Ref. Ares(2019)6775563 - 31/10/2019

Project Title:	ECOPOTENTIAL: IMPROVING FUTURE ECOSYSTEM BENEFITS THROUGH EARTH OBSERVATIONS
Project number:	641762
Project Acronym:	ECOPOTENTIAL
Proposal full title:	IMPROVING FUTURE ECOSYSTEM BENEFITS THROUGH EARTH OBSERVATIONS
Type:	Research and innovation actions
Work program topics addressed:	SC5-16-2014: “Making Earth Observation and Monitoring Data usable for ecosystem modelling and services”

Deliverable No: 7.4

Final Report on Prototype Products

Due date of deliverable:	31st May 2019
Actual submission date:	31st, October 2019
Version:	Final
Main Authors:	Deltares, ETHZ, UGR, UB, EBD-CSIC, BGU, ISPRA,

This project has received funding from the *European Union’s Horizon 2020 research and innovation programme* under grant agreement No 641762

Project ref. number	**641762**
Project title	**ECOPOTENTIAL: IMPROVING FUTURE ECOSYSTEM BENEFITS THROUGH EARTH OBSERVATIONS**

Deliverable title	Ecosystem service mapping with Bayesian Networks – a manual
Deliverable number	D7.4
Deliverable version	Final
Contractual date of delivery	31st May 2019
Actual date of delivery	31st October 2019
Document status	Submission
Document version	Final
Online access	Yes
Diffusion	Public
Nature of deliverable	Other
Workpackage	WP7
Partner responsible	Deltares
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Approved by	
EC Project Officer	Gaëlle Le Bouler

Abstract	This Deliverable outlines the final results of developed and applied prototype products for Ecosystem Services within ECOPOTENTIAL. This includes descriptions of the results and details on the implementation and potential porting of the products and processes to other areas of interest.
Keywords	Ecosystem Services, Prototype Products, Bayesian Belief Networks, Uncertainty, Mapping, Stakeholders

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1. Executive summary

The high variability of the Protected Areas and types of services addressed in ECOPOTENTIAL has lead to a wide variety in the final outputs and prototype products delivered through the project. Mapping and modelling Ecosystem Services (ESs) required wide varieties of data, incorporating Remote Sensing with the efforts of WP4, monitoring campaigns and data sets from WP5, model outputs, both statistical and process-based from WP6, and has culminated and various aggregations presented here in the form of protype product. This deliverable focuses on showcasing the outputs of tools defined in the tools deliverable D7.3 as well as some of the visualization potentials for ecosystem services resulting from application in modelling and mapping. These results incorporate the different sources of information, varying in spatial and temporal aspects, with the aims of providing simple and understandable infographics and outputs that can be utilized by policy makers as well as managers for the betterment of ESs within PAs.

Following the Framework for Ecosystem Services (ESs) based on DPSIR adopted by ECOPOTETNAIL and explained in detail within Deliverable 7.2, the protected areas within the project applied an array of methods to map, model, project, and quantify ESs. This framework leads from a starting point derived through Deliverable 7.1, an assessment of the status and evolution of ecosystem service indicators to investigate the impacts of current management and policy pathways upon the functionality of PAs and the impacts resulting from various identified drivers and pressures on the systems. This has resulted in a multitude of products ranging from conceptual diagrams, serious games, Bayesian Belief Networks (BBNs), model outputs, and maps of ecosystem services for PAs. An overview of the generic tools implemented in order to achieve these outputs can be found in Deliverable 7.3: Toolbox for Decision Support. This deliverable will showcase a selection of the prototype products that have been developed through the efforts of WP7 within the ECOPOTENTIAL project in relation to PAs and the delivery of ESs.

The deliverable is broken down by Protected Area, showcasing a selection of the completed products as representations of the final achievements overall within ECOPOTENTIAL. Further information and details in the methodologies and assessment capacities can be found in Deliverables 7.1 and 7.3, whereas this deliverable focus on the final outputs.

2. Introduction

Ecosystems provide a wide range of benefits to humans and society either directly in clearly tangible forms, such as provisions of food stuffs including oysters, mussels, and agricultural products, or indirectly through more conspicuous means, i.e. regulating nutrient flows and regulating the erosive forces of the sea or rivers and floodplains. Anthropogenic pressures coupled with land and sea management schemes have a direct impact on the functioning and health of the ecosystems which provide such services and underpin human well-being. It is therefore important to understand how ecosystems have historically adapted to changes in climate, pressures, and drivers as well as the resulting shifts in the services which they provide for humanity. This can be done through the integration of observations and forecasts either remotely through Unmanned Autonomous Vehicles (UAVs) or Satellite programmes using combinations of sensors, both optical and radar, process-based and statistical models, Bayesian Networks (BNs) and expert informed opinions, or direct site monitoring through field campaigns and monitoring networks. Such approaches yield information sets which can help to plan, manage, and monitor these ecosystems in order to ensure the benefits they provide and their functionality will continue onwards for posterity. These information sets are taken up by regional and area managers, policy makers, and scientists to inform decisions and actionable plans, thereby securing the livelihoods and health of future generations.

The prototype products are broken down by Protected Area. While some products may have been developed for multiple PAs, not all redundancies are listed within this deliverable in order to avoid excessive repetitions. These prototype products includes means for visualizing and representing data and information on Ecosystem services, their indicators, or proxies. They cover provisioning, regulating and maintenance, as well as cultural services to varying degrees and utilizing a broad set of methodologies. Many of these methods can be found in the Deliverable 7.3 Toolbox for Ecosystem Services as well as more in depth explanation on the processes behind and equation involved in Bayesian Belief Networks.

3. Sierra Nevada, Spain

Sierra Nevada (Andalusia, SE Spain), is a mountainous region with an altitudinal range between 860 m and 3482 m a.s.l. covering more than 2000 km2. The climate is Mediterranean, characterized by cold winters and hot summers, with pronounced summer drought (July-August). Additionally, the complex orography of the mountains causes strong climatic contrasts between the sunny, dry south-facing slopes and the shaded, wetter north-facing slopes. Annual precipitation ranges from less than 250 mm in the lowest parts of the mountain range to more than 700 mm in the summit areas. 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 (25% and 20% of Spanish and European flora, respectively), being considered one of the most important biodiversity hotspots in the Mediterranean region (Blanca et al., 1998). This mountain area comprises 27 habitats types from the habitat directive. Aditionally, there are 61 municipalities with more than 90.000 inhabitants in this mountain range which also has several legal protections: Biosphere Reserve MAB Committee UNESCO; Special Protection Area and Site of Community Importance (Natura 2000 network); and National Park. The main economic activities are agriculture, tourism, cattle raising, beekeeping, mining, and skiing (Bonet et al., 2010)

3.1 Cultural Contributions of Ecosystems via Satellites, Social media, and GIS

This product aims to infer the contributions of ecosystems to cultural aspects of the Sierra Nevada park system. Through the utilization of GIS data, satellite remote sensing, and social media content, an analytical framework for assessment was developed Figure 3.1-1. Such an approach utilizes known and mapped physical elements such as roads, trails, elevation, etc. in order to derive a spatial maps of the physical and visual accessibility of the region, denoting which areas are reachable by tourists and visitors to the region and furthermore, what is the visual range or objects which can be viewed from these points by persons located at that position. This information provides critical information on the physical accessibility of regions with the PA as well as the visual accessibility, denoting what can be seen, from these sub regions which are physically accessible. This information is further enhanced by including features of cultural interest such as public facilities, protected sites, cultural heritage landmarks, and various as well as landscape and biophysical properties on the landscape's diversity, structure, and configuration. Furthermore visual and sensory attribute resulting from the further processing of Sentinel-2 satellite images provides insight into the functional classifications of the environment as well as the colour diversity which is seen as an attractiveness quotient and appeal to tourism and those whom would take scenic photos of the area.

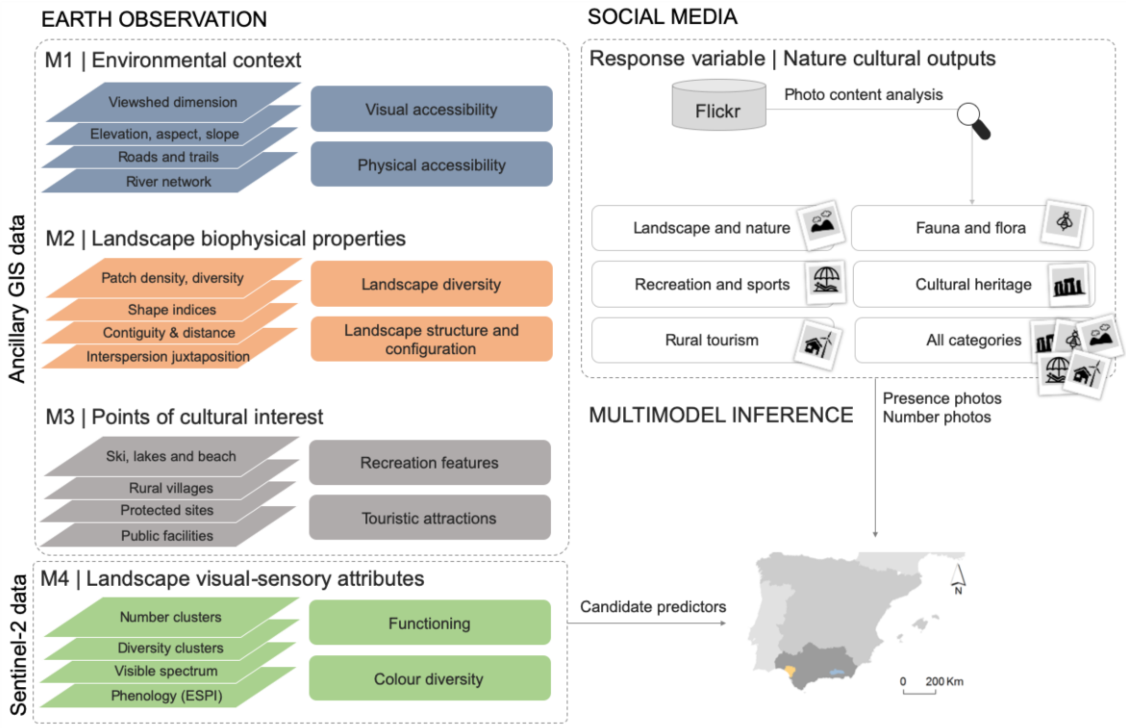

Figure 3.1-1: Analytical framework for the assessment or cultural contributions of ecosystems from Sierra Nevada National park utilizing a combination of GIS layers, social media inputs, and remote sensing application to derive visual sensory attributes.

Utilizing a multi-model inference approach, photographs harvested from Flickr and separated into categories of cultural outputs (as denoted in Figure 3.1-1) and processed to determine the predictive capacity of the four primary categorizations for delivery of services. The results of this approach can be seen below in Figure 3.1-2. It was observed that distinct models associated to different predictors could explain the prevalence of cultural benefits in Sierra Nevada. In general, the best model explaining the amount of cultural benefits Sierra Nevada, though satellite information could also captured most of the variability on cultural benefits, the location and access to points of cultural interest (such as villages and sky resort), showed to be of highest importance.

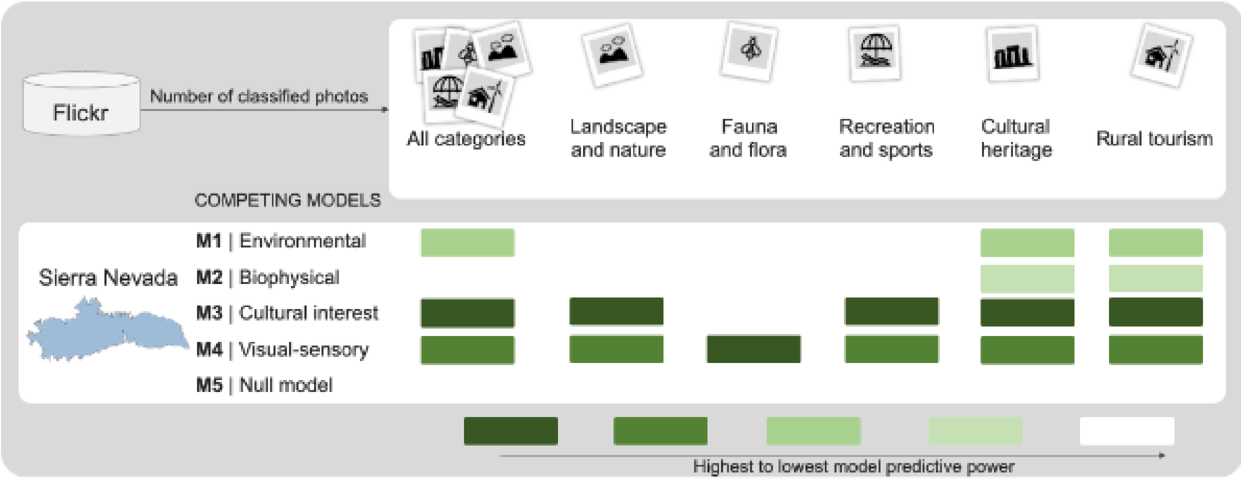

Figure 3.1-2: Results of multi-model approach for predicting cultural service presence.

3.2 Historical assessment of ecosystem services

Sierra Nevada has a long history of being actively managed and altered by anthropogenic pressures which in turn has shaped and altered the ecosystem throughout time. Through these efforts to describe and analyse the interactions among highlighted ecosystem services in Sierra Nevada through time, the synergies and trade-offs between various services can be clearly identified and utilized for future management. As indicated within Figure 3.2-1, the primary ESs considered are those of pastures for livestock, crop production, aquifer recharge, flood regulation, and erosion protection. Historical data was collected spanning form 1956 to 2007, making use of available maps, production and taxation records, remote sensing, and other viable data sets providing information into these services and their proxies. This data was aggregated in space and time into a master data set with which was used to evaluated the overall shifts in the composition of these services for the time range. The historical assessment considered five time periods, corresponding to the years 1956, 1977, 1984, 1999 and 2007. For each year, a land cover map of Sierra Nevada was considered and a grid of 90 m pixel size was considered. In each pixel, and based on the relative area of each land use category, we evaluated the potential provision of five ecosystem services: pastures for livestock (supporting service), crops production (provisioning service), and aquifer recharge, flood regulation and erosion protection (regulating services). Each ecosystem service was evaluated considering local-specified modelling approaches (for instance, we used the locally adapted WiMMed model to evaluate regulating services). Afterwards, bundles of ecosystem services were identified, as well as their synergies and trade-offs through time, by means of descriptive analysis (flower charts), multivariate models (PCA) and correlation tests (Pearson tests).

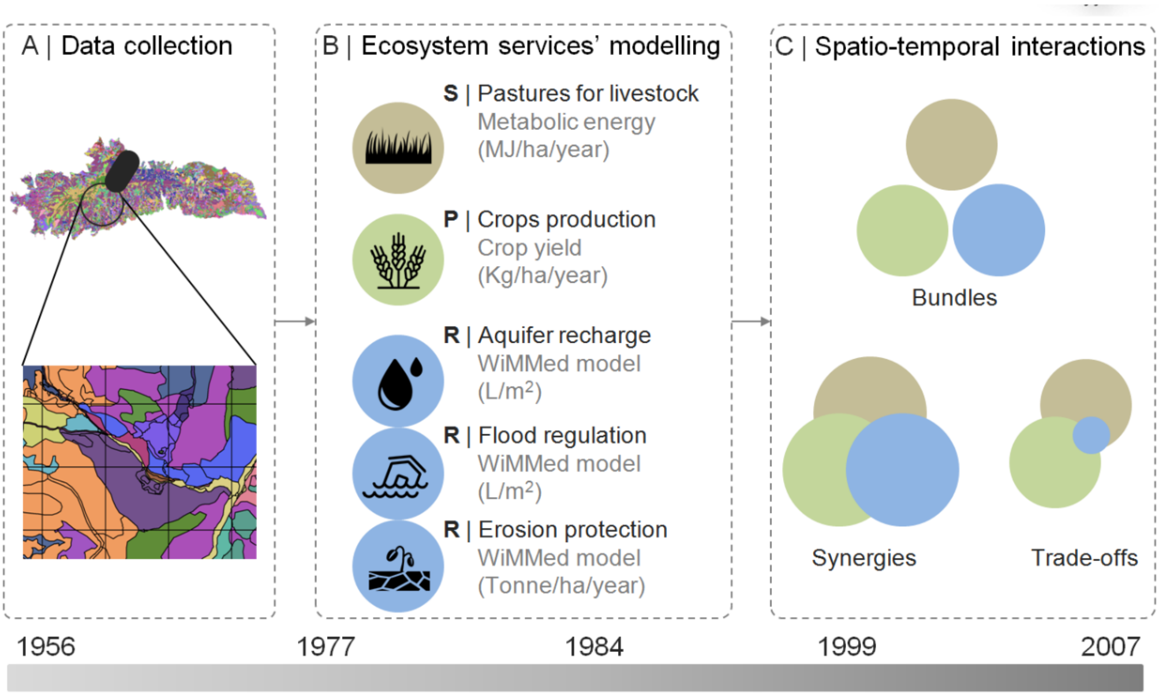

Figure 3.2-1: Analytical Framework for the historical evaluation of ESs within Sierra Nevada

It was observed that the potential provision of ecosystem services changed over time. In general, the flow charts showed an increase over the years of pastures for livestock, but a reduction of aquifer recharge. Crops production showed both a steep decrease followed by a gradual and more recent increase. Aquifer recharge showed a general decrease, whereas the remaining regulating services showed a steady provision though time. Such an approach can showcase the evolution of services in a region or protected area over time and also provide insights into areas where bundles of services become complimentary or exclusive in order to better understand the dynamics not only of the ecology and ecosystem, but also the potential benefits resulting thereof.

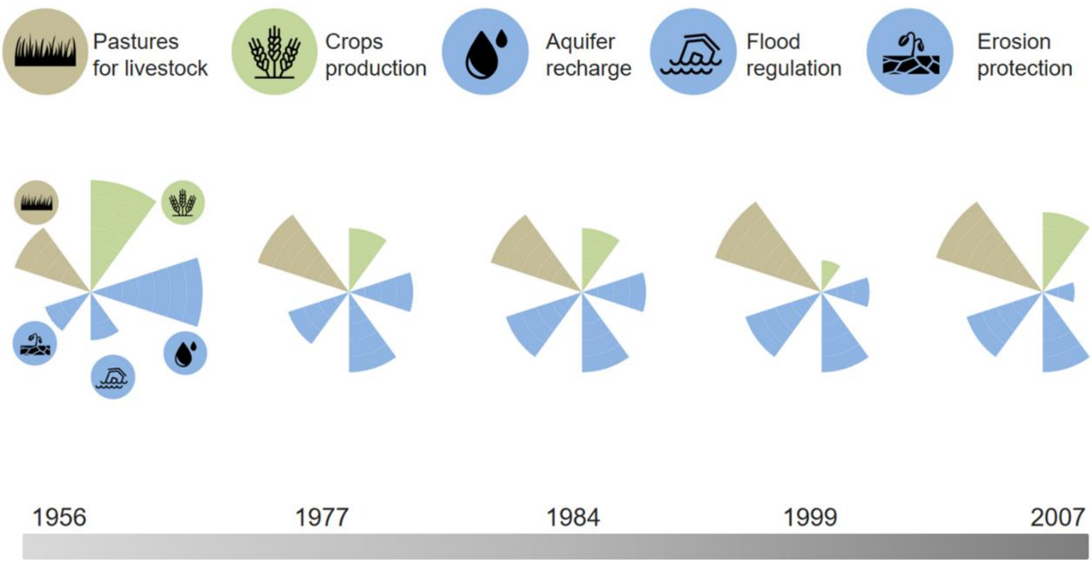

Figure 3.2-2: Services composition evolution along time for Sierra Nevada showing the transition of the ecosystem's service portfolio for the highlighted services from 1956 until 2007, the temporal domain for the study.

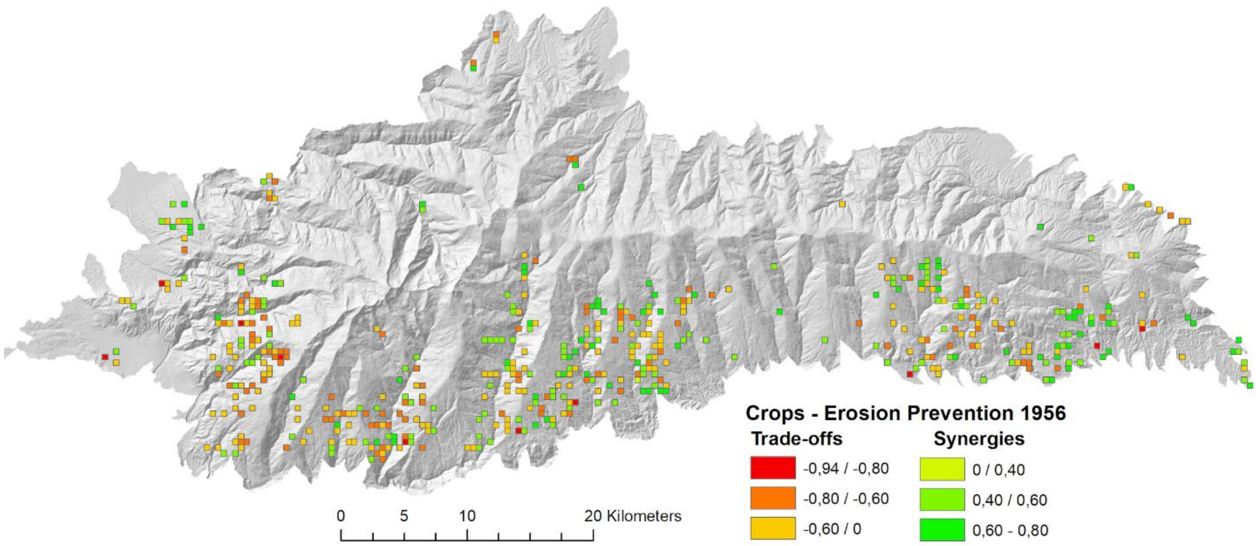

Figure 3.2-3: Spatial map showing the synergies and trade-offs between crop production and the potential for erosion prevention, highlighting the relationship between these two services and how the two can work in synergy or have incompatible impacts in the delivery of the services. Highlighted are the locations of significant synergies and trade-offs (95% confidence level from Pearson correlation test) between crop production and erosion protection.

3.3 Land-use Scenarios Prediction Utilizing a BBN

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

The main purpose of this study is to facilitate the land-use management of Protected Areas (PAs) based on ecosystem services (ES). A BBN is being designed to develop future land-use scenarios for the Sierra Nevada under different environmental and management conditions. Afterwards, we will implement these scenarios in other ES assessment models. The analysis of ES trade-offs in several scenarios will help managers to predict the state of ES and their relations in the future.

Interviews were initially carried out with expert researchers on changes in land use and agricultural activity in the Sierra Nevada. In the interviews, the drivers found in the literature were discussed. It was analyzed which drivers were relevant for the Sierra Nevada case. An initial structure of the Bayesian network was discussed, without addressing the states of the variables. Afterwards, three workshops were carried out with experts and stakeholders, one in each differentiated zone of Sierra Nevada: north-west, south, and east. Stakeholders in attendance were cattle ranchers, farmers and irrigation organisations. Participating experts were rural development agents and technical staff from the local agricultural offices.

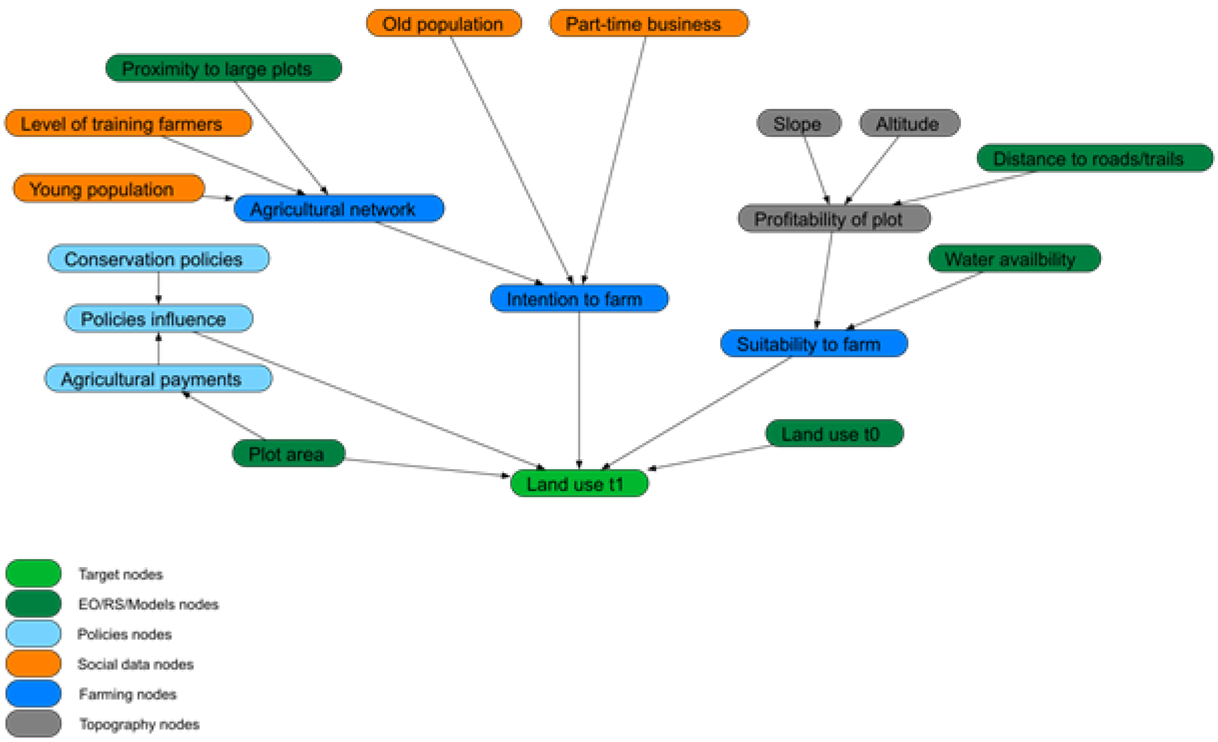

Figure 3.3-1: Bayesian Network developed to model the land use changes in Sierra Nevada (Spain). The nodes are grouped and coloured based on the types of variables they represent. Spatial inputs are EO/RS/Model and topography nodes, while other inputs include policy and social data.

The BBN is developed to assess future land use scenario in a spatial way. There are three types of spatial nodes in the BBN:

· Target node. Land use on time 0 and time 1 are the main spatial nodes, where land use at time 0 is an input to the model, while land use at time 1 is the output.

· EO/RS/Model nodes. Several nodes are spatial information from Earth Observation/Remote Sensing/Model outputs: proximity to large plot, plot area, distance to roads and water availability.

· Topography nodes. Slope and altitude are topographical variables used as input in the BBN.

The spatial information come from different sources and formats. Raster information has 10 meters' resolution while vector information is on a scale of 1:25,000. The extent of the study is the limit of Natural and National park of Sierra Nevada.

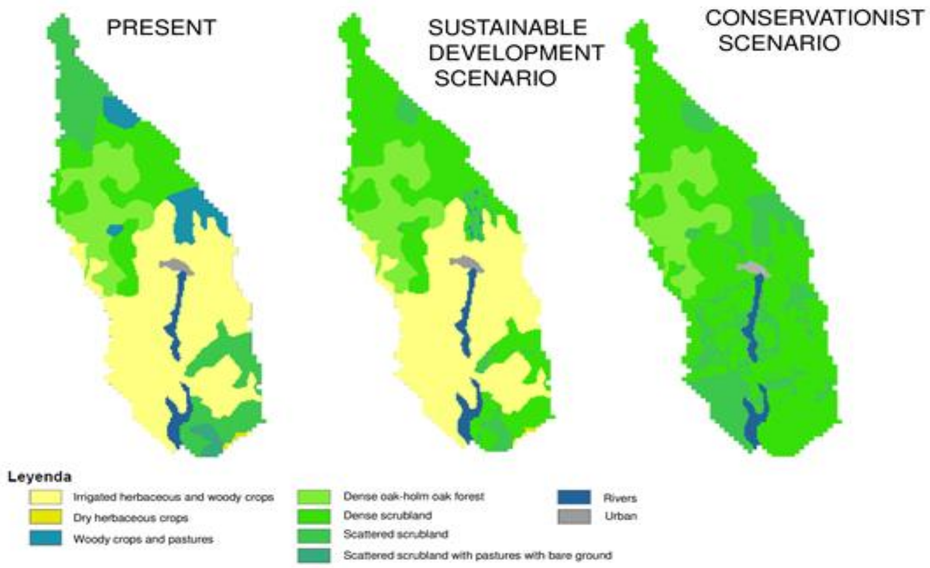

Figure 3.3-2: Modelled land uses scenarios using BN-spatial R package. Preliminary implementation of Sierra Nevada BBN in a watershed of Nevada municipality. The map shows the most likely class of land use.

4. Davos, Switzerland

Being a high alpine locale, a key element for the region of Davos is protection from natural hazards such as avalanches is one of the most important ecosystem services provided by mountain forests. Forests decrease the probability of an avalanche release (Bebi et al. 2009), and reduce the mass and velocity of avalanches that flow through them (Feistl et al. 2014). The capacity of forests to provide avalanche protection depends on other side on their structure and species composition, which can be derived from EO data. On the other side, the demand for avalanche protection depends on the risk to human life and infrastructure, which can also be mapped using remote sensing. While data and models exist for some components of the avalanche protection system, they have not been integrated into a comprehensive model of the ecosystem service, and are associated with large uncertainties.

4.1 Avalanche Protection with a BBN

Protection from natural hazards such as avalanches is one of the most important ecosystem services provided by mountain forests. Forests decrease the probability of an avalanche release (Bebi et al. 2009), and reduce the mass and velocity of avalanches that flow through them (Feistl et al. 2014). The capacity of forests to provide avalanche protection depends on other side on their structure and species composition, which can be derived from EO data. On the other side, the demand for avalanche protection depends on the risk to human life and infrastructure, which can also be mapped using remote sensing. While data and models exist for some components of the avalanche protection system, they have not been integrated into a comprehensive model of the ecosystem service, and are associated with large uncertainties. We address this issue by developing a BN, which integrates existing models, EO data, and expert knowledge. The BN is used to more precisely map the ecosystem service and quantify the associated uncertainties

Information on forests' potential to prevent avalanches was available in the form of an empirical logistic model (Bebi et al. 2001). Included this model into the network using a Netica equation, including the model parameter uncertainty by incorporating the parameters not as single values, but as nodes with their probability distribution (normal distributions defined by the parameter estimates B and their standard errors). However, this procedure results in a very large CPT for the node (a line for each combination of parameters and predictor variables). Since the parameter nodes will not be modified with evidence, we can reduce the CPT by using the function "Absorb nodes", which removes the nodes from the network, but retains the associated information in the reduced CPT.

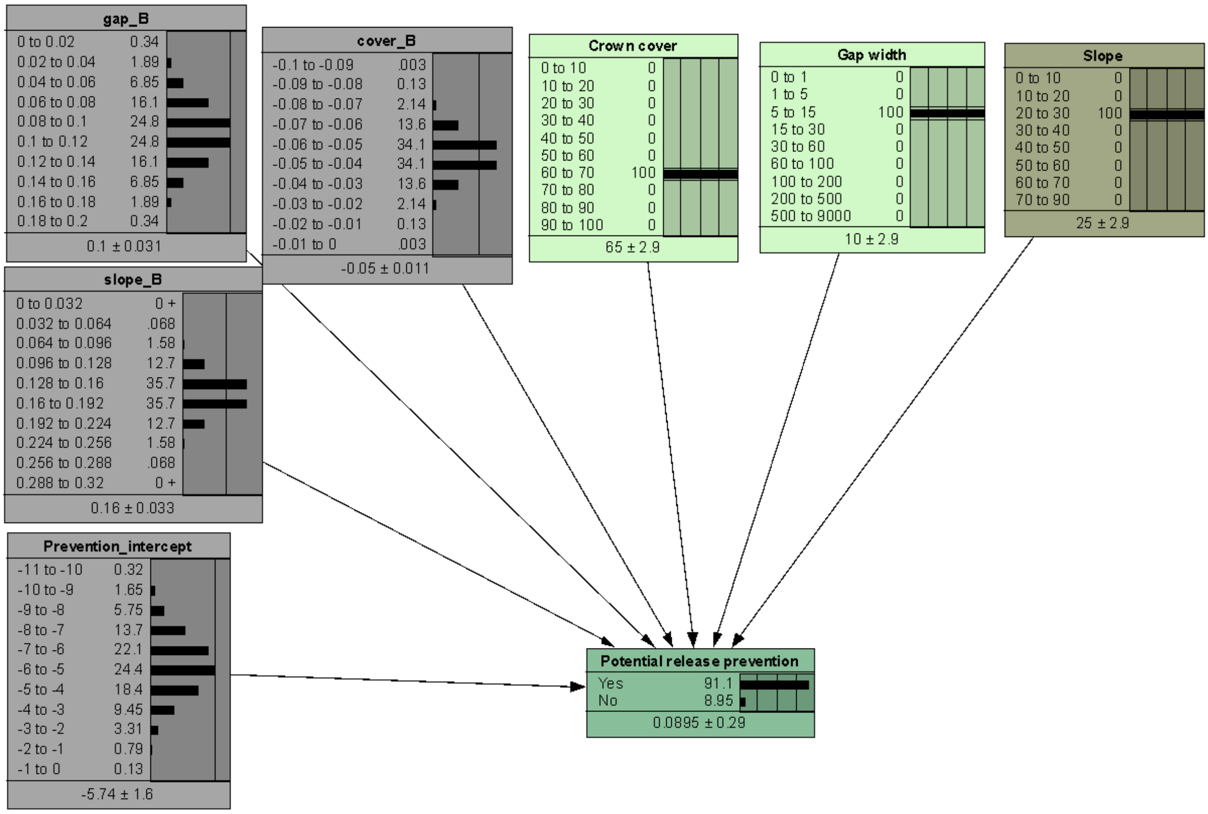

Figure 4.1-1: The parameters of an empirical model can be included explicitly as nodes in the network, to account for model uncertainty when calculating the CPT. Then, these nodes can be "absorbed" to reduce the size of the CPT.

The spatial inputs to the avalanche protection BN are remote sensing variables, including a land cover classification (derived from a combination of Sentinel2 and aerial LiDAR data) and variables derived from high-resolution aerial LiDAR, such as crown cover, terrain roughness, and detected buildings. In addition, modelled avalanche velocities under two scenarios, extreme (300-year) and frequent (30-year), provide information on the spatial patterns of the avalanche hazard.

Using raster inputs, we performed inference for each pixel in a 5 m resolution raster of the study area. Since the provision and demand for avalanche protection do not occur at the same location, and spatial processes could not be modelled in the pixel-based BN, we quantified provision and demand separately. Thus, we obtained posterior probability distributions of avalanche protection provision and demand for each pixel. In order to map the outputs, we calculated the per-pixel median and entropy (uncertainty) of the posterior probability distributions.

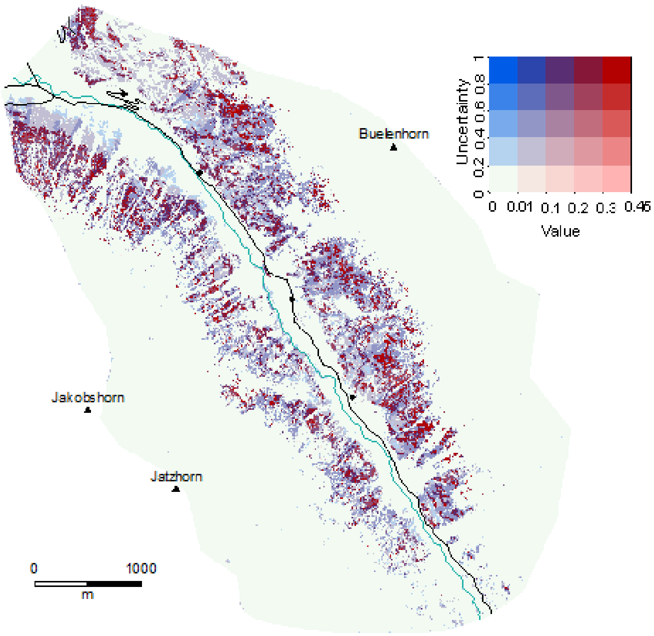

Figure 4.1-2: Modelled provision of avalanche protection in the Dischma valley (5 m resolution). The value is expressed in m of snow, while the uncertainty is calculated as the entropy of the posterior probability distribution. Most areas with a high value of the service also have a high uncertainty (dark red), as do some forested areas with a predicted low protection value (dark blue). Only areas with a zero or very low (light blue) value of the service show a high certainty. From (Stritih et al. 2019).

Overall, the uncertainties related to avalanche processes contribute more to the final uncertainty in ES provision than uncertainties about ecosystem structure. For example, the node "Release" (describing whether a pixel is in a potential avalanche release area) has an important influence on subsequent nodes in the network, but findings on its parents ("Slope", "Roughness (measured)" and "Curvature") can only reduce a small part of its entropy, so it is a major source of uncertainty in the model. Some remote sensing inputs have a strong effect on the knowledge about ecosystem structure ("Gap width" and "Crown cover"), while others have higher uncertainty (e.g. "Roughness").

5. Doñana, Spain

Doñana National Park is a natural reserve in Andalusia, southern Spain, in the provinces of Huelva (most of its territory), Cádiz and Seville. The park is an area of marshes, shallow streams, and sand dunes; established as a nature reserve in 1969 when the World Wildlife Fund joined with the Spanish government and purchased a section of marshes to protect it. The eco-system has been under constant threat by the draining of the marshes, the use of river water to boost agricultural production by irrigating land along the coast, water pollution by upriver mining, and the expansion of tourist facilities. Doñana National Park has a biodiversity that is unique in Europe, although there are some similarities to the Parc Naturel Régional de Camargue of the Camargue river delta in France, with which Doñana Park is twinned. The park features a great variety of ecosystems and shelters wildlife including thousands of European and African migratory birds, fallow deer, Spanish red deer, wild boars, European badgers, Egyptian mongooses, and endangered species such as the Spanish imperial eagle and the Iberian lynx.

5.1 Social surveys versus photo content analysis

In this study the aim was to understand whether the content analysis of social media photos reflect the type of tourists ("the who") and their nature-based experiences ("the what") as obtained from traditional surveys. This resulted in a comparison of social media information on tourist types and nature-based experiences in Doñana. The approach was independently tested in two UNESCO Biosphere Reserves from Southern Spain: Doñana and

Sierra Nevada. Firstly, photographic data was collected from the online social media platform Flickr, considering a stratified sampling procedure for each Biosphere Reserve: Doñana (number of photos, n = 11 441). Secondly, we classified the photos from each Biosphere Reserve according to the type of tourist and the prevailing nature-based experience by means of content analysis. Thirdly, we distributed online surveys to the Flickr users responsible for each photo, in order to gather their stated information on the type of tourist and prevailing nature-based experience . Finally, we compared the classification results from the photo content analysis with those from the online surveys, using multiple evaluation metrics. This overall process can be seen below in Figure 5.1-1.

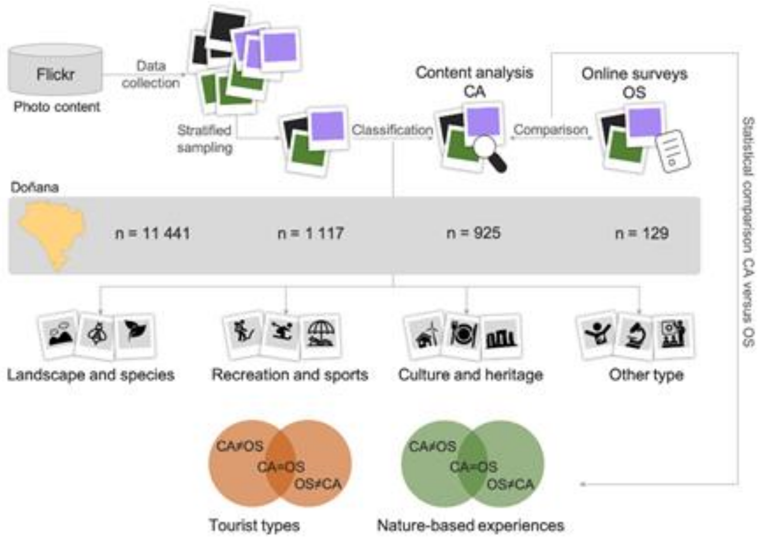

Figure 5.1-1: Procedural Framework for social survey versus photo content analysis

Overall, the classifications obtained from content analysis and online surveys showed different distributions in the number of photos assigned to each category of tourist types and nature-based experiences. When evaluating the general congruence between classification methods, in general, we found poor to medium agreement and accuracy levels between both content analysis and online surveys, depending on the biosphere reserve (colour figure on the right). This results suggest that considering information based on the content analysis alone can lead to inaccurate information and evaluations of the natural and cultural capital.

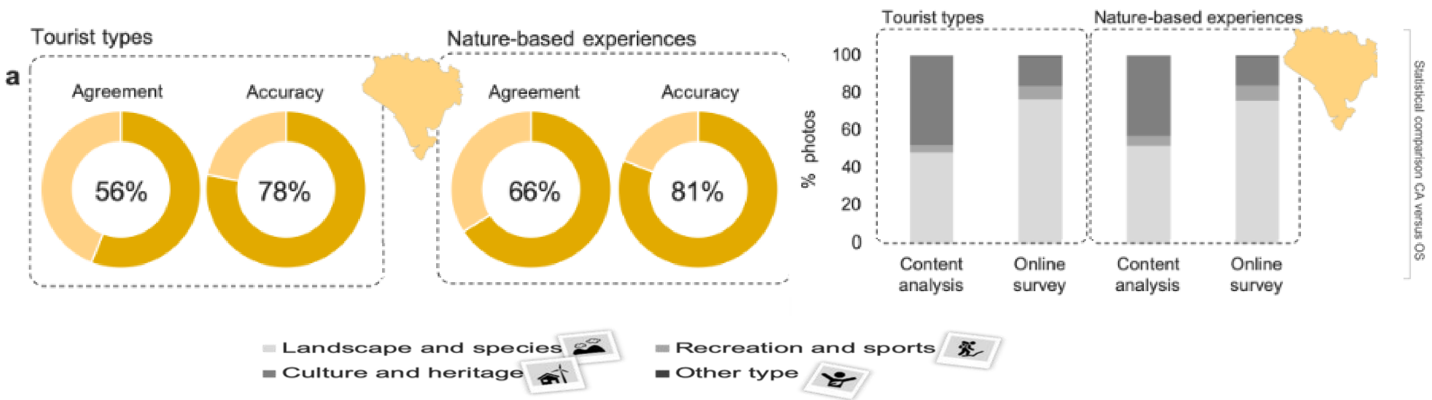

Figure 5.1-2: Classification from content analysis for nature-based experiences and tourist types

5.2 Provisioning of services through a Bayesian network

To build the BN network, which we formally call the model's Directed Acyclic Graph (DAG), we first developed a conceptual model of our study system during a first workshop (1st Stakeholders Workshop, April, 2017) involving key decision makers, general stakeholders and experts. At the outset of the workshop, to trigger initial discussion with participants, we presented recently published statistical analyses published in the context of ECOPOTENTIAL that identify a set of environmental predictors of water bird distribution and habitat use in Mediterranean wetlands under climate change, including the Doñana marshes (Ramírez et al. 2017). Then, we held a structured discussion about the criteria that Doñana's water bird community must fulfil to be considered in a "good conservation status". We focused on the richness/diversity of the community and the population trends of common, threatened and representative/indicator species. Finally, we built the conceptual model asking participants to identify factors (i.e. variables), either environmental (e.g., salinity) or social (e.g., management interventions, policies), that would ensure the accomplishment of a final goal established in the prior activity: a stable, diverse and representative water bird community in Doñana. In a back-casting fashion, participants identified from primary factors directly affecting the final goal (primary causal variables) to secondary factors affecting the primary ones (secondary causal variables), and so on. The process consisted of subsequent participation rounds that ensured the concurrent intervention of all participants (round robins), repeated until everyone considered the model (Figure 6.3-1) saturated.

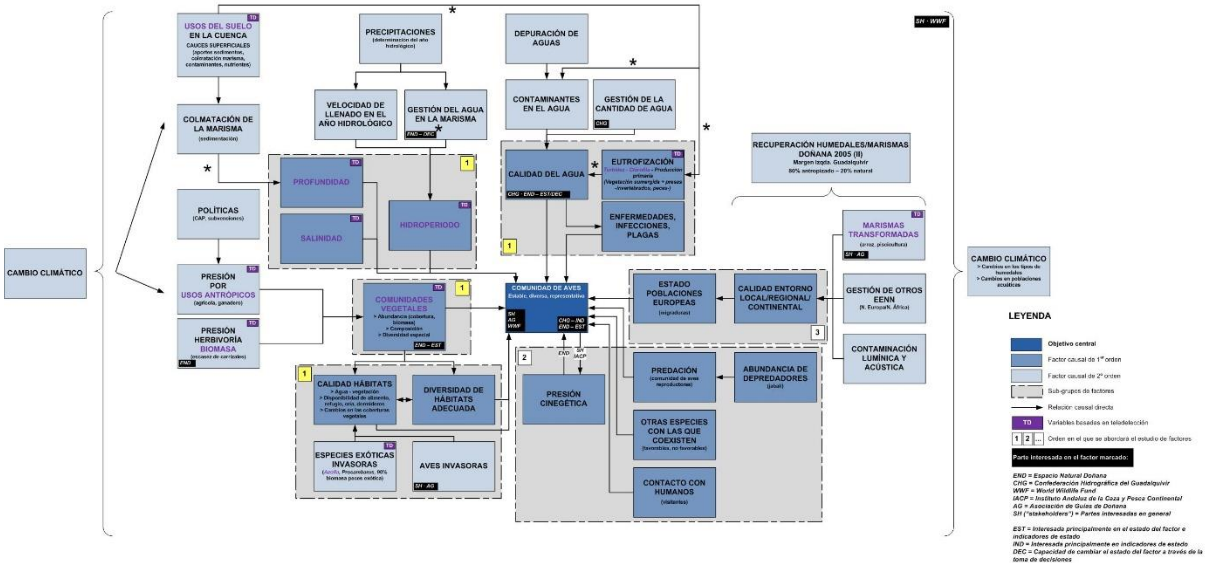

Figure 5.2-1: Conceptual model of our study system developed during the 1st Stakeholders Workshop.

Second, we built a preliminary DAG of the study system in laboratory, based on the workshop's conceptual model, including only a subset of environmental input variables as parent nodes. The selection of input variables was based on the opinion obtained from key experts at the previous workshop, and the existence of empirical data for the environmental variables so as to allow for future model validation, testing and use for predictive or diagnostic purposes. It was also aimed to assess potential shortcomings of the future BN model derived from data limitations or incorrect variables or interactions, as well as to reduce its complexity (i.e. enhancing its parsimony) thus easing the ascription of probabilities during its parametrization using expert judgement (see below). Nodes were classified using Cain's (2001, pp. 20-21) (Cain 2001) categories for generalizing network structure, in order to distinguish among decision, random and utility nodes. We used as few states as possible to keep resulting CPTs tractable (Marcot et al. 2006).

In a third stage, we defined our ecological output variables of interest in the DAG. We classified waterbird species in different groups based on the statistical analyses mentioned above. After that, we consulted with two in-house experts as a means of validation of our classification. Based on the final classification obtained, we devised and introduced into the DAG the ecological variables as an output child node.

5.3 Cultural Contributions of Ecosystems via Satellites, Social media, and GIS

This product aims to infer the contributions of ecosystems to cultural aspects of the Doñana National park system. Through the utilization of GIS data, satellite remote sensing, and social media content, an analytical framework for assessment was developed Figure 5.3-1. Such an approach utilizes known and mapped physical elements such as roads, trails, elevation, etc. in order to derive a spatial maps of the physical and visual accessibility of the region, denoting which areas are reachable by tourists and visitors to the region and furthermore, what is the visual range or objects which can be viewed from these points by persons located at that position. This information provides critical information on the physical accessibility of regions with the PA as well as the visual accessibility, denoting what can be seen, from these sub regions which are physically accessible. This information is further enhanced by including features of cultural interest such as public facilities, protected sites, cultural heritage landmarks, and various as well as landscape and biophysical properties on the landscape's diversity, structure, and configuration. Furthermore visual and sensory attribute resulting from the further processing of Sentinel-2 satellite images provides insight into the functional classifications of the environment as well as the colour diversity which is seen as an attractiveness quotient and appeal to tourism and those whom would take scenic photos of the area.

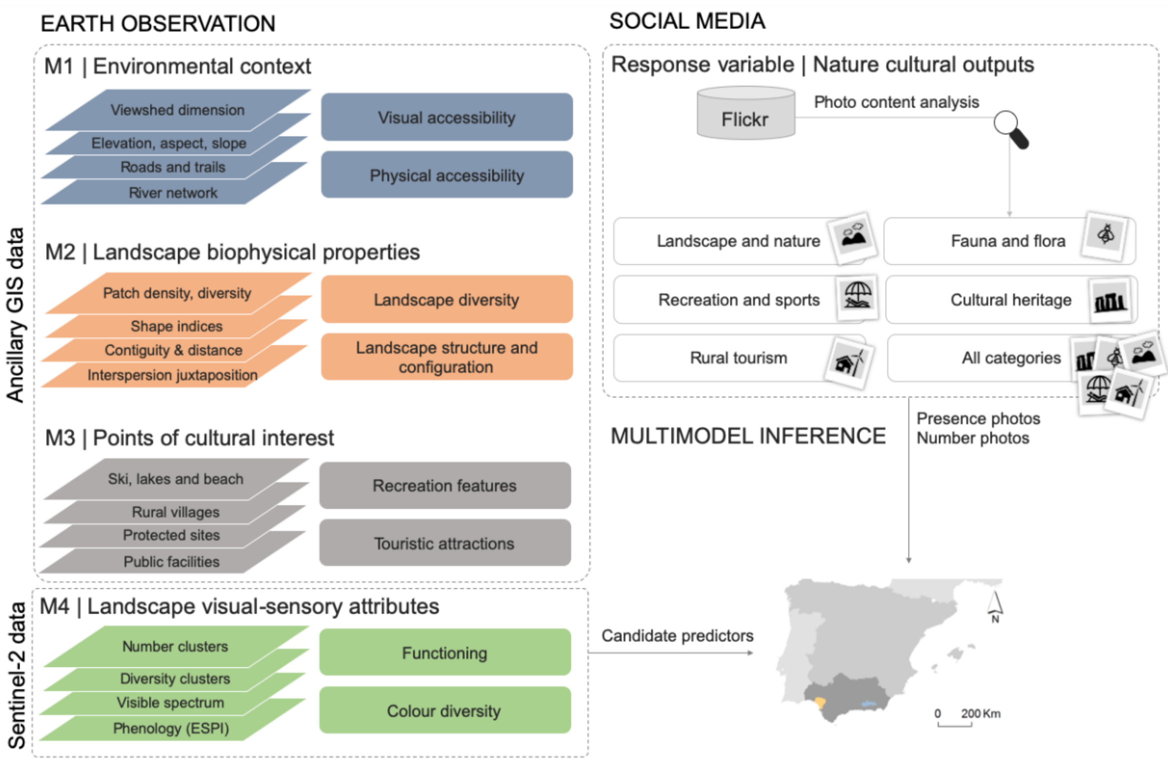

Figure 5.3-1: Analytical framework for the assessment or cultural contributions of ecosystems from Doñana National park utilizing a combination of GIS layers, social media inputs, and remote sensing application to derive visual sensory attributes.

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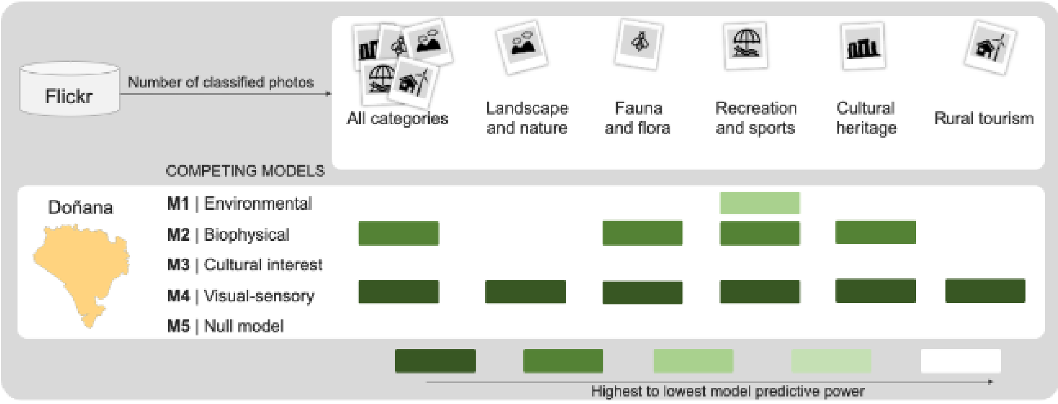

Figure 5.3-2: Results of multi-model approach for predicting cultural service presence.

6. Danube Delta, Romania

The Danube Delta is the second largest delta in Europe, after that of the Volga River and one of the best preserved in the world. The geomorphology of the area is formed by the dynamics of the river arms, low altitudes and the presence of the sea, creating a complex landscape of freshwater ecosystems (canals, shallow lakes, and wetlands), flood plains, alluvial forests, reed-beds, lagoons and coastal area. Due to its high biodiversity and uniqueness of landscapes, the delta attracts about 150000 tourists every year, which is ten times the number of inhabitants.

6.1 The impact of aquatic ecosystems provisioning services on tourism

We developed a storyline aimed at assessing trade-offs between ecosystem provisioning services and tourism and recreation in the delta. System productivity is reflected by water quality and biodiversity, which may influence the tourists' distribution and interests within the area. This model is based on the experts' views and consultation with stakeholders' aimed at describing the relationships between the provisioning services and the tourism and recreation activities as cultural ecosystem services provided by the ecosystems from the Danube Delta Biosphere Reserve. In a first step, we develop a diagram integrating the essential variables described in the storyline and potential indicators or models that can be used to assess them (Figure 6.1-1).

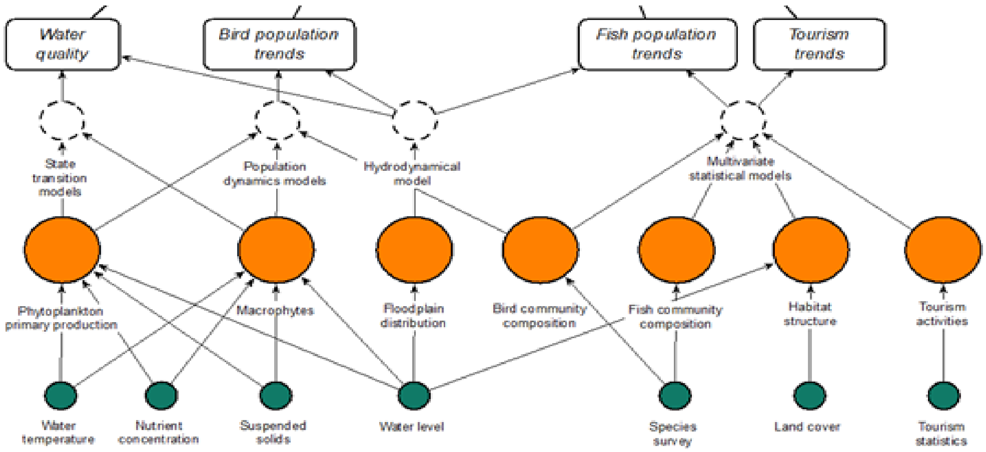

Figure 6.1-1: Diagram representing the storyline developed for the Danube Delta, including the identification of essential variables at the storyline level.

The second step is to develop a BBN, focusing on exploring the link between aquatic ecosystem provisioning services and tourism and recreational activities. We built a network considering several variables that influence the quality/productivity of aquatic ecosystems (e.g. nitrogen phosphorous ratio, total suspended solids, phytoplankton, fish species, macrophytes, and benthic invertebrates) and tourist attractions (e.g. habitat quality, fish productivity, bird density and accessibility) (Figure 6.1-2). Together with stakeholders (mainly researchers), we developed a graphical representation showing causality relationships between the variables that are influencing the system productivity and the recorded distribution of tourists.

Three categories of stakeholders were involved in the process: researchers specialized in ecology, ornithology, fishery and chemistry (form the University of Bucharest and from Danube Delta National Institute), managers from Danube Delta Biosphere Reserve administration and representatives of local companies dealing with tourism and commercial fishery.

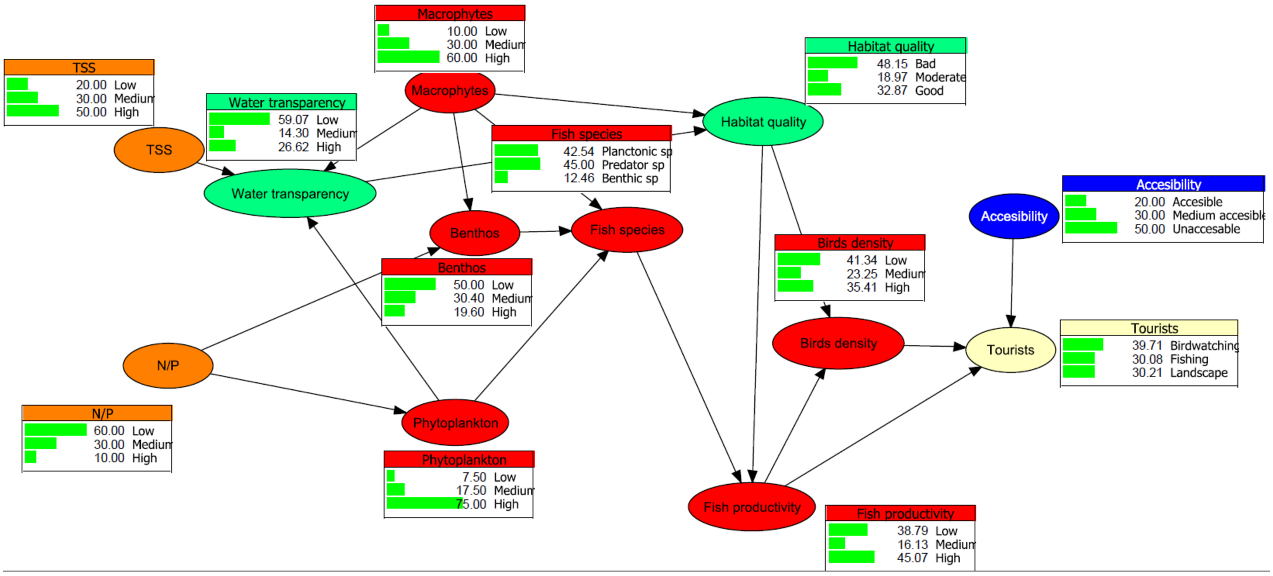

Figure 6.1-2: Bayesian Belief Network developed for assessing the trade-offs between provisioning services and the tourism and recreation in the Danube Delta. The nodes are grouped and coloured based on the types of variables they represent using a Drivers, Pressures (orange), State (green), Impact (red), Response (blue) approach model. Total suspended solids (TSS), phytoplankton (represented by chlorophyll-a) and macrophyte cover are both remote sensing and in-situ data. The outputs of the network are the tourists' interests, bird densities and fish productivity. Arrows represent causalities, between different ecosystem properties and ES.

The BBN is planned to be run spatially at full extent of the Danube Delta protected area, using an ecosystem distribution map, interpolated layers of variables measured in-situ (e.g. chlorophyll a, total suspended solids, fish and birds abundance, number of tourists) and remote sensing data describing the water quality (e.g. water chlorophyll content, water suspended solids, land surface temperature, and hydroperiod). The output resolution would be about 1 square km.

6.2 Social media used to reveal the cultural services

Through the use of social media platform FlickR and image harvesting capacities, a collection of images taken within the Danube River Delta were abstracted from the platform. These images were manually classified into four sub-categories of cultural ESs including the following: Physical interactions, experiential interaction and activities, Intellectual and representative interactions, and Spiritual or emblematic categories. These activities resulted in the acquisition of 3965 unique pictures throughout the region that can be mapped to determine hotspots and regions of highest interest Figure 6.2-1. The location of these photos were determined to be predominantly on public access pathways which provide the easiest access for tourists to reach locations and enjoy the surroundings. This follows through with expectations that infrastructure and accessibility provide a primary means for cultural services.

Figure 6.2-1: Geo-Location of the 3965 unique pictures harvested from FlickR and mapped within the Danube River Delta region applied within this application

The manual classification of images shows that a majority of interactions within the region are through physical interaction, i.e. hiking, boating, and physical recreation activities. These images can also be further dissected into temporal categories which revealed that, as expected, a bulk of the tourism activities occur in the warmer portions of the year (Spring through Fall) with the bulk of images and activities, as denoted through number of images, taking place during the summer months. Such results allow for the inspection of tourism intensity to be evaluated as well as supply management with information on what types of scenic elements or activities are drawing the largest tourism potential, again as seen through images via FlickR users. These results can be skewed due to the nature of the platform, where a dominant presence is held by those who take scenic or nature photography rather than the casual user or recreant.

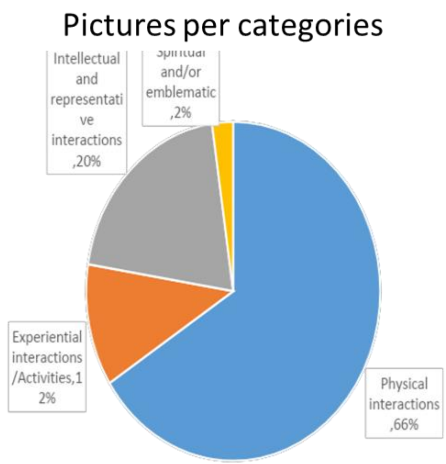

Figure 6.2-2: Percentage of FlickR images as a portion of the total images harvested per use category

7. Dutch Wadden Sea, the Netherlands

The Dutch Wadden Sea lies between the coast of north-western continental Europe and the range of low-lying Frisian Islands, forming a shallow body of water with tidal flats and wetlands. It has a high biological diversity and is an important area for both breeding and migrating birds. In 2009, the Dutch and German parts of the Wadden Sea were inscribed on UNESCO's World Heritage List and the Danish part was added in June 2014. The Wadden Sea at large is one of the world largest uninterrupted and interconnected chain of mudflats and estuaries and provides critical spawning and migratory stop-overs for a wide range of bird species as well as proving a unique and special habitat which provides sanctuary for many species and serves as a large reservoir of economic activity for the countries it lays abreast.

7.1 Conceptual models for DPSIR Relationships

Evaluating interactive effects of global factors with local pressures is one of the major challenges for future management of the Wadden Sea. Global pressures like sea level and temperature rise, and invasive species act on a large scale. For future management strategies it is vital to understand effects of global drivers and their influences on a regional level (van Beusekom, J. E., Buschmann, C. & Reise 2012). In combination with local anthropogenic activities, global pressures can have significant effects on the ecosystem. When modelling the marine environment and its ecosystem services, it is therefore vital to include global and regional pressures such as climate change (global pressures) and eutrophication, fisheries and pollution (regional pressures) that may frequently occur as non-linear interactions (Petersen et al. 2017). The following research was divided into two separate studies to limit its complexity. The first part dealt with a trade-off analysis between two different ecosystem services developing a rather large Bayesian Network. Whereas the second part developed a much smaller Dynamic Bayesian Network showing cumulative and cascading effect on the ecosystem and its services in the Dutch Wadden Sea.

In order to get a better qualitative understanding of the system, the risks for the system were identified with a DPSIR. Information was gathered from literature. The DWS is a complex system that has various *driving forces*. Anthropogenic drivers dominate the system over natural drivers. The most influential anthropogenic drivers are commercial fishery, water pollution, maintenance and other activities. Climate change is a global driver and the low lying coastal land is the result of tectonic movement. While both of these factors are not manageable, their impacts can be minimized.

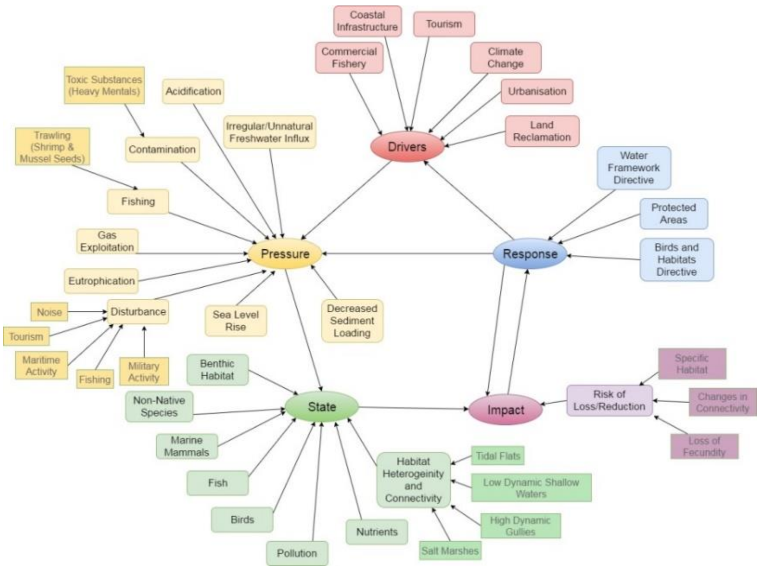

Figure 7.1-1: DPSIR Model of the Dutch Wadden Sea

Once the DPSIR framework and the possible trade-off analysis were done, a generic conceptual model of the Dutch Wadden Sea could be prepared. The aim of this exercise was to get a better understanding of the relationship between the two chosen ESs. The red squares represent the drivers and therefore the starting point. The arcs between different types of squares depict the general direction of the cause-effect relationship within the system. The model includes different kinds of topics that affect fish populations (blue), bird watching (green) or both alike (yellow). The conceptual model is a fairly holistic view of the DWS as it includes factors that cover various time and spatial scales within the DWS. In order to build a BBN from the conceptual model, it needs further simplification, even though it already describes a simplified world. However, it is important to also be aware of the underlying causal relationships and the system complexity when building a BBN. Furthermore, making a conceptual model helps to identify which variables are impacted by which variables, hence illustrating the relevance of some factors such as 'Forging Habitats' over others (e.g. 'Grazing'). All in all, this model helped to translate the immense amount of information identified above into more tangible variables.

The construction of a DBN model is not a linear process but rather an ongoing cycle in which new information from field tests, literature and other sources can be included once they become available. A conceptual model of the system should be created prior to building a BN which syntheses existing knowledge. It is possible to build various conceptual models when showing different level of detail, perspectives or scales. This stage provides a visualized summary of drivers and their direct and indirect relations (link) to other variables and outputs. The conceptual model can help expose weaknesses, therefore (Jakeman et al. 2006) advised to always undergo the conceptualisation step. Experts are able to review the conceptual model after the model has been built. Their feedback may also help to recognize the most important variables, processes and possible errors can be corrected (Chen & Pollino, 2012).

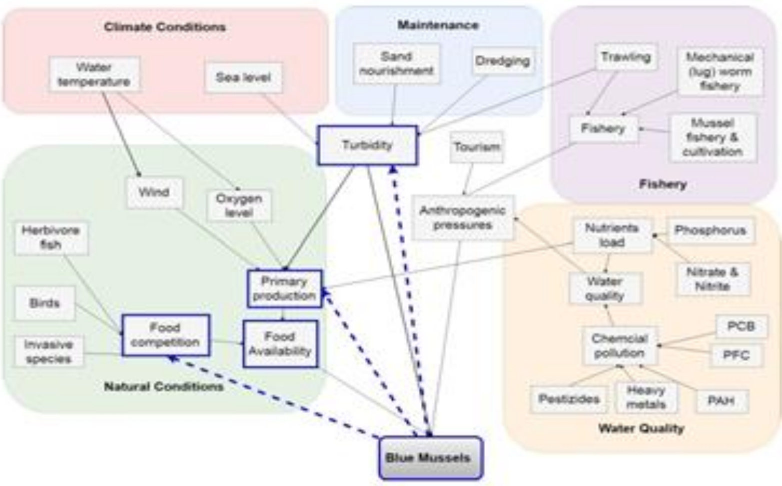

Figure 7.1-2: Conceptual Dynamic Bayesian Network

After this step, the physical variables that are to be included are chosen and it is decided how detailed the model is supposed to be. When defining the variables it is important to do it in a way that all users are able to understand the represented variables (Kragt 2009). Kragt (2009) and Marcot et al. (2006) recommended to keep the number of parent variables to three or fewer in order to bound the CPT size. For the same reason, their states should be maximum five (Marcot, et al., 2006). These recommendations keep the CPT small enough to be tractable and understandable. A large amount of intermediate variables, also known as latent variables, will contain uncertainty propagation.

7.2 Using Bayesian Networks to Capture Trade-offs Between Ecosystem Services

During the first phase, good background knowledge about the study area and its resulting ESs were gained. Additionally, information on the directional correlation between mussel dynamics and bird populations was acquired. On the basis of that a literature based BN was constructed. The whole network was comprised of more than 40 nodes which had an effect on each other in one way or another. Each node was either trained with data or expert knowledge. To train the network, measurements from the last 10 years were taken. Monthly and weekly averages were determined during the data analysis to see whether there are big differences between these two distributions.

The proposed literature based BN conceptual model structure was improved and enhanced and turned it into a fully functional BN model. This was done by consulting with experts from Deltares, the Netherlands. The first round of expert elicitations focused on a discussion of the proposed literature based BN model as well as its purpose. Furthermore, the suitability of the chosen nodes and links was discussed. This was done via face-to-face meetings. These meetings led to the identification of superfluous nodes which were defined during the literature review, but were deemed inappropriate in the context of the Dutch Wadden Sea and therefore exchanged, deleted, or redefined.

Different test and experiments were conducted once the network was trained to see how certain nodes would affect other nodes. For example, not only parent nodes can be filtered. The BN is able to show the probabilities of parent and even “grandparent” nodes when a child node is filtered. Looking at a snippet of the whole BN, when the Commercial Fishing node is set to a very low state, it can be seen that this implies a certain state in the parent nodes (Mussel Stock) and even “grandparent” nodes (NPP, O2, and Water Temperature). In this case the model assumes a low mussel stock when Commercial Fishing is decreased. In case the fishing activity is set to very high, the fish stock increases. It is worthwhile to mention that this assumption was not entered into the model at any time but is an effect of the given and trained data.

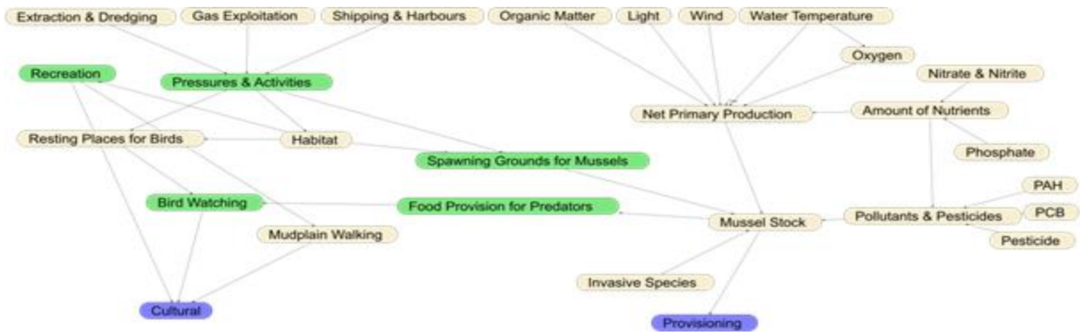

Figure 7.2-1: Complete BN Structure

7.3 Using Dynamic Bayesian Networks to Capture Cumulative Effect on Ecosystem Services

After carrying out expert surveys some changes had been made from the original conceptual model to the BN created as the first step in the design phase (see Figure 6.5-5). It was pointed out that the recruitment success and standing stock is highly dependent on predator (such as birds, fish, shrimp and sea stars). Another change was made for nutrient load which is highly connected to primary production and has a positive effect on mussel biomass. On the other hand, chemical pollution has rather a negative effect. Therefore, nutrient load is not connected to water quality anymore. As this node has only one input left (chemical pollution) it could be removed from the network in order to simplify it.

When defining the variables for this BN, data sources were taken into account and whether a variable is static or dynamic. There follows, the CPT's for the expert elicitations (turquoise). The blue coloured variables CPT's are learned with in-situ data apart from the *Nutrient Load* and *Chemical Pollution* variables which are summarizing variables (red). Most of the temporary (dynamic) variables CPT's are also trained with in-situ data (pink): *Turbidity, Primary Production, Predators,* and *Blue Mussel* (Blue), apart from *Food Availability* (Purple) which is trained with the help of Expert Knowledge.

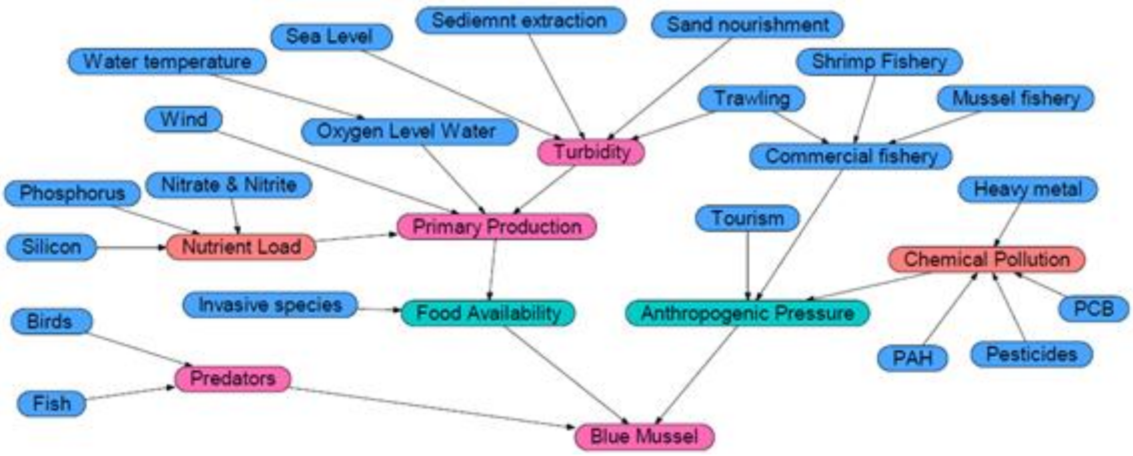

Figure 7.3-1: BN Various Anthropogenic Pressures and Natural Conditions Affecting Blue Mussel Abundance

Figure 6.5-5 shows the developed DBN of this study. The blue coloured variables are primarily derived by in-situ data. The pink coloured variables represent the temporal variables. The variables of the first time-slice are: *Turbidity [0], Primary Production [0], Food Availability [0], Predators [0], and Blue Mussel [0]*. The second time slice contains the variables *Turbidity [1]*, *Primary Production [1], Food Availability [1], Predators [1], and Blue Mussel [1]*. Expert variables are the *Food Availability* in both Time slices and *Anthropogenic Pressure*.

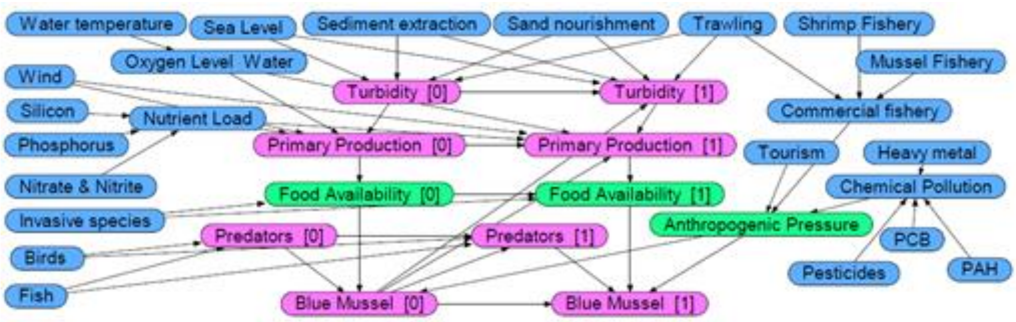

Figure 7.3-2: DBN Various Anthropogenic Pressures and Natural Conditions Affecting Blue Mussel Abundance - Post Time Expansion

7.4 Ecosystem Service interdependencies and interactions

While the Bayesian networks, explained in sections 7.1, 7.2, and 7.3 amongst others, are dependant on the causal relationships between indicators and ecosystem functions described in the networks, the relationships and intensity of relationships between ecosystem services is not always clear. A tool with which the interconnectivity of these services and functions is the Circle for ESs. Such a representation is derived from generating a matrix of the ecological functional dependencies underpinning the various Ecosystem Services considered. These can be expertly derived, from literature, or through the development of Bayesian Networks. By crating a structure through which the interconnection and either positive or negative influences of Services upon one another can be expressed, discussion and facilitation with managers, policy makers, and other scientists can be strengthened and enhanced. Furthermore, such a tool has the capacity to directly show the explicit relationships and trade-offs between services when known. This prototype is currently expertly informed, however, by underpinning such a structure with a complex and fully seeded Bayesian network, the strengths of connections can be data driven and expert validated, providing situational and quantitative trade-off analyses in a simply and easy to interpret infographic and discussion medium.

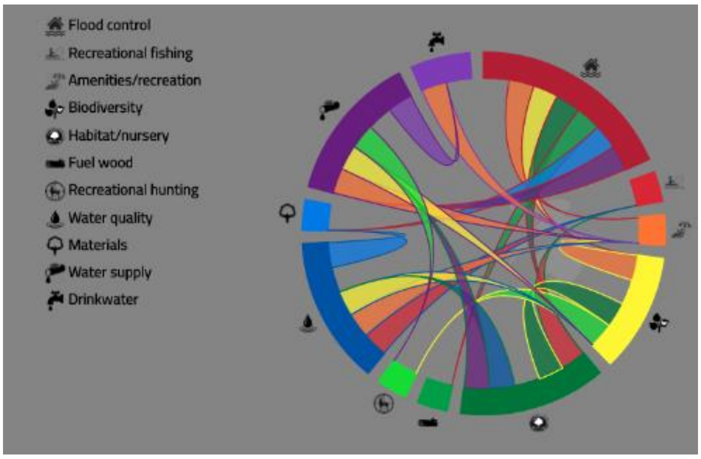

Figure 7.4-1: Prototype Circle tool showing the interlinkages and inter dependencies between selected Ecosystem Services. Such a schema allows for the highlighting and explanation of the inter-dependencies within Ecosystem and their services

7.5 Serious gaming for Ecosystem Services

The amount of data and information available to us is becoming ever more abundant and becoming ever more complex. Because of this, being able to effectively communicate ideas and highlight important information in meaningful and engaging ways is increasingly challenging. Serious Gaming (SG), as proposed here, aims to integrate relevant information, knowledge, and processes into an interactive platform which allows both single users or groups to engage with dynamic systems and stimulate discussion while conveying a collection of Remote Sensing, modelling, and monitored data blended with expert opinion and refined through stakeholder engagement. In order to have an effective Serious Game, all stakeholders must have periodic input into the identification of critical elements and come to a mutual agreement on the dependencies between different elements of the system. The procedural generation and definition of such a game can be seen in Figure 7.5-1.

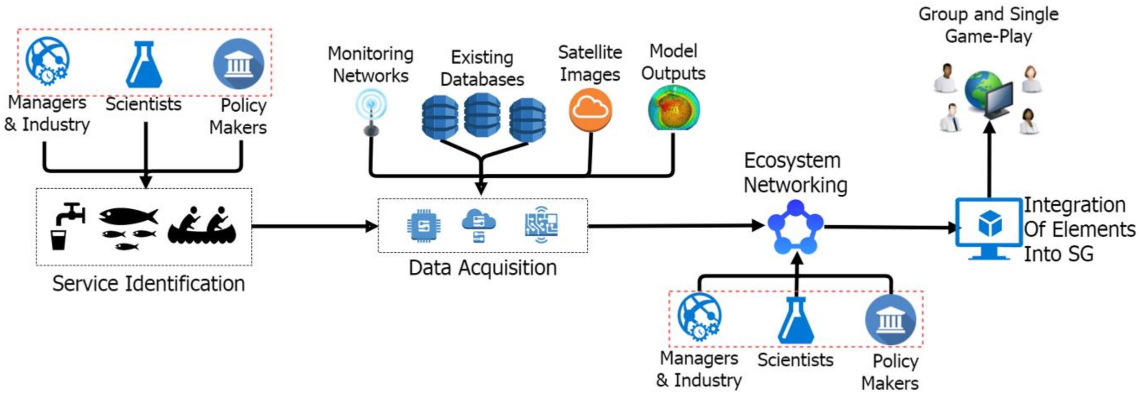

Figure 7.5-1: Conceptual Guidelines for Ecosystem Service Serious gaming

Generating such a game has several objectives. Firstly, to generate a more realistic and engaging approach to engaging with the Protected Area stakeholders and policy makers. Secondly, to facilitate the integration of various available data sources into an interactive product which conveys information and facilitates discussion. Lastly, to ensure consistency between researchers, policy makers, industry, and managers on the relationships and importance of various elements within Protected Areas. The final output is a game which is based on real data and models, takes advantage of both scientific and managerial knowledge, and is able to convey the trade-offs between Ecosystem Services within a Protected Area while exposing the difficulties of agreeing on policies to be implement in order to achieve objectives. Furthermore, such a game can take advantage of the uncertainties captured in management techniques as realized through Bayesian Networks and can be used to present the data underpinning such a construct such as the conditional probability tables, process-based model outputs, and mapping or ecosystem indicators. Figure 7.5-2 showcases the potential of such games to provide an engaging and interactive environment with which information can be communicated to citizen, stakeholders, and managers. Such games can provide a critical tool in facilitating and enabling discussion and planning for PAs.

Figure 7.5-2: Snapshot of a Serious Game's potential to provide an interactive environment while presenting data and maps coinciding with the impacts generated from electing various management measures

7.6 3-D Visualization of Ecosystem Service Indicators with Uncertainties

Through modelling and mapping ecosystem services, the results of models are usually represented in terms of key indicators for services rather than the services themselves. In the terrestrial domain, many of these services are traditionally mapped in two-dimensional space as they are accounted for occurring in a planar sense. However, in the aquatic and especially marine environments, the indicators and proxies being modelled for ESs evaluation can occur in 3-dimensional space and are usually compressed into 2-dimensional maps for ease of use and legibility. However, this taken on certain assumptions and removed the end-user and decision maker by another degree from the true information. By representing indicators and proxies in the 3-d modelled space it is possible to showcase the entire system and, through the utilization of opacity as an function of model uncertainty, to give a more accurate and representative indication of the values of said indicators and proxies as well as the confidence in the model outputs. Such a representation for the Wadden Sea can be found below in Figure 7.6-1. Such representation bring the model outputs one step closer to being able to be incorporated into Serious Games in a similar fashion and schema as described in section 7.4.

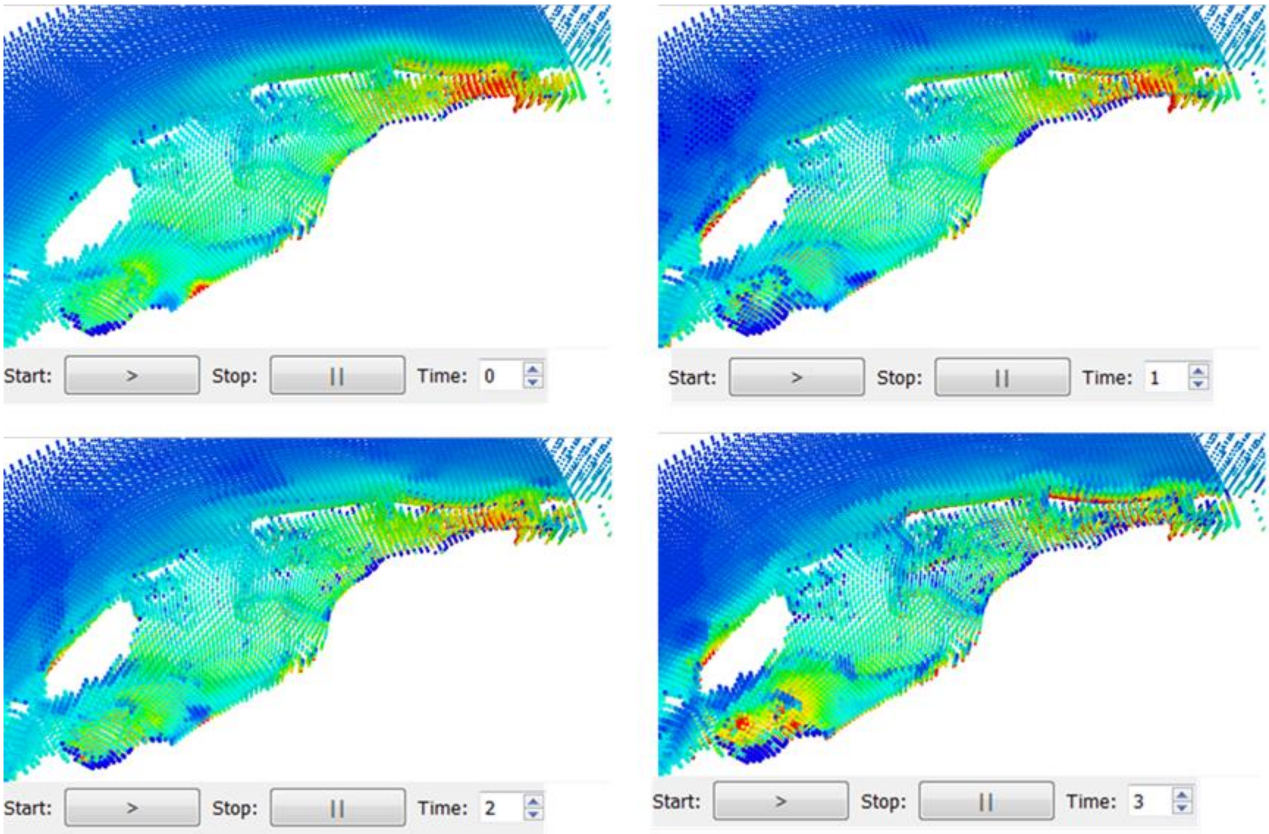

Figure 7.6-1: Representation of a 3-Dimentional visualization of Indicators for Ecosystem Services within the Wadden Sea. In this case, sediments as an indicator for the regulation and maintenance of erosion within the Wadden Sea

8. Pelagos Sanctuary, Mediterranean

The Pelagos Sanctuary is a marine protected area (MPA) in the Mediterranean Sea aimed to protect all marine mammals. Due to a combination of climatic, oceanographic and physiographic factors, the area has good conditions for the feeding and breeding habitat of several whale and dolphin species (Notarbartolo di Sciara and Reeves 2006). At the same time, it is surrounded by well-developed regions with high economic activity. For tourists and locals, whale watching has become an increasingly popular activity, and is therefore an important cultural ecosystem service in the MPA. However, cetaceans in the area are threatened by pollution, ship strikes, and noise. Disturbance due to whale watching is also thought to be harmful to whales, but data on the activity and its impacts are scarce. A BN was developed to map the value of whale watching by combining data on cetaceans with expert knowledge on whale watching activities in the Pelagos Sanctuary.

8.1 Whale Sightings via a Bayesian Network

A draft network was initially constructed through literature review, particularly regarding threats to cetaceans. Since literature on whale-watching behaviour and value of cetacean sightings is lacking, this part of the network was developed based on a workshop with stakeholders (local researchers, conservationists, and whale watching companies). Then, the network was developed further in an iterative process of discussion with experts, collecting data, and testing. The network contains nodes on cetacean presence (sightings and potential feeding grounds), threats to cetaceans, whale-watching behaviour, and the social value of cetacean sightings.

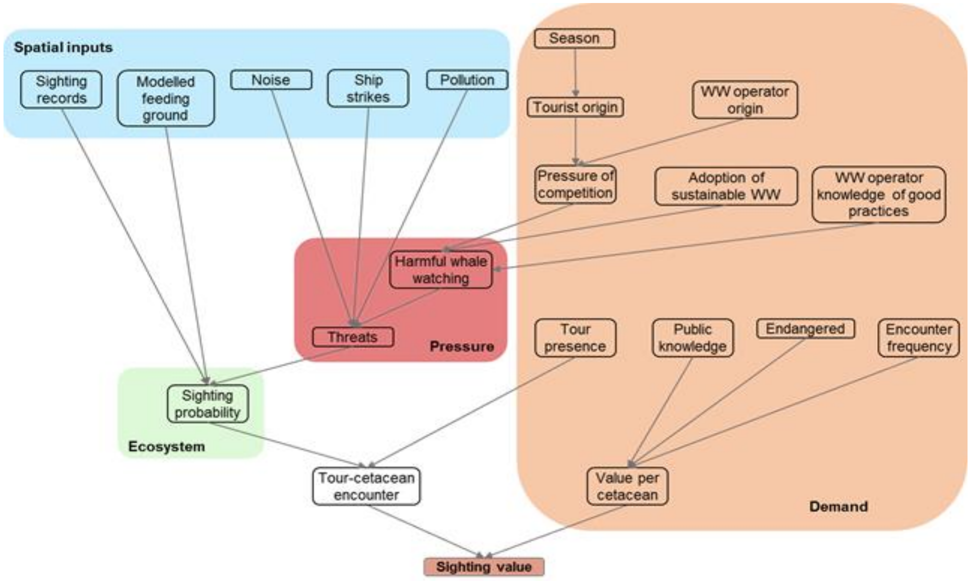

Figure 8.1-1: Bayesian Network developed to model the ES of whale watching

Expert interviews were conducted to populate nodes describing the behaviour of whale watching companies, their harmfulness to cetaceans, and the impacts of other threats on cetacean wellbeing. Furthermore, the social value of cetacean sightings (dependant on the level of public knowledge, perceived cetacean vulnerability, and frequency of encounters) was estimated based on expert knowledge.

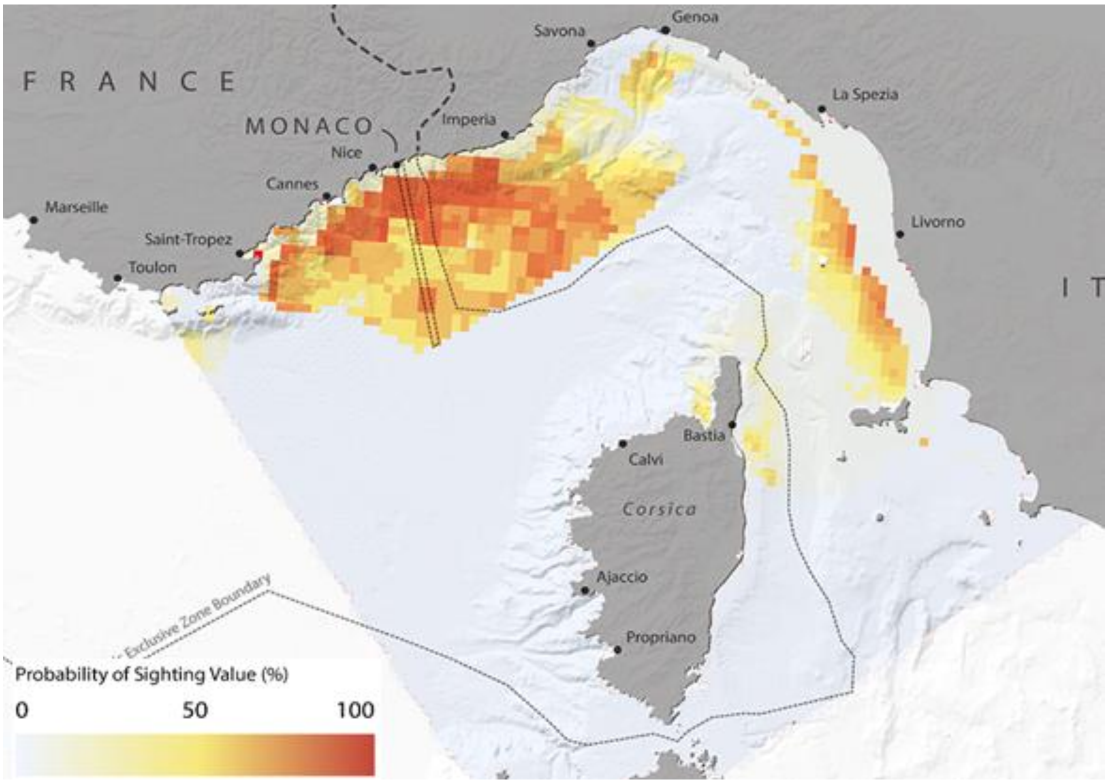

Figure 8.1-2: A map of the "Sighting Value" of whale watching in the Pelagos Sanctuary, calculated using the BN.

8.2 Fish vitality and Growth Potential via EO products

The potential for aquaculture and food provisioning from the marine habitat is of critical interest an Europe and the Global community seek to increase the productivity or marine and coastal zones. In order to maximize the productivity of such endeavours, yielding the highest return on services, Earth Observation data sets can be used together in order to determine regions where the vitality and growth potential for various aquaculture species is at its highest. One such method is through the utilization of a toolbox, developed by ISPRA, which generated feasibility scenarios which denote feasible and unviable locations for species specific fish growth utilizing key indicators derived from Remote Sensing products such as sea temperature, Ph values, dissolved oxygen, and many more which are critical to evaluating productivity and viability. This toolbox provides suitable scenarios in terms of the potential fish biomass to be harvested from each of the regions or locations as denoted in the toolbox. An example of this system can be seen in Figure 8.2-1. Full information on this system can be found in the following open access article: Valentini, E.; Filipponi, F.; Nguyen Xuan, A.; Passarelli, F.M.; Taramelli, A. Earth Observation for Maritime Spatial Planning: Measuring, Observing and Modeling Marine Environment to Assess Potential Aquaculture Sites. Sustainability 2016, 8, 519.

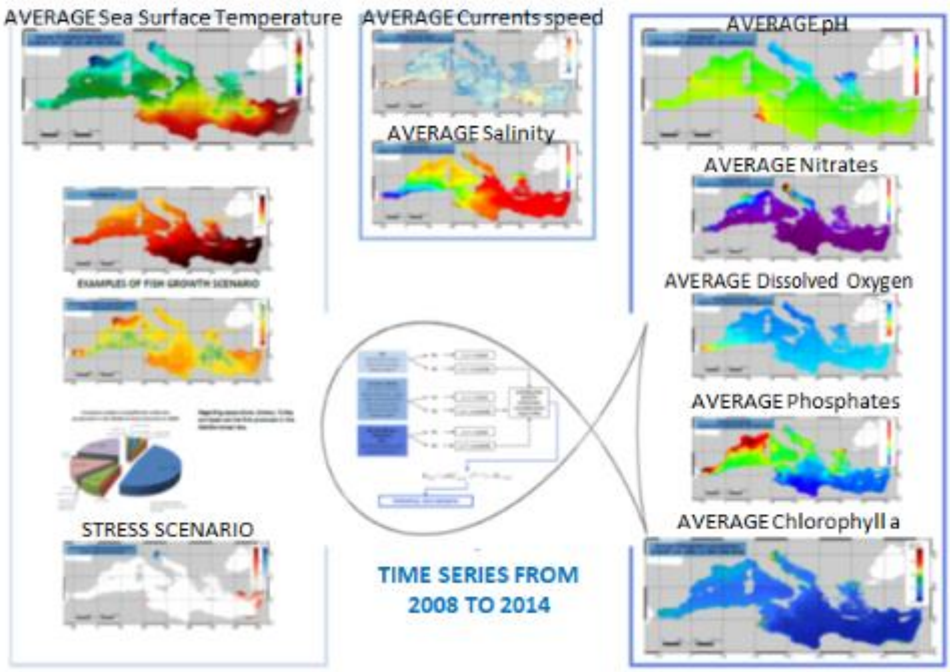

Figure 8.2-1: Fish Viability and Groth Potential Schema for the toolbox developed by ISPRA

9. Har Negev

Har Negev Reserve (HNR) is a part of the central Negev Highlands. Due to the desert climate, water is an important limiting factor in the distribution of species in time and space in the region. There are very few natural springs within the reserve and most water comes from ancient waterholes and more recent waterholes maintained by the local Bedouin population. Such natural springs and waterholes are the cause of great conflict between human recreation and the need of animals for water. Currently there are a few hundred Bedouins living in several small settlements very close to the reserve and a significant part of their grazing is done within the reserve. There is very little information regarding the impact of grazing on the vegetation within such a hyper-arid environment. With the introduction of modern agriculture into the vicinity of the reserve, there is a growing conflict between wildlife and farmers. A conflict that is predicted to grow in the coming years, yet we know very little about the impact of human settlement and agriculture on the wildlife in the hyper dry region.

9.1 Landscape perceptions for cultural and touristic services

This aimed to understand whether the content analysis of social media photos reflect the type of tourists (“the who”) and their nature-based experiences (“the what”) as obtained from traditional surveys. With continual development within the region impacts the landscape and what is sometimes defaulted to as the natural and clear aesthetic appeal of the region, such a survey was utilized in order to better determine which factors, anthropogenic or otherwise, are considered to be part of the natural beauty of the region. Such an approach required the generation of booklets wherein a series of photos representing the various landscapes and stages of development of the region are included. Participants who come to engage with the landscape are utilized for this study. For the series of photos within the booklet, the participants are asked to rank the personal preferences of the landscapes resulting in a quantification and subsequently provide a more detailed explanation on the rationale behind the ranking, the qualitative aspect. The results of these surveys are processed according to social-cognitive theory for environmental concern, a nature related index as outlined by Nisbet et al 2009, and taking into consideration demographic characteristics of the participants. Below in Figure 9.1-1, the results of a univariate regression test against the elements registered are presented showing the inclinations of preference per the categorization of the photographs within the booklet. This provide insights into which functions of the landscape and degree of utilization and development are deemed acceptable and aesthetically pleasing to visitors to this region.

Results - Univariate Regressions

		Intensive	Clean/Pristine	Extensive	Vegetation
					
Environmental values (Schultz)	Altruistic				
	Biospheric		0.14*		0.17**
	Egoistic				
Nature relatedness (Nisbet)	Intellectual		0.16**		0.13*
	Spiritual			0.13*	
	Experiential		0.25***		0.12*
	Ambivilent	0.22***	-0.11*		-0.12*
	Anthropocentric				
Demographic variables	Education (elementary)	-0.74**	1.39***	-0.67**	
	Language (Hebrew)		0.84***	-0.62***	

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

Figure 9.1-1: Results of Uni-variate regressions applied to acquired survey datasets within the categorical hierarchies

10. Conclusions for Further Work

As protected areas and ecosystems continue to develop and adapt to existing and new pressures and drivers, there always remains the needs for further monitoring, analysis, and generation of new projections as new management techniques are developed and information become available. The prototype products as they are presented here should be updated and continually enhanced in order to best serve the needs of the management and policy makers of protected areas. These prototypes provide a viable routes through which Roadmaps for current and future protected areas can be informed and supported. Therefore, this deliverable is closely linked with D9.4 which outline such roadmaps for current and future PAs.

The prototype products discussed in this deliverable are being aggregated into a paper to be submitted for publication at the end of 2019 which encapsulates the procedural framework applied to ESs within ECOPOTENTIAL as well as the benefits of such products and prototypes. Furthermore, such products can be linked and connected to the GEO community, of note, GEO ECO, as showcases for the potential application of the methods and frameworks to additional regions, including other PAs and beyond.

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