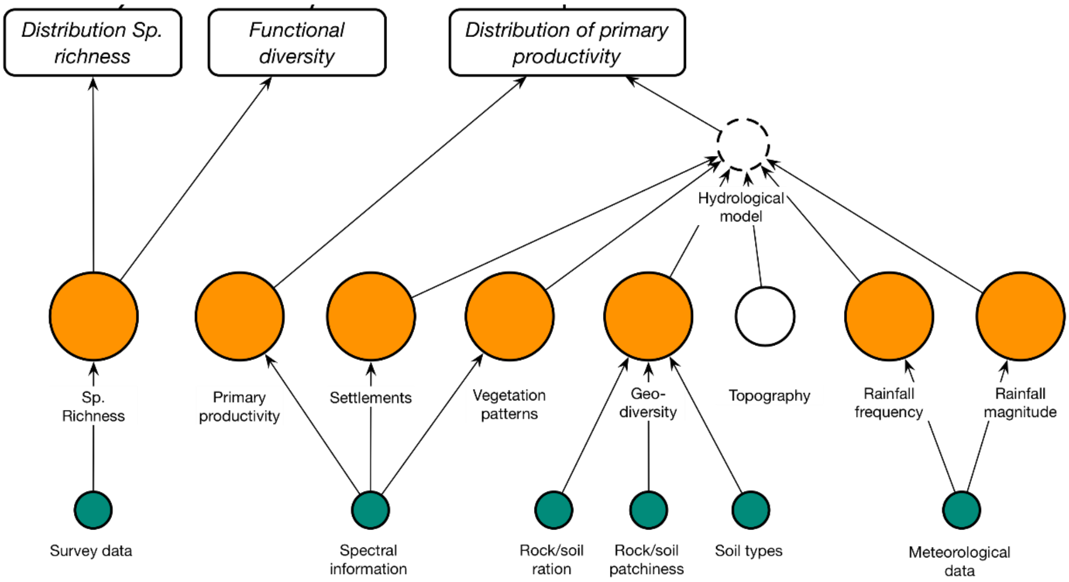

Figure 3.2.1.1: Diagram representing the storyline developed for the Har Hanegev, including the identification of essential variables at the storyline level (Source: Ecopotential Deliverable 2.2).

The socio-ecological character of Israel's Negev Desert is indicative of these global trends. The Negev Desert constitutes 60% of the Israel's land mass and is sparsely populated, with only 7.5% of the country's population (Central Bureau of Statistics of Israel, 2010). The northern, more mesic 40% of the country has among the highest population densities among developed countries. As such, there has been a sustained effort in Israel to increase population settlements in the country's geographic peripheries, and in particular in the Negev Desert (Orenstein et al., 2011). Residential development in the Negev includes urban and exurban communities, dispersed Bedouin settlement, and small family farms and homesteads. Residential development, and its associated human pressures (e.g. infrastructures, tourism, grazing and agriculture), is considered to pose a challenge to preserving ecological integrity, biodiversity and ecosystem service provision in the Negev (Portnov and Safriel, 2004; Orenstein et al., 2009).

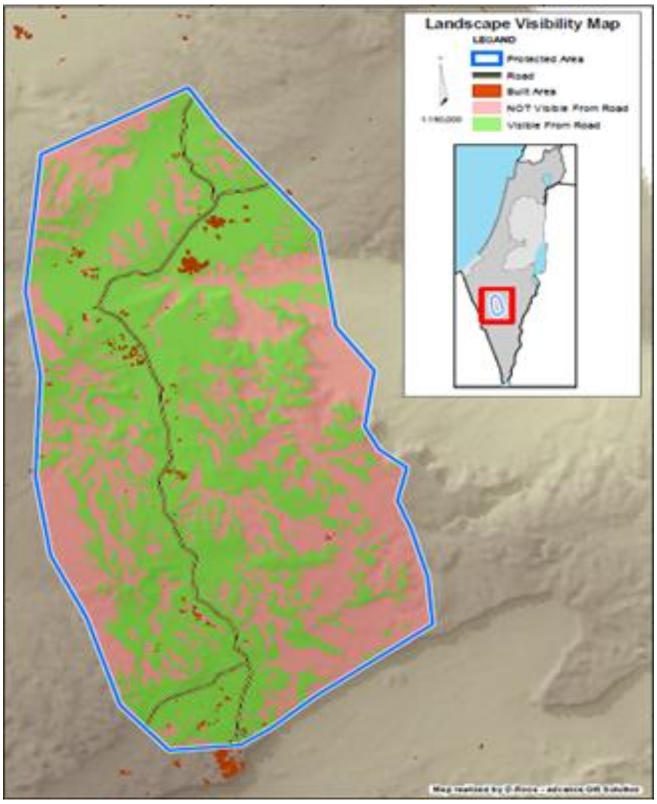

Figure 3.2.1.2: The Negev Highlands Protected Area (map emphasizes proportion of area visible from the main road (Road 40) that transects the PA.

Figure: 3.2.1.3: Sample photographs used in the landscape preference survey. Clockwise from the upper left: Wadi with natural and planted vegetation, Bedouin village, "undisturbed" wadi, and single-family farm.

The EcoPotential project in Israel is focused on the Negev Desert Highlands Protected Area (see Figure 3.2.1.2). Ecosystem productivity in the Negev Highlands is characterized by the interaction between hydrological, pedological and energy cycles that determine the distribution of water, soil and nutrients across the landscape. These interactions create and sustain the patchy distribution of vegetation across the landscape, which – along with faunal activity – augment and further sustain biological life in this arid environment (Hoekstra and Shachak, 1999; Shachak et al., 2008). Because of past hunting and overall lack of resources to sustain large mammals, there are few organisms of large biomass in the region (Nubian ibex being one of the more extroverted and visible examples). However, the Israeli Nature and Parks Authority (NPA) has engaged in wildlife reintroduction programs, namely the reintroduction of the Asiatic Wild Ass, or Onager (Saltz and Rubenstein, 1995). The reintroduction program has been considered a success, and the current population of Onagers consists of approximately 250 individuals (Gueta et al., 2014).

NPA officials, participating in EcoPotential as stakeholders, suggest that cultural ecosystem services, specifically landscape aesthetic values, are among the most important ecosystem services offered in the Negev Highlands. This contention gains support both from previous research on cultural ecosystem services in Israel's deserts (Sagie et al., 2013; Orenstein and Groner, 2015). The contention also derives support from the tourism literature, in which nature and scenery playing an important role in attracting tourist to the region (Lerner and Haber, 2001; Reichel and Uriely, 2003). In this work package, as a response to the request of our EcoPotential stakeholder partners, we studied the impact of residential and agricultural development on landscape preferences in the Negev Highlands.

Aesthetic value

Demand

Landscape aesthetic value is emerging as a major component of culture ES evaluation, with some researchers advocating for the adoption of the terminology of "landscape services" in lieu of ES (Termorshuizen and Opdam, 2009; Brown et al., 2012). Landscape preference studies are conducted using a variety of methodologies, including questionnaires, interviews and focus group discussion, and using a variety of visual media, including photographs (Steinitz, 1990; Natori and Chenoweth, 2008), large-screen projections (Orenstein et al., 2015) and 3-D imagery (Bowman and McMahan, 2007). In this research, we combined the use of a questionnaire and a 16-photograph photo-album of color, A4-sized Negev landscapes.

The photographs selected for this inquiry were selected to minimize landscape contrast with the exception of the particular landscape feature we wanted to assess (Figure 3.2.1.3). Most photographs featured a desert flat foreground with a wadi (dry riverbed), hills and sky in the background, although some did not include these features as a compromise to assure inclusion of the range of other landscape features. Photograph included agriculture, roads, electric wires, ancient terraces, Bedouin settlement, single-family farms, urban development, natural vegetation, planted groves of trees, people, and goats. Several photographs were selected as "controls" with no explicit human intervention in the landscape.

We had three objectives: 1) To assess which landscapes were preferred by respondents; 2) To assess how underlying environmental and nature-based values correlate with landscape preferences, and; 3) To assess differences in landscape preferences according to demographic profile. The questionnaire was divided into four sections:

1. Landscape preference. Respondents rank the degree to which they liked 16 landscapes depicted in photographs on a Likert scale of 1 to 5.
2. Environmental value-based questions (derived from Schultz, 2000).
3. Questions measuring nature-relatedness (Nisbet et al., 2009).
4. Socio-demographic questions (place and year of birth, place of birth of parents, level of formal education, resident/tourist, and reason for visit).

Questionnaires were prepared in Hebrew, Arabic and English, and were distributed over a one-month period across multiple locales in the PA, including residential areas, commercial areas, tourist attractions, and rest areas. We targeted specific populations to assure representation of local residents, particularly regarding the single family farms and Bedouin communities. 408 completed questionnaires were collected.

Results regarding landscape preferences revealed the highest preferences for the landscapes with the greatest amount of vegetation (i.e. green), regardless of whether the vegetation was agricultural (most highly preferred), planted ("limanim," which are artificial catchments with a grove of planted trees) or natural. With the exception of vineyards, all other human landscape interventions tended to lower the overall preference for the landscape. These interventions included (in declining order of preference) Bedouin settlement, infrastructures (power lines, roads) and urban development.

Factor analysis of landscape preferences yielded four distinct factors. The first factor, “vegetation” included five landscapes characterized by natural vegetation in river beds and/or planted groves of trees. The second factor, “extensive development”, included landscapes with extensive development including road and electricity infrastructure and Bedouin settlement. The third factor, “pristine”, was comprised of ostensibly the most undisturbed landscapes although one of the three in this factor included three individuals hiking. The fourth factor, “intensive development”, grouped together pictures of single-family farms and a more urbanized landscape.

Results using the environmental values characterization questions provided by Schultz (2000) were organized into factors as predicted, and provided egoistic, altruistic and biospheric factors. These factor loadings from this analysis were used in a correlation analysis with the landscape preference factors loadings. There were two significant and positive correlations revealed: 1) between the biospheric values factor and “vegetation” and, 2) between biospheric and “pristine”.

Results using the nature-relatedness index (Nisbet et al., 2009) produced similar (though not precisely overlapping) factors as Nisbet and colleagues’ original analysis. They reflected 1) a strong consciousness and connectedness to nature and the environment (“personal/intellectual”), 2) a strong spiritual and emotional connection to other species (“personal/spiritual”), 3) an experience-based connectedness to nature (“experiential”), 4) an ambivalent perspective on the human role in nature (“ambivalence”), and 5) a dominance-orientation to nature (“humans first”). Factor loadings of these factors also yielded several significant correlations to landscape preferences.

Correlations between nature-relatedness and landscape preferences suggest that those respondents with a stronger nature identity (intellectual or experiential) show preference for vegetated and pristine landscapes. On the other hand, those with a “personal/spiritual” nature connection showed a relatively high affinity for “extensive development”. Finally, those with an ambivalent relationship to nature were positively correlated to “intensive development” and negatively correlated to vegetated and pristine landscapes.

These results indicate that values orientations can be effective predictors of landscape preferences in dryland environments. Respondents whose underlying environmental concern is based on biospheric considerations (that is, all life, and not just humans), prefer landscapes with no explicit signs of human intervention. This is also true of those individuals whose nature-relatedness is based either on a strong awareness of environmental and nature in day-to-day life, or those who enjoy experiencing nature through physical involvement. On the other hand those whose concerns are more oriented towards human wellbeing and who feel that human intervention in nature is both justifiable and benign with regard to its impact are logically more predisposed to landscapes that are modified by humans.

With regard to demographic characteristics, here too, we identified several significant relationships. Some examples include:

- Bedouin respondents showed a strong preference for extensive development (which included their own communities), for vegetation and for intensive development (e.g. farms).
- Older respondents showed higher preference for vegetated landscapes than younger respondents.
- Tourists showed a strong, negative preference for landscapes with extensive development (including Bedouin communities) relative to those who live in the region.
- While all education classes showed a negative preference for extensive development, this relationship was stronger with higher educational achievement. Thus, respondents with more formal education prefer a desert landscape that is more pristine.

This study reveals insights of both theoretical and applied relevance. With the possible exception of local respondents with high formal educational achievement, the majority of the respondents strongly prefer green landscapes in this desert environment. Agricultural fields received the highest preference overall. A similar trend is observed in which only respondents with a strong biocentric relationship with nature similarly preferred pristine landscape to those with explicit human intervention. This suggests that most visitors (and some residents) do not look upon human landscape interventions as negative; to the contrary, most prefer green in the desert (though not necessarily other forms of intervention, like settlement, electricity infrastructure or roads). Some of these results are consistent with the literature on landscape preferences, for instance with those studies that should particular population groups preferred nature with human intervention to those landscape with no explicit signs of human intervention (Zube et al., 1982; Buijs et al., 2009; Zimroni et al., 2017). Further, in the tourism research (which focused particularly on the Negev), researchers recommended a management regime most suitable for tourist needs that combined infrastructure development with nature experience (Reichel and Uriely, 2003). As such, it appears that in order to maximize the positive benefits provided by landscape services in the Negev Highlands, limited greening should be considered a viable management strategy. If such a strategy should be deemed ecologically destructive, then other tools (e.g. education and outreach) are required to influence landscape preferences of the public. Gee and Burkhard (2010), for example, that landscape preferences can shift (regarding wind farms, in their example), when there is heightened concern regarding anthropogenic climate change.

Recreation

A Flickr analysis shows that photos uploaded per year have increased until 14, before declining in 2015 and slightly recovering in 2016 (Figure 3.2.1.5), a positive trend is suggested by Mann-Kendall test (S = 27, tau = 0.6, P < 0.05).

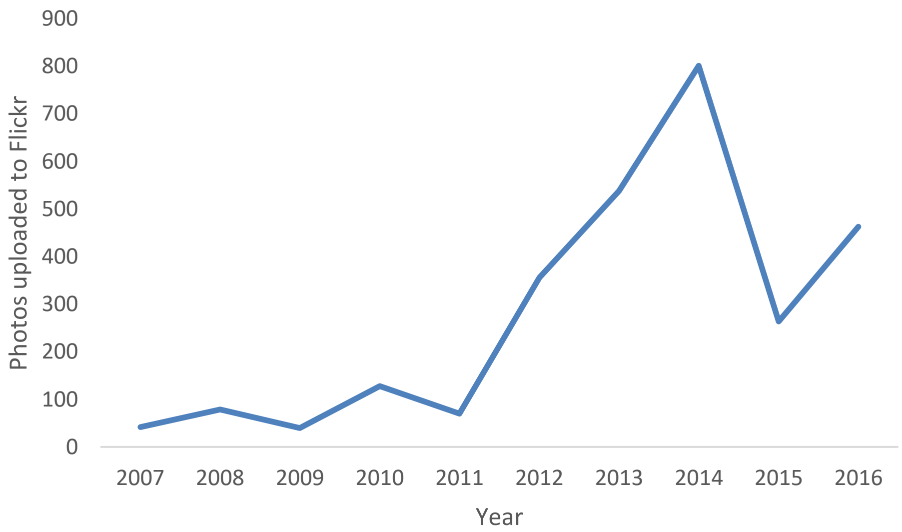

Figure 3.2.1.5: Changes in photos uploaded to Flickr for Har Hanegev. Years are filtered by the date the photo was taken.

3.2.2 Kruger National Park (South Africa)

Kruger National Park (KNP) is a fenced National Park located in the north-eastern part of South Africa. KNP is one of Great Limpopo Transfontier Park, including Limpopo National Park in Mozambique and Gonarezhou in Zimbabwe. KNP is located in the dry savanna biome, and was established in 1898 to protect wildlife. The location of KNP is well-placed in the savanna ecosystems with open canopy forests (about 50% or less tree cover) made of heterogeneous layers of grass and woody plants (Ben-Shahar and Coe 1992). Savanna is one of the largest biomes in sub-Saharan Africa which host a large proportion of the African population, generally the poorest communities who rely extensively on ecosystem services, e.g. fuel wood, timber, grazing resources and edible fruits. The woody component or tree cover plays a key role in ecosystem functioning, impacting on the fire danger, rates of transpiration and biomass production, nutrient cycling, soil erosion, carbon sequestration and water distribution, and more widely on food and energy security (i.e. fuel wood). While the grass component, plays a crucial role in the provision of grazing areas for livestock and wild herbivores (Prins and van Langevelde, 2008; McNaughton, 1990).

The major drivers of vegetation distribution are abiotic components such as geology, topography and soils. Two main geological types exist in KNP which influence the density of trees and high grass biomass. Basalt geological type is characterised by high fertility soils dominated by grasses with *Acacia* trees. On the other hand, granite geological types are characterised by low fertile soils dominated by high tree cover, especially the *Combretum* species. The abiotic and climatic factors make a dry savanna a complex ecosystem. Two seasons exist in this area, wet and dry season which in combinations with grass quality and quantity as well as tree greening and leaf off influence the feeding patterns and movements of animals. Grazing areas are often threatened by the encroachment of woody species (bush encroachment), land use and climate changes. To continue conserving biodiversity and ensure that rural people have future access to natural resources, assessment of critical ecosystem services/ functions as indicated above is critical. There is a need for spatial explicit assessment of ecosystem services within KNP and surrounding areas to be able to understand the state, quality, quantity and extent of the ecosystem function such as vegetation production (grass biomass, tree cover), tree-grass interaction (ecosystem extent), nutrient cycling (e.g. grass nutrients) and biodiversity (Figure 3.2.2.1).

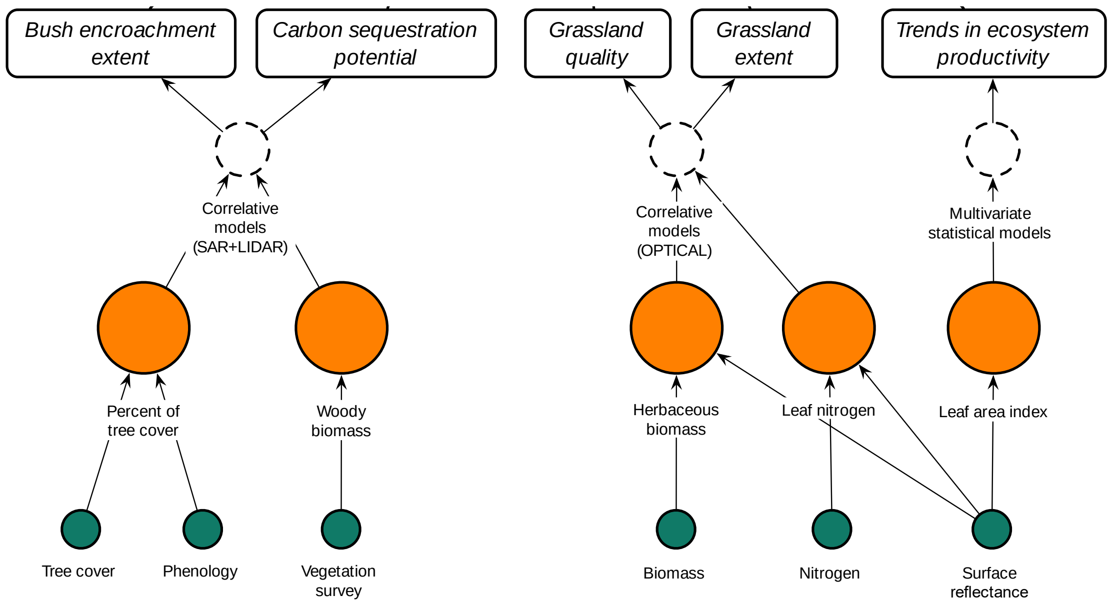

Figure 3.2.2.1: Diagram representing the storyline developed for the Kruger National Park, including the identification of essential variables at the storyline level (Source: Ecopotential Deliverable 2.2).

Supply

Changes in biomass can be seen between 2001 and 2015 (Figure 3.2.2.2), with biomass dropping between 2001 and 2007 and 2012, then an increase upto 2015. Individual site biomass was calculated on an annual basis (Figure 3.2.2.3) and Mann-Kendall tests calculated, finding a positive trend for Crocodile Bridge, Satara, Letaba and Klipkoppies, though a negative trend was seen in Punda Maria (Table 3.2.2.1).

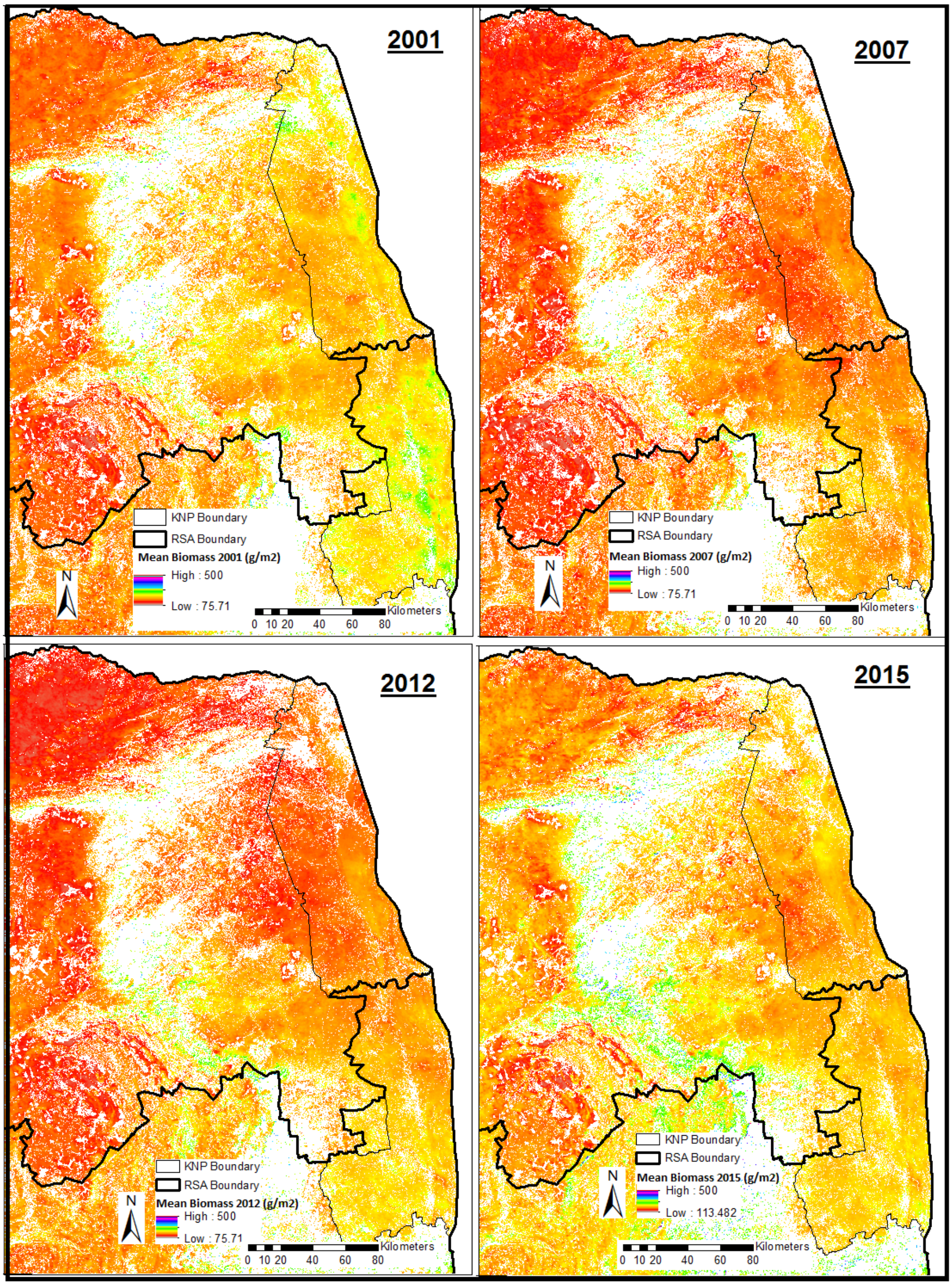

Figure: 3.2.2.2: Change in biomass between 2001 and 2015 in Kruger National Park.

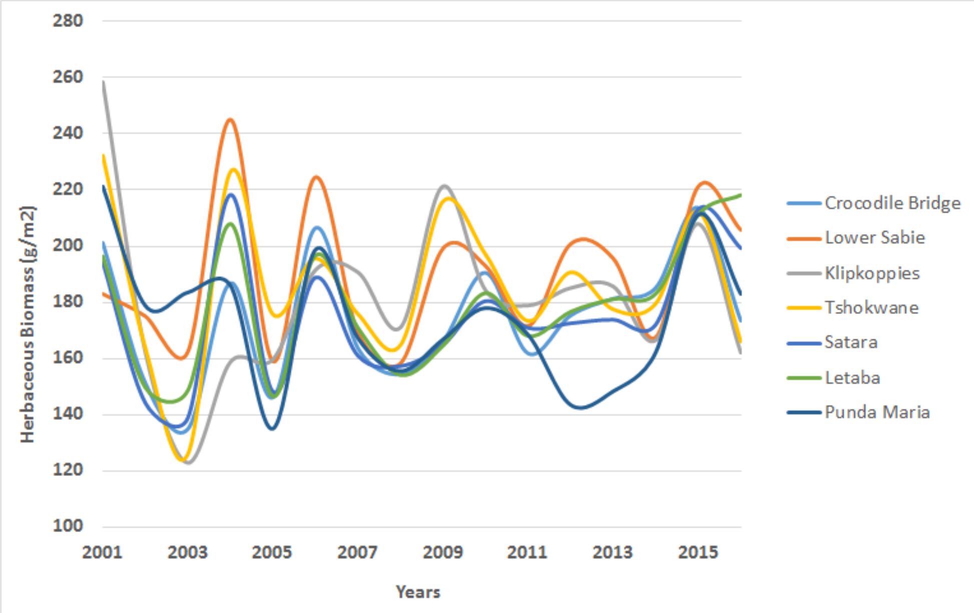

Figure 3.2.2.3: Mean Annual Biomass (g/m^2) for various sites within KNP derived from MODIS data.

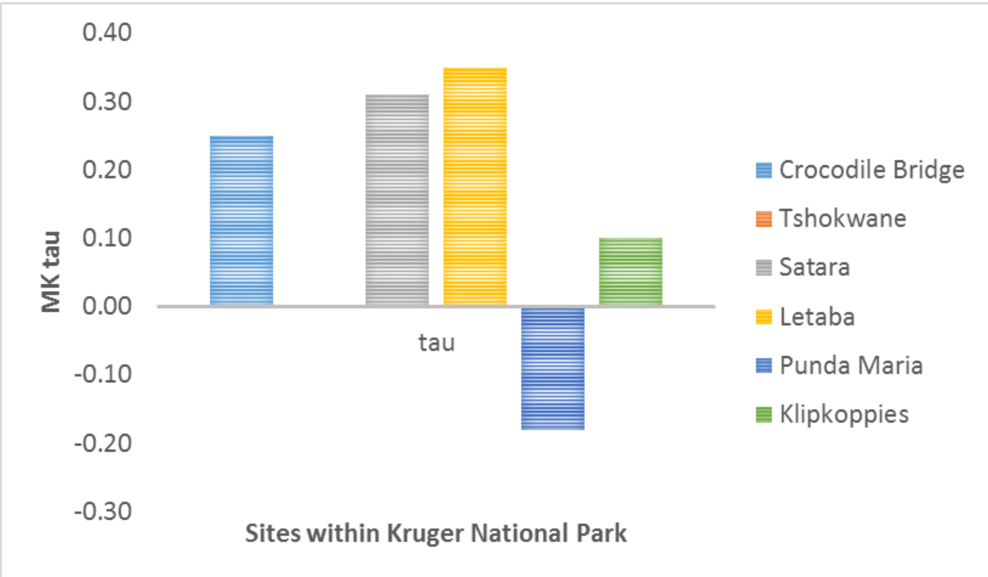

Figure 3.2.2.4: Mann-Kendall's tau for various sites within Kruger National Park, indicating positive trends of herbaceous biomass.

Table 3.2.2.1: Mann-Kendall Statistics for different sites within Kruger National park.

Site	S	Z-stats	tau	P-value
Crocodile Bridge	30	1.3057	0.25	0.1917
Tshokwane	0	0.0000	0.00	1.0000
Satara	38	1.6658	0.31	0.0958
Letaba	42	1.8459	0.35	0.0649
Punda Maria	-22	-0.9455	-0.18	0.3444
Klipkoppies	12	0.4953	0.10	0.6204

Recreation

A Flickr analysis shows that photos uploaded per year have increased between 2007-2014, and have then dropped (Figure 3.2.2.5), a positive trend is suggested by Mann-Kendall test (S = 31, tau = 0.689, P < 0.01).

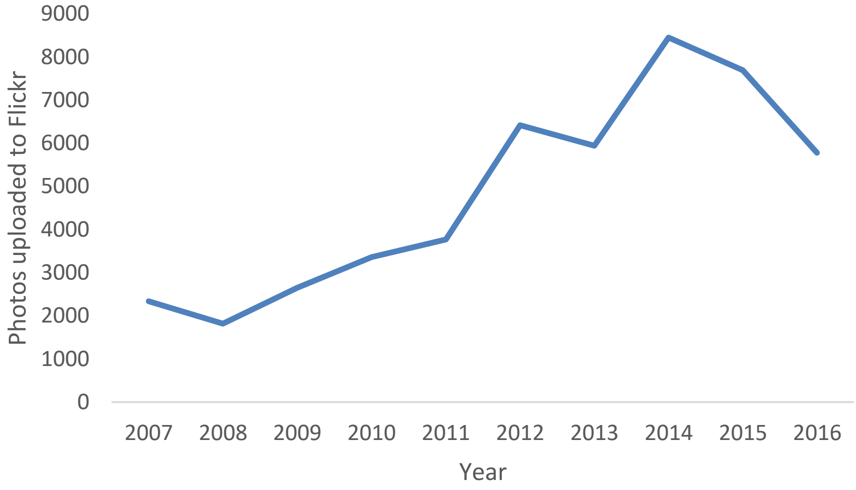

Figure 3.2.2.5: Changes in photos uploaded to Flickr for Kruger National Park. Years are filtered by the date the photo was taken.

3.3 Coastal/Marine

3.3.1 Doñana (Spain)

Wetlands are a diverse array of dynamic ecosystems formed in the contact of land and water. They have long been considered unproductive and unhealthy and transformed into farmlands, afforestations, rice paddies, aquaculture farms, or transportation channels. Only recently it has been realized the importance of wetlands for the conservation of biodiversity, and for the ecosystem services they provide. The Doñana National Park (537 km2) was created in 1969 for the protection of waterbirds and its aquatic habitats, after two thirds of its original extension were drained mainly for agriculture (Méndez et al. 2012). Doñana is a UNESCO Biosphere Reserve (since1980), a Ramsar Site (1982), a Natural World Heritage Site (1984) and it is integrated in the Natura 2000 network, which also includes the surrounding Natural Park with a similar extent. It contains one of the largest wetlands in Western Europe (García and Marín 2005), an intricate matrix of marshes (270 km2), phreatic lagoons, and a 25 km-long coastal dune ecosystem with its shoreline and representative Mediterranean terrestrial plant communities (around 100 km2).

The Doñana wetlands provide an excellent service for scientific research, as well as for educational, spiritual and symbolic purposes. They also attract ecotourism interested in bird observation. The migratory waterbird populations they support provide many other services at a continental scale along the flyway such as quarry for hunting, vectors for plant and invertebrate dispersal, and regulators of pests (Green and Elmberg 2014). Some of Doñana's wetlands are also important for water purification: water filtration, nutrient sequestration and storage. However, these services can compete with food production (grazing by livestock, or transformation into agriculture or aquaculture) (Figure 3.3.1.1).

The main challenges posing a threat to conservation and the provision of ecosystem services in Doñana are related to underground water extraction, surface water diversion, modification of hydrological regimes, pollution, overgrazing, and the introduction of exotic species. Although most Doñana's marshland and wetland ecosystems are nowadays protected, they are highly dependent on catchment areas or aquifers much larger than the protected area and thus subjected to anthropogenic degradation. In addition, climate change will affect the hydrology of most wetlands. Recent research suggest that global (climate change), regional (water extraction, eutrophication) and local (modification of hydrological and grazing regimes) stressors could act in synergy and can push the ecosystem to an undesirable conservation state (Green et al. 2017).

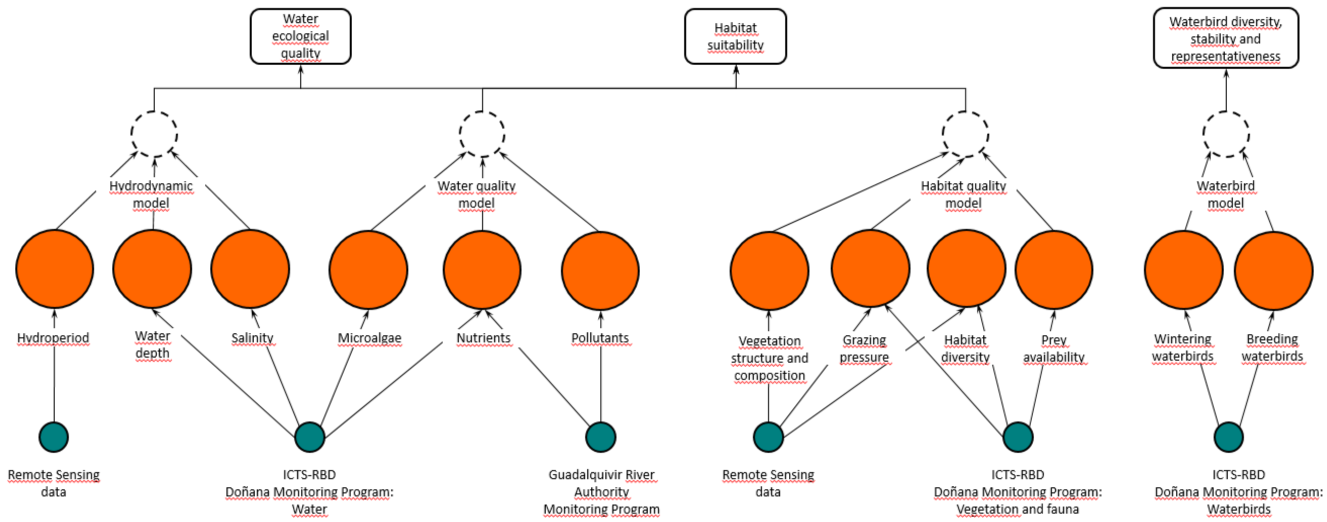

Figure 3.3.1.1: Diagram representing the storyline developed for the Doñana National Park, including the identification of essential variables at the storyline level (Source: Ecopotential Deliverable 2.2).

Main drivers of change and conservation challenges for the sustainable provision of ecosystem services in Doñana Protected Area

Water quantity in floodplain wetlands like Doñana marshes depend on river discharge and rainfall in the drainage basin. The diversity of wetland habitats (e.g., Espinar and Serrano 2009), which are strongly linked to the aquatic vegetation inhabiting them, depends on key variables such as the (micro)topography of the floodplain, the variability of rainfall (amount and seasonal pattern) and the water management of transformed areas. Groundwater levels influence the presence of phreatophytic vegetation and the hydroperiod of ephemeral ponds on aeolian sands (another type of wetlands present in Doñana National Park). In both types of wetlands, water transparency and nutrient levels influence the growth of primary producers, and the dominance of submerged macrophytes vs. microalgae (including cyanobacteria). Water levels and their fluctuations will influence the presence of emergent vegetation.
The main drivers of hydrological change in Doñana marshes are:

- Water abstraction for agriculture in the drainage basin of Doñana protected area, mainly groundwater abstraction with some surface flow diversion (Guardiola-Albert and Jackson 2011).
- Groundwater abstraction in touristic resorts on the coast for human consumption and for watering golf courses and gardens.
- Water pollution due to agricultural run-off but also waste water from villages upstream.
- Synergy with climate change is increasing the impacts of water abstraction and nutrient loading. It will also increase evapotranspiration and will modify the precipitation regime.
- Suspended solid transport and marsh siltation is probably increasing due to increasing agriculture in the basin (although this could differ in other deltas).
- Overgrazing can be a problem in the marsh and livestock cause bioturbation increasing water turbidity.
- Introduction of alien species can cause important impacts on plant and animal communities (e.g. cyprinid fish, crayfish, Azolla) (Aragonés et al. 2009, Díaz-Delgado et al. 2011, Espinar el al. 2015).

Biodiversity in general, and waterbird diversity in particular, are the main reasons to protect Doñana and behind its attractiveness for ecotourism. They are critically dependent on high productivity (primary and secondary), as well as on the high spatial and temporal diversity of wetland habitats. Different waterbird species use habitats with different characteristics (e.g., water depth, vegetation cover, salinity, duration of flooding period) and also at different times of the year (e.g., breeding, stop-over, wintering). Moreover, the high inter-annual variability in flooding regime is also important to maintain the diversity of the waterbird community, avoiding the dominance of a few common species and creating opportunities for rare species (Sebastián-González and Green 2015). In relation to productivity, waterbird diversity is highly sensitive to the impact of eutrophication and overgrazing on benthic producers, emergent plants and floodplain meadows.

Hydroperiods
Supply

A key element of structuring waterbird communities in Doñana protected area temporary ponds are hydroperiods. The aeolian sands of Doñana protected area include a system of Mediterranean temporary ponds highly variable in depth and size. They are of considerable importance for biodiversity conservation in Europe, because they harbour a large part of the aquatic biodiversity at the landscape scale, and are home to rare and endangered species (Díaz Paniagua el al. 2010, Zacharias and Zamparas 2010, Florencio et al. 2014, Díaz Paniagua el al. 2015). Indeed, they are a priority habitat in the European Union (Code 3170, Habitats Directive 92/43/ECC). However, pressures and impacts from urbanization and agriculture, acting in synergy with climate change, are threatening these habitats at the global scale (Zacharias and Zamparas 2010).

The Doñana's system of ponds consists of an extensive group of small dynamic water bodies that are highly dependent on precipitation, groundwater seepage and water table oscillation (Sacks et al. 1992, Serrano et al. 2006, Díaz-Paniagua et al. 2015). Climate change has resulted in a decline by aridification since the "Little Ice Age" (Sousa et al. 2006), acting together with dessication due to an increased anthropogenic pressure from groundwater abstraction for agriculture or for tourism (Sousa and García-Murillo 2003, Sousa et al. 2009, Díaz-Paniagua and Aragonés 2015). Nevertheless, differing levels of environmental protection of the different areas of the aeolian sands since 1969 have strongly influenced both the degree of conservation and the flooding dynamic of these temporary surface waters (Bustamante et al. 2016).

The hydroperiod of the temporary ponds, defined as the duration of their flooding period in an annual cycle (Grillas 2004), is a key ecological parameter determining the composition of plants and waterbirds community that uses these ponds for breeding and completing their life cycle (Díaz-Paniagua et al. 2010). In recent research funded by ECOPOTENTIAL project, Bustamante et al. 2016 used the Landsat series of satellite images (1985 to 2014) to study the temporal dynamic of the hydroperiod of these small waterbodies in relation to two other key factors: the protection level and the distance to water abstraction pressures from agriculture and residential areas. That research highlights how, even with resolution limitations, the Landsat images time series is a great source of information to study the temporal trends, hydrological evolution and the landscape effect of different conservation actions in the system of Doñana's temporary ponds.

The main results of that study show that the protected areas of the aeolian sands hold a better preserved system of temporary ponds. Its flooding dynamic fluctuates with precipitation and is affected, although in a complex way at the landscape level, by water abstraction for irrigation agriculture and, to a smaller extent, by residential areas. Mean hydroperiod has increased by the creation of new irrigation and recreation ponds in agricultural and residential areas, respectively.
Regarding natural ponds, the flooding regime of some is linked to fluctuations of the groundwater table due to water abstraction, while other ponds are probably receiving excess irrigation water, or are directly transformed into reservoirs. In general, the unprotected area shows an increase in mean hydroperiod duration, and surface flooded, and a decline in hydroperiod variability. One of the main conclusions of the study is that, while it is true that mean hydroperiod of water bodies over an extensive area is probably not a good indicator of the degree of conservation of temporary ponds, a low correlation with precipitation and a low coefficient of variation of hydroperiod could probably be indicators of the degree of artificialization of an area. In addition, flooding dynamics and flooding anomalies (differences from mean values or mean trends), as determined by remote sensing data, could be used to classify and identify different types of water bodies and evaluate their degree of artificialization.

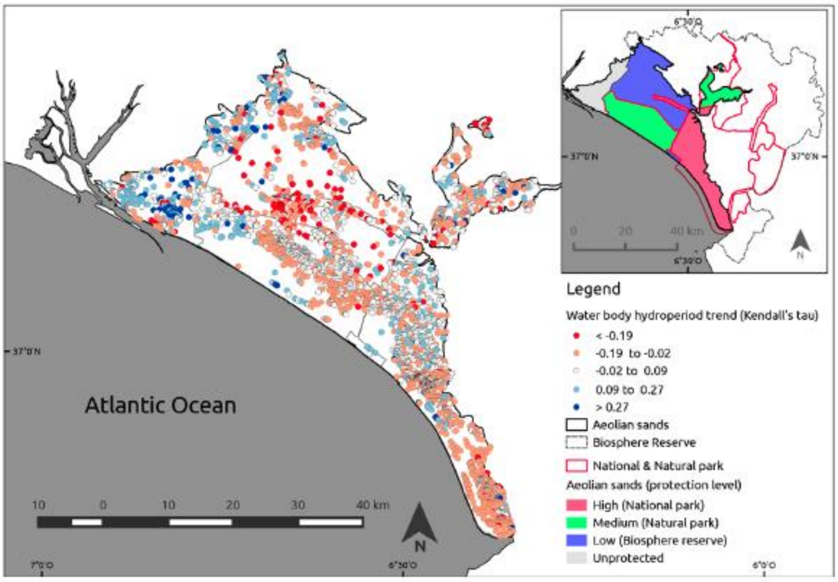

Figure 3.3.1.2: Hydroperiod trend (Kendall's tau) of water bodies on the Doñana's aeolian sands. Points represent the centroid of the water body. Blue colors represent increasing hydroperiods and red colors decreasing hydroperiods. The reference image indicates with color the levels of protection. Source: Bustamante et al. 2016.

Informing the management of natural resources in protected areas: Modelling biomass production in the seasonal wetlands of Doñana National Park

Freshwater wetlands are ideal sites to rear feral cattle. In the Doñana marshland feral cows and horses have been reared for ages using specific breeds capable to resist the extreme conditions (wet winters and dry hot summers). Its highly productive pastures allow for a considerable amount of animals, although this amount should be adjusted to carrying capacity in order to avoid degradation of the marshes' ecosystem. Primary production of the marshland is related with its hydrological conditions. In Mediterranean areas such as Doñana rainfall can vary considerably between years. Moreover, climate change will negatively affect rainfall, and, together with increasing temperatures, flooding period will shorten. Additionally, water management and exploitation of water resources by humans will also affect the availability of pasture. Remote sensing allows for modeling primary production in relation to water availability. Such models can be used for decision making on the amount and spatial distribution of cattle in the marshes, seeking for the optimal situation taking also into account the conservation of wildlife.

A recent study by Lumbierres et al. 2017 proposes a method to estimate standing aboveground plant biomass using NDVI Land Surface Phenology (LSP) derived from MODIS, calibrated and validated in the Doñana National Park's marsh vegetation. Out of the different estimators tested, the Land Surface Phenology maximum NDVI (LSP-Maximum-NDVI) correlated best with ground-truth data of biomass production at five locations from 2001–2015 used to calibrate the models (R^2 = 0.65). Estimators based on a single MODIS NDVI image performed worse (R^2 = 0.41). The LSP-Maximum-NDVI estimator was robust to environmental variation in precipitation and hydroperiod, and to spatial variation in the productivity and composition of the plant community. At Doñana National Park, the determination of plant biomass using remote-sensing techniques, adequately supported by ground-truth data, may represent a key tool for the long-term monitoring and management of seasonal marsh ecosystems.

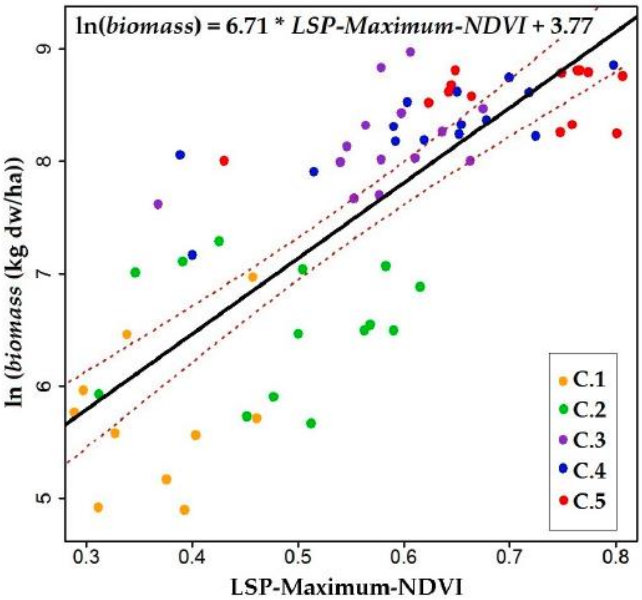

Figure 3.3.1.3: Model calibration. Relationship between the best NDVI estimator tested (LSP-Maximum-NDVI) and the logarithm of biomass production (kg dw/ha). Continuous line: regression line. Dotted lines: 95% confidence intervals. The dot colours represent the five different locations of the calibration biomass plots.

Recreation

A Flickr analysis shows that there was a increase in photos uploaded until 2015, where figures then decline for 2016 (Figure 3.3.1.4), a positive trend is suggested by Mann-Kendall test (S = 37, tau = 0.822, P < 0.01).

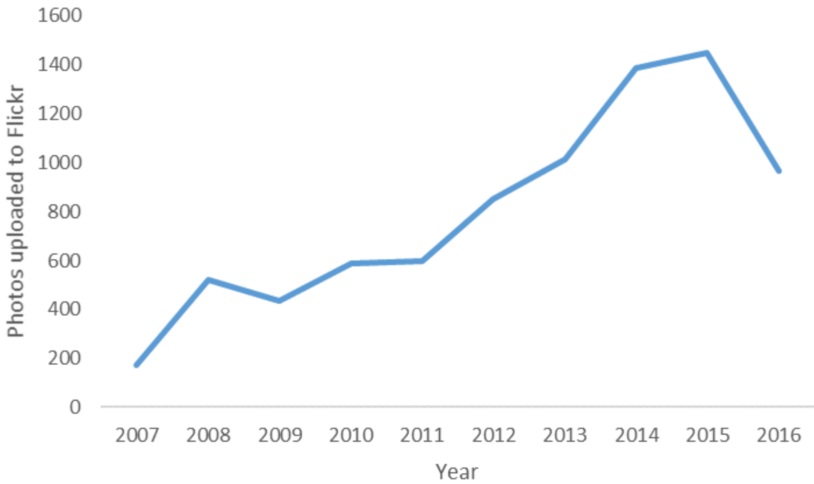

Figure 3.3.1.4: Changes in photos uploaded to Flickr for Doñana. Years are filtered by the date the photo was taken.

Co-funded by the European Union

3.3.2 Curonian Lagoon

The Curonian Lagoon – the largest European lagoon – is a shallow water body (total area 1584 km2, mean depth 3.8 m; maximum depth 5 m). Situated in the southern part of the Baltic Sea, the lagoon receives water from the River Nemunas, the third-largest contributor (after the Vistula and Oder) of total nitrogen and phosphorus to the Baltic Sea). The salinity of the water in the northern part of the lagoon fluctuates between 0.1 and 7 PSU; marine, brackish and freshwater species inhabit the lagoon.

The whole Lithuanian part of the Curonian lagoon has been designated as NATURA 2000 area (both habitat and bird directive protected territories). The northern part of the Curonian Lagoon is designated as a Baltic Sea Protected territory by HELCOM. The Curonian spit along with the adjusting portions of the lagoon is designated as a National park both in Lithuania and Russian federation. In 2000, the Curonian Spit cultural landscape was as well inscribed on the UNESCO World Heritage List. Two of the oldest ornithological stations in area are there in Lesnoje (Russia) and Vente (Lithuania) Bird protection is important as migratory routes South-Nord pass the Curonian lagoon. There are 62 protected bird species in the area of the lagoon. There are also 2 protected areas is adjacent to site – Luzija and Tyru high moors designated as protected territory according to the Habitats Directive and Tyru high moor designated as protected territory according to the Bird Directive. The Nemunas delta has separately the regional park protection status with several strict reserves inside.

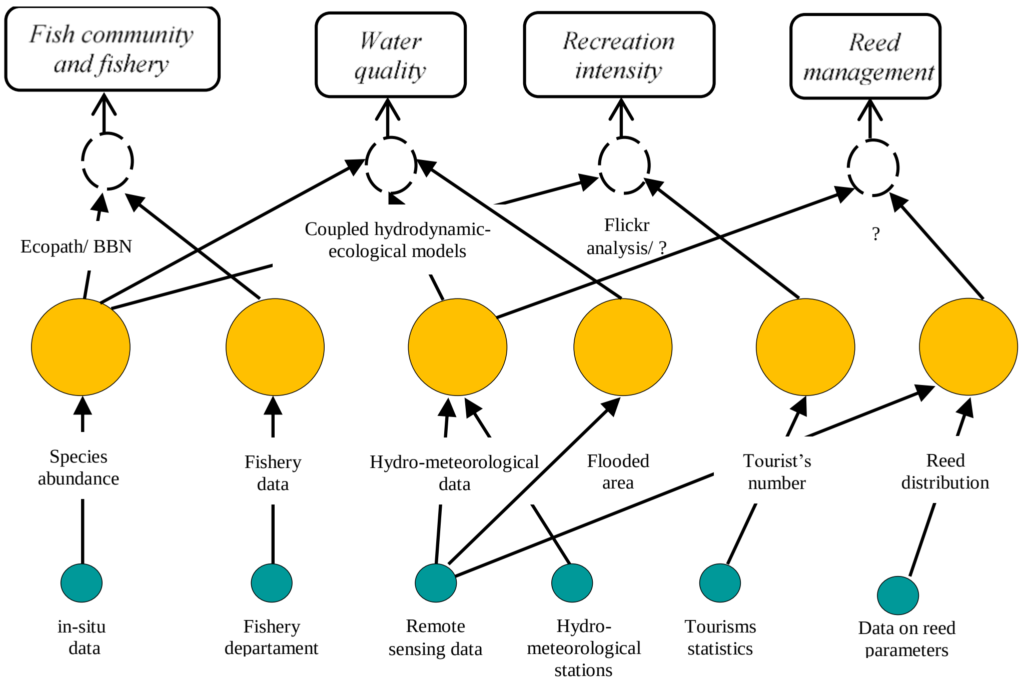

Figure 3.3.2.1: Diagram representing the storyline developed for the Curonian Spit National Park and Nemunas Delta Regional Park and, including the identification of essential variables at the storyline level.

Fishery

We have selected two ecosystem service indicators, which are considered to be the important in the PA. First one is the fishery which could be easily assessed by the commercial landing statistics which is available from 1953 to present in terms of individual fish species landings.

We did use the official landing statistics as the **demand** for the fishery ecosystem service, while CPUE(Catch Per Unit Effort) as the **supply** for this ecosystem service. However the CPUE was possible to calculate only for the latest period of observations.

Supply

Co-funded by the European Union

We used calculated CPUE for the time window of 2001 to 2011 to characterize the fish stock supply. The Kendall test (tau = -0.636, 2-sided pvalue =0.0081234) points towards negative trend in supply

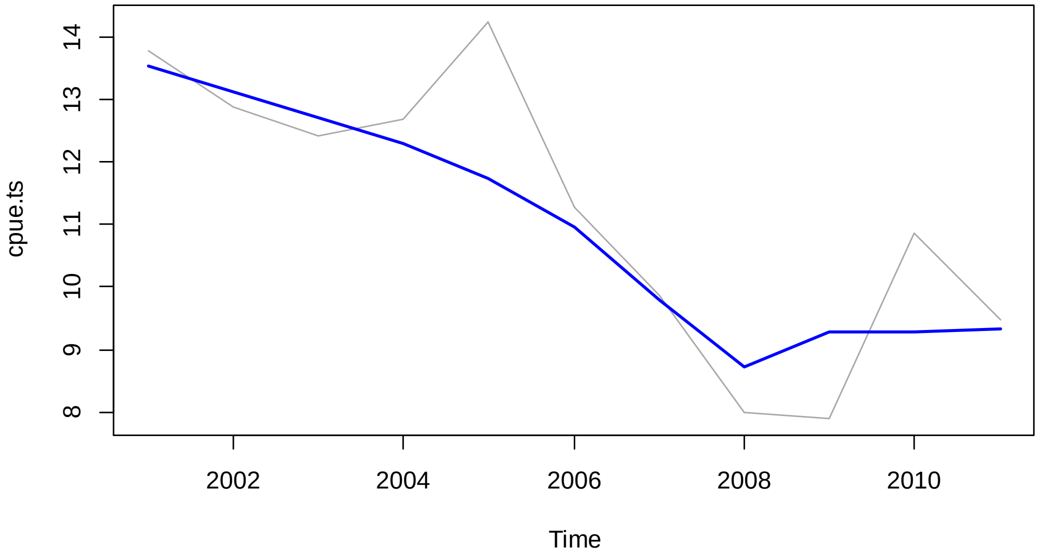

Figure 3.3.2.2: Changes in CPUE of commercial fish species in the Lithuanian part of the Curonian lagoon during the period of 2000-2011. The CPUE data are in kg/CPUE.

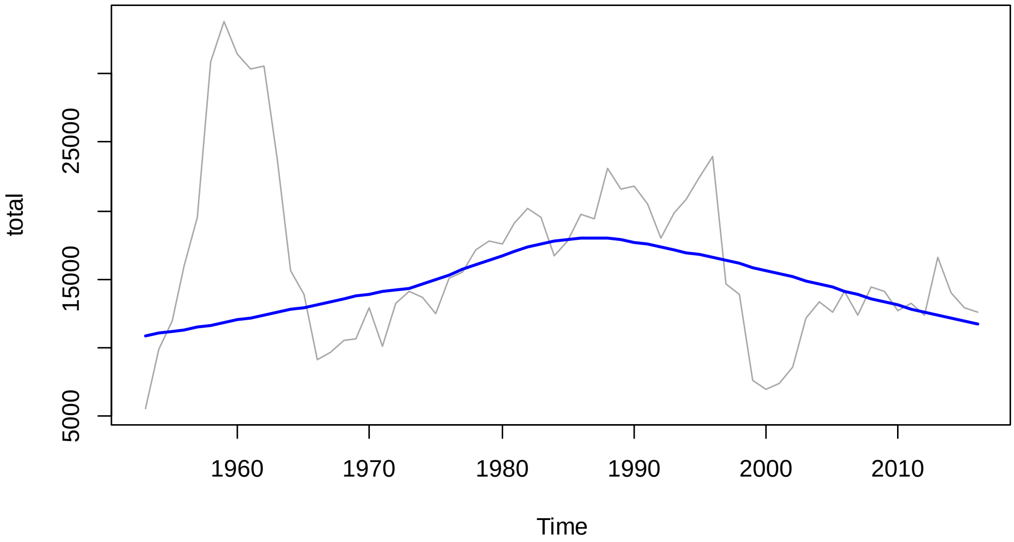

Figure 3.3.2.4: Changes in total landings of commercial fish species in the Lithuanian part of the Curonian lagoon during the period of 1953-2016. The landings data are in CWT.

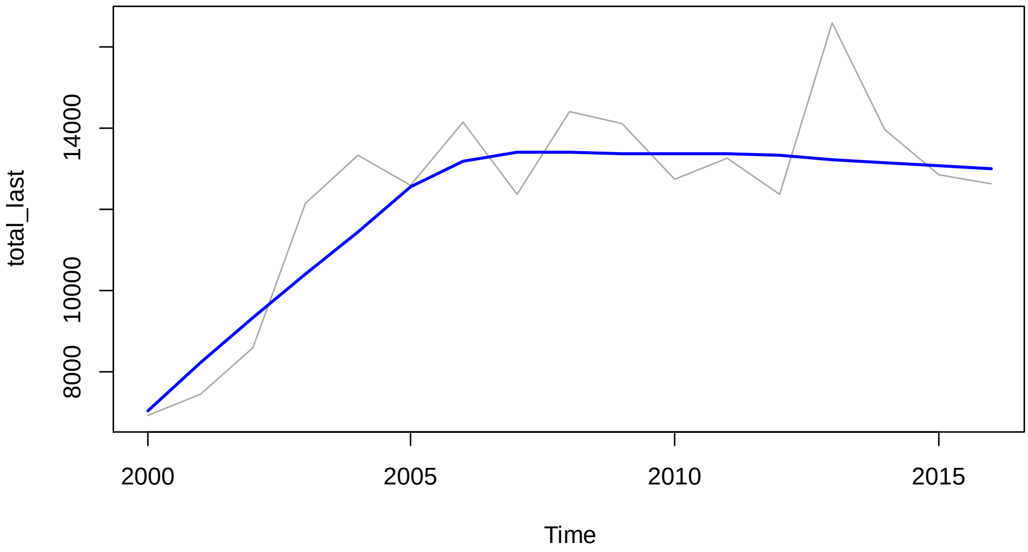

Figure 3.3.2.5: Changes in total landings of commercial fish species in the Lithuanian part of the Curonian lagoon during the period of 2000-2016. The landings data are in CWT.

However due to changes in fishery practice the time series for the whole period appeared to show no significant trend (results of the kendall test :tau = -0.0823, 2-sided pvalue =0.3391), so we decided to analyse the latest period (2000-2016) separately, which improves the trend probability (tau = 0.397, 2-sided pvalue =0.02902).

As it could be seen from the analysis, in the time window of 2000-2016, there is a mismatch between the supply and demand in commercial fisheries in the Curonian lagoon; the supply expressed as CPUE ha a negative trend while the demand expressed as a commercial landings exhibits an increase.

Recreation

As the Curonian lagoon area is under the protection of the national and regional parks, Natura 2000, and UNESCO, it attracts many tourists seeking for various entertainment types. First ice fishing on the frozen Curonian lagoon is important activity for both PA, because it attracts hundreds fishers from the whole country.

Mostly summer tourists come for sandy beaches, dunes, forests, and settlements in the Curonian Spit National Park where tourism infrastructure is developed and already raising the environmental problems.

Different situation is in the Nemunas Delta Regional park which has a unique landscape in the Nemunas Delta, river floods, and the importance for wildlife especially migratory birds. The most important types of tourism types in the territory are fishing (angling), birdwatching, and water tourism. Despite the area uniqueness, level of tourism is low and overall tourism infrastructure is poor. The PA administration seeks for tourism development and focuses to ecological/ nature tourism.

Current confrontations of the interests of tourisms business in the PAs, environmentalists, fishery and agriculture rise important issues for Pas administrations and stakeholders seeking for effective environmental protection, society needs and sustainable development.

A Flickr analysis shows that there was a general increase in photos uploaded between 2007 and 2016 (Figure 3.3.2.6), a positive trend is suggested by Mann-Kendall test (S = 33, tau = 0.733, P < 0.01). There is possibility of increased number of tourists in the PAs in the Curonian lagoon region. There could be other comparable methods to evaluate tourist number in the PAs as ferry tickets, voluntary PA tickets, number of fishing licenses etc. Some of these data could be relevant to a comparison with current Flickr analysis. Moreover, further analysis of the Flickr photos might provide information on the most popular places among the tourists, seasonality of visits, the most important activities for recreational in the area.

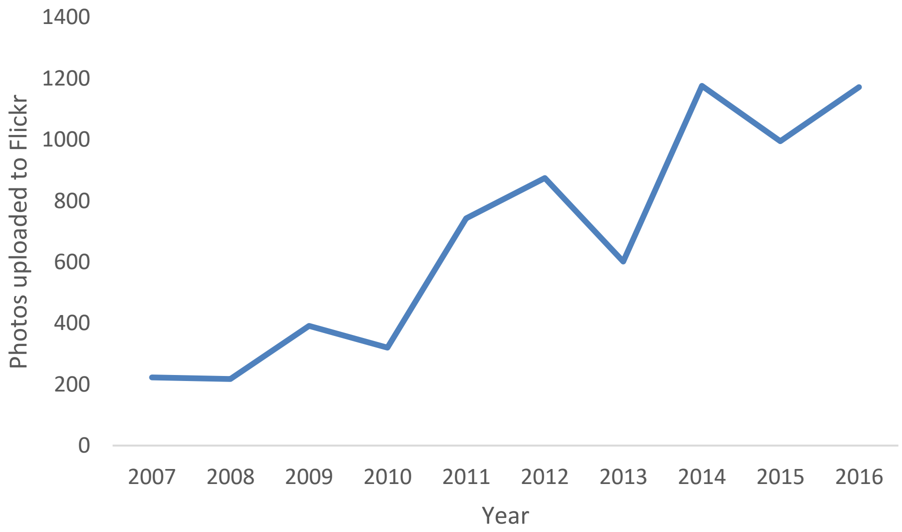

Figure 3.3.2.6: Changes in photos uploaded to Flickr for the Curonian Lagoon. Years are filtered by the date the photo was taken.

3.3.3 Pelagos

The Mediterranean Large Marine Ecosystem (LME) is a huge and complex environment, characterized by biotic and abiotic richness, that encompasses numerous Protected Areas and that can provide many ecosystem services (ESSs) (provisioning, regulation and maintenance, and cultural). These ESSs, in the form of functions (e.g. coastal protection) or goods (e.g. biomass), benefit several categories like protected area managers, citizens, private companies, etc. At the same time these services are influenced and affected by a great amount of stressors who can threaten them (Figure 3.3.3.1).

Biomass provisioning

Supply

In the Mediterranean LME the nutrition – biomass provisioning ecosystem service (provisioning ESS) is of extreme interest as it exploits both the natural marine ecosystem potential in terms of fish biomass (Figure 3.3.3.2) ("Wild animals and their outputs" according to CICES classification v4.3) and the marine aquaculture ecosystem potential in terms of fish biomass (Figure 3.3.3.3) ("Animals from in-situ aquaculture" according to CICES classification v4.3). In both cases, the supply (biomass) responds to the demand of fish for nutrition, but the beneficiaries are different. For "Wild animals and their outputs" beneficiaries are fishery companies and fishermen that have biomass available for commercial and subsistence fishing, and consumers. For "Animals from in-situ aquaculture" beneficiaries are aquaculture farmers and consumers. Provisioning benefits can therefore be summarized as economic revenue and food availability.

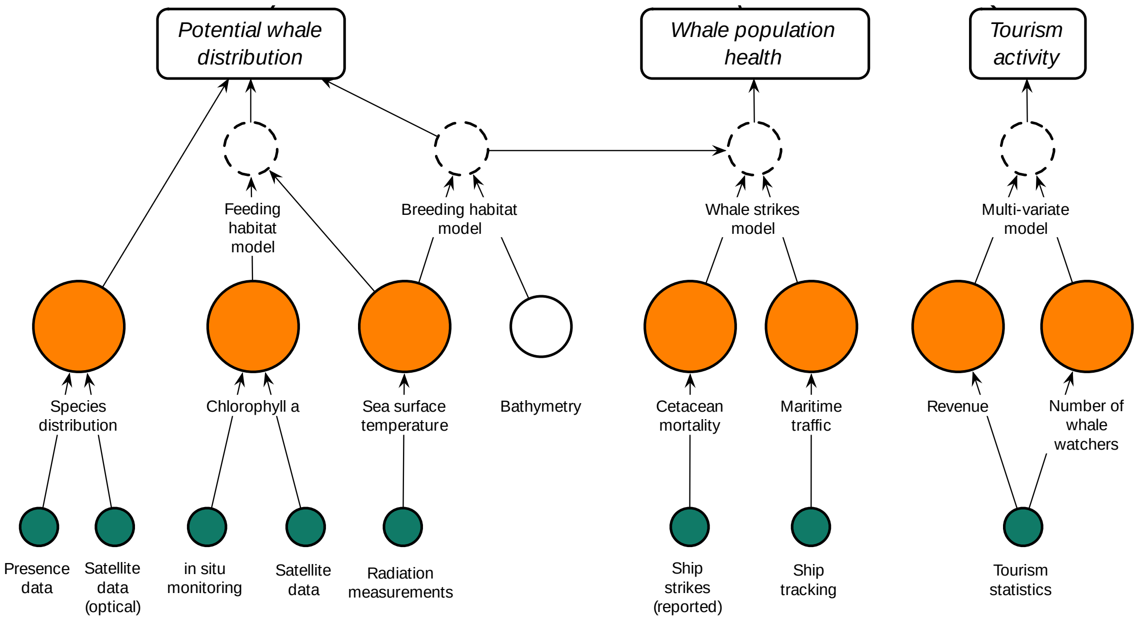

Figure 3.3.3.1: Diagram representing the storyline developed for the Pelagos Sanctuary for marine mammals, including the identification of essential variables at the storyline level (Source: Ecopotential Deliverable 2.2).

As a proof of the importance of these ecosystem services, it has to be noticed that many provisioning services are traded in markets, thus sustaining economies, but in some cases, especially in least developed countries they benefits directly single household. According to Food and Agriculture Organization (FAO), the natural and aquaculture marine potentials in terms of fish biomass, significantly contribute to nutrition, employment, and earnings worldwide, and aquaculture provides half of all fish for human consumption. Moreover FAO states that for the Mediterranean Sea aquaculture the most common native species are *Dicentrarchus labrax* (Linnaeus, 1758) (common name sea bass), *Sparus aurata* Linnaeus, 1758 (common name sea bream). The EU Commission as well has prioritized the “blue economy” as a key focus area in terms of growth and job creation to support economic recovery and sustainability.

The pressures affecting nutrition-biomass provisioning services in terms of biomass production or biomass growth enabling conditions are: fishing overexploitation, change in food-web structure, eutrophication, expansion of human activities producing pollution or subtracting maritime space (tourism, maritime transport, resource extraction), climate change, exotic a/o invasive species.

The main factors controlling the fish growth are related to fish vitality, fish weight, and aquaculture technical constraints, and more in general to the local physical-chemical and biological properties of the water that affect directly the fishes or their habitat. Physical, chemical and biological characteristics of seawaters are therefore the primary descriptors to assess the spatial and temporal dimensions of marine ecopotential productivity performances in terms of fish growth. Among these characteristics, seawater temperature is the Essential Variable (EV) to characterize fish vitality and thus marine food provisioning service, as it influences many other parameters and as consequence the entire life cycle of marine organisms.

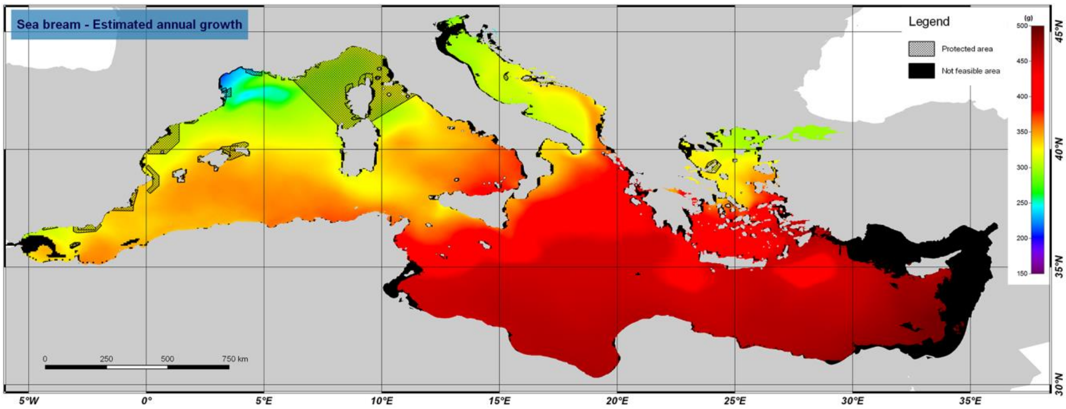

Figure 3.3.3.2: Natural marine nutrition provisioning potential: estimated annual fish growth for sea bream

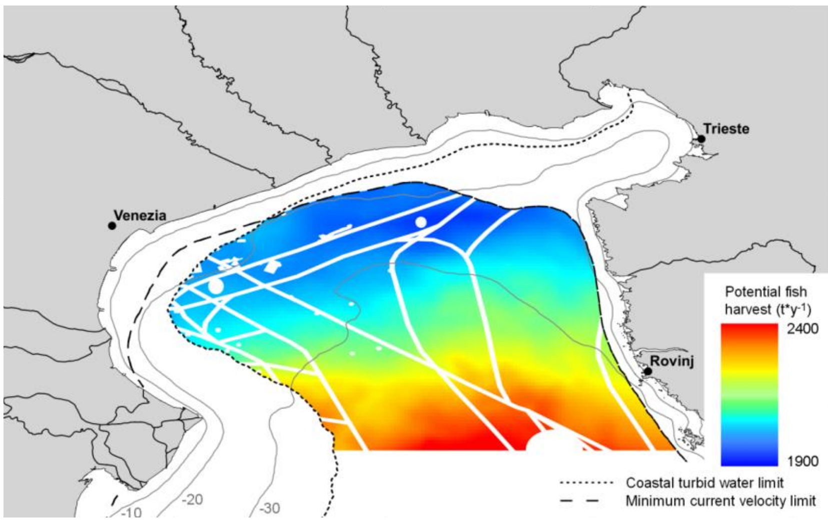

Figure 3.3.3.3: Aquaculture marine nutrition provisioning potential: potential fish harvest estimated within the area identified as feasible for aquaculture (current maritime uses have been subtracted to the overall feasible area).

MARINE CAPTURE PRODUCTION: FAO MAJOR FISHING AREAS

FISHING AREA CODE	FISHING AREA NAME	AVERAGE 2003–2012	2013	2014	VARIATION AVERAGE (2003–2012) –2014	VARIATION 2013–2014	VARIATION 2013–2014
			(Tonnes)		(Percentage)		(Tonnes)
21	Atlantic, Northwest	2 136 378	1 853 747	1 842 254	−13.8	−0.6	−11 493
27	Atlantic, Northeast	8 969 599	8 454 196	8 654 722	−3.5	2.4	200 526
31	Atlantic, Western Central	1 450 734	1 297 541	1 186 897	−18.2	−8.5	−110 644
34	Atlantic, Eastern Central	3 929 634	4 222 622	4 415 695	12.4	4.6	193 073
37	Mediterranean and Black Sea	1 484 499	1 243 330	1 111 776	−25.1	−10.6	−131 554
41	Atlantic, Southwest	2 021 094	1 974 086	2 419 984	19.7	22.6	445 898
47	Atlantic, Southeast	1 479 746	1 380 608	1 574 838	6.4	14.1	194 230
51	Indian Ocean, Western	4 313 756	4 579 366	4 699 560	8.9	2.6	120 194
57	Indian Ocean, Eastern	6 274 406	7 617 838	8 052 256	28.3	5.7	434 418
61	Pacific, Northwest	20 256 795	21 374 002	21 967 669	8.4	2.8	593 667
67	Pacific, Northeast	2 831 978	3 205 426	3 148 703	11.2	−1.8	−56 723
71	Pacific, Western Central	11 298 748	12 398 778	12 822 230	13.5	3.4	423 452
77	Pacific, Eastern Central	1 825 231	2 024 994	1 907 785	4.5	−5.8	−117 209
81	Pacific, Southwest	642 355	581 852	543 030	−15.5	−6.7	−38 822
87	Pacific, Southeast	11 716 946	8 518 117	6 890 058	−41.2	−19.1	−1 628 059
18, 48, 58, 88	Arctic and Antarctic areas	161 608	236 617	311 896	93.0	31.8	75 279
WORLD TOTAL		80 793 507	80 963 120	81 549 353	0.9	0.7	586 233

Figure 3.3.3.4: Marine capture production in FAO major fishing areas (FAO, 2016).

AQUACULTURE PRODUCTION BY REGION AND SELECTED REGIONAL MAJOR PRODUCERS: QUANTITY AND PERCENTAGE OF WORLD TOTAL PRODUCTION

REGIONS AND SELECTED COUNTRIES		1995	2000	2005	2010	2012	2014
Bangladesh	(thousand tonnes)	317.1	657.1	882.1	1 308.5	1 726.1	1 956.9
	(percentage)	*1.30*	*2.03*	*1.99*	*2.22*	*2.60*	*2.65*
India	(thousand tonnes)	1 658.8	1 942.5	2 967.4	3 785.8	4 209.5	4 881.0
	(percentage)	*6.80*	*5.99*	*6.70*	*6.42*	*6.33*	*6.62*
Southern Asia, excluding India and Bangladesh	(thousand tonnes)	57.1	72.8	219.7	397.5	483.8	547.4
	(percentage)	*0.23*	*0.22*	*0.50*	*0.67*	*0.73*	*0.74*
Western Asia	(thousand tonnes)	51.7	118.0	189.5	256.3	294.5	331.4
	(percentage)	*0.21*	*0.36*	*0.43*	*0.43*	*0.44*	*0.45*
Europe	**(thousand tonnes)**	**1 580.9**	**2 050.7**	**2 134.9**	**2 544.2**	**2 852.3**	**2 930.1**
	(percentage)	***6.48***	***6.33***	***4.82***	***4.31***	***4.29***	***3.97***
Eastern Europe	(thousand tonnes)	183.5	195.9	239.0	251.3	278.6	304.3
	(percentage)	*0.75*	*0.60*	*0.54*	*0.43*	*0.42*	*0.41*
Norway	(thousand tonnes)	277.6	491.3	661.9	1 019.8	1 321.1	1 332.5
	(percentage)	*1.14*	*1.52*	*1.49*	*1.73*	*1.99*	*1.81*
Northern Europe, excluding Norway	(thousand tonnes)	205.6	309.0	327.6	363.5	391.3	402.8
	(percentage)	*0.84*	*0.95*	*0.74*	*0.62*	*0.59*	*0.55*
Southern Europe	(thousand tonnes)	480.6	640.8	541.5	573.5	579.3	595.2
	(percentage)	*1.97*	*1.98*	*1.22*	*0.97*	*0.87*	*0.81*
Western Europe	(thousand tonnes)	433.6	413.7	365.0	336.0	282.0	295.3
	(percentage)	*1.78*	*1.28*	*0.82*	*0.57*	*0.42*	*0.40*
Oceania	**(thousand tonnes)**	**94.2**	**121.5**	**151.5**	**189.6**	**186.0**	**189.2**
	(percentage)	***0.39***	***0.37***	***0.34***	***0.32***	***0.28***	***0.26***
WORLD	(thousand tonnes)	24 382.5	32 417.7	44 297.7	58 972.8	66 465.6	73 783. 7

Figure 3.3.3.5: Aquaculture production by region and selected regional major producers: quantity and percentage of world total production (FAO, 2016).

In the Mediterranean and Black Sea marine capture is declining as catches have dropped by one-third since 2007 (Figure 3.3.3.4), this reduction in food provision, and therefore in demand, is compensated by an increase in the aquaculture production (Figure 3.3.3.5) for the entire Europe that in about twenty years (1995-2014) is almost doubled.

EO products used widely for the assessment of Nutrition - Biomass Provisioning Ecosystem service

Among the main factors controlling the fish growth there are: temperature, currents, salinity, dissolved oxygen, pH, nitrates, phosphates, and Chlorophyll. All of these variables can be collected from the Copernicus Marine Environment Monitoring Service (CMEMS - http://marine.copernicus.eu/) as products (SST, Cur, Sal, dox, pH, nit, pho, Chl) and are the result of satellite observations or reanalysis using numerical modeling and data assimilation. Depending on the variable being considered the spatial resolution ranges from 1km to 7km, while the temporal resolution is daily mean or monthly mean.
CMEMS modeled-derived products are available up to 72 depth layers to account for the whole water depth in the basin, while available temporal coverage can vary.

Other EO source for these kind of products are for example: the OceanColor archive (https://oceancolor.gsfc.nasa.gov/) where the daily Level 2 Sea surface temperature (SST) from MODIS at 1km spatial resolution is available from 2002 to present; and the MERIS archive for the period 2002-2012 (https://merisfrs-merci-ds.eo.esa.int/merci/welcome.do) containing data that can be downloaded to be processed in order to produce Chlorophyll (Chl-a) and Colored Dissolved Organic Matter (CDOM) products according to selected algorithms.

Other physical and biological variables influencing fish vitality and growth, whose estimation is not directly retrievable from Remote Sensing data, can be derived from numerical modeling assimilating remote sensing and in-situ measured data. In addition to all these data and products the assessment of natural marine nutrition provisioning potential requires a fish growth model (based on in situ species growth coefficients) while the aquaculture marine nutrition provisioning potential requires farm operational parameters and cages parameters (e.g. minimum current speed and minimum bathymetry) as well as the fish growth model.

Current status AND temporal evolution of SST and of Nutrition - Biomass Provisioning

Sea Surface Temperature (SST) has been widely recognized as an essential variable (both Essential Climatic Variable - ECV and Essential Ocean Variable-EOV), namely a measurement required for the study, the monitoring and the management of climate change issues and the marine environment. Moreover the SST, influencing seawater properties (i.e. growth enabling conditions) and the life cycle of marine organism like fishes (fish vitality and growth rate), has to be considered as the Essential Variable to assess nutrition – biomass provisioning services.

Current status and temporal evolution of service delivered and to be delivered in the future (estimated fish growth rate) can therefore be observed as reaction to variation in SST and as a projection of the trend resulting from the analysis of the SST time series. Basically SST is to be considered as a proxy of the nutrition – biomass provisioning services. SST of the Mediterranean LME over the last three decades is analyzed in order to observe change in space and time that can be reflected in provision service change. Series of daily SST estimated for the period 1982-2016 from multi-sensor satellite data were collected from CMEMS and analyzed.

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 as well as future climate projections. Time series analysis results 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.

SST trend analysis (**Errore. L'origine riferimento non è stata trovata.** 3.3.3.6) revealed an increasing SST trend in he entire Mediterranean Sea basin for the period 1982-2016 ranging among 0.02 and 0.08 degrees×year^{-1}, corresponding to an average value of 1.4 Celsius degrees.

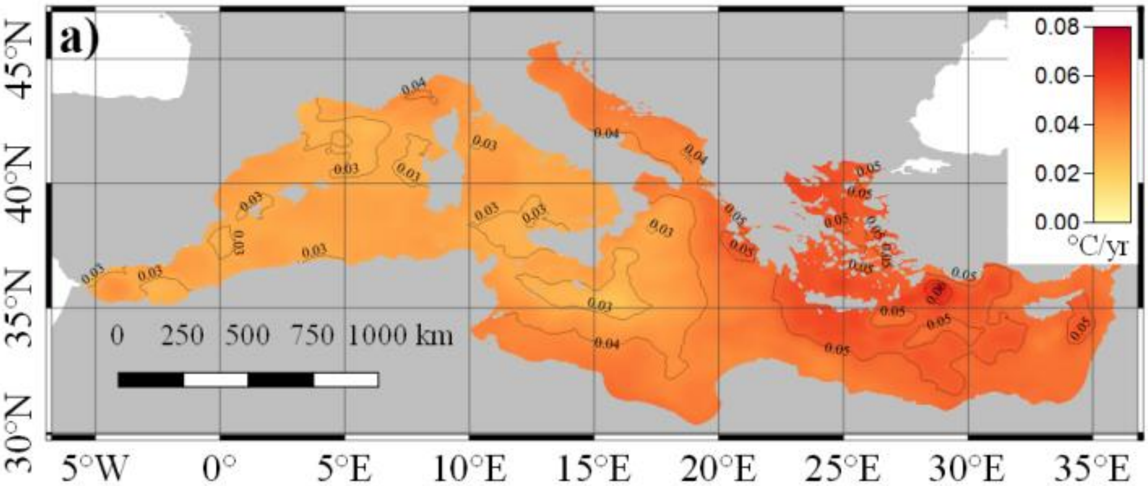

Figure 3.3.3.6: SST trend using Seasonal Trend Decomposition analysis for the period 1982-2016 (Mann – Kendall test resulted in p-values<= 0.0001 for all the pixels

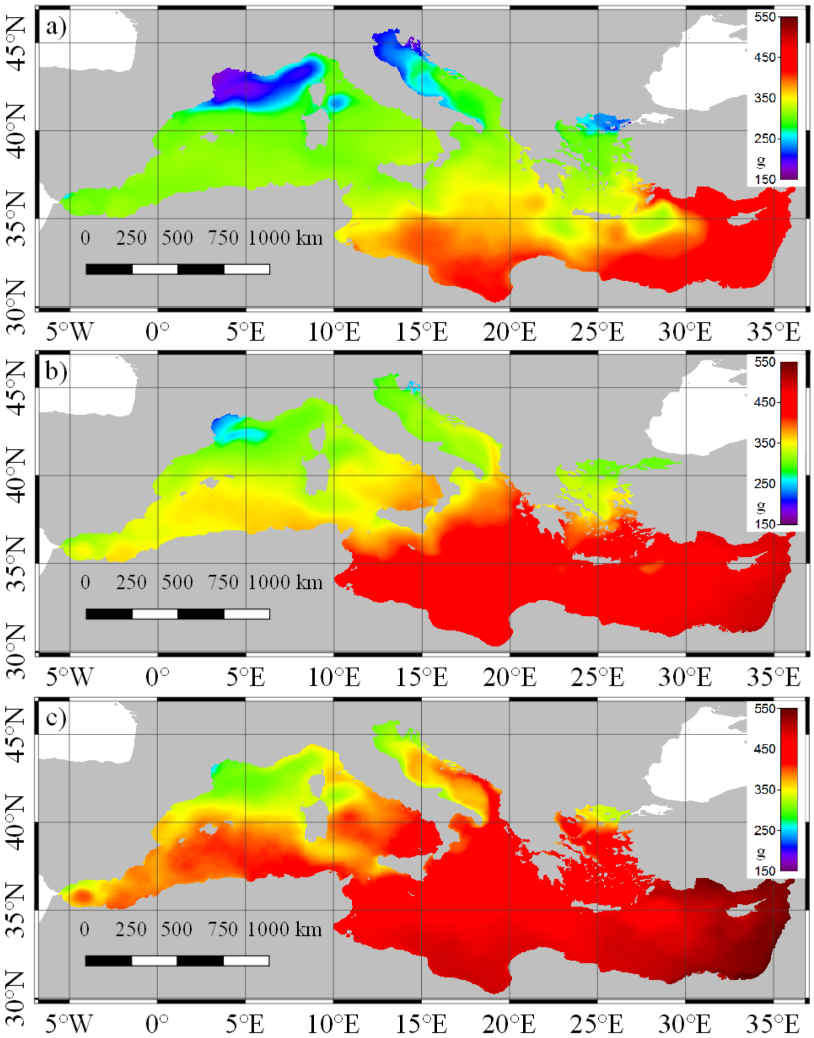

Figure 3.3.3.7: Estimated annual fish growth for sea bream fish species: (a) scenario for the period 1984-1987; (b) scenario for the period 2011-2014; (c) scenario for the period 2038-2041.

Scenarios of food provisioning ESS status were generated for three periods: 1984-1987 (past status), 2011-2014 (near past status) and 2038-2041 (projection of future status). The scenarios based on SST status and future trends show the estimated weight in grams of sea bream fish species (**Errore. L'origine riferimento non è stata rovata.**3.3.3.7). Figure 3.3.3.7 shows that the service delivered (in terms of extent of areas with highest annual fish growth) has increased and will continue to increase over the examined period, as result of the rise of corresponding SST values. At the same time it has to be noticed that higher SST values:

- cause the spreading of areas with maximum yearly temperature exceeding fish vitality condition;
- affect fishes thermal habitat and thus fish vitality;
- favor the spreading of competing alien species (e.g. Lionfish);
- and trigger fish diseases and lower dissolved oxygen in seawater, causing anoxia events and consequently fish blights.

Recreation

A Flickr analysis shows that photos uploaded per year have generally increased until 2013, where figures then start to slightly decline (Figure 3.3.3.8), no significant trend is suggested by Mann-Kendall test (S = 19, tau = 0.422, P = 0.107).

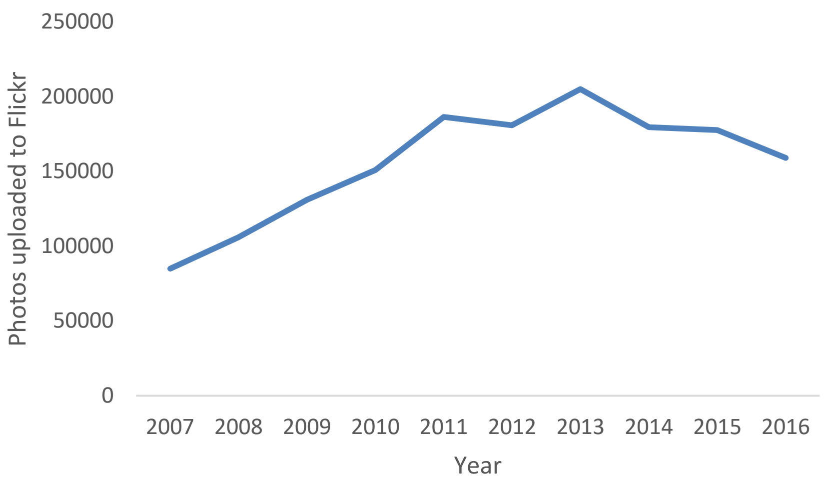

Figure 3.3.3.8: Changes in photos uploaded to Flickr for the Pelagos. Years are filtered by the date the photo was taken.

3.3.4 Wadden Sea

The Wadden Sea is an international, highly productive estuarine area, and one of the largest coastal wetlands in the world. Situated abreast mainland Europe in the south-eastern portion of the North Sea, it borders Germany, the northern portion of the Netherlands, and western Denmark, thereby requiring tri-lateral cooperation in the management and protection of the system. This coastal area is a biodiversity hotspot due to its positioning as a convergence point of multiple domains, including terrestrial, fresh water, brackish and marine habitats. This multi-faceted combination allows for the support of a wide breadth of biota. The Wadden Sea is characterized by extensive tidal mud flats, saltmarshes, and deeper tidal creeks between the mainland and chain of islands which denote the outer boundary between the Wadden and North Sea. This mosaic of systems interacts dynamically due to wind, wave, tidal and riverine/runoff forcing functions, resulting in the creation of different types of coastlines. As with many lagoonal and estuarine systems, the variety of habitats and high productivity lends itself to having a large biodiversity of invertebrates, fish, birds and marine mammals.

The high value ascribed to the Wadden Sea comes from its important regulatory and maintenance functions for the south-eastern coastal portion of the North Sea, its diverse aesthetic values, and the protection it offers against westerly storms to the German, northern Dutch, and western Danish coasts. The Wadden Sea is a nursery area for many fish species as well as a resting and fuelling station for a wide variety of wading birds. More than half of the juvenile plaice, a flatfish, population of the North Sea grow up in the area. Moreover, more than 10 million birds spend varying degrees of time in the region, often on migratory routes between nesting grounds near the North Pole to wintering sites as far south as Africa. This treasured combination of varied species and aesthetics draws a high volume of tourists in many forms, including but not limited to island visitors, game fisherman, boating and mudflat walking excursionists, and commercial operations. Commercial activities include industrial fishing for commercial fish and shellfish; recently aquaculture for shellfish has been introduced. One of the objectives of the application of protected area status to the Wadden Sea is to limit the degree of exploitation by the commercial shellfish industry whose high degree of pressure through mussel extraction has significantly impacted the system's capacity to support the large volume of migratory birds. An excerpt of the storyline developed for the Wadden Sea can be seen in Figure 3.3.4.1.

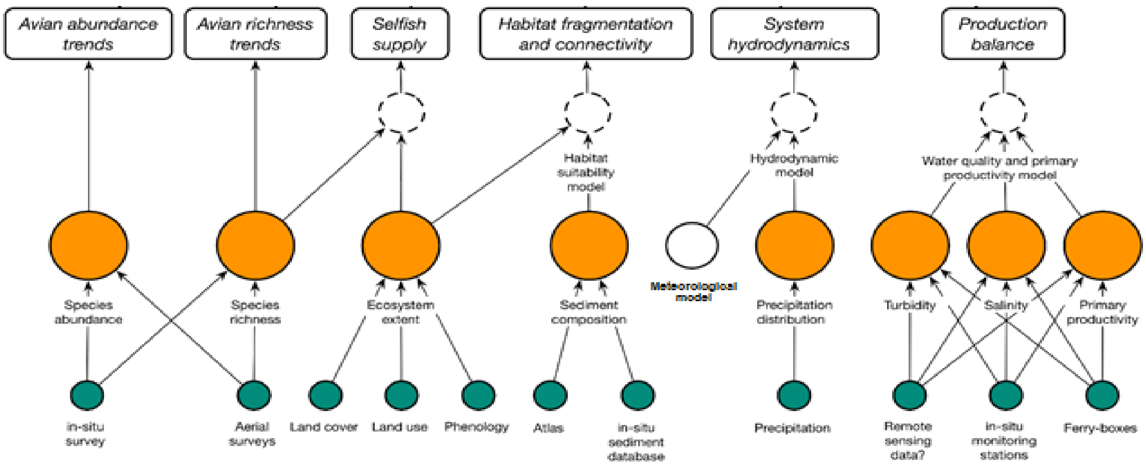

Figure 3.3.4.1: Diagram representing the storyline developed for the Wadden Sea, including the identification of essential variables at the storyline level (Source: Ecopotential Deliverable 2.2).

Ecosystem services

Provisioning of Mussels & Maintenance of Nursery Grounds and Habitats & Water Quality

Supply

The most important function of the tidal flat areas is primary and secondary production, contributing for an important part to the habitat heterogeneity and the biodiversity of the protected area and the function as undisturbed habitats in densely populated Western Europe. Related specific services are therefore functioning as feeding grounds for birds and fish, resting places for birds and mammals; provisioning of food for man (e.g. (manual) cockle fisheries, collection of fishing bait) but also cultural services as the aesthetics of the area and the important function for tourism e.g. mudflat walking and bird and seal watching. A monitoring and evaluation scheme should focus on these important functions and services but should also keep track of the major threats. These threats (for the identified ecosystem services) are a reduction of the intertidal area (e.g. effects of gas exploitation, sea level rise and changing hydrodynamics), invading species (with effects on habitats and food web structures), presence of shellfish fisheries and related potential over-exploitation and sediment disturbance, disturbance by visitors (recreants and food-collectors), and the visual ruining of the landscape from the aesthetic point of view (windmill parks). To cover these, information on the seabed level (altitude/depth profile), physical characteristics of the sediment (sedimentation/erosion) and water column (tidal information and hydrodynamics) and developments therein is essential. Also the monitoring of macro-zoobenthic communities (including commercial shellfish stocks), phytoplankton monitoring, monitoring of the fish communities and monitoring of the birds and marine mammals present in the area are essential. Moreover, insight in the developments of human use are of importance (e.g. tourist numbers, numbers of pleasure boats, mudflat walkers) and shipping, aircrafts or military activity in the vicinity, but also expansion of built-up area, harbors and industries and the presence of windmills. Optical – (e.g. MODIS), laseraltimetry - and radar data (e.g. Sentinel 1), potentially available with sufficient temporal and spatial resolution, can therefore be of use and form the basis of modelling of the developments particularly towards the status of the intertidal areas.

The major ecosystem function of low dynamic shallow waters in the PA of the Wadden Sea is the one of providing heterogeneous habitats and primary and secondary production. Related ecosystem services are providing a nursery area for shrimps and fish, which delivers a nutrition service (feeding ground) for birds and fish. Other services are the provisioning of shellfish (including ‘mussel-seed’) for fisheries and aquaculture, and the recreational service of providing opportunities for recreational boating and pleasure fishing. Major threats to these are the risk of overfishing, the impact of gas-exploitation (and seabed lowering) potentially resulting in a reduced area of low dynamic shallow waters, the potential impact of invading species on benthic communities, and the potential disturbance by many tourists. Essential monitoring data are altitude and water depth information, water current flow, wave climate and tidal characteristics, primary productivity, mussel bank conditions, amongst others. Also monitoring data for the macrobenthic communities including commercial shellfish presence, fish and epifauna communities, and bird count data are necessary. Especially optical data (MODIS, Sentinel-3) and radar (Sentinel 1) provide sufficient temporal and spatial resolution to be of use for monitoring and modelling. In the assessment of the current status and to have the ability to render future projections, a three dimensional, process-based model for the North-western continental shelf is used. This model has a refined grid on the Dutch portion of the Wadden Sea which allow for in-depth investigations within this particular area. The larger overall domain allows for more general perturbations to be adapted at the boundaries; the effects being normalized throughout the domain rather than instilling close point sources of disturbance to the domain of interest, the Wadden Sea, which could cause bias due to the location the disturbance is induced. In this manner, global circulation inputs can be appended to the boundaries and climatological data applied across the entire domain. Due to marine environments well mixed nature and ability to transport nutrients, pollutants, and various dissolved and particulate matter great distances, the larger domain is found to be supportive of a more comprehensive evaluation. Calibration and validation of the model through hindcasting has proved its ability to mimic the primary production cycle which supports the wide array of benthic organisms and grazers which in turn provide sustenance for the migratory bird populations. Additionally, the outputs of the model contribute not only to understanding the total production capacity of the system, but also the speciation, which in turn, informs on the limitations of additional growth, be it either light or nutrients for example, which is further investigated by evaluating the impact of increased nutrients within existing runoff and potential increases in total land runoff as seen in Figure 3.3.4.2.

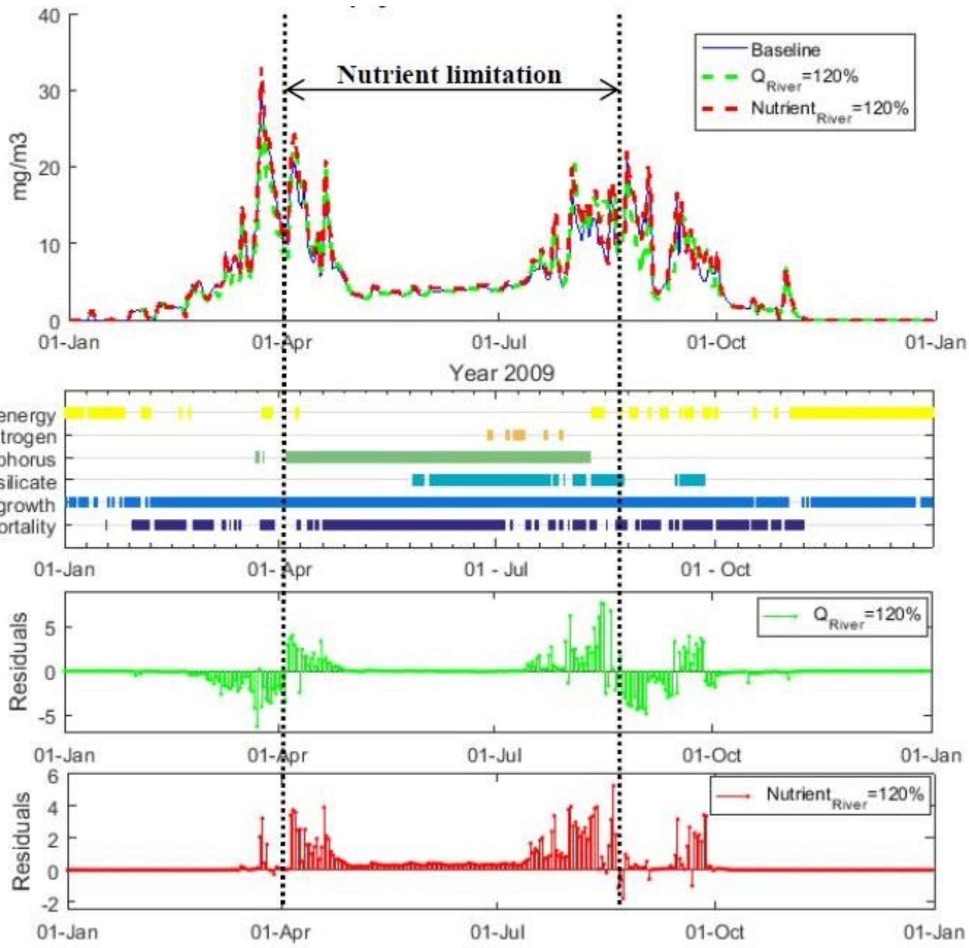

Figure 3.3.4.2: Simulation results showing the impact of variations in riverine discharges at a site within the Wadden Sea and the Resulting variation in algal species type as defined by the BLOOM component within the Delft-3D Water Quality Module.

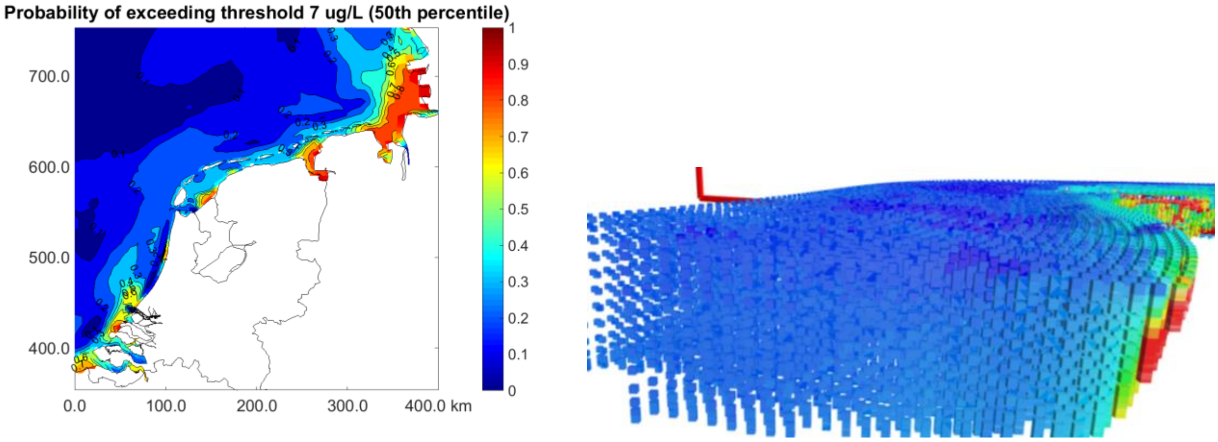

Figure 3.3.4.3: Aggregation of an ensemble of model runs in order to determine the probability of exceedance of a 7 microgram per litre threshold (L) and a 3-D visualization of the water quality outputs from the Delft-3D model which allows for evaluation of suspended sediments in the water column and the dispersion within the Wadden Sea (R).

The model is spatially explicit which allows for critical evaluations of the total algal and phytoplankton concentrations within the Wadden Sea. Such executions can provide information on the total primary productivity of the system which can then be used to infer a potential carrying capacity for grazers and consumer of primary producers. Additionally, an excess of algal production can result in a Harmful Algal Bloom (HAB) which impacts the ecology in multiple ways. Such event can lead to the production of dangerous toxins that can negatively affect organisms in the environment, hypoxia, and also alterations in the seasonality and duration of more moderate blooms which have corresponding effects on benthic grazers carrying capacity and growth rates, which subsequently impact migratory and nesting avian populations. Such sequential impacts are still under investigation. Probabilistic evaluation of such blooms utilizing the outputs from the model have been generated as seen in Figure 3.3.4.3, and the conditional exceedance of acceptable levels of algae as denoted by accords such as OSPAR have also been produced. Additionally, the three dimensional nature of the model allows for the investigation of the stratification of production as well as the reporting of water quality parameters such as nutrient loadings, salinity, temperature, amongst others.

Maintenance – Mediation of Flows

Supply

Key parameters: tidal current velocities, hydrodynamic and morphodynamic modelling, sediment transport modelling and remote sensing applications

The tidal movement of water creates a unique interlacing of habitats including intertidal flats, gullies, and saltmarshes. The extent of variation can be clearly seen when considering the high velocity currents located adjacent to the sea (up to 2 m/s) to the slower ebb and flow of tidal shift along the mudflats or when considering the contrast between the deep gullies reaching depths of 40 meters to intertidal zones which are discontinuously submerged. Towards the inland part of the water bodies the currents decrease and siltation can occur, leading to tidal flats to the side of the gullies and saltmarshes attached to the mainland. Human interventions have especially a large influence here: coastal works (reclamation) decrease the coastal saltmarsh surface; dredging for shipping channels creates siltation/high turbidity and decreased water quality. Creating sluices and dams at the entrance of water bodies causes sand and silt hunger, whereby, due to lower current velocities, gullies are filled with sediments and tidal flats eroded.

High dynamic gullies are particularly of importance having a function to provide secondary production and being an environment with certain hydrodynamic conditions and a surface area. This especially to provide services for fisheries and for transportation (in the Wadden Sea especially for ferries). These functions and services are however under threat of overfishing, extension of port areas and disturbance of the food web by pollutants. Therefore monitoring of human activities (e.g tourism, shipping, dredging), the water quality related to nutrient and toxic substances loads, and the physical characteristics of sediment (erosion/sedimentation) and the water column in terms of tidal and water current flow characteristics, are essential. Therefore particularly radar such as Sentinel 1 prove useful to both monitor and also enhance modelling activities through the inclusion of variables such as significant wave height while MERIS and Sentinel-3 can provide information on the sediment transport components by identifying the water turbidity. Through the combination of hydrodynamic modelling efforts coupled with the subsequent application of sediment transport modelling, the impacts of dredging, sand mining, coastal nourishment projects, shipping, and other human activities can be identified.

The shear stresses induced by ships are calculated using the wave field from SWAN, an extension within the Delft-3D modelling suite which is applied to a North Sea Shelf model with a refined gridding within the Dutch portion of the Wadden sea in order to give better insight into this area. In SWAN, the data for the significant wave height (Hs) is determined via the model outputs and is compared with in-situ measurements from buoys located within the Wadden Sea. Ships are not singular sources for these stresses, in spite what the name might suggest. Hydrodynamic conditions such as waves, storms, and currents all have an effect in some extent to the magnitude of these shear stresses. The outcome of this analysis is shown in Figure 3.3.4.4. Because the shear stresses are recalculated within SWAN, a link is established with the hydrodynamic forcing in the model. A series of shear stress conditions have been analyzed which represent a potential impact form increased shipping within the deeper channels of the Wadden Sea on the resuspension and total turbidity of select monitoring locations, however, due to the nature of the shear stresses, a similar conditions could be found in increasingly stormy years where the hydrodynamics are exacerbated due to increased energy within the system from stormy conditions.

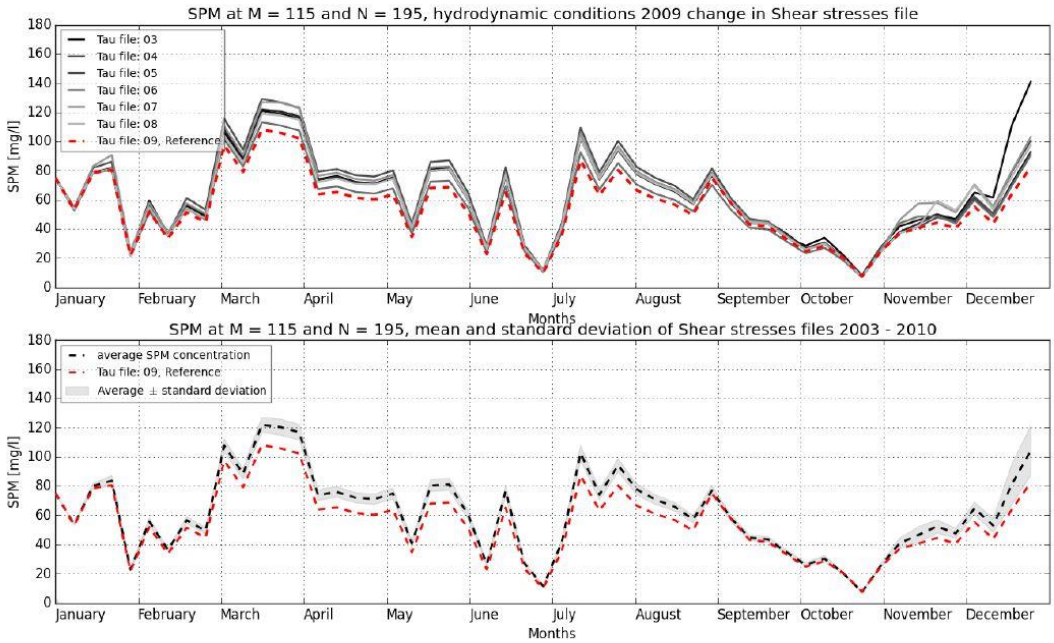

Figure 3.3.4.4: Simulation results showing the impact of varied increases in the shear stress exerted on the sea floor sediments within the Wadden Sea through a combination of SWAN and sediment transport modules within Delft-3D and subsequent averaging of those results with a standard deviation band.

Additionally, different types of sediments have different resuspension and stabilization properties; erosive resistance of cohesive sediments is dependent on multiple characteristics including the water content, mineralogy, salinity, pH, physical and chemical characteristics. These are not static characteristics, they can be modified by organisms within the environment including MicroPhytoBenthos (MPB), macrofauna, and other benthic organisms through two primary means, the stabilisation and deposition through binding functions or the erosion and suspension through bioturbation. Various benthic organisms secrete extracellular polymeric substances which have a binding effect on the particles in the nearby vicinity, increasing the sediment stabilization and facilitating deposition. Mycrophytobenthos are known to excrete substances which increase the cohesion of the sediment upon which they reside, thereby increasing the shear force required to erode sediments or suspend them, whereas molluscs similarly generate biodepsotis which increase the mud content of sediments. Therefore, through the identification of sediment types and identification of such communities such, the ecosystem’s increased capacity to resist erosive forces as well as the increase deposition which occurs through the activities of such filter feeders can be assessed and attributed to an increase in stabilization of the sea bed. Molluscan shell beds which consist primarily of mussels and oysters thrive alongside tidal channels and contribute to sedimentary deposition processes. In a sedimentary environment dominated by unconsolidated grains, the mollusk beds act as natural hard substrate that helps in wave attenuation and aids in stabilizing sediments. We attempt to achieve a mapping of microphytobenthos and mollusc beds by processing and analysing parameters which are indicators of their locations. These other indicators such as sediment grain size and total suspended matter concentrations can be obtained from existing datasets as well as the information provided by the hydrodynamic and sediment transport models and can subsequently be developed to see the relationships between them that would indicate microphytobenthos occurrence. By exhausting the accessible and available information, an integrated monitoring method can be used to map microphytobenthos in the Dutch Wadden Sea. We utilize a random forest algorithm in order to integrate information on the various indicators selected in order to produce a projection of current and future states of the MPB within the Wadden Sea, drawing upon model outputs, remote sensing of photosynthetically active radiation, suspended sediments, and chlorophyll-a concentrations, and in situ measurements. Additionally a soil characterisation generated through combinations of remote sensing products and in situ measurements assisted as additional inputs for the training of the random forest algorithm. The predictive outputs can be seen in Figure 3.3.4.5 below and shows the variations in concentrations predicted in the late spring versus the late fall period. Through a combination of mollusc predictions from model outputs and MPB predictions through the algorithm, changes in the stabilization of the sea floor and the ability to cope with increased shipping traffic or the effects of large storms can be assessed.

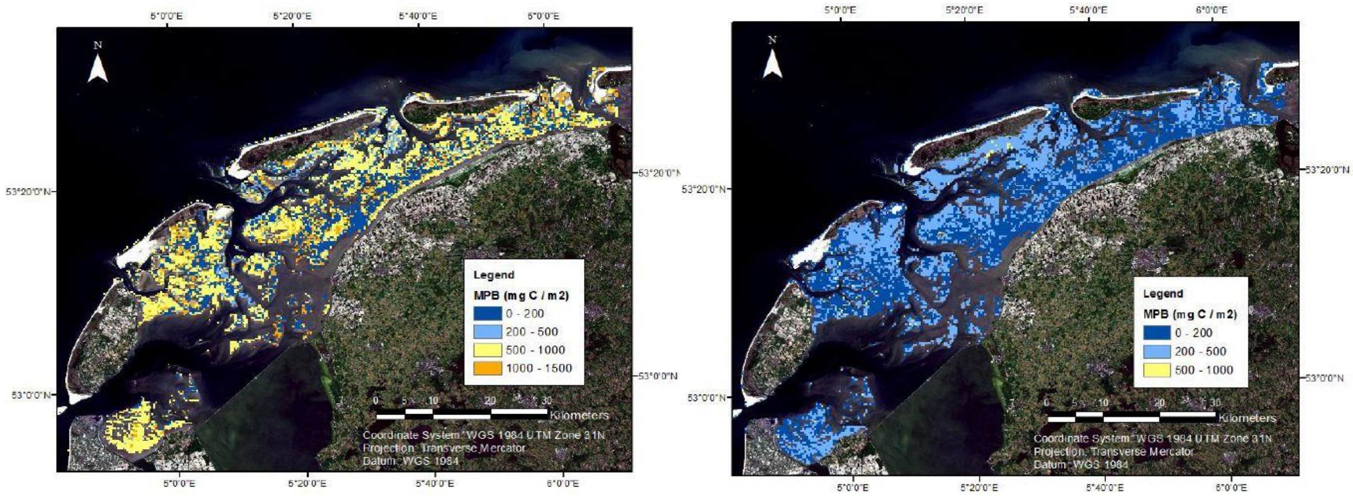

Figure 3.3.4.5: Simulation results showing the predicted concertation of MPB within the Dutch Wadden Sea for the late spring period of May 2008 (L) and also for the fall season of September 2008 (R).

Recreation

A Flickr analysis shows that photos uploaded per year have generally increased until 2014 (with a dip in 2012), and then declines slightly in 2015 and 2016 (Figure 3.3.4.6), a positive trend is suggested by Mann-Kendall test ($S = 31$, $\tau = 0.689$, $P < 0.01$).

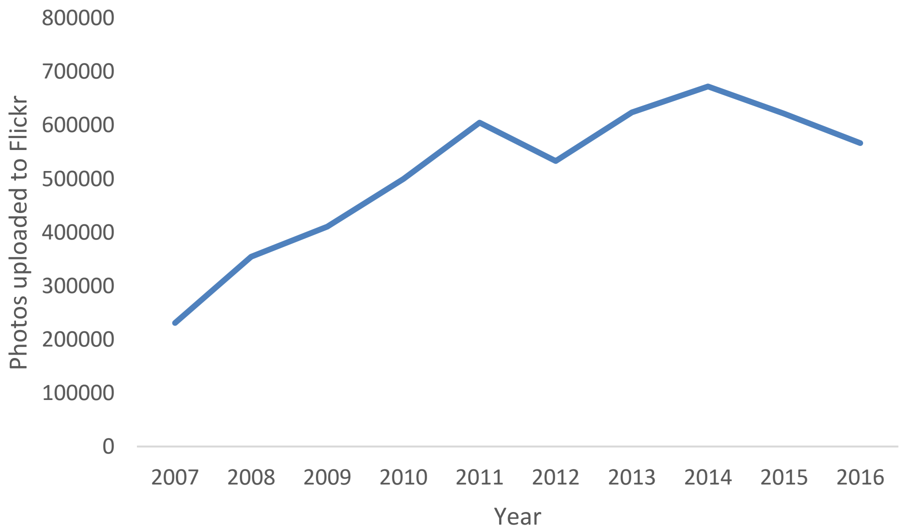

Figure 3.3.4.6**:** Changes in photos uploaded to Flickr for the Wadden Sea. Years are filtered by the date the photo was taken.

3.3.5 Camargue (France)

The Camargue Biosphere Reserve in the Rhône delta covers 193 000 ha, including natural habitats such as lagoons, brackish/freshwater marshes with emergent or aquatic vegetation, as well as halophilous scrubs and steppes. These ecosystems are intermingled with agro-systems dominated by rice, an irrigated crop. Through a complex network of irrigation and drainage channels, 730 millions of cubic meters of water are pumped from the Rhône on average each year to compensate for river embankment, to avoid soil salinization, enhance primary production (overcome summer drought) and create suitable breeding habitat for waterbirds either for sustaining commercial hunting activity or conversely enhancement of bird populations for conservation (Figure 3.3.5.1). The Tour du Valat (TdV) is a private research centre located on a 2600 ha estate (of which 1 800 ha are classified in natural reserve) in the Camargue (Rhône delta), south of France. Created in 1954 and legally recognised as a non-profit-making association, it has set itself the mission to halt and reverse the destruction and degradation of Mediterranean wetlands and their natural resources and promote their wise use.

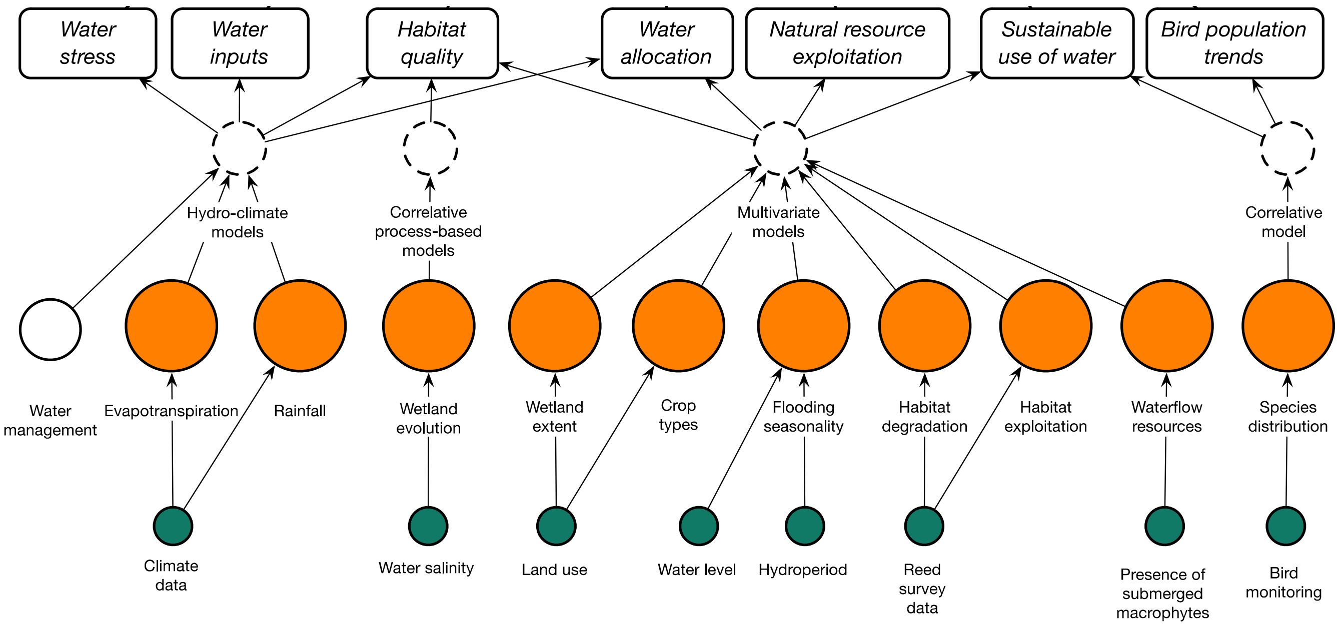

Figure 3.3.5.1: Diagram representing the storyline developed for the Camargue Biosphere Reserve, including the identification of essential variables at the storyline level (Source: Ecopotential Deliverable 2.2).

Ecosystem services

Mediation of water flow- supply vs demand

The availability of water for biomass, habitats and biodiversity in the Mediterranean basin is largely dependent on water availability, notably in the hot season with certain Mediterranean wetlands habitats drying up completely. Whether or not there is any surface water is easily visible when it considers an open habitat, however, in most case the absence of water is not easy to determine due to the presence of a dense vegetation cover (Perennou et al., *Accepted*). To improve our understanding and estimations of the presence of water underneath vegetation cover, we are working together with Aurelie Davrange from the university of Angers, France, to develop a model to have an informed interpretation of remote sensing data. To be able to use Landsat an Sentinel2 images, we adapted and existing model which uses spot5 data and which was developed in collaboration by Aurelie Davrange (Davranche et al., 2013). We have currently adapted the model and have performed a first test of its capacity to detect water under the vegetation throughout the year (Figure 3.3.5.2). We are currently in the next phase in which we adapt the model based on the errors detected in this first test phase, to improve the automated detection of water under vegetation.

Based on this improved understanding of on the surface water flow dynamics we develop a better idea on the quality of habitats provided and its interannual variations. Additionally, it provides important knowledge on whether or not surface water is being used sustainably or not.

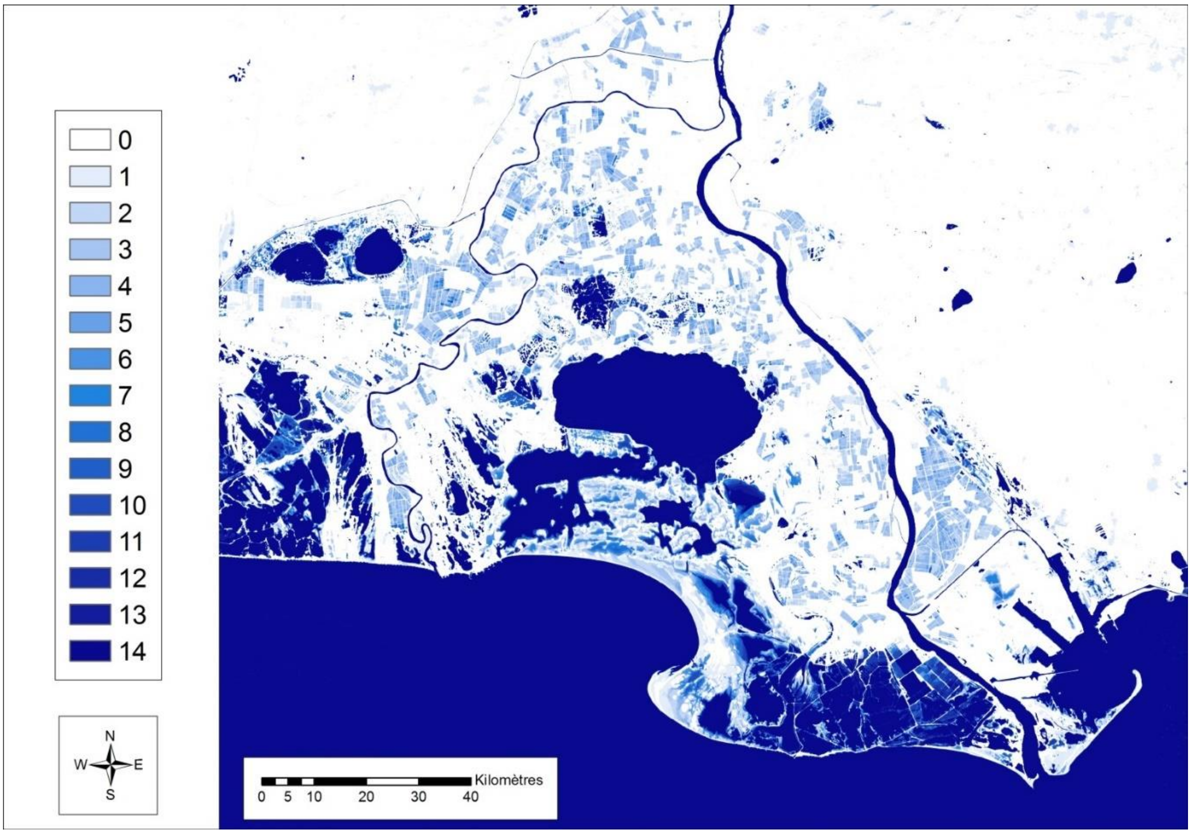

Figure 3.3.5.2: Annual projection of the duration of water cover within different habitats in the Camargue based on 14 sentinel2 images.

Natural resource exploitation and Habitat quality- supply

In the Camargue reed beds are used for different purposes by both people and species. Reed habitats form important resting, nesting and breeding habitats for among others birds, insects and amphibians. For the habitats for provide this service, two key criteria are the moment in the year that the reed vegetation is present and the duration the vegetation is present for. One of the pressures for these habitats is the harvesting of reed at local scale. The harvested reed is used for different purposes, but mainly for the thatching of roofs. The harvest of the reed is done in a particular manner and harvested reed beds are easy to detect in-situ and during flights. It therefore seems like a promising supply and use aspect of this particular ecosystem service flow to monitor through remote sensing.

To have a better estimation of where and the surface of reed beds that is being cut and harvested in the Camargue, to determine the affected habitats, we have been working to develop a manner to detect the harvesting of reed beds automatically from remote sensing data. The objective is to develop amodel that uses sentinel1 and sentinel2 images to detect the spatial patterns in reed harvesting practices and that is validate by in-situ data. This study is ongoing and at this moment two years of data on reed harvesting has been obtained via observation flights of a small airplane in the larger Camargue delta (Figure 3.3.5.3). We have started the exercise to model the reed bed dynamics using sentinel1 images (radar), and we are currently in the process of developing formula to combine the use of both sentinel1 and sentinel2 images. Once this model has been validated by the in-situ data, we can continue with the development of the automated identification process of the images.

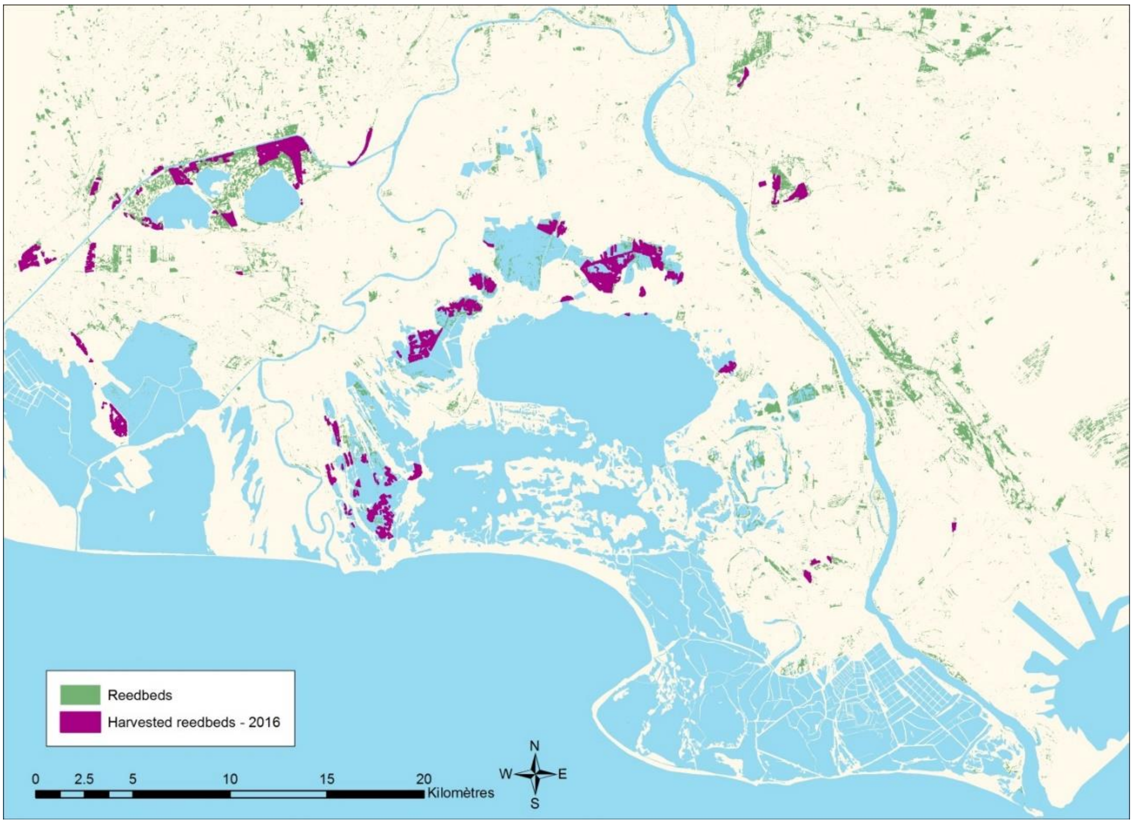

Figure 3.3.5.3: Presentation of the reedbeds cut in 2017.

Recreation – demand and beneficiaries

For the ecosystem services recreation we have undertaken a study with Guy Ziv and Arjan Gosal of University of Leeds to determine patterns in the use of the ecosystem services (Gosal & Ziv, 2018). A Flickr analysis shows that photos uploaded per year have increased between 2007-2016, apart from a dip in 2015 (Figure 3.3.5.4), a positive trend is suggested by Mann-Kendall test (S = 37, tau = 0.822, $P < 0.01$).

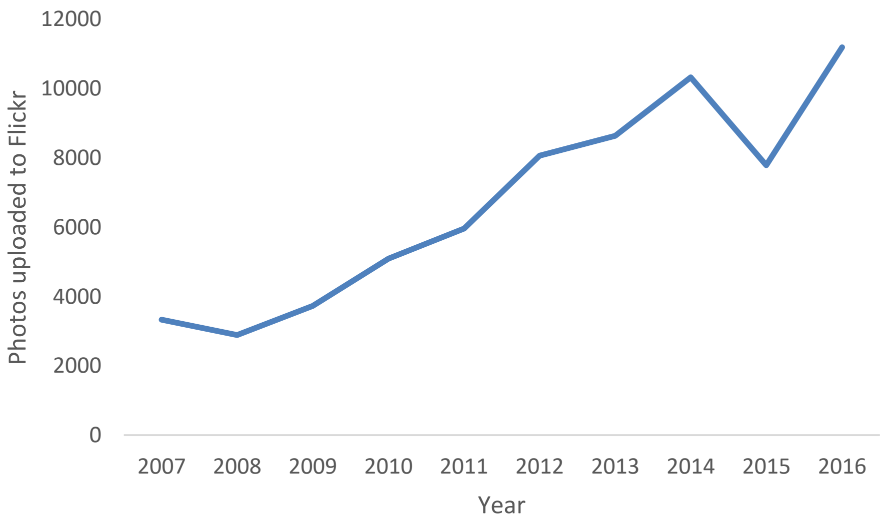

Figure 3.3.5.4: Changes in photos uploaded to Flickr for the Camargue. Years are filtered by the date the photo was taken.

Combining this information with the keywords allocated to the photos allowed to identify the spatial patterns in where distinct groups of visitors took photos in four seasons in the year. Six main categories of visitors, included people that tend to visit major sightseeing sights and look out points, their objects in the photos including a large share of natural elements and species (e.g. saltpan, flamingo's, the Camargue cattle) (Figure 3.3.5.5). Some other groups had preference for either more cultural aspects of the Camargue, for instance the annual pilgrimage or an air show. There was also a large group interested only in the water related elements in the Camargue, such as the beach or fishing (Figure xB).

The identification of these groups and the spatial and temporal pattern in the way they visit the Camargue provide important information on when there is demand for the service and therefore when the supply of the services should be assured. If within the Camargue delta we would like to increase the nature based ecosystem services of recreation, we can also use the maps to identify where and when we may find the visitors of the Camargue that come for something else, but that might be receptive to appreciate other aspects of the Camargue.

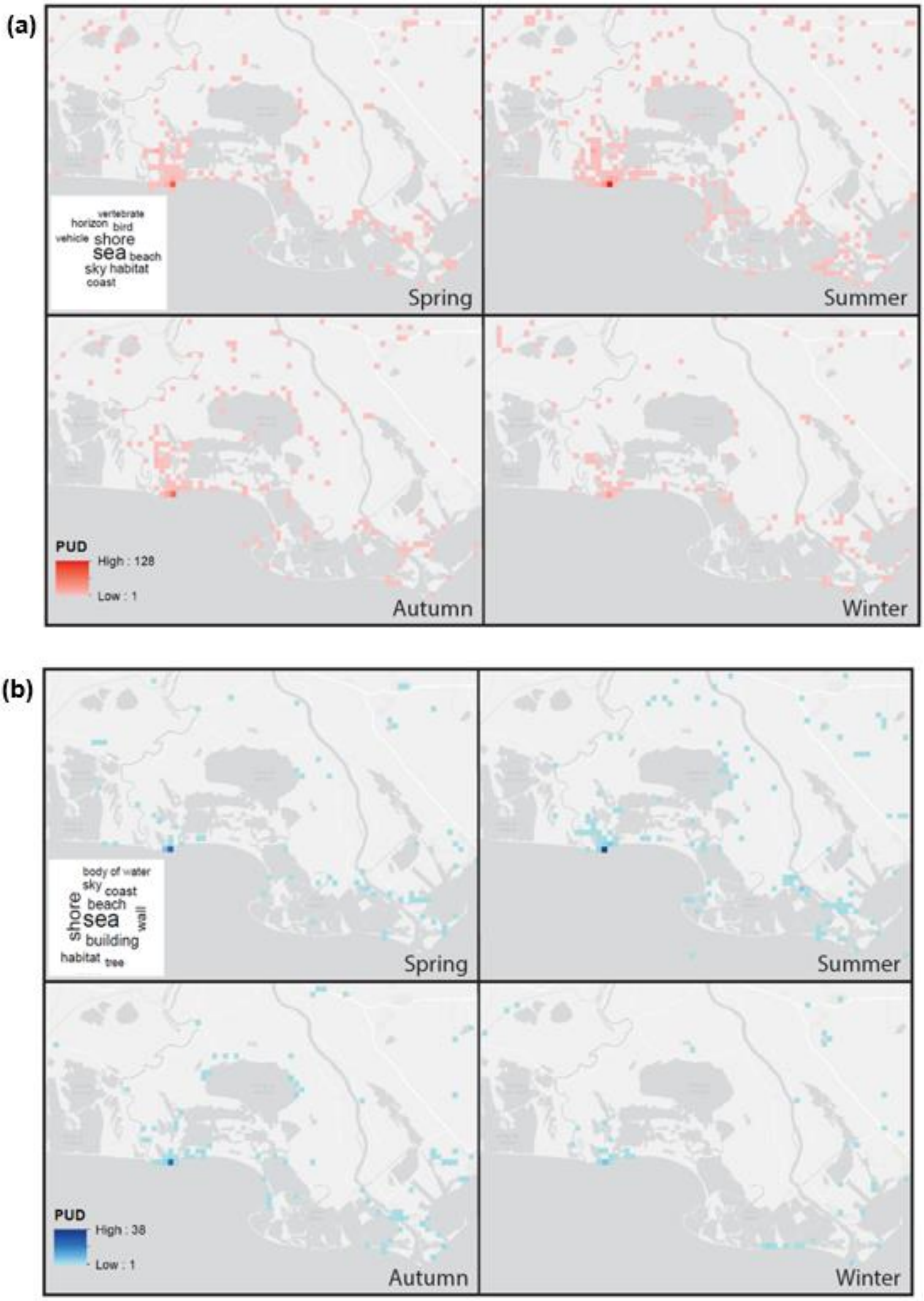

Figure 3.3.5.5: The spatial pattern pictures taken and uploaded in Flickr of two different groups of visitors in the Camargue in four seasons in 2007-2012. Above (a) depicts the photos of a visitors generally interested in sightseeing and nature in the Camargue, below (b) photos of a groups of visitors that visits primarily water and the beach (e.g. (for fishing and sports) (Gosal & Ziv, 2018).

4. Discussion

The aim of this study was to investigate a selection of ecosystem indicators and how they can be used to monitor ecosystem services in range of PAs from mountain, coast and marine, and arid ecosystems. It is clear than the range of ES considered by the PAs highlights the individuality of assessments, which infers the strong need for custom management of individual PAs. ES assessments and valuations are often designed in ways that do not maximize their potential impact, policy relevance and practical usefulness (Berghöfer, et al., 2016). Berghöfer et al. (2016) suggest that the assessment process needs to be linked with public policy-making and tailoring ES assessments to their 'practical purpose. It becomes an oversight to recommend a set of indicators without first scoping and framing the assessment for the PA under investigation. Hence a tailored approach is required so that the diversity of ES in PAs are not homogenized arbitrarily and assessment is tailored to demand, supply and the beneficiaries.

Individually adapted approaches makes the comparison between the PAs difficult, apart from one the exception; the recreation assessment using Flickr. As recreation was assessed for all PAs using frequency of images uploaded to Flickr on a yearly basis, Mann-Kendall tests were used to ascertain temporal trends (see Table 4.1). All mountainous and arid/semi-arid ecosystem PA types showed positive trends, generally suggesting an increase in recreation between 2007 – 2016. Except for the Pelagos, all coastal/marine areas showed positive trends. This is interesting as the remaining coastal/marine areas all showed some of the strongest trends in the entire collection of PAs. The local spatial scale and annual temporal scale used here provide a more robust analysis for recreation and follow recommendations by Burkard et al., 2014. It must be noted that the rise or fall in photograph could be of an indication of the use of Flickr, rather that the appreciation of the recreational value of the PA, though this approach allows an insight into potential recreational usage of an area. Additionally, the utilization of a bounding box that 'envelopes' the area of study, rather than focusing on a distinct polygon boundary of the area is a limitation that could be addressed in future work.

The distribution of **supply, demand and beneficiaries** assessed also varied between the different area types (see Table 4.2). Cultural services were most considered in all areas, though this is in part due to a centralized Flickr photo analysis investigating demand for each PA. Across all area types, supply was most often considered, followed by demand, with beneficiaries receiving the least focus. Regulation and maintenance services were most often investigated in mountainous areas, with a lack of analysis in arid/semi arid areas, and to a lesser extent coastal and marine areas. Cultural services were most assessed in arid/semi-arid areas, with no regulating/maintenance services being investigated. In coastal/marine areas, after cultural services, provisioning services (fisheries) were most often considered. Overall the supply-side of the ecosystem service was most investigated and was to be expected with historical ecosystem service assessment focusing on supply. Further research on the demand-side and beneficiaries is needed. Further analysis of the ecosystem service assessments for the Protected Areas was carried out in Work Package 8; a summary of this can be seen in Table 4.3.

Although we do not recommend a standardized set of ES indicators for assessment in PAs, **multiple methods for engaging with ES indicators** are recommended. It is suggested that the more robust analysis for PAs include the case studies that include supply and demand indicators with times series with Mann-Kendall trend tests are included. An excellent example is Lakes Orhid and Prespa in Macedonia, where the investigators have firstly engaged strictly with the CICES classification investigating both Maintenance of physical, chemical, biological conditions (lifecycle maintenance, habitat and gene pool protection) and Physical and intellectual interactions with biota, ecosystems, and land-seascapes (scientific domain). The analysis of both supply and demand/beneficiaries allows a fuller understanding of ES through a more complete adoption of the ES approach. In some cases, the framing of the individual studies could have been improved through a stricter focus on ESS.

Cultural ES assessment often are conceptually more difficult to assess due to methodological challenges that can lead to biased representation in ES assessments (Plieninger et al., 2013, Daniel et al., 2012, Hernández-Morcillo et al., 2013). Investigators in Har Hanegev were able to demonstrate how landscape aesthetic value was assessed in this arid ecosystem area using questionnaires and landscape images. Landscape preference and how environmental and nature-based values correlated to these preferences were investigated showing preference towards the highest amount of vegetation in the area. The results showed how a strong localised approach could elucidate aesthetic preference in a PA.

In **conclusion**, ES indicators that should be chosen by PAs are a very individual and site-specific choice, though the utilization of methods to monitor these ES can be made more robust through the analysis of both supply and demand, whilst keeping consideration of the beneficiaries. Utilizing temporal, as well as spatial, approaches allows trends in ES to be investigated, which can often be important for PA management.

Table 4.1: Temporal trends in recreational usage of PAs using Mann-Kendall tests.

Ecosystem type	Protected Area	Mann-Kendall results			
		S	**tau**	**P**	**Trend**
Mountains	Peneda-Gerês	25	0.556	< 0.05	Positive
	Swiss National Park and Landschaft	23	0.511	< 0.05	Positive
	Gran Paradiso National Park	33	0.733	< 0.01	Positive
	Lakes Orhid and Prespa	33	0.733	< 0.01	Positive
	Sierra Nevada	29	0.644	< 0.05	Positive
Arid/semi-arid	Har Hanegev	27	0.600	< 0.05	Positive
	Kruger National Park	31	0.689	< 0.01	Positive
Coastal/marine	Doñana	37	0.822	< 0.01	Positive
	Curonian Lagoon	33	0.733	< 0.01	Positive
	Pelagos	19	0.422	0.107	None
	Wadden Sea	31	0.689	< 0.01	Positive
	Camargue	37	0.822	< 0.01	Positive

Table 4.2: Frequency of ecosystem services (using CICES) in mountainous, arid/ semi-arid and coastal/marine environments analysed in this report by supply, demand and beneficiaries. *Grassland extent and productivity were both used as an indicator for the provisioning ecosystem service of materials (biomass) for Gran Paradiso National Park and are counted together as one in this table.

CICES classification	Mountain			Arid/semi-arid			Coastal/marine		
	Supply	Demand	Beneficiaries	Supply	Demand	Beneficiaries	Supply	Demand	Beneficiaries
Cultural									
Physical and experimental interactions (physical use)		5/5			2/2			5/5	
Intellectual and representative interactions (aesthetic)					1/2				
Intellectual and representative interactions (scientific)	1/5	1/5	1/5						
Total CES	*1*	*6*	*1*		*3*			*5*	
Provisioning									
Nutrition (biomass)	1/5						4/5	1/5	
Nutrition (water)									
Materials (biomass)	2/5*	2/5*	2/5	1/2					
Materials (water)	1/5	1/5	1/5						
Total Provisioning	*4*	*3*	*3*	*1*			*4*	*1*	
Regulation and maintenance									

Maintenance of physical, chemical, biological conditions (Lifecycle maintenance, habitat and gene pool protection)	2/5	2/5	2/5				1/5		
Maintenance of physical, chemical, biological conditions (Atmospheric composition and climate regulation)	1/5								
Mediation of flows (liquid flows)	1/5						3/5		
Total Regulating	*4*	*2*	*2*				*4*		

Table 4.2: Summary of a first compilation of ESS assessments in the ECOP PAs (source: Ecopotential Work Package 8).

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	n/a 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 1999 2007)	Decline	Farming			Decline in primary sector

	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													
Arid/semi-arid													
Har HaNegev						Recreation	Flickr 2007-2016	Increase until 2014					
Kruger 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, 2016. Reedbed occurance from sentinel 1 and 2 + in situ data	No trend				

						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				

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