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: 7.2

Framework for ESS based on DPSIR

Due date of deliverable:	31st January 2018
Actual submission date:	15th May 2018
Version:	V1
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This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 641762

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Deliverable title	Framework for ESS based on DPSIR
Deliverable number	D 7.2
Deliverable version	1.0
Contractual date of delivery	January 2018, Month 32
Actual date of delivery	May 2018, Month 36
Document status	Final
Document version	1.0
Online access	ECOPOTENTIAL website: http://www.ecopotential-project.eu
Diffusion	Public
Nature of deliverable	Report
Work Package	7
Partner responsible	Deltares
Author(s)	Ghada El Serafy, Cristina Marta-Pedroso, Alexander Ziemba, Tiago Domingos, Arjen Boon, Sonja Wanke, Jennifer Schulz, Lia Laporta, Daniel Orenstein, Aletta Bonn, Janina Kleemann, Cláudia Carvalho-Santos, Mihai Adamescu, and others
Editor	
Approved by	
EC Project Officer	Gaëlle Le Bouler

Abstract	This document corresponds to the ECOPOTENTIAL deliverable D7.2 which is one of the expected outcomes from WP7 ‘Ecosystem Services’ and is expected to convey the outcomes of Task 7.2 “Conceptual Framework for valuation of ecosystem services in PAs”. Over the past several decades, and particularly since the publication of the Millennium Ecosystem Assessment (Reid, et al., 2005) and subsequent establishment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services in 2012 (IPBES, 2017), the Ecosystem Services (ES) concept has become a dominant conceptual framework for development of sustainable land use policy and management (Seppelt, et al., 2012). In particular, the IPBES calls on participating nations to conduct comprehensive ES assessments in order to generate knowledge regarding impact of humans on the environment and to help map out policies that can assure ecosystem

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	integrity and the continued flow of ecosystem services to human beneficiaries (Díaz, et al., 2015). As such, numerous frameworks for assessment have been proposed and implemented for identifying, characterizing and valuing ES and their temporal and spatial dynamics (e.g. Brown & Fagerholm, 2015; de Groot, Wilson, & Boumans, 2002; Kareiva, Tallis, Ricketts, Daily, & Polasky, 2011; Maes, et al., 2012). Since these efforts are relatively recent, what is less well studied is how the results of such assessments have been integrated into land use management, planning and policy. Given context above overall WP7 objectives and the ECOPOTENTIAL outcomes already available, the challenge in place was to develop a DPSIR based framework by considering the data and information being gathered within the project (EO and in-situ data, PA's socio-ecological characterization, including current flow of ES, stakeholders and management challenges (Drivers and Pressures), and management options (Responses). Our proposed methodology encompasses a **stepwise iterative approach** (SIA) that consists of three main components: • a **DPSIR-based storyline** detailing the current state of the ecosystem and major elements such as drivers and pressures influencing the area of interest, • a causal network map **(Mind Map)** unravelling the relationships from particular ecosystems of the PAs to the respective ES and up to (EO based) indicators, • a tool such as **Bayesian Networks (BN)** which provide end users with visualizations representing probabilistic future states of protected areas given various management pathways. A cornerstone of the proposed three steps approach described above is **stakeholder engagement** along the entire methodological pathway and a stepwise approach from the storylines, to structural expression of the storylines in mind maps, which in turn are used as a basis for the respective BNs.
Keywords	Stepwise-Iterative-Approach, Ecosystem Services, DPSIR analysis, Bayesian Network, Methodological Framework

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List of Acronyms

BN	Bayesian Network(s)
CICES	Common International Classification of Ecosystem Services
CPTs	Conditional Probability Tables
DPSIR	Drivers, Pressures, State, Impact and Response
ExtEnSity	Environmental and Sustainability Management Systems in Extensive Agriculture
DPCER	Driver, Pressure, Chemical state, Ecological state, Response
EF	Ecosystem Function(s)
EO	Earth Observation
ES	Ecosystem Service(s)
MPA	Marine Protected Area
NPA	Nature and Park Authority
PA	Protected Area(s)
ptMA	Millennium Ecosystem Assessment for Portugal
WFD	Water Directive Framework
SES	Social-Ecological systems
SIA	Stepwise-Iterative Approach
SNNP	Sierra Nevada National Park
SNP	Swiss National Park
WP	Work Package

Executive summary

This document corresponds to the ECOPOTENTIAL deliverable D7.2 which is one of the expected outcomes from WP7 ‘Ecosystem Services’ and is expected to convey the outcomes of Task 7.2 “Conceptual Framework for valuation of ecosystem services in PAs”.

Over the past several decades, and particularly since the publication of the Millennium Ecosystem Assessment (Reid, et al., 2005) and subsequent establishment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services in 2012 (IPBES, 2017), the Ecosystem Services (ES) concept has become a dominant conceptual framework for development of sustainable land use policy and management (Seppelt, et al., 2012). In particular, the IPBES calls on participating nations to conduct comprehensive ES assessments in order to generate knowledge regarding impact of humans on the environment and to help map out policies that can assure ecosystem integrity and the continued flow of ecosystem services to human beneficiaries (Díaz, et al., 2015). As such, numerous frameworks for assessment have been proposed and implemented for identifying, characterizing and valuing ES and their temporal and spatial dynamics (e.g. Brown & Fagerholm, 2015; de Groot, Wilson, & Boumans, 2002; Kareiva, Tallis, Ricketts, Daily, & Polasky, 2011; Maes, et al., 2012).

Since these efforts are relatively recent, what is less well studied is how the results of such assessments have been integrated into land use management, planning and policy.

Given context above overall WP7 objectives and the ECOPOTENTIAL outcomes already available, the challenge in place was to develop a DPSIR based framework by considering the data and information being gathered within the project (EO and in-situ data, PA’s socio-ecological characterization, including current flow of ES, stakeholders and management challenges (Drivers and Pressures), and management options (Responses).

Our proposed methodology encompasses a **Stepwise Iterative Approach** (SIA) that consists of three main components:

- a **DPSIR-based storyline** detailing the current state of the ecosystem and major elements such as drivers and pressures influencing the area of interest,
- a causal network map **(Mind Map)** unravelling the relationships from particular ecosystems of the PAs to the respective ES and up to (EO based) indicators,
- a tool such as **Bayesian Networks (BN)** which provide end users with visualizations representing probabilistic future states of protected areas given various management pathways.

A cornerstone of the proposed three steps approach described above is **stakeholder engagement** along the entire methodological pathway and a stepwise approach from the storylines, to structural expression of the storylines in mind maps, which in turn are used as a basis for the respective BNs.

1. Introduction

In the last few decades, anthropogenic pressures on the ecosystems around the globe have increased. In order to optimise the benefits in the face of increasing pressures, knowledge-based conservation, management and restoration policies are urgently needed. One of the key elements in achieving an optimization regime is an effective monitoring and modelling program which allows for the extraction and interpretation of the trends and states of each ecosystem and its services. Existing and new Earth Observation (EO) products as well as field data monitoring data are combined with interpretation and trend detection tools, data services, and ecosystem models. In this way, the information generated from multiple disciplines can be integrated in a complimentary manner, thereby enhancing information content of the final outputs and allowing for better-informed policy decisions and management operations. This is especially true for Protected Areas (PAs) which fall under fine scrutiny of international and local mandates but continue to provide essential services which are utilized to varying degrees by society.

The ECOPOTENTIAL project aims to provide blended information sets and decision support tools in order to monitor and optimize Ecosystem Services (ESs) derived from internationally recognized PAs through the use of EO , models, and information systems which are tailored to end user needs through a processes of stakeholder involvement. Such stakeholder involvement is realized through the combination of efforts undertake across work packages including collaborative modelling in Work Package (WP)6 and 7, interviews and surveys intended to assess information needs and current implementations measures undertaken by WP11, and the future needs and aims of PAs and management agencies executed under WP9. This critical information is aggregated within the WP7 ES DPSIR based framework as the current management and also monitoring strategies, supplemented by information arising from both WP 4 and 5, must be included with modelling efforts from WP6 in order to provide a current status assessment as realized through Deliverable 7.1. Additionally the future management and policy scenarios derived through WP9 and climate change projections realized within WP8 must be compatible and injected within modelling frameworks in order to effectively provide information on potential future states and optimization regimes which is a critical component of any decision and information support system developed further within WP7. Therefore, whilst the focus within this WP is on the assessment of Ecosystem Services, a framework to achieve such ends as realized through this deliverable requires multiple inputs and project wide crosscutting in order to achieve such ends. While this approach has been acute defined within the context of this project, the methodology and step-wise requirements have been generalized for universal applicability via the framework defined within this deliverable.

The overall objective of Work Package (WP) 7, ‘Ecosystem Services’, is to combine multiple sources of ecosystem data (EO, in-situ measurements and ecosystem modelling) as input for spatial and temporal mapping of ecosystem services and their benefits, in particular, at the level of protected area management. The completion of the set of WP7 objectives is expected from the developments arising from four individual tasks though well defined and articulated in pursuing the WP 7 goals.

This document corresponds to the ECOPOTENTIAL Deliverable (D7.2) which is one of the expected outcomes from WP7 ‘Ecosystem Services’ and is expected to convey the outcomes of Task 7.2 “Conceptual Framework for valuation of ecosystem services in PAs”.

The Task 7.2 “Conceptual Framework for valuation of ecosystem services in PAs” aims to:

1. Enhance the knowledge created in Task 7.1 (“Assessment of the services of protected areas”) by further defining the possible drivers of change (and their related pressures/mechanisms) that would affect the ecosystem services provided by the PAs, and assess/quantify the associated uncertainties in the data sources and the risk of impact on ecosystem services (Task 6.3).
2. Develop a conceptual framework aimed at sustainable protection, management and monitoring of ecosystem service use in the selected protected areas. This will consider multi-driver and multi-pressure analysis of impacts on ecosystem state adopting DPSIR framework (information from Task 6.2 and 6.3).
3. Apply this framework to guide actions of enhancing protection levels in the focal protected areas (WP9) and as a protocol for the definition of future protected areas (feed in last Task of WP9).

Deliverable 7.2 is designed to enhance the knowledge generated within Deliverable 7.1 through the inclusion of drivers of change, including pressure mechanisms, and an integration of the potential impacts on the ecosystem state and future delivery of services that such pressures and mechanisms may have. Additionally, this deliverable includes a generalized ESs DPSIR based framework which is developed within the project and specifically applied to the PAs within the scope of EOPOTENTIAL, accounting for the various layers and interconnectivity of information requirements outlined above. This generalized approach can be applied to other areas around the globe regardless of protection status in order to investigate and evaluate the delivery and status of ESs as realized through this project. The results of the framework application to ECOPOTENTIAL PAs are also detailed within the deliverable. Not all Protected Areas have achieved the same level progress by the time this deliverable was submitted due to delays in information requirements, scheduling interviews or collaborative sessions, amongst other reasons. However, the application thereof will continue throughout the remained of the project and will be reported in subsequent deliverables as marked achievements.

2. Policy and Research Context

Over the past several decades, and particularly since the publication of the Millennium Ecosystem Assessment (Reid, et al., 2005) and subsequent establishment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services in 2012 (IPBES, 2017), the Ecosystem Services (ES) concept has become a dominant conceptual framework for development of sustainable land use policy and management (Seppelt, et al., 2012). In particular, the IPBES calls on participating nations to conduct comprehensive ES assessments in order to generate knowledge regarding impact of humans on the environment and to help map out policies that can assure ecosystem integrity and the continued flow of ES to human beneficiaries (Díaz, et al., 2015). As such, numerous frameworks for assessment have been proposed and implemented to identify, characterize and value ES and their temporal and spatial dynamics (e.g. Brown & Fagerholm, 2015; de Groot, Wilson, & Boumans, 2002; Kareiva, Tallis, Ricketts, Daily, & Polasky, 2011; Maes, et al., 2012). Since these efforts are relatively recent, what is less well studied is how the results of such assessments have been integrated into land use management, planning and policy.

Given its importance in the European policy context, and connection with ECOPOTENTIAL goals and challenges addressed, we next provide a brief description of the MAES (Mapping and Assessment of Ecosystems and their Services) framework developed under the scope of the EU 2020 Biodiversity Strategy (Maes, et al., 2016; Maes, et al., 2012).

Indeed, at EU (European Union) level the 2020 Biodiversity Strategy (which goal is halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restoring them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss) includes targets to maintain and restore ecosystems and their services (Target 2, Action 5). The major framework provided to Member States as a means to achieving this target is the Mapping and Assessment of Ecosystems and their Services (MAES). The framework is based on the premise that biodiversity contributes to ecosystem functioning and therefore to delivering ecosystem services (Cardinale, et al., 2012). MAES provides steps that can be taken to increase the knowledge and status of ecosystems and their services but seems to be more applicable on a regional or national level rather than on a protected area level. EO is not explicitly mentioned in the Biodiversity Strategy. The MAES framework has been worked out methodologically, but its application still is in its infancy. Various EU projects have been developed (and finished) lately that take MAES as a starting point from which the application of the ES concept is further developed (e.g. MESEU, MARS, ESMERALDA). For the marine and coastal aquatic environment in particular, the methodology is insufficiently developed. The European Environment Agency (EEA) is currently undertaking work to further develop and operationalize the MAES approach for the marine environment for application at the EU level.

Philosophically, the ES approach may have been conceived as a response to the perceived lack of success of previous approaches for addressing regional and global environmental degradation (Armsworth, et al., 2007). For instance, in the 1990s, the biodiversity concept was advocated by many ecologists and others as a focus for land use management and conservation policy (Wilson, 1988; Mace, 2014). Biodiversity conservation, as a policy objective, was criticized from a number of perspectives, including that it was heavily value-laden, reflecting the personal biases of its advocates (Takaks, 1996), it was a scientifically vague concept, it led to decisions that neglected human well-being, or that it just was not serving a productive role in slowing degradation of habitat and loss of biodiversity (Armsworth, et al., 2007). ES, on the other hand, were connected explicitly to the benefits humans derive from ecosystems (and the biodiversity contained within), and therefore to human well-being in general (Reid, et al., 2005). Whereas biodiversity was as much a biocentric concept (when its intrinsic value was emphasized) as an anthropocentric one (when it embodies a direct value to humans), the ES concept was unabashedly anthropocentric in its emphasis. While the IPBES, with its slogan “Science and Policy for People and Nature”, emphasizes biodiversity alongside ES, it does so by recognizing that biodiversity lies at the foundation of the provision of ES (Díaz, et al., 2015; Cardinale, et al., 2012; Díaz, et al., 2018). The IPBES differentiates between intrinsic and anthropocentric value of biodiversity, focusing on the latter (Díaz, et al., 2015). While not without critics (e.g. Dempsey & Robertson, 2012; Kosoy & Corbera, 2010; Spangenberg & Settele, 2010), the ES framework is currently a predominant and preferred framework in contemporary conservation research.

The contrasting emphases of the ES and biodiversity approaches has led researchers and managers to explore trade-offs among ES and biodiversity (Faith, et al., 2010). PA managers throughout the world are currently negotiating between these two approaches in attempts to slow and reverse environmental degradation and its negative impact on humans and biodiversity.

The idea of trade-offs between ES and biodiversity is in fact a very costly idea, diverting time and resources from the real problems of sustainable management. In fact, one key element is the meaning of biodiversity and if we view biodiversity as: i) the diversity of ecological systems viewed as life supporting entities; ii) the diversity of biological systems (species diversity); iii) the genetic diversity and ultimately; or iv) the cultural diversity of socio-economic systems, all of this integrated in a hierarchy of ecological systems then it becomes clear that the natural capital is the foundation of any socio-economic system. If the environment is being seen as an unstructured group of elements: water, air, fauna, all having an effect on the human populations and not as a network of self-organised and hierarchical systems that provides ecosystem services, then the conservation of biodiversity is a lost endeavour. The transition should be made from: i) a static understanding of the ecosystems (we are not conserving "a status" we are conserving in fact "trajectories" that different systems could take), ii) from a short term view to a long term understanding of the system dynamics, iii) from a "collection of factors" to a hierarchical organised system view (Vadineanu, 2001), iiii) from a species centred conservation to an ecosystem approach and in fact to a network based conservation planning (taking into consideration the connectivity aspects). The idea to consider the integration of DPSIR and ES is based mainly on the need to respond to the transition mentioned above and will be described in the following section. The DPSIR is useful in the context of evaluating and examining the current status of biodiversity, the ecosystem, and its ES. A DPSIR model depicts various drivers which produce pressure and finally affecting the overall state of the system; hence, influencing existing ES.

3. Roadmap to a DPSIR Based Ecosystem Services Framework

The DPSIR (Drivers, Pressures, State, Impact and Response) framework can be used to describe in a coherent way the ecosystem services and the responses that management of protected area could take to solve environmental problems (Turner, et al., 2010). *Drivers* of change (D), such as population, economy and technological development, exert *Pressures* (P) on the *State* (condition) of ecosystems (S), having *Impacts* (I) on biodiversity, which in turn affect the level of ecosystem services they can supply. Based on this, policymakers at different levels could implement relevant *Responses* (R) by taking action that aims to tackle negative effects or optimize the delivery of a selection of services within a defined operational or objective plan. Such responses will seek to attain a portfolio of services that have been identified by stakeholders, managers, and policy makers which, when combined, achieve the objective management goals as well as addressing all existing policy and procedural requirements such as the Water Framework Directive (WFD) and habitat directive (Borja, et al., 2006) amongst others. The iterative nature of this framework allows for the assessment and redefinition of such objective through the integration of information and data sources, modelling and projection software, and both probabilistic and deterministic analytic tools which aid in defining if optimization goals are achievable, practical, or achievable given defined *Response* implementations.

Given the context above, the challenge was in developing a robust and contextually relevant DPSIR based framework by considering the data and information nexus required to support and inform the identified elements of DPSIR. These include but are not limited to EO and in-situ data. Each PA's socio-ecological characterization including current flow of ES, stakeholders and management challenges (Drivers and Pressures), and management options (Responses) are all required in order to effectively execute such a comprehensive framework. While some of these elements are more easily attainable, such as Remote Sensing (RS) and in-situ data sets derived from WP4 and WP 5 respectively, relevant to key variables as outlined in Deliverable 2.1, others, such as the managerial and policy based responses, require engagement strategies in order to develop. These stakeholder engagement sessions have been executed via surveys as well as round-table discussions, which were hosted by the partner institution most closely affiliated with each PA resulting in Deliverables 11.1 and 11.2. With such a diverse set of information required in order to supply the relevant information for a DPSIR ES framework, a method of organizing each of the steps required is deemed necessary in order to provide a roadmap to executing such a framework. Therefore a general sequence of elements developed within WP7 has been contextualized within Figure 3.1– Optimising PA Management. These elements clearly rely and must poses synergies with various other efforts across the project. As all modules progress at various paces, the methodology of interconnecting each of tasks and work packages must allow for and take into account possible time delays in delivery of materials. Therefore, an iterative approach is proposed in order to account for time dependant advancements in various components of the framework, this approach is called the Stepwise-Iterative Approach (SIA).

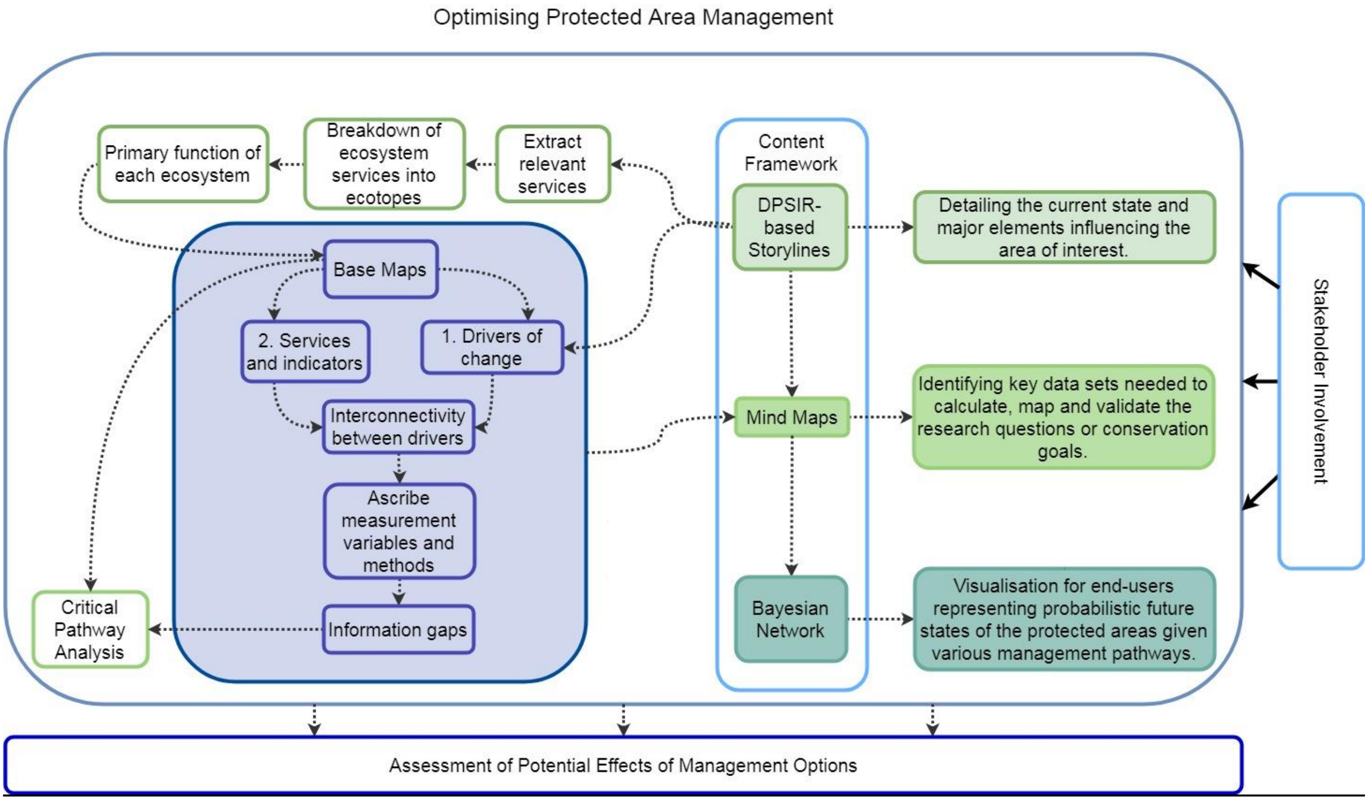

Figure 3.1: Optimising Protected Area Management

Stepwise Iterative Approach (SIA)

The SIA is a methodology for organizing and improving the workflow and information exchange within Work Package 7 (WP7) and between WP7 and the other Work Packages (WPs). It was also introduced to help the setup of, and improve the 'essential' DPSIR causal network per PA, without doing an over-dimensioned ecosystem description, modelling and data collection, and to be a priori clear about who should do what for the end-to-end modelling of the ES capacity. Ecosystems are highly complex and dynamic, whereas our knowledge is commonly comprised of only partially known and knowable, predominantly static descriptions of components and interactions (processes). Hence, it is highly relevant to organize and prioritize the partial ecosystems of the PAs that are most important for the ES assessment based on stakeholders (such as park managers) perceptions, and to use this reduced and focussed model for assessing the ES capacity assessment and optimisation.

DPSIR Based Storylines

The causal chain of the DPSIR framework as a tool to integrate knowledge from diverse disciplines has been widely adopted in environmental assessments but less applied in the context of PA management. Our findings indicate that DPSIR has potential to involve stakeholders in addressing the complexity of PA management given scenarios of future land use scenarios. Although we argue that DPSIR framework is a relevant tool for structuring communication between scientists and end-users of environmental information, allowing policy-makers to understand more easily the environmental problems in place it has to be completed by aspects addressing uncertainty. Without these, the DPSIR framework may appear as a deterministic and linear 'causal' description of environmental issues, which inevitably downplays the complexity of the environmental and socio-economic systems.

Mind Maps

A mind map is a diagram for visually organizing and brainstorming information by showing hierarchical relationships among pieces of the whole structure. The origin is a central concept or subject to which associated ideas, topics etc., are added by using branches, such that a framework is constructed around the central concept. These branches can then be further split and create a radial diagram that represents semantic or other connections to structure the main contents of a topic hierarchically (Eppler, 2006). This visual structure can depict monotonous information in an organized way and facilitate the analysis of the central concept. A mind map resembles how our brain actually works and improves therefore the ability to recall and memorize information (Farrand, et al., 2002). Apart from the old-fashioned way of creating a mind map with a pencil and a sheet of paper, there are mind-mapping programs that can organize large amounts of information and digitizing mind maps. Gathering information and turning it into mind maps works as a first step to the creation of a unified knowledge base as well as being the basis for BN modelling.

Bayesian Networks

Bayesian Networks (BNs) have been used to address a wide variety of applications, such participatory ecosystem service mapping (Pelagos), modelling scenarios of land use change (Sierra Nevada), to analysing uncertainty in ecosystem service assessments. They are useful to start the examination of a complex issue where quantitative data are limited but relevant knowledge is available, or where various types of data, models, and knowledge need to be integrated. BNs facilitate sharing knowledge between scientists and other stakeholders, where interdisciplinary work is required. This is useful when modelling systems that are highly sensitive to decision-making of stakeholders, such as farmers in the Sierra Nevada, or whale watching operators in Pelagos. In task 7.2 we tested the use of BNs based on the premise that it could provide a methodology for integrating qualitative and quantitative knowledge in a nonlinear manner.

The Importance of Stakeholder Engagement

Stakeholder engagement has become, over the past 50 years, an almost axiomatic central component of planning, policy and management, particularly in the environmental and natural resource sphere (e.g. (Arnstein, 1969; Clark, 2011; Reed, 2008)). Similarly, the sustainability literature focuses on participatory processes as a prerequisite for realizing sustainability goals, and this is further reflected in the criteria of environmental and sustainability initiatives at the regional (Orenstein & Shach-Pinsly, 2017) to the international scale (United Nations, 1992; United Nations Convention to Comnat Desertification, 2009). It is telling that participatory processes are considered such an important prerequisite towards achieving sustainability goals that the presence of participatory processes is considered an indicator of success (Holzer, et al., 2018; Weaver & Lawton, 2007).

A set of case studies (PA) being part of the ECOPOTENTIAL project tested the proposed conceptual DPSIR based framework to ES valuation (though only a few WP7 partners have developed the entire cycle of the above described framework).

As mentioned in the previous section there is little consensus on an overarching methodological framework that is adapted to include such a wide variety of data sources and inputs and is an integrated approach to address the complex issues linked with protected area management. Our proposed methodology encompasses a SIA that consists of three main components: a DPSIR-based storyline detailing the current state and major elements influencing the area of interest, a causal network map (mind map), and decision support tools such as Bayesian Networks (BNs) and Serious Games (SGs) which provide end users with visualizations and statistics representing probabilistic future states of protected areas given various management pathways (Serious Games will be addressed within WP9). As illustrated Figure 3.1 the DPSIR based storyline contains the full array of Services which are identified as prioritized or relevant to management policies and include critical services which are highlighted by either researchers or stakeholders. These services are contextualized in the narrative and categorized per ecotope within which they are provided and grouped by the ecosystem function which supports the service. Additionally the narrative explicitly identifies previous research and knowledge of the DPSIR elements influencing each service and function, outlining the current state of system understanding as well as prospectus already identified by researcher knowledge and published literature on management techniques and condition. This information is distilled into an infographic version of the narrative through the execution of a mind mapping exercise. The manner through which this exercise is executed is clearly outlined in a detailed manual produced within the project and is supported via a webinar. These maps highlight the different areas through which services are delivered and are used to illustrate the coverage of services across the PA ecotopes, identifying services delivered in various domains and the interdependencies on which these services rely. For example, while the food provisioning of fisheries may take place in the near shore marine environment, the nursery and spawning areas required to support said fisheries may exist within the shallow low-dynamic waters in estuarine environments. Furthermore, ascribed to each of the services and functionality are the information pathways which can be used to provide data or investigate these elements. This includes remote sensing applications, in-situ monitoring programs and data sets, as well as modelling applications. In this way, services which possess neither monitoring nor modelling applications can be identified, information gaps assessed, and potential but on-utilized sources of information ascribed. Mind maps such as these can vary in complexity and subsequently be reduced in order to highlight the specific interactions and relationships occurring between diverse ES as a communication tool amongst researches and also with stakeholders or managers in order to reinforce or explain causalities and fundamental understanding of the PAs in question. A simple example of the Dutch Wadden Sea can be found in Figure 3.2.

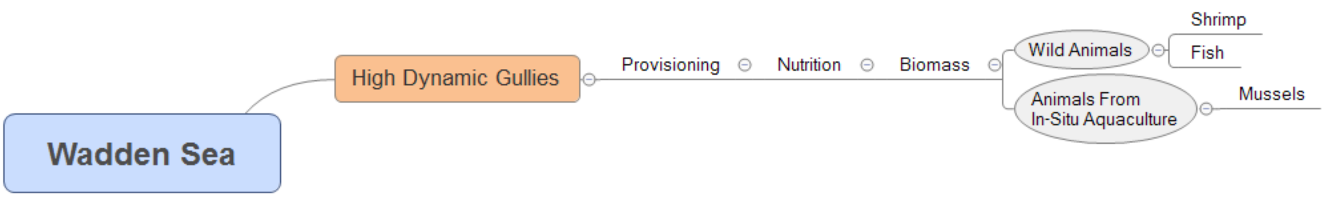

Figure 3.2: Simple Example Mind Map of One Ecosystem in the Dutch Wadden Sea

These maps can be further adapted to include the DPSIR elements as well, however, due to interpretability issues, this is done only for the parred down versions of the mind maps as, otherwise, the interconnectivity becomes convoluted and almost indecipherable, a state which some have coined "a horrendogram". In such a state, the multiple points of stress exerted by pressures across multiple critical ES can be visualized, initializing and fostering effective collaborative modelling exercises and allotting for assessment of the far-reaching implications of singular pressures across swathes of services.

A cornerstone of the proposed three steps approach described above is stakeholder engagement along the entire methodological pathway.

In the following section, we present a methodological literature review organized by the proposed framework components and then we discuss the potential of their combined use as proposed in this deliverable and explain how it is applied to several test case studies in the larger context of the ECOPOTENTIAL project (http://www.ecopotential-project.eu/). The test cases range from PAs in mountains, coastal and arid ecosystems.

4. Revision of the Proposed Methodology

4.1 Stepwise Iterative Approach

The Stepwise-Iterative Approach (SIA) is a methodology for organizing and improving the workflow and information exchange within Work Package 7 (WP7) and between WP7 and the other Work Packages (WPs). It was also introduced to help the setup of, and improve the 'essential' DPSIR causal network per Protected Area, without doing an over-dimensioned ecosystem description, modelling and data collection, and to be a priori clear about who should do what for the end-to-end modelling of the ES capacity. Ecosystems are highly complex and dynamic, whereas our knowledge is commonly comprised of only partially known and knowable, predominantly static descriptions of components and interactions (processes). Hence, it is highly relevant to organize and prioritize the part of the PA ecosystem that is most important for the ES assessment the stakeholders are interested in, and to use this 'essential' model for assessing the ES capacity assessment and optimisation.

The SIA was also meant to help other WPs to better relate to and interact with each other, and in an iterative way. This way, the work packages working at the more technical part of the project (data collection, aggregation, modelling) receive more focused questions from the work packages focusing on ES and stakeholder interactions. Vice versa, the ES and stakeholder-oriented WPs could improve the understanding and applicability of the data provided and results from the modelling for ES assessment and management decision support.

The iterations were meant to increase focus and detail each round an iteration was completed. With each iteration, the components described in the sections would gain increases in complexity and focus after each iteration. As a result, the process of mind mapping the social - ecological system can be performed using a structured and explicit means of set up, development and application, adding complexity where needed, and simplifying where possible. Having done a first iteration of mind mapping, BN, modelling, and data acquisition would result in a better understanding within and between WP of the complexity of the issues dealt with, improve communication in and the ontology for the project.

Below, the SIA is presented, which we developed in the first year of the project and used up to now. As, said, it has a focus on the work within WP7, but also a description of its relationships with the other WPs. The SIA has the shape of a mind map, a format applied throughout the project to simplify the inherent complexity of the social-ecological systems working with in this project.

In the Figure 4.1, WP7 boxes are green, other WPs are red, the steps are numbered and in blue boxes, which are connected through dashed lines. Feedback loops (through which iterations start), are illustrated by solid, fat lines.

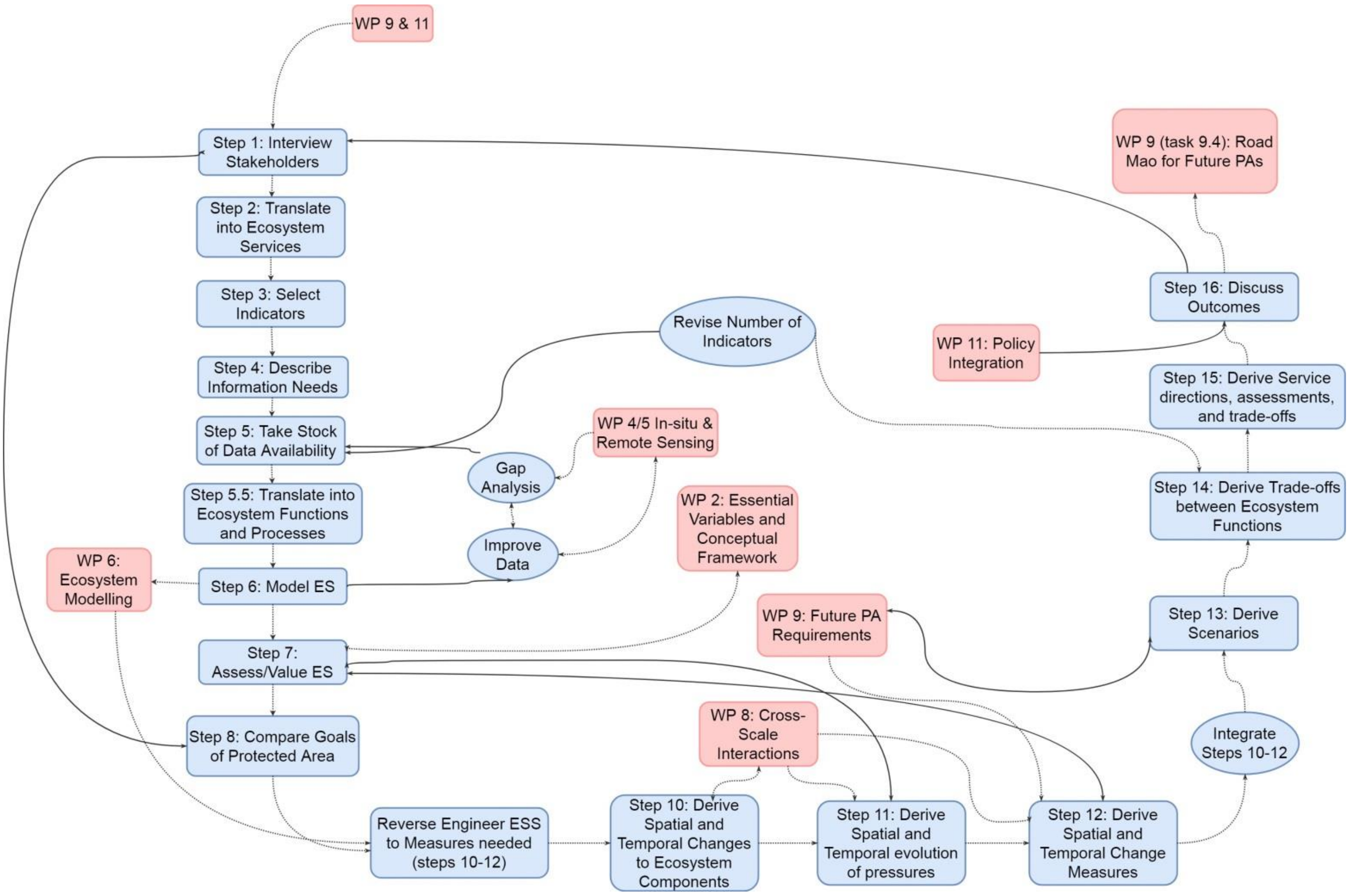

Figure 4.1: The Stepwise-Iterative Approach for improving workflow, communication and shared understanding within WP7 and between WP7 and the other WPs

The functionality of this rather elaborated is as follows. The issues ('threats') managers have to deal with in various PAs are discussed and selected in a first interview. One of the issues is chosen to start working with, e.g. sandflat degradation due to dredging (perceived 'state' change with perceived cause 'pressure'). This is translated into the ES (e.g. shellfish biomass for harvesting) capacity it contributes to and indicators (relevant parameters) are chosen that represent the ES functioning; this could be done at different levels: at the pressure level (frequency and location of dredging), at the state level (extent and degree of sandflat degradation), and at the system function level directly underpinning the ES (biomass/numbers of shellfish). To be able to apply this, data are needed, and a causal understanding of these levels. The need for specific data (with a spatial and temporal resolution) is described, and compared to what is available both from in-situ measurements and from remote sensing. The gap between these two needs to be made explicit and where possible, filled (feedback no. 1 for data); knowing what we know contributes to assessing the reliability level of management options later on in the project. At this stage, mind maps of the social-ecological system (also called linkages frameworks or causal networks) play an importance to assess the completeness and reliability of causal relationships, data need and availability. When data have been taken stock of, and relationships have been quantified, the modelling of the ecosystem processes can start. This modelling does not yet incorporate uncertainty, but is meant to assess the (capacity to) supply ES. When the results are then compared to the PA goals (feedback no. 2 for current PA goals), an additional iteration for completeness or adjustment of the goals, ES choice and data can be performed. In the following three steps (10-12), a more detailed analysis is done on the relationships between the ES and measures needed to improve this ES, but especially also on the trade-offs with other ES. Taking measures to increase one ES may lead to the decrease of another ES. Also, other pressures may contribute to the undesired state change. These trade-offs need to be made explicit; on the other hand, there may also be synergies of ES, that are supported by the same ecosystem function. In the example of sandflat erosion, a synergy could be the increase in biodiversity due to a more stable habitat (less frequent colonization needed).

From then on, the work focus changes to assessing the effect of the possible management measures to prevent, compensate or mitigate undesired effects, and the likelihood of the most successful measure scenarios to abate the undesired effects. In essence, this is going the reverse direction of the one described above, but with more detail. The extent to which detail needs to be added depends on the outcome of the scenarios in terms of ES supply (feedback 3: ES assessment), the comparison with the original goals (feedback no. 4: future PA goals and requirements), assess uncertainty level and likelihood level of the different scenarios (through BNs, and feedback no. 5: modify number of relevant parameters to include in the assessment). The end of the SIA consists of a series of quantitative comparisons between the trade-offs of ES supply, choosing the most likely successful scenario, and discuss this with the PA management. Here, a last feedback is possible, by testing against the actual PA goal, the feasibility of measures, a cost-benefit analysis etc.

It has to be said that this approach was set up at the beginning of the project, and that in reality, many more feedback loops were created between the WPs and within WP7, and that sometimes an iteration was more a thought process than actually doing sets of calculations. Also, sets of feedbacks could sometimes be aggregated, e.g. the feedback for the assessment of improved ES as a result of a possible measure, and the choice for parameters (indicator) improvement, when the ES and ecosystem functioning were causally very strongly related. Although not followed by the book (and which most likely never is a preferred approach, also the SIA needs an iteration to improve...), the SIA was a good means to the end of improved workflow and information sharing, and an understanding of sense of place in a large, and complex project with over 40 partners and subcontractors.

4.2 DPSIR Based Storylines

Within ECOPOTENTIAL, storylines link real-life issues which have broad relevance to many PA included in the project. The storylines specify the needs for EO data and in-situ data for ecosystem modelling, ecosystem services, cross-scale topics, demands for future protections, policy and capacity building. Each storyline is focused within at least one PA and it puts the basis for further operational work in the field. Storylines are iterative processes whose flow of activity and practical implementation evolves with the increase of knowledge and the demands by stakeholders. A detailed description of storylines can be found in Deliverable 2.1.

The DPSIR is a system analysis approach for describing the interactions between society and the environment, adopted by the European Environment Agency (EEA, 1999). The DPSIR framework distinguishes five elements (Figure 4.2) starting with ‘Drivers’ (e.g. population, land use, industry, agriculture), through ‘Pressures’ (e.g. production of waste, land use change, emission of chemicals, excessive use of environmental resources), ‘States’ (health, soil -, water- and air quality, biodiversity), ‘Impacts’ (economic or environmental impacts of changes) to ‘Response’ (societal or policy response). As such, the DPSIR framework is aimed at describing the causal chain of events from the initial natural or human-induced drivers of environmental changes, to feedbacks on these driving forces and thus relationships between the DPSIR elements.

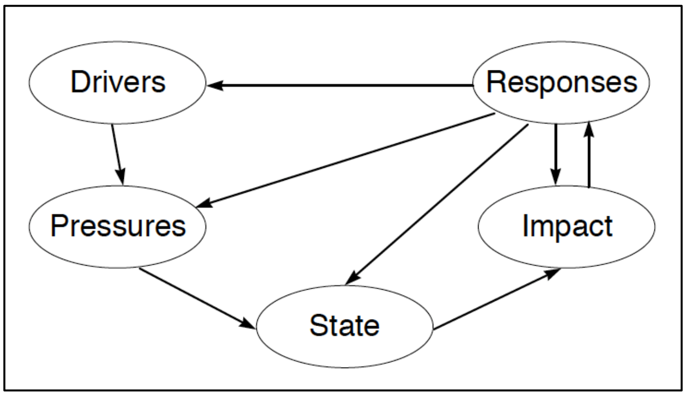

Figure 4.2: DPSIR Framework components (Source: EEA, 1999)

The DPSIR framework has been widely used within environmental assessments of the multitude of social-ecological systems, but mainly in the EU areas. One of the key discrepancies in the practical application of the DPSIR terminology results from the assignment of the individual variables to one of the five framework categories. For example, species invasion is sometimes considered as ‘Driver’, and sometimes as ‘Pressure’ (cf. (Gari, et al., 2015)). The DPSIR framework has not only been extensively used, but it has been subject to substantial criticism (Gari, et al., 2015). The need for more comprehensive frameworks for describing the origins and consequences of environmental problems has been addressed throughout the evolution of the DPSIR over time. In particular, the DPSIR framework has been modified by different researchers, considering more or different categories and variables. For example, to address the practical aspects of the Water Directive Framework (WFD) implementation process (Rekolainen, et al., 2003) have modified the DPSIR into the DPCER (Driver - Pressure - Chemical state - Ecological state – Response) framework. Within the DPSIR evolution, human welfare has gained more importance. For example, the DPSWR framework (Cooper, 2013; O'Higgins, et al., 2014) uses ‘Welfare’ instead of ‘Impact’ and is aimed at reducing definitional uncertainties of its predecessor. Within the DPSER framework (Kelble, et al., 2013), the ‘Impact’ is replaced by ecosystem services (E) to highlight negative and positive impacts on the ecological system. Other authors (Müller & Burkhard, 2012) are also identifying the ES as ecological indicators perceiving them as impacts under the DPSIR framework (see below a detailed explanation of the authors’ conceptualization). Indeed, there is an increasing trend to adopt the concept of ES within DPSIR based frameworks and, as such, the concept of societal wellbeing. For instance, the DAPSI(W)R(M) (pronounced dap-see-worm) framework (Elliott, et al., 2017) addressing the challenges of the marine environmental management, ‘Drivers’ of basic human needs require ‘Activities’ which lead to ‘Pressures’; the ‘Pressures’ are the mechanisms of ‘State’ change on the natural system which then leads to ‘Impacts’ (on human ‘Welfare’) requiring ‘Responses’ (as ‘Measures’). The evolution of the DPSIR suggests developments in different directions, towards natural sciences and towards social sciences. However, it is striking that in the recent years there have been more modifications towards the social sciences, with several efforts to adapt the original framework to encompass social wellbeing and inherently the concept of ES, highlighting the rise the ES in the last decades as bridging concept (ecological and socio-economic systems).

A search on "ecosystem services" and "DPSIR" reveals 318 results (listed in ISI Web of Science journals), but if we include all papers published between 2004 to 2017 (343 papers) we can see an increase in the number of publication dealing with both DPSIR and ecosystem services. It has to be stress that the number of articles considering both DPSIR and ecosystem services is an indication on the research effort that has been dedicated to understanding the main drivers, pressures as well as the state and impacts of change within social-ecological systems (SES) that can alter the ecosystems dynamics (structure and functions) to the point where not only the human well-being is threatened but even the based life support systems are endangered.

Müller and Burkhard (2012) considered the above explained DPSIR framework together with the ecosystem services cascade (Haines-Young & Potschin, 2010)and depicted how both system analysis approaches can be coupled. The authors’ conceptualization is shown in Figure 4.3. According to the mentioned authors, the *state* is described by several biophysical structures and processes (ecosystem properties) which are processually linked in the cascade component of ecosystem functions. They are understood as the basic producers of ecosystem services and *impact* refers to the ecosystem service modifications with their consequences for human-well-being and the respective valuation. The consequences of ecosystem services changes are reflected on the *responses* component that would then act over the *drivers* and forthcoming *pressures*.

Although others have further developed the linkages between both system approaches, this conceptualization is a cornerstone for the research conducted within Task 7.2 as it highlights the relation between service provision, human well-being, social and economic valuation, management and policy, dimensions of analysis seen as crucial for PA management.

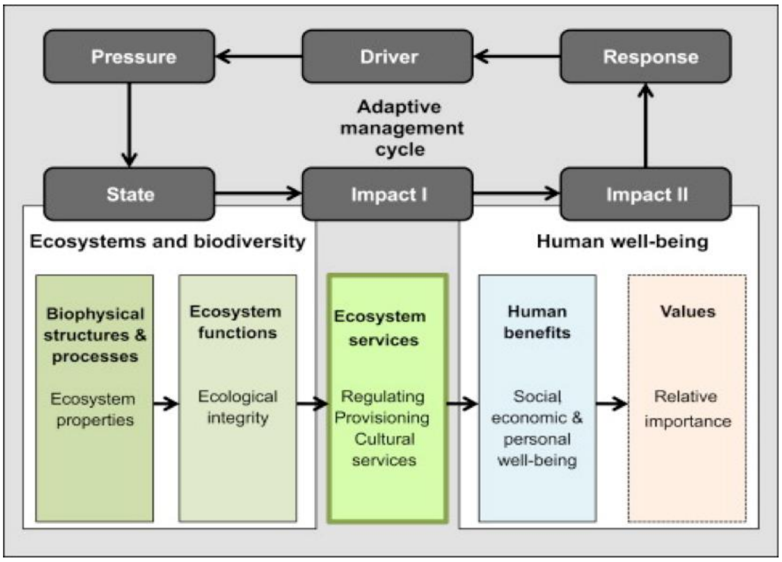

Figure 4.3: Ecosystem Services as part of the adaptive DPSIR Cycle for human-environmental systems

(Source: Müller and Burkhard, 2012)

4.3 Mind Mapping

The mind mapping technique was first described by Buzan (1976) and was designed as a technique for note taking and visually representing information (Buzan, 1976; Buzan, 1993). Mind maps can represent ideas that are linked around a central theme and are considered an easy method of organizing and visualizing complex data and the interactions among data (Crowe & Sheppard, 2012). Hence, a mind map is a diagram for visually organizing and brainstorming information by showing hierarchical relationships among pieces of the whole structure. The origin is a central concept or subject to which associated ideas, topics etc., are added by using branches, such that a framework is constructed around the central concept. These branches can then be further split and create a radial diagram that represents semantic or other connections to structure the main contents of a topic hierarchically (Eppler, 2006). This visual structure can depict monotonous information in an organized way and facilitate the analysis of the central concept. A mind map resembles how our brain actually works and improves therefore the ability to recall and memorize information (Farrand, et al., 2002).

Mind maps have applications in various situations, e.g. in personal and family situations or business situations, for educational purposes (Willis & Miertschin, 2006; Batdi, 2015; Davies, 2011; Mento, et al., 1999), scientific contexts, such as for structuring case study data (e.g. (Kotob, et al., 2016)), organizing research methods (Crowe & Sheppard, 2012), or mapping policy options (Peneder, 2008). Further research as well as practice applications supported by mind maps are organizing and analysing data in public participation processes (Burgess-Allen & Owen-Smith, 2010) by facilitating communication in these processes e.g. within conservation community groups (Luke, et al., 2014) and eliciting and representing knowledge of diverse actors (Meier, 2007). The hierarchical organization of concepts and ideas in mind mapping, allows the creation of a unified knowledge base that can be useful for decision-making processes (Pascual, et al., 2016). According to Eppler, 2006, some of the advantages of mind maps are their easy application and their capacity to provide a concise hierarchic overview of complex data with possibilities for extension of further content within processes, although they might also become overly complex and hard to read for others Eppler, 2006. Mind maps are most valuable for the objective to develop a comprehensive understanding of all the key concepts in one subject area (Meier, 2007). Relationships between variables, data sources, Ecosystem Function (EF) and ESs have been tabulated, described, and placed into various sorts of lists in the past as expressed in (Balvanera, et al., 2006) and (Cardinale, et al., 2012), however, such applications do not allow for clear or concise relational pathways to be detailed or described. Pascual, Pérez Miñana, & Giacomello, 2016 had shown that a mind map, based on literature review, could effectively incorporated together biodiversity, ecosystem functions, services and human well-being whilst explicitly denoting the interconnectivity between these elements. Additionally, the European project BiodivERsA (http://www.biodiversa.org/) used a similar approach in order to identify relevant stakeholders while creating relationships and identifying important data sets. This method of aggregating information was noted to not only assist in the identification of critical pathways and structures, but also served as a very useful communication tool (Durham, et al., 2014).

Apart from the old-fashioned way of creating a mind map with a pencil and a sheet of paper, there are mind-mapping programs that can organize large amounts of information and digitizing mind maps. One of these tools is XMind which enables the possibility of digital brainstorming and mind-mapping. For creating mind maps of ecosystem services of the ECOPOTENTIAL PAs, we used XMind 7 (http://www.xmind.net/de/).

In ECOPOTENTIAL, the mind maps resulted in a stratified effort of organizing ecosystem processes and functions with respective modelling tools and data sources to represent ecosystem services in a given region. EO data component for modelling or indicator based data play here an important role for ecosystem services characterization. The storyline of each PA served as basis for the structure, complemented with stakeholder inputs. For comparative situations with distinct informants such as different PAs in the ECOPOTENTIAL context, it was important to build up a rigid mapping protocol to achieve mind maps based on a similar structural logic. A common protocol for setting up and formatting the mind maps was elaborated by WP7 partners. Hence, the mind maps of ecosystem services in the different PAs were constructed based on the Common Classification of Ecosystem Services (CICES, https://cices.eu/) of the European Environment Agency (EEA), following the order: Ecosystem Service (ES) section → ES division → ES group → ES class → class type (specification). The next level after CICES based ESs are the ecosystem functions supporting the particular service followed by proxies/ indicators/ surrogates which can be used to evaluate the ecosystem functions. Finally, for each of these proxies/ indicators/ surrogates, available data (in situ, EO or model-based) are indicated. Overall, the "base" mind map structure is as follows (see also Figure 4.4**Errore. L'origine riferimento non è stata trovata.**):

1. PA or study region (e.g. Wadden sea - the "central" node);
2. Ecosystems in which the ES are utilized (first level of branches);
3. Within each ecosystem – branches of most important ESs based on the storylines of PAs structured by the above-mentioned subdivision according to CICES;
4. For each ES - Ecosystem functions supporting the service;
5. For all functions - proxies/indicators/surrogates to evaluate the functions;
6. For each proxy or indicator - EO data, models, or in-situ measurements.

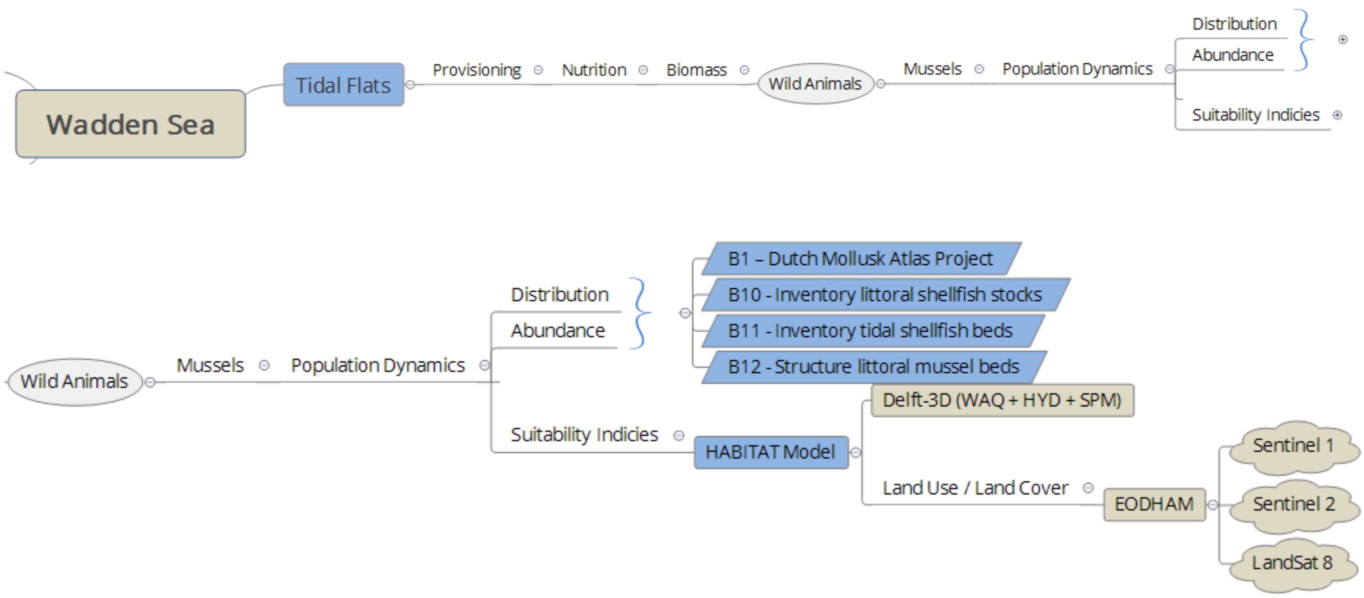

Figure 4.4: Overall base structure of mind maps

Storylines provide a conduit through which the generality of ecosystem states, pressures, drivers, and interconnectivity within target protected areas are explained. This narrative acts as an encompassing introduction to the relevant processes involved and states of various ecosystem functions. Past management actions, developing trends within the systems, and areas of research interest are also included throughout the story. The combination of this wide breadth of information provides a wholesome understanding of the ecosystems present and the functionality of the protected area. However, as the document exists as a broad overview of the protected area, focal characteristics which will be investigated through the project require further emphasis, not only as to exactly which components are of highest relevance, but also to relay the manner through which they can be investigated.

For the purpose of facilitating this, the scientific community executing the study has come together in order to determine what measureable characteristics are available and which parameters can be derived from remote sensing or modelling applications. The identification of these components denotes proxies or indicators for the evaluation of the services being rendered and monitored within the PA. They should serve as a method to gleam insight into and evaluate the capacity for the delivery of the various services derived from ecosystems present. There are, however, interdependencies between the services, pressures, and functions themselves. This fact is not always clear to conceptualize in the form of tabulations, and relationships can be overlooked or undervalued. Because of this, a relationship network connecting the functions, services, and evaluation measures can prove very beneficial in order to enhance the understanding of the complex systems being evaluated. More often than not, through the action of creating a network diagram, such as a mind map, additional connections become evident and allow for a more comprehensive understanding of an ecosystem's functioning. When indicators or proxies are ascribed to these connection pathways, a new, more complete paradigm of understanding comes to light. Because this is a visualization exercise, the end product also makes clearly visible the compounding factors present not only in the assessment of the delivery of ecosystem services, but also in regard to the drivers of change and potential methodologies evaluation. The complementary and supplementary nature of remote sensing, in-situ, and modelling applications can be easily extracted through such an exercise, and any information gaps clearly identified.

Mind maps are the third step in the identification and classification of relevant indicators as proxies for ES. They are highly adaptive and serve as the connection framework between an overview of protected areas and higher level scientific work, which often focuses on specific indicators or proxies. By creating such a relational network, one is able to concretize the importance of various parameters being investigated and monitored by the scientific community. Mind maps act not only as a distillation of the overall understanding of protected areas and how they inter-relate to ES, but as a tangible representation of the interdependencies inherent within the wider spectrum of ecosystem functions occurring throughout a protected area. Through an evaluation of these interdependencies and modes of functioning, critical pathways for the delivery of ecosystem services can be identified. This identification of critical pathways thereby demarcates veins for focused investigation of the ecosystem in order to quantify the current state and supply of services while simultaneously identifying and connecting a range of dynamic pressures acting upon the system.

In the exercise of creating such a mind map, the first step is to extract the relevant services being delivered as stated through the storyline. Because the storyline has been compiled through a combination of scientific inquiries and inputs from PA managers, it contains a spectrum of insights from scientific curiosities to the practicalities of management needs. A comprehensive list of services, both supporting and direct ecosystem services, is able to be crystalized from this narrative. Due to the variety of protected areas involved in the storyline and the different investigations involved in each, the full development of each of the storylines is a unique process. However, each possesses common overlays. In each, specific ecotopes deliver particular services. The breakdown of services into ecotopes helps to specify the primary functions of each ecosystem; the same service may be delivered by multiple ecotopes, however will have higher or lower relevance within each. Also, the remote sensing and modelling capabilities within each of the ecosystems varies; breaking down the delivery by ecosystem type allows for a more accurate evaluation of the services and eventual evaluation and projection methods. From this process, the base map is created.

This base map provides a means through which the connections and interdependencies of supporting services to primary services within each of the ecosystems can be expressed. By creating these connections, it is possible to determine the critical pathways and supporting services responsible for the successful delivery of final ES. This process ensures a comprehensive evaluation of the protected area as a whole rather than focusing on only the components directly involved with delivered ES. Each of the supporting services and connection pathways can be ascribed an evaluation measure such as a proxy or indicator. These indicators are the manner through which earth observation and modelling can be applied in order to evaluate the delivery of services.

With this base diagram in place and potential indicators ascribed to the connection and evaluation levels, a new layer including the drivers of change within the PA can be added. These drivers of change, similarly to the services, can be distilled from the storyline. A first step is determining the interconnectivity between the drivers themselves. This allows a visualization of the feedback loops and compounding of certain elements. This is a unique opportunity to clearly appreciate that some of the variables being measured are in fact a cumulative impact being realized by multiple drivers of changes. For example, underwater noise evaluated as a single measurement of noise can be ascribed to shipping traffic, tourism traffic, wind turbines, commercial fishing vessels, etc. To understand that one variable is accounting for a broad range of pressures and to have it clearly visualized not only assists in communications with policy makers and PA managers but reinforces the fact that such a measurement must be accounted for with all drivers in mind. Once these interactions are created, it is possible to begin ascribing measurement variables and methodologies for these drivers. By consulting the range of earth observation measurements available, a list of remote sensing, in-situ, and modelling measures can be developed. This list should contain the level of detail which can be extracted for each of these sources so that complimentary and supporting measurements can be identified. For example, if there is satellite imagery available for the chlorophyll-a concentrations in a specific marine habitat, indicating the presence of in-situ data and possible modelling applications as well allows for a clear connection between the three. Thusly, it can be expressed that the field measurements possessed can be applied to the satellite imagery for validation purposed, and both can be integrated into modelling applications to have the most robust information source possible for this measure.

This process is once again completed for the services and indicators base map. Depending on the complexity of the system, it is sometimes beneficial to separate out the variables into biotic and a-biotic spectra. The earth observation and modelling applications identified through the first iteration of pressure identification can be further applied to the list of ecosystem services and indicators. Through this exercise, it becomes evident what phases of the critical pathways developed in this first step have information gaps. This requires an evaluation of the system in order to identify other sources of information which can be integrated into the protected area evaluation in order to have a comprehensive accounting for each of the indicators within critical pathways.

4.4 Bayesian Networks

Bayesian Networks (BNs) are graphical probabilistic models that represent a set of variables and their conditional dependencies in directed acyclic graphs (Jensen, 2001; Kjærulff & Madsen, 2013). BNs are often used to model complex socio-ecological interactions, as they provide a fast and transparent way to model a large number of variables (Getoor, et al., 2004). Due to the explicit consideration of uncertainty and risk, predictions are closer to the (uncertain) reality (Reichert & Omlin, 1997). BNs can handle systems with low data availability (Hamilton, et al., 2015) or systems with diverse data types (Reckhow, 1999; Varis, 1997) including expert (Grêt-Regamey, et al., 2013b; Celio, et al., 2014), or stakeholder knowledge (Bromley, 2005). Furthermore, their graphical representation allows the visualization of causal relationships between variables, facilitating communication with stakeholders (Cain, 2001; Grêt-Regamey, et al., 2013a; Celio, et al., 2015). Furthermore, BNs allow fast data integration as soon as new data becomes available, supporting adaptive management (Marcot, et al., 2006; Gonzalez-Redin, et al., 2016), and scenario modelling can provide fast outputs to be discussed with stakeholders. Sensitivity analysis of BNs can help to identify nodes which have the highest influence in the BN and which should therefore have the highest accuracy (Coupe, et al., 2013; Kjærulff & Madsen, 2013).

Nonetheless, BNs also have some limitations, such as not being able to incorporate direct feedback loops (Landuyt, et al., 2013). Feedbacks can only be included through cumbersome approaches such as time-slicing (Jensen, 2001), where multiple networks represent the system at different time steps, and outputs of one network are inputs to the next. Furthermore, only discretized variables can be included in the BN, which can cause information loss (Jensen, 2001). On the other hand, discretization also allows BNs to capture non-normal distributions and non-linear relationships between variables (Uusitalo, 2007). Hybrid BNs have been developed to allow the use of continuous data (e.g. (Aguilera, et al., 2010)), but they are limited to variables with Gaussian distributions (Kjærulff & Madsen, 2013). When expert knowledge is used to build a BN, there is a risk of under- or overestimation of their confidence (Speirs-Bridge, et al., 2010). The model can be seen as too subjective if only a few experts or experts from only one discipline are involved (McBride, et al., 2012). If a model is too simplified, it also lacks credibility and acceptance by the public, researchers and politicians, while an overly complex model can be difficult to communicate. A summary on advantages and challenges in using BN is provided in (McCann, et al., 2006), (Uusitalo, 2007), and (Landuyt, et al., 2013).

BNs have been used to support management decisions on watersheds (Bromley, 2005; Keshtkar, et al., 2013), marine landscapes (Stelzenmüller, et al., 2010), agriculture (Cain, et al., 2003; Kleemann, et al., 2017), forests (Cyr, et al., 2010), and conservation (Newton, et al., 2007). Other uses include environmental impact assessments (Marcot, et al., 2001; Tattari, et al., 2003) and habitat suitability modelling (Smith, et al., 2007; Hamilton, et al., 2015). BNs have also been made spatially explicit (Aspinall, 1992; Landuyt, et al., 2015), and used for risk assessment (Grêt-Regamey & Straub, 2006) land use change modelling (Celio, et al., 2014), and ecosystem service mapping (Grêt-Regamey, et al., 2013a; Gonzalez-Redin, et al., 2016).

In the following, we describe the procedure to develop a BN to model ES.

1. *Defining the model purpose and context*

Before constructing a BN, it is crucial to define the aim of the model and the problem it should address. Here, the mind maps can help to identify the focal ecosystem services to be modelled in the BN. However, in contrast to mind maps, only the ES most relevant to the modelled problem should be included in order to avoid large, unwieldy networks. The spatial and temporal scale and extent of the model should also be clearly defined.

It is important to define how the BN model will be used. BNs can be used to improve system understanding, to analyse scenarios, trade-offs, or uncertainties, to support and inform management, or for a combination of these purposes. The complexity of the model and the methods used to construct it should be adapted to its aim and target audience. For example, a simpler BN is more suited to communicate with stakeholders, while a more complex model may help integrate various data and models to produce more precise ES maps. Furthermore, if a BN is aimed at communicating with stakeholders or managers, these should be involved in the development of the network.

2. *Defining variables of the network*

Once the purpose and context of the BN are defined, we select the variables that should be represented as nodes in the network. The BN can include the following sets of variables:

- Focal ecosystem services as target nodes;
- Ecosystem properties (structure and processes) that influence the provision of these services;
- Controlling factors that affect the relevant ecosystem properties (drivers, pressures);
- Variables describing the demand for the ES;
- Management interventions and scenarios;
- Proxies and indicators for variables that cannot be directly assessed, including remote sensing variables.

The nodes of the network are selected based on the mind map of the modelled system, but only the variables most relevant to the objective of the BN should be included.

3. *Designing the network structure*

In the next step, the relationships between the nodes are included as directed links in the network. The links represent causal relationships, not to be mistaken with the flow of information. For example, an EO product such as a land cover classification is an input node to the network, as it provides information about the actual land cover. However, in terms of causality, the classification depends on the actual state, not vice versa, so the link should be directed from the land cover to the classification. Defining links based on causality maintains the logical structure of the network. However, it is not always easy to define causality, and sometimes a pragmatic approach is necessary, where links are defined in a way that they facilitate the construction of CPTs.

During this step, we follow the following guidelines:

- Nodes with no parents should be either controlling variables or interventions;
- Nodes with no children should be the ES of interest or additional impacts (these only if their inclusion is relevant to the modelled problem);
- If possible, there should not be more than three parents for each child node (the size of a CPT grows exponentially with the number of parents);
- Feedback loops are not allowed in BNs. In case of a feedback effect, consider which direction of impact is more relevant for the modelling purpose and within the temporal and spatial scale of interest. The alternative is to use a dynamic BN consisting of several BNs at different time steps.

The resulting network is reviewed by other experts, and (if aimed for communication and management) by the relevant stakeholders. During the process, it is often necessary to return to step 2 and define new nodes or redefine existing nodes.

4. *Defining states for all the variables*

For every node in the network, we define whether they should be described as categorical (e.g. land cover) or continuous (e.g. biomass) variables. For categorical variables, a finite set of mutually exclusive states should be defined. The number of states exponentially increases the complexity of the CPTs, and is therefore kept to a minimum that still represents the states relevant for the system. Continuous variables need to be discretized into intervals, and the number of intervals is defined in a way that it maintains the shape of the distribution.

5. *Quantifying the links between variables*

The links between nodes in a BN are represented by conditional probability tables (CPTs), where a probability distribution of a child node is defined for every combination of states of its parent nodes. Depending on the availability of data or models, various methods can be used to populate CPTs. During this process, we may find it necessary to return to previous steps and redefine the nodes, their states, or the links between them.

Often, some parts of the network have already been extensively researched and empirical or process-based models are available in literature. In this case, the model can be incorporated in the BN in the form of probabilistic equations. This usually means that the probability distribution of the child node is a normal distribution, where the mean is a function of its parents, and the standard deviation is derived from the reported uncertainty in the model. Other types of distributions can also be used.

Where sufficient data is available, CPTs can be “learned” directly from data within a BN software. Learning a CPT requires a dataset of cases with information on the child node and its parents. Various algorithms (e.g. Expectation Maximisation (EM) or gradient descent) can be used to find the maximum likelihood BN, which is the network that is most likely given the data. This approach can also be used to translate process-based simulation models into the BN. We run the simulation over the range of input values, and use the results as cases for learning the BN. Parameters that are not included in the network should also be varied in the simulation, in order to capture the uncertainty in the model.

When data is lacking, the CPTs can be filled manually by experts or by stakeholders. Usually, this means that the experts should specify the probability of each state of the child node given each combination of parent nodes. When a node has many parents with several states, many rows of CPTs need to be filled, which can lead to fatigue and boredom, and it is difficult to ensure consistent distributions (Das, 2004). This is why it is important to limit the number of parents, and the number of node states. When node states are binary or ordered (e.g. “low”, “intermediate”, “high”), this problem can be reduced by using various interpolation methods (Cain, 2001; Das, 2004; Baker & Mendes, 2010).

Distributions of continuous variables can also be elicited from experts. One useful approach is the four-point estimation method (Speirs-Bridge, et al., 2010), where we ask experts for the expected value of the node for a specific combination of parents, the expected upper and lower bounds of possible values, and their confidence in their estimate. Using this information, we can estimate a probability distribution (e.g. a normal or triangular distribution). Similarly, fuzzy logic can be used to link continuous variables to categories (Liu, et al., 2013; Petrou, et al., 2013).

When using expert elicitation, more than one expert should be involved whenever possible. Then, we can evaluate the differences between the experts, and test the sensitivity of the network to these differences. This may be particularly interesting when developing a network with different stakeholder groups. For a final network, the CPTs are usually combined by averaging the values from different experts.

6. *Testing, evaluating, and updating the Bayesian Networks*

After compiling the BN, it can be tested by trying to setting evidence on input values and observing the resulting probabilities in the outcomes and intermediate nodes. The network and its behaviour under different scenarios are discussed with experts and stakeholders, and their feedback is used to adjust the structure of the network, the states of the variables, or to update the CPTs.

Sensitivity analysis is a useful tool that determines the influence of individual variables on the target nodes. This can help evaluate the network, understand the system, and identify where additional information would be most useful to reduce uncertainties.

7. *Spatially explicit Bayesian Networks*

ES models are often used for mapping, to observe spatial patterns and trade-offs between ES. This requires running the BNs with spatially explicit inputs. Within ECOPOTENTIAL, we are developing a toolbox that links the BN to spatial (raster or vector) data. For each pixel (or polygon), the values in the input data are used as evidence in the network, and inference is performed to obtain the posterior probability distribution of the target nodes. Then, the posterior distributions of the target nodes are written into a new spatial file.

Spatially explicit BNs can be a useful tool for decision making in fields such as landscape planning (De Grassi, et al., 2007) ES modelling (Grêt-Regamey, et al., 2013a; Landuyt, et al., 2013), land-use change (Celio & Grêt-Regamey, 2016) and protected area management (Douglas et al, 2004). Spatially explicit BN models may include “scenario-defining nodes” (Bromley, 2005). These nodes are variables that the modeller can change according to different scenarios, e.g. related to climate change or management decisions, and can also be spatially explicit. The model then provides information on how the target node (as defined by the management objectives) may change in space under different scenarios, as well as the associated uncertainties, which can support the evaluation of management alternatives.

4.5 Stakeholder Engagement

Over the past 50 years, stakeholder engagement has become an almost axiomatic central component of planning, policy and management, particularly in the environmental and natural resource sphere (e.g. (Arnstein, 1969; Clark, 2011; Reed, 2008). Similarly, the sustainability literature focuses on participatory processes as a prerequisite for realizing sustainability goals, and this is further reflected in the criteria of environmental and sustainability initiatives at the regional (Orenstein & Shach-Pinsly, 2017) to the international scale (United Nations, 1992; United Nations Convention to Comnat Desertification, 2009). It is telling that participatory processes are considered such an important prerequisite towards achieving sustainability goals that the presence of participatory processes is considered an indicator of success (Holzer, et al., 2018; Weaver & Lawton, 2007)

ES assessments, such as that conducted within the context of ECOPOTENTIAL, is also increasingly considered a process that requires the input of stakeholders at every point of assessment, from identification of the services, to valuing them in various terms, through considering the optimal policy responses to potential changes in the provision of ES. As a wholly anthropocentric phenomenon, it is reasonable to assume that an assessment of ES begins with a query of stakeholders who reflect diverse preferences, values and knowledge bases (Chan, et al., 2012; Jax, 2010). This is particularly true for cultural ES, which can only be assessed and valued through the prism of those experiencing the services themselves (Gould, et al., 2014). The advantages of adopting participatory approaches to ES assessment include the ability to identify and value cultural services, achieving a better understanding of complex socio-ecological systems and their feedbacks, ensuring greater social relevance of the assessment outcome, and strengthening the policy relevance of the assessment (Orenstein & Groner, 2014). Multiple methodological approaches have been developed to integrate stakeholders into ES assessment, including focus groups, participatory GIS, social research (e.g. interviews and public questionnaires), and community discussions and mutual learning exercises (Angelstam, et al., 2017; Brown & Fagerholm, 2015; Hauck, et al., 2013; Milcu, et al., 2013; Plieninger, et al., 2013; Raymond, et al., 2013).

As stated in the methodological section of this document, multiple methodological approaches have been developed to integrate stakeholders into ES assessment, including focus groups, participatory GIS, social research (e.g. interviews and public questionnaires), and community discussions and mutual learning exercises (Angelstam, et al., 2017; Brown & Fagerholm, 2015; Hauck, et al., 2013; Milcu, et al., 2013; Plieninger, et al., 2013; Raymond, et al., 2013). In Table 1 we present the stakeholders’ engagement methods applied for the set of PAs where the proposed framework was applied.

Table 1 Synthesis of the Stakeholder engagement methods used for the PAs

Protected Area		Stakeholders	Methods for stakeholder engagement
Typology	**Designation**		
Mountains	Sierra Nevada	• Farmers, cattle ranchers, entrepreneurs, local managers and local development actors. • Expert of land uses in Sierra Nevada	• Several interviews were made to select the variables and their states. After the interviews with experts, the initial BN was discussed with stakeholders in several workshops. Finally, surveys are currently in progress to fill CPTs • The selection of variables was validated with interviews and workshops with experts in the area of Sierra Nevada.
	Peneda-Gerês	• ICNF - Institute for Nature Conservation and Forests that includes the Park authorities and managers	• Meetings for the discussion around the PA's storyline and to show preliminary results about the project. • Participation of PA's managers in events promoted by ECOPOTENTIAL (WP9 workshop, training week).
	Swiss National Park and Davos[1]	• National Park management and staff	• Meetings to discuss the relevant ecosystem services in the area, potential threats and conflicts, and data needs. • Focus groups with PA staff are planned for participatory mapping of cultural ecosystem services (UFZ/iDiv).
Coastal	Wadden Sea	• National Park management (Rijkswaterstaat)	• Meetings to discuss the objectives of the project and share information on the human activities and ecosystem services in the area • Participation of PA's managers in events promoted by ECOPOTENTIAL (WP9 workshop, training week).
	Pelagos Sanctuary	• Representatives of whale watching companies (from France, mainland Italy, Sardinia), and oceancare research and conservation organisations (TETHYS, ACCOBAMS)	• Participatory mapping of whale watching activity • Interviews to identify the strengths of different factors influencing cetacean well-being and whale-watching behaviour (used to quantify BN)
	Danube Delta	• INCDD- "DANUBE DELTA" National Institute for Research and Development • DDBRA - Danube Delta Biosphere Reserve	• Interview and discussions regarding the variables to be included in the storyline; discussion about the data availability • Further discussion on the developed BN will be held • Several FCM will be developed with the help of the stakeholders

Mountains	Montado	• ICNF - Institute for Nature Conservation and Forests, the public entity responsible for the implementation of nature conservation and forestry policies in protected areas in Portugal • UNAC - Mediterranean Forest Union (association of forest owners)	• Interviews and brainstorming regarding the storyline narrative and variables • Active Participation of PA Manager in events promoted by ECOPOTENTIAL
	Negev Highlands	• Nature and Parks Authority (NPA; the primary land management authority) • General public	• NPA ecologists were integrated into every aspect of the project as participants; they were given authority to determine the focal topics for study • The general public was queried via a public survey on landscape preferences and the impact of development on aesthetics (the topic was requested by NPA ecologists). • Public survey (450+ respondents); Ongoing dialogue between NPA ecologists and stakeholders regarding management of wild animals.
[1]For the region of Davos, our work is based on a previous project (MOUNTLAND, Huber et al. 2013) with strong stakeholder involvement. Huber, R., H. Bugmann, A. Buttler, and A. Rigling. 2013a. Sustainable land-use practices in European mountain regions under global change: An integrated research approach. Ecology and Society 18(3).			

5. Application of the Suggested Framework in the Context of Protected Area Management

In this section, we present a set of case studies (PA) that being part of the ECOPOTENTIAL project tested the proposed conceptual DPSIR based framework to ecosystem services valuation. Only a few WP7 partners have developed the entire cycle of the above described framework. Notwithstanding at least one of the methodological component of our framework have been tested in PAs participating in Task 7.2. Hereafter we present the outcomes aggregated by ecosystem types (Mountains, Coastal and Arid). The complete storylines are not in this deliverable but can be found on the website: www.ecopotential-project.eu.

5.1 Mountains

Mountains are important ecosystems for the provision of ES and biodiversity conservation. Mountain ecosystems have provided essential services such as food, timber, and protection from natural hazards (e.g. avalanches, landslides, and rock fall) for centuries, enabling mountain societies to thrive in these marginal environments. In recent decades, other ES have also been recognized as important, not only to local inhabitants, but to a wider society. Mountain ecosystems have a high aesthetic value and offer many opportunities for recreation, provide habitats to rare and charismatic species (such as ibex and capercaillie), and contribute to climate regulation. Sometimes, trade-offs occur between these different ES. For example, high populations of wild ungulates (e.g. deer, ibex, and chamois) attract hikers and tourists, but compete with cows for grazing and lead to conflicts with dairy farmers. Such trade-offs (as well as potential synergies) should be taken into account when managing mountain landscapes.

5.1.1 Peneda-Gerês

The Peneda-Gerês National Park in Portugal is a complex mountain system with 70 000 hectares and 1500 m elevation range, hosting more than 800 native plant species as well as an outstanding representation of Portugal's indigenous fauna. Through centuries the land has been managed under a mixed farming and pastoral system, which maintained high levels of landscape and species diversity, as well as ecosystem services provision. However, the gradual collapse of this interlinked social-ecological system has induced profound changes in land use patterns, and consequently on the extent and status of various habitat types. This decline of human-nature interactions has increased the Park's vulnerability to drivers of global change, such as modified fire regimes, invasion by non-native species, and climate change. The PA storyline served as a basis for the elaboration of the Mind Map (Figure 5.1), which presents vegetation dynamics as a core set of processes underlying current and future societal benefits and socio-ecological changes.

The mind map incorporates the ecological functions and processes underlying the provision of five focal ecosystem services (reared animals, habitat maintenance, climate regulation, hydrological cycle maintenance, control of erosion rates) in the several types of ecosystems (grasslands, native forests, heath and scrub, and production forests), as well as the methods to evaluate the services provision (processing of EO-data, dynamic modelling, training and testing with in-situ data). This evaluation is being done under task 6.3 through modelling exercises (correlative and process-based models).

Figure 5.1: Mind Map for Peneda-Gerês

5.1.2 Sierra Nevada

The Sierra Nevada National Park (SNNP; Andalusia, southeast Spain), is a mountainous region with an altitudinal range between 860 m and 3482 m a.s.l. covering more than 2000 km^2. The climate of SNNP is Mediterranean, characterized by cold winters and hot summers, with pronounced summer drought (July-August). Sierra Nevada mountain range hosts a high number of endemic plant species and it is considered one of the most important biodiversity hotspots in the Mediterranean region.

The SNNP provide very diverse and important services which are critical to the livelihood of large human population in the park and downstream. Water, food, fibre, geological material, and energy are the most relevant provisioning services. All of them are experiencing an increase in their importance at a local scale. Cultural services related to traditional knowledge, recreation and nature tourism activities have a high influence in the local economy. In fact, nature tourism is becoming an important pillar for economic development in Sierra Nevada. Water regulation services are of utmost importance in a mountain area like Sierra Nevada. Soil protection (by halting erosion) is also a very relevant ecosystem service that has been quantified in some case studies.

The traditional presence of human settlements in Sierra Nevada makes land use change one of the most relevant drivers of global change. Almost 50% of the total area of Sierra Nevada (170,000 hectares) has suffered changes in land use since 1956. This land use change rate has affected both the type and the amount of ecosystem services provided by Sierra Nevada. As in many other mountainous systems, climate change will be another major driver shaping ecosystem services.

The main purpose of the work carried out within Task 7.2 was to analyse trade-offs of ES caused by changes in land uses in the past. So, we analysed the state of different ES in Sierra Nevada in 1956, 1977, 1984, 1999 and 2007 and their spatial time trends (Figure 5.2). In this way, we assess the land use changes that were being produced and the trade-offs of ES linked to them. This knowledge is very useful for a land use management in protected areas. This is also the basis for the BN that is being designed to develop future land-use scenarios.

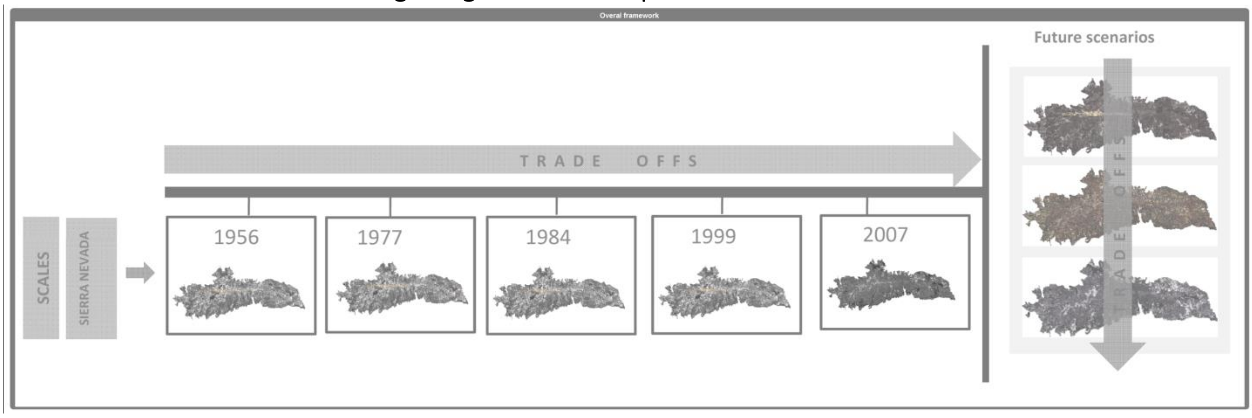

Figure 5.2: Overall framework of "Temporal evolution evaluation of ecosystem services in Sierra Nevada"

The mind map is focused on the past assessment of ecosystem services (Figure 5.3). In this sense, ES, functions and indicators are defined for provisioning, regulation and cultural services. The data sources vary depending on the type of analysis. Past evolution of ES is mainly based on in situ past information and socioeconomic data. 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 have been assessed through aesthetic value indicator (Schirpke, et al., 2013). However, land uses and fragmentation indexes at different timestamp in the past were developed based on EO data. On the other hand, future scenarios inputs are more concerned with Remote Sensing and EO. This information is used to run the models we work with (Figure 5.4; Light brown arrows represent inputs in the models. Red arrows represent outputs of the models. Orange arrows are information used in assimilation. Blue ones are "EO" or "RS" data used as input in the ecosystem services assessment. Finally, green arrows represent "In situ” data used as input in the ecosystem services assessment).

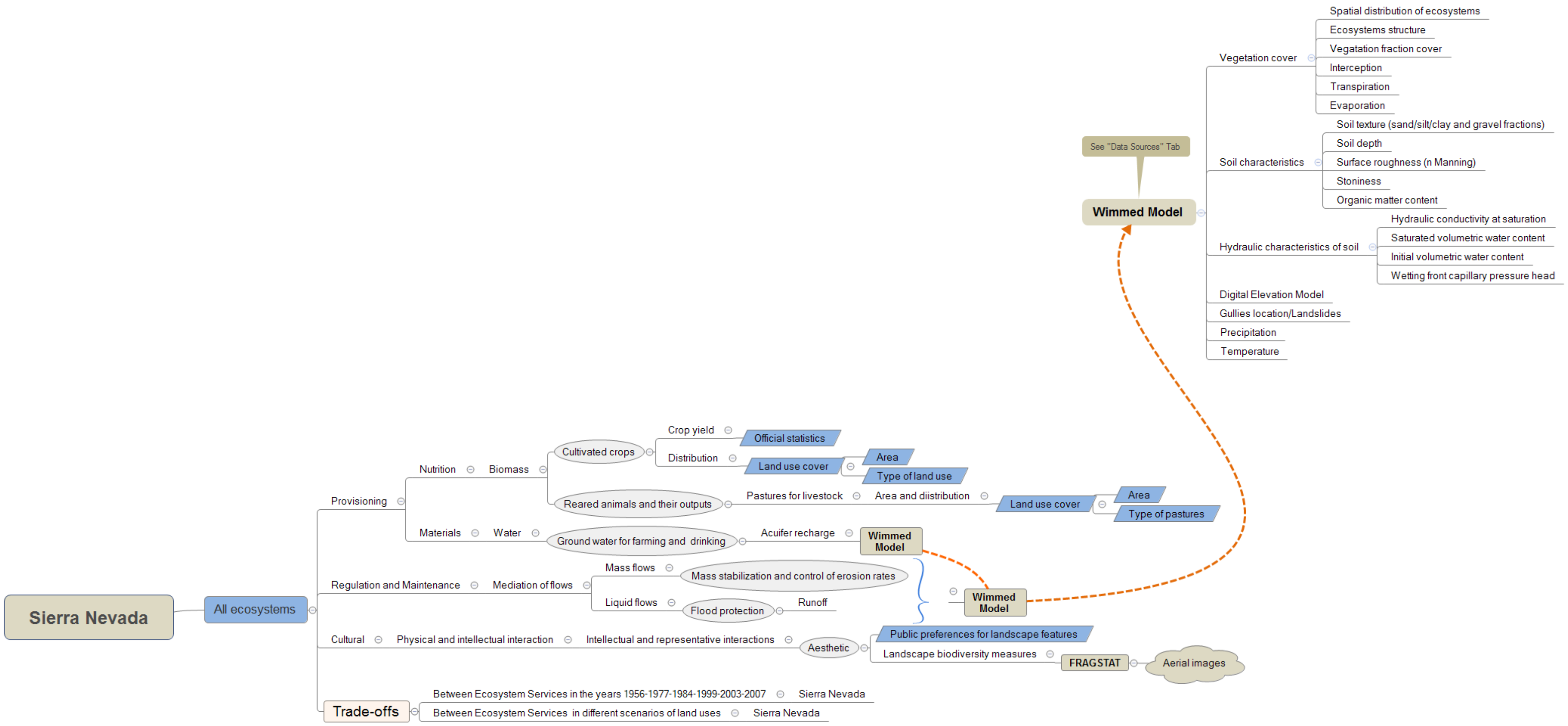

Figure 5.3: Mind Map of past assessment of ecosystem services for Sierra Nevada

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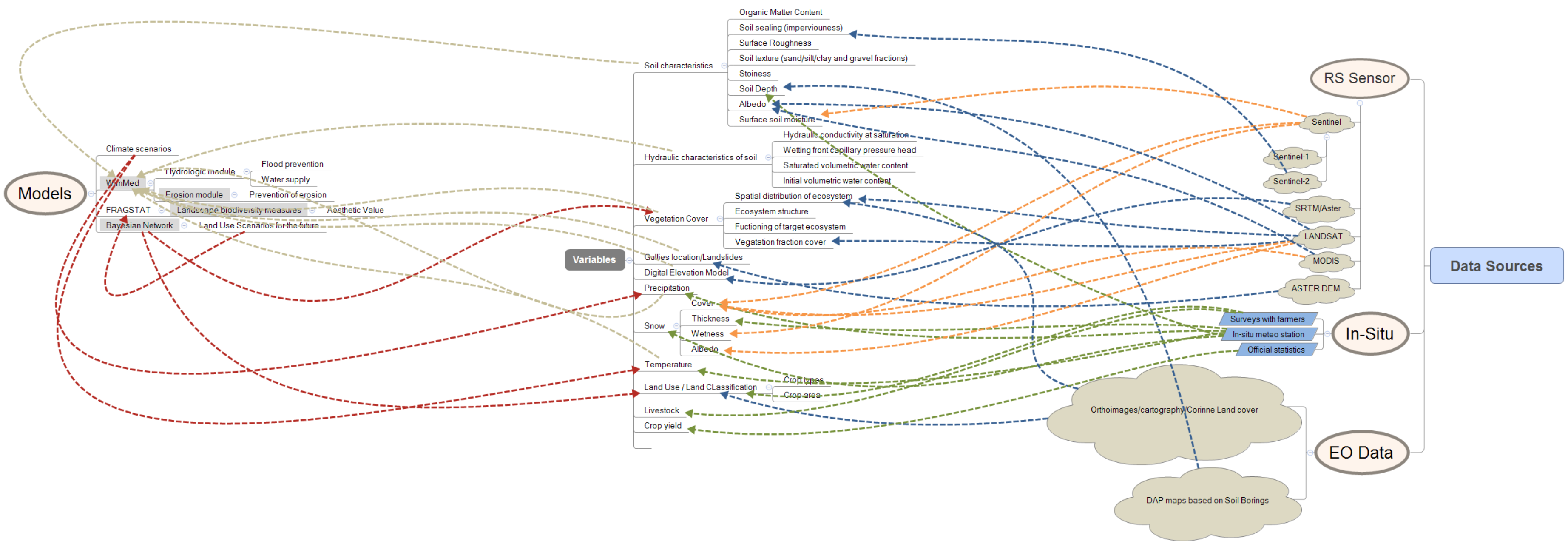

Figure 5.4: Data sources of past and future assessment of ecosystem services for Sierra Nevada.

As stated above, and expressed along the mind mapping exercise, land-use change (deforestation for crops and pastures, reforestation, firewood removal, etc.) constitutes one of the primary drivers of global change, since human activity is to a greater or lesser degree altering the vegetation cover of the planet. The combined effects of climate change and shifts in land use determine the distribution and structure of the vegetation of the Sierra Nevada, and the associated ES. The surface cover of tree formations in Sierra Nevada has expanded from 15% to 51.23% over the last 60 years. Similarly, a densification of the scattered tree cover and the natural forests and a decline in the surface area occupied by cultivated fields (from 17.8% to 4.72%) has occurred in the last six decades (Zamora, et al, 2016). Therefore, it is important to ascertain future land use change and its effects on the vegetation cover.

Since the main purpose of this study is to facilitate the land-use management of PA based on ES a preliminary implementation of a spatially explicit BN in a watershed of Sierra Nevada 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.

The development of Sierra Nevada BN started with an extensive review of literature in order to find the main variables that influence land-use changes in mountain regions. Social variables as population structure (Díaz, et al., 2011) and part-time business (Celio, et al., 2014) influence the intention to farm. Likewise, topography variables determine the profitability of a plot to crop (Celio & Grêt-Regamey, 2016). Policies influences in actors´ decisions are very useful to explore future scenarios. Such variables have been incorporated in various models of land use change (Celio, et al., 2014; Lamarque, et al., 2013; Renwick & Revoredo-Giha, 2008).

Stakeholders engagement was an important part of the process, namely for the BN development. The selection of variables was validated with interviews and workshops with experts in the area of Sierra Nevada. Likewise, the states of the variables and the preliminary structure of the network was established (Figure 5.5). The initial BN was discussed with stakeholders that affect the land-use change in Sierra Nevada: farmers, cattle ranchers, entrepreneurs, local managers and local development actors. In the next step, stakeholder and expert knowledge will be elicited to fill the CPTs of the network (Bromley, 2005; Cain, 2001).

The BN assess the probabilities of the land use change to one of the land use class in the present (t0) to any class in the future (t1) (Figure 5.6). The main variables that have considerable influence in land use changes are suitability to farm, intention to farm and policies influence. These nodes are conditioned by others variables like water availability, old population level of training of farmers and conservation policies. The states of the target node (land use) are: forest, gallery forest, scrubland, pastures, irrigated woody crops, irrigated horticultural crops, dry woody crops and urban.

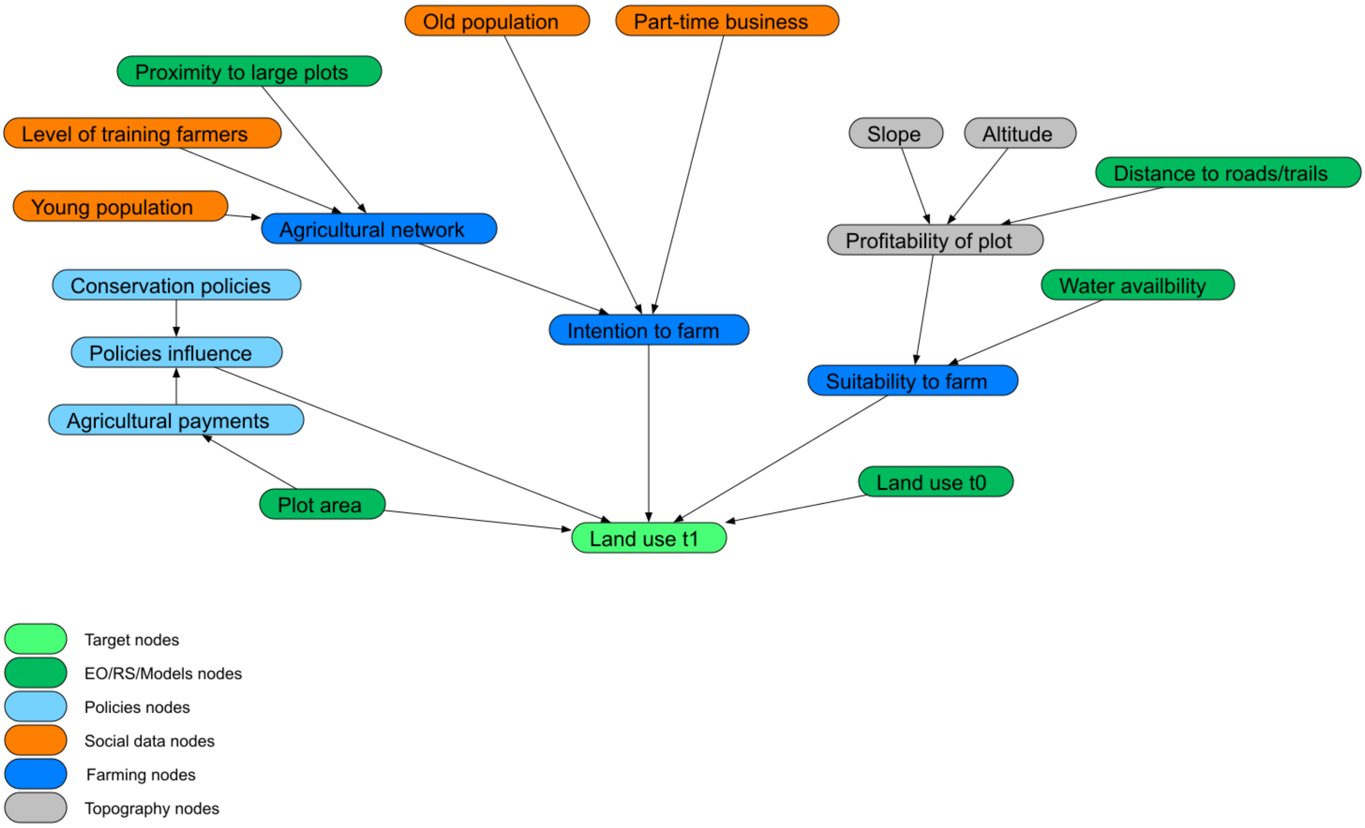

Figure 5.5: Bayesian Network for land-use scenarios

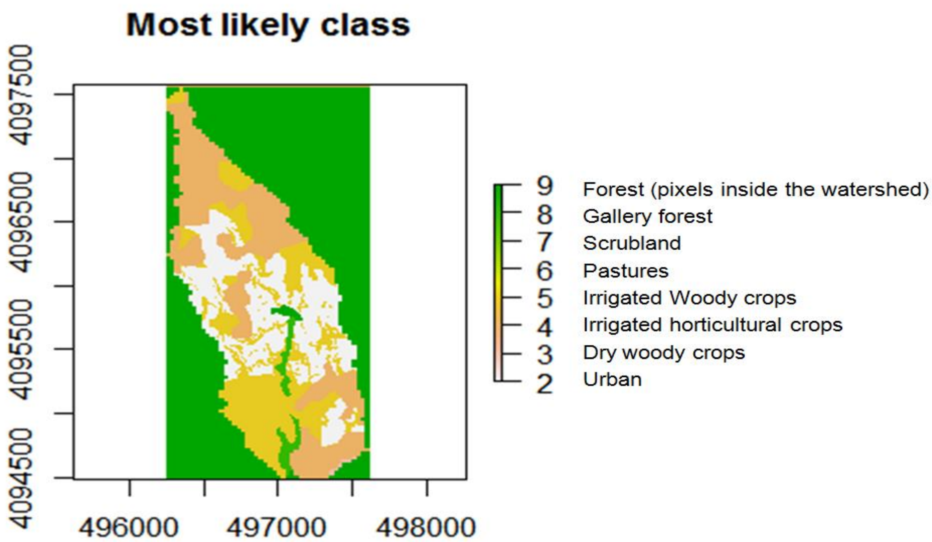

Figure 5.6 Preliminary implementation of Sierra Nevada BN in a watershed of Nevada municipality.

5.1.3 Swiss National Park/Davos

A common measure aimed at preserving the cultural value and biodiversity of mountain ecosystems is the establishment of protected areas. The Swiss National Park (SNP) was established in 1914 as the first national park in the Alps, with the aim to minimize human disturbance and let natural processes take their course. Today, the park covers an area of 170 km^2, consisting of forests (28%), alpine meadows (21%), rock and scree. Although subject to strict regulations, around 150 000 people visit the park every year. The inner-alpine high mountain area of Davos is comparable to the Swiss National Park in terms of bio-physical conditions and landscape composition. The study area includes the municipality of Davos and covers an area of 254 km^2. The local population amounts to approximately 13,000 people and there are approximately 25,000 guest beds. The principal town, Davos, with its well-established urban and tourist infrastructure, is located in the central part of the main valley. The rest of the main valley and the three side valleys have remained relatively rural with a few small, scattered settlements and a landscape still strongly dominated by mountain agriculture, mainly pastures and meadows. Although the productivity of grasslands is likely to increase due to climate change (Briner, et al., 2012), agricultural use has been decreasing over the over the past century (Lundström, et al., 2007). Land abandonment and climate change also have an effect on forests, with an upward shift in the tree line and densification of previously grazed forests at high elevations (Kulakowski, et al., 2011). The changing forest structure is accompanied by a shift in species composition, with recruitment of spruce in previously larch-dominated stands. 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), which may impact the level of biodiversity. The scenic beauty of the region, which is important for tourism, may also decrease (Grêt-Regamey, et al., 2007). Overall, the supply of ES demanded by people in the region and outside the area is therefore vulnerable to the changes in temperature and land use (Huber, et al., 2013).

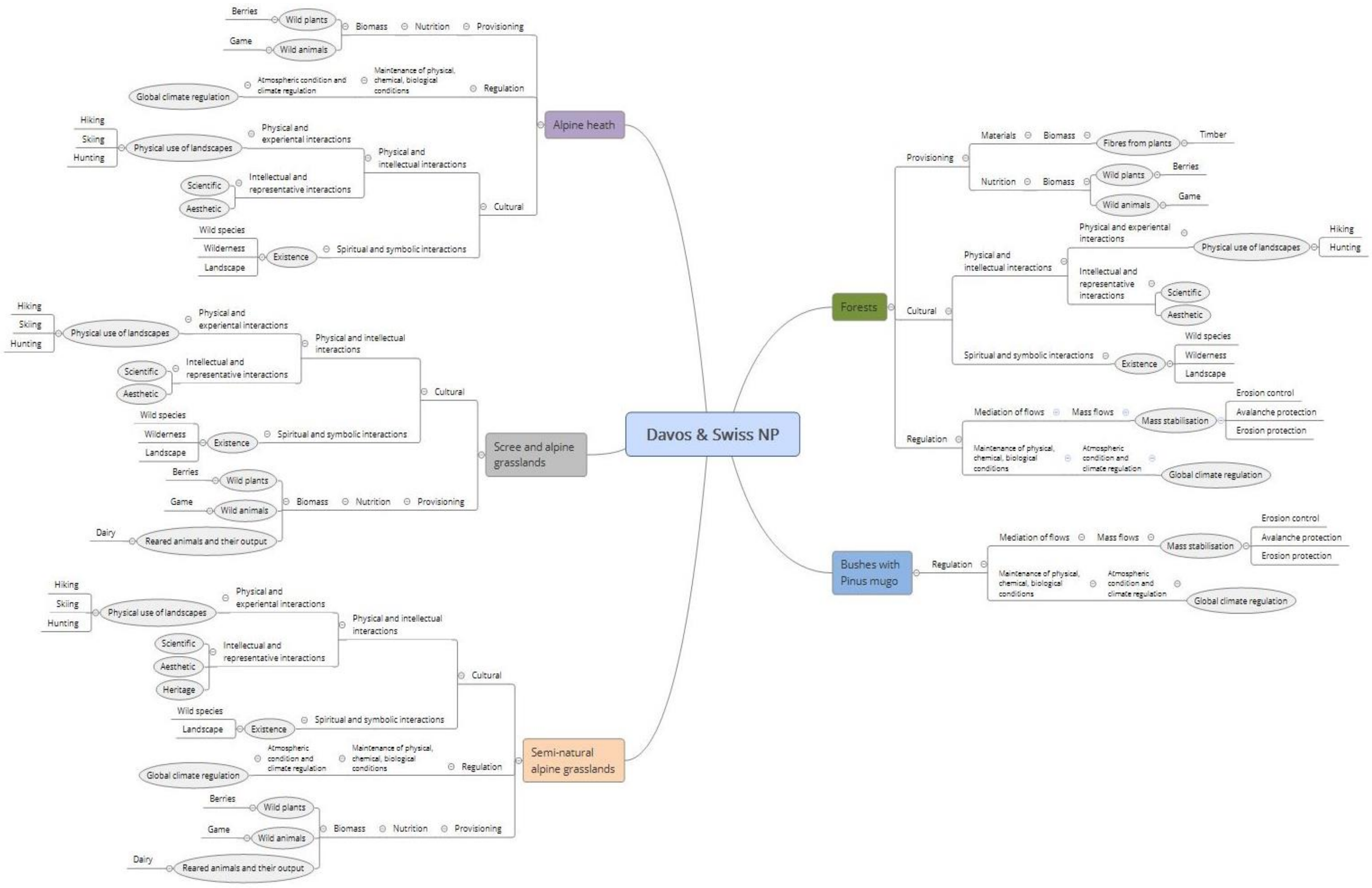

Figure 5.7: Mind Map for SNP & Davos

ES mapping is a useful tool in spatial planning and conservation, to manage the changes in ES and the trade-offs between them. Such mapping requires the integration of EO with in-situ data, models, and expert knowledge, and is associated with large uncertainties (Figure 5.8). We address this issue by developing Bayesian network models, which help to more precisely map the ES, and identify the main knowledge gaps that contribute to uncertainty in the ES assessment. Here, this BN approach is illustrated on the example of avalanche protection in the region of Davos.

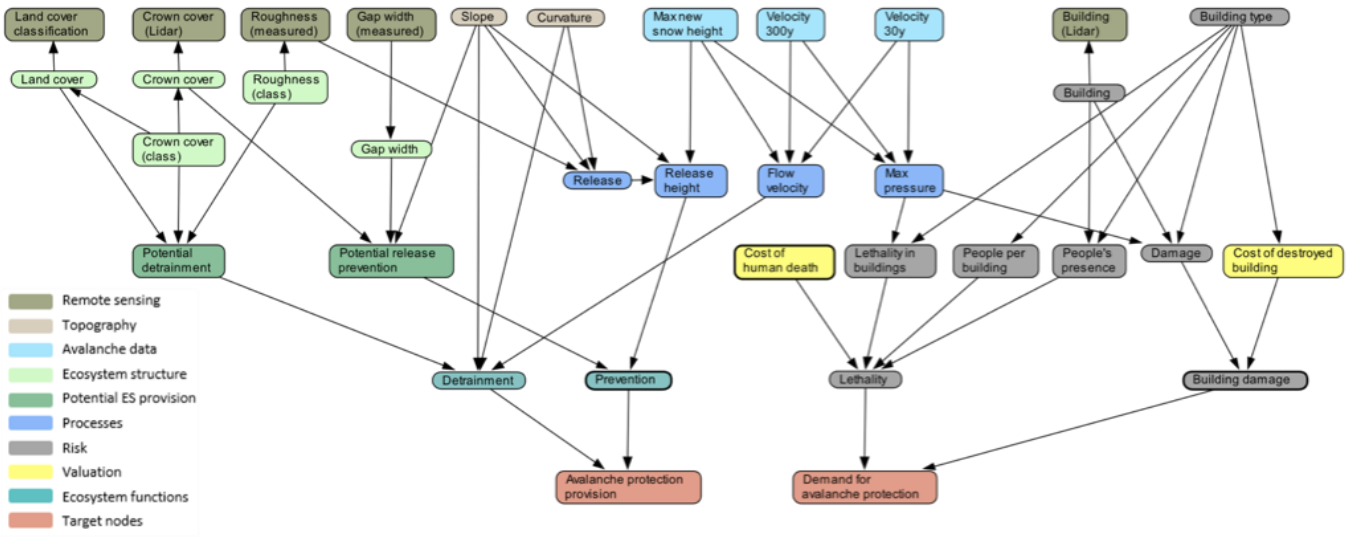

Figure 5.8: Bayesian Network for avalanche protection

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.

The BN for avalanche protection Figure 5.9) integrates remote sensing and in-situ data, existing models and expert knowledge. The main inputs to the model are in-situ data on the temporal and spatial distribution of avalanches, and remote sensing variables, which are proxies for the actual state of the ecosystem. Ecosystem structure and processes are linked to ecosystem functions using expert knowledge, an empirical model from literature ("Prevention" (Bebi, et al., 2001)) or learning from numerical simulation (Christen, et al., 2010) results ("Detrainment").

Two methods are used to incorporate expert knowledge: fuzzy logic, which helps translate continuous variables into categories, and the four-point method (Speirs-Bridge, et al., 2010) to estimate the distribution of continuous nodes. A probabilistic risk assessment approach was used to quantify the demand for avalanche protection (Grêt-Regamey & Straub, 2006).

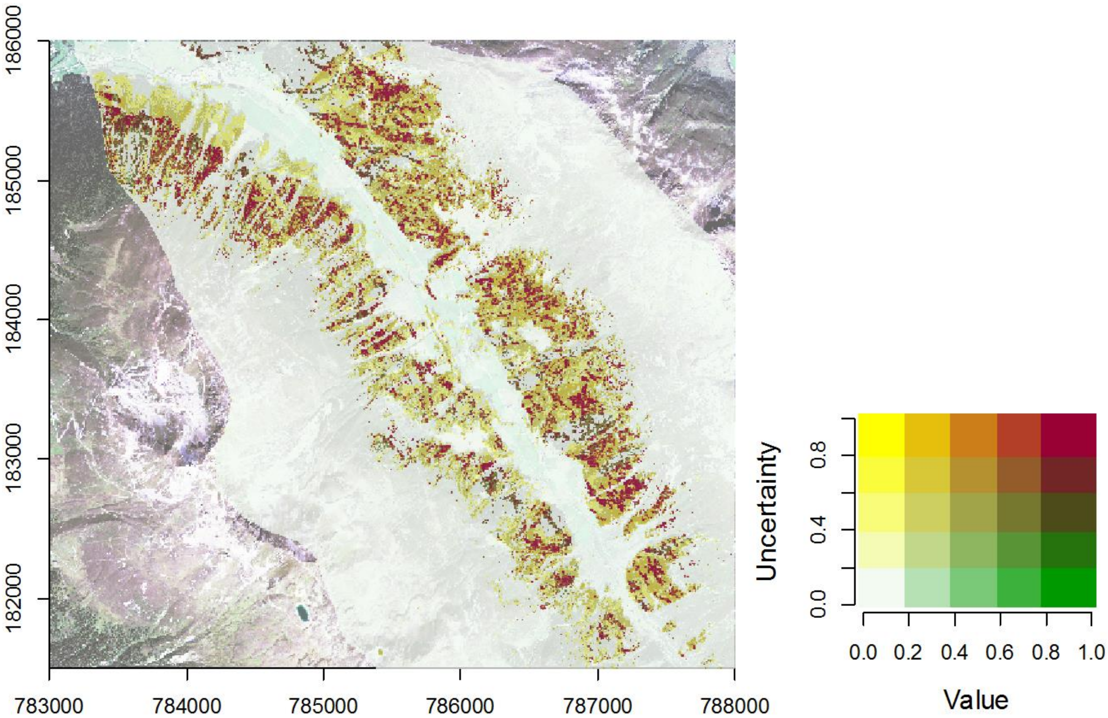

Figure 5.9: Modelled provision of avalanche protection of forests and the associated uncertainty in the Dischma valley, Davos

The results of mapping avalanche protection with the BN model show high uncertainties, particularly in areas where the provision of the service is expected to be high. Based on sensitivity analyses of the network, we have identified that most of the uncertainty is due to the high natural variability of avalanche release conditions, and limited data available about the natural hazard process. Nonetheless, areas that are crucial for avalanche protection can be identified, and should be managed in a way that maintains their protective function.

5.2 Coastal

The coastal including deltaic systems are systems with a great potential for ES. At the same time, many of these systems have been subject of human induced transformation. Several coastal systems are part in the ECOPOTENTIAL project.

5.2.1 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. The common composition of such a coastline includes one or all of the following: i) a barrier coast with lido, barrier islands, mudflat systems and coastal lagoons, ii) deltaic systems and iii) bar-built and funnel-shaped estuaries. In the case of the Wadden Sea, all aspects are present to varying degrees providing habitat to a range of biota under water as well as above.

The area has UNESCO World Heritage, RAMSAR and Natura 2000 status. Its coastline is approximately 500 km long with a surface area of around 9000 km^2, a quarter of which is located within the Netherlands. Almost the entire region is submerged at high tide, and half the area (the mud flats where many birds feed) is exposed during low tide. 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 high 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. This in turn attracts large marine mammals such as seals. In 2016 approximately 5000 grey seals and 25.000 harbour seals were counted in the Wadden Sea. 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, therefore this is one of the primary trade-offs and relationships explored through this work. Not only the shellfish industry poses a pressure on bird populations but other fishing activities do so too. The following Mind Map in Figure 5.10 shows a prioritized selection of Ecosystem Services which are relevant to modelling and monitoring exercises to be undertaken in ECOPOTENTIAL and the BN shows trade-offs including data from EO and expert opinions on specific nodes Figure 5.11.

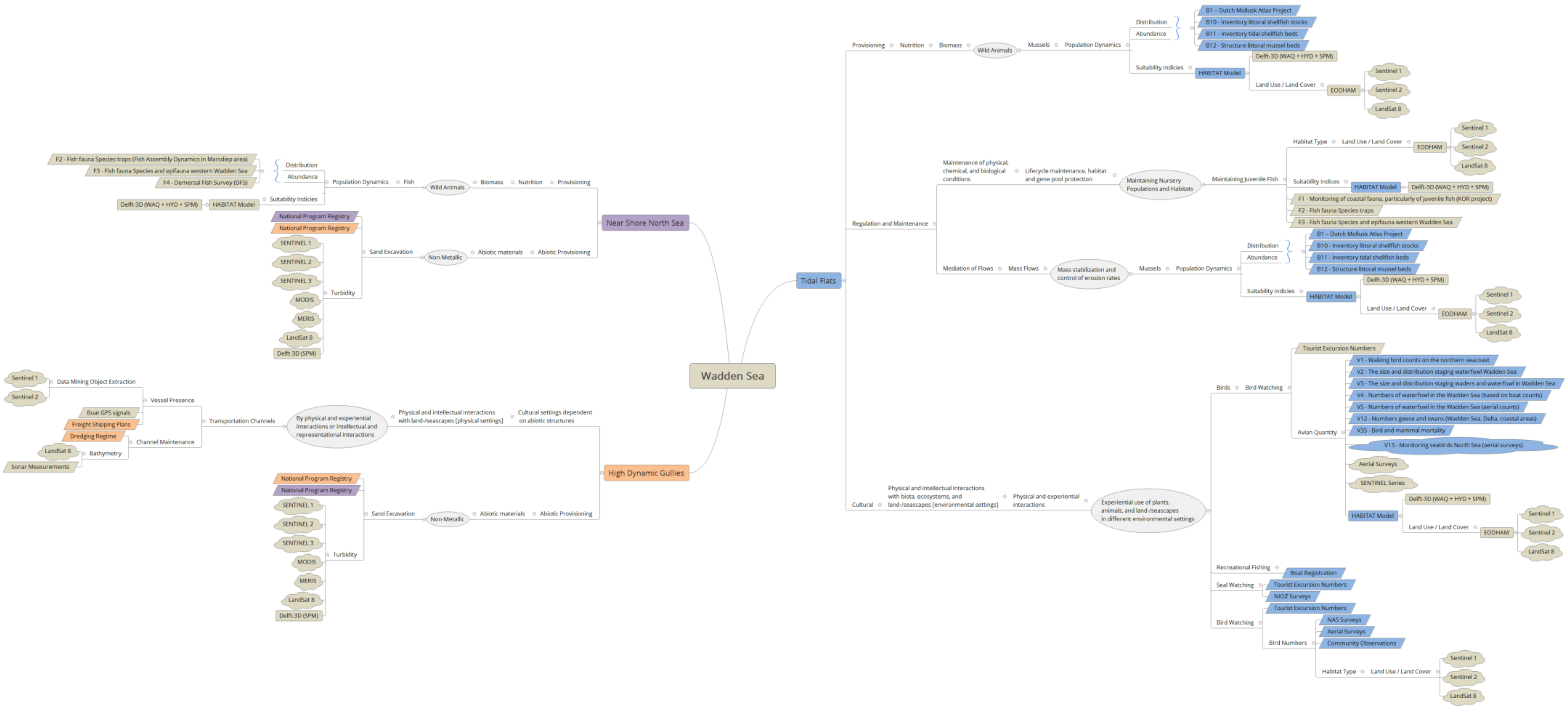

Figure 5.10 Mind Map of Prioritized Ecosystem Services for the Wadden Sea

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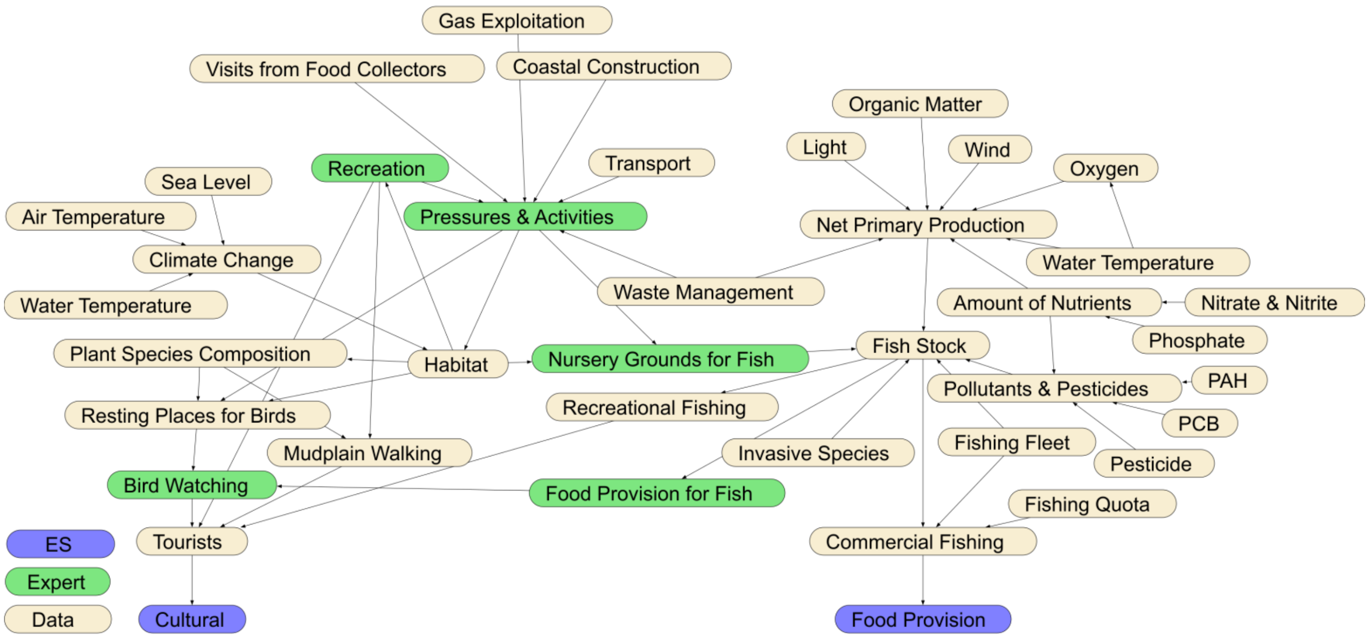

Figure 5.11: Bayesian Network for Wadden Sea

5.2.2 Pelagos Sanctuary

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 & 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.

The spatial inputs to the BN are data on cetacean presence (reported sightings and habitat suitability) and threats to cetaceans, as well as information on tour locations that was collected at a stakeholder workshop. 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 well-being. Furthermore, the social value of cetacean sightings was estimated based on expert knowledge.

The resulting BN (Figure 5.12) is a representation of the current knowledge of the system, and as such can be a useful tool in discussions with decision-makers or stakeholders.

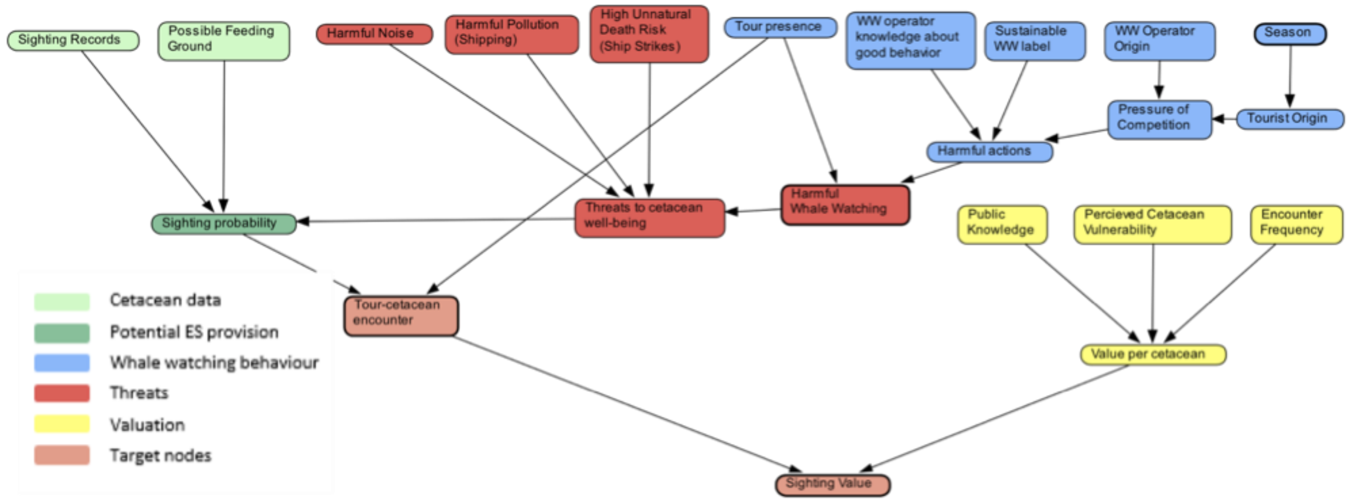

Figure 5.12: Bayesian Network for whale watching in the Pelagos Sanctuary for Mediterranean Marine Mammals

The map of "Sighting value" (Figure 5.13) is associated with high uncertainties, which indicate the need for further research. Nonetheless, the spatial distribution of the ES can be observed. Based on a sensitivity analysis of the network, the most important threat to cetaceans is pollution. Whale watching operators' knowledge is an important factor in reducing the negative impacts of whale watching.

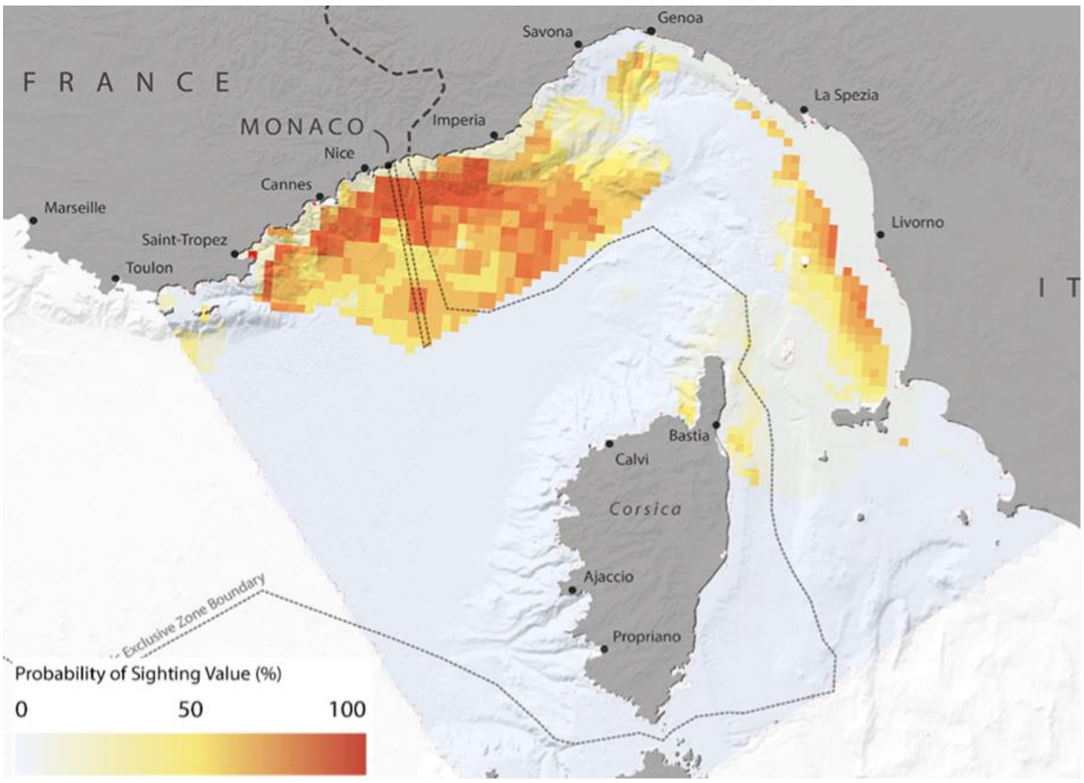

Figure 5.13: "Sighting Value" of whale watching in the Pelagos Sanctuary, calculated using the BN

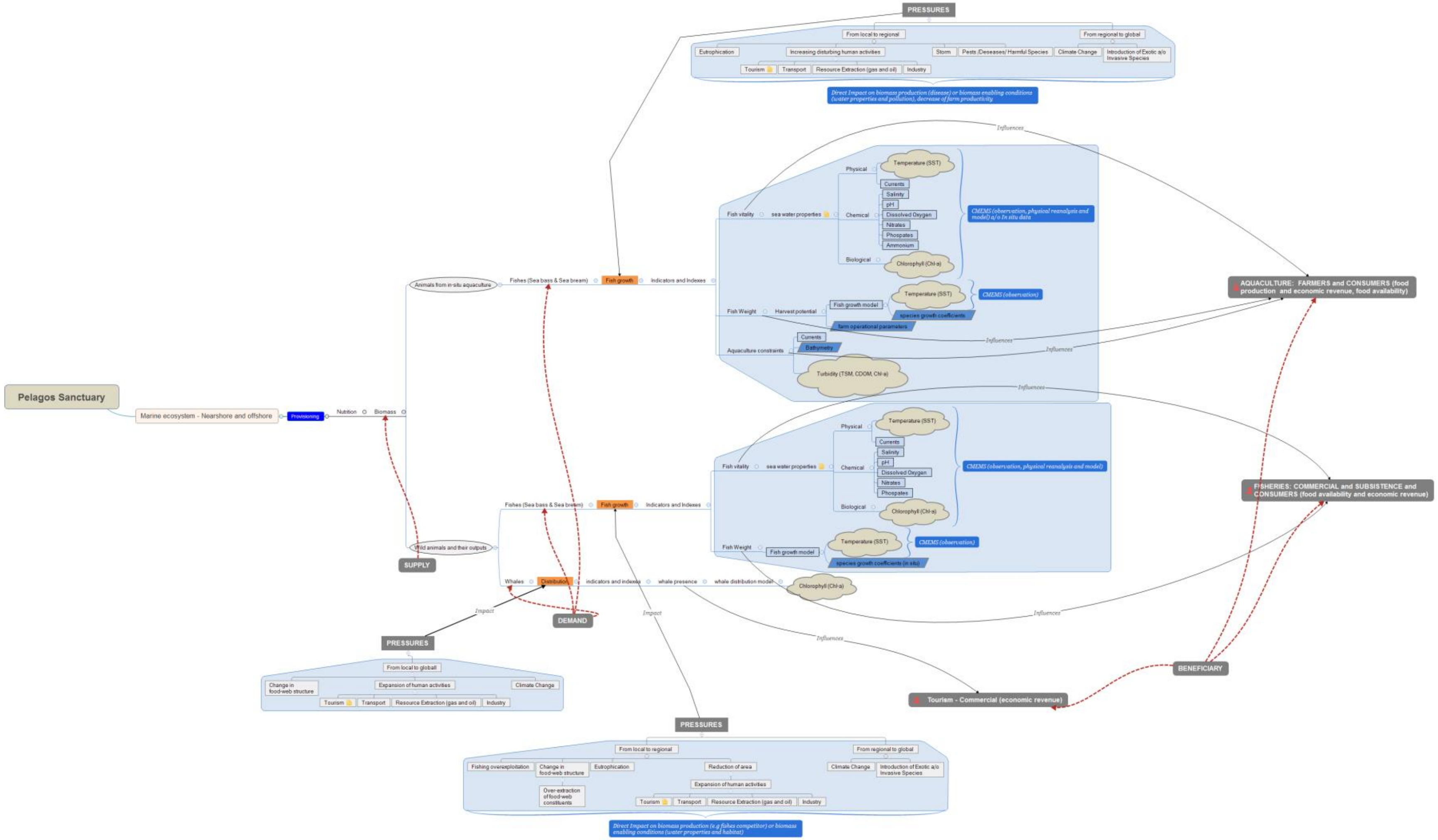

Figure 5.14: Mind map of the Pelagos Sanctuary

5.2.3 Danube Delta

The Danube River catchment spreads across nineteen European countries before reaching the west coast of the Black Sea. Just before reaching the sea, it creates a delta covering about 5100 km^2, consisting of a complex of ecosystems, dominated by wetland, with a great social, ecological and economic importance. Nowadays, we are witnessing an increasing interest to use the concept of ES for supporting the decision-making process within PA and as a communication tool. ES are defined as the benefits that humans are taking from natural and semi-natural systems. Failure to understand the complexity among the components of biodiversity is often leading to losing valuable ES. In order to solve this issue, tools to incorporate concepts and knowledge aimed at guiding decision-makers, are needed.

In order to sort out the complexities and relationships between variables a resulting mind map was first produced (Figure 5.15).

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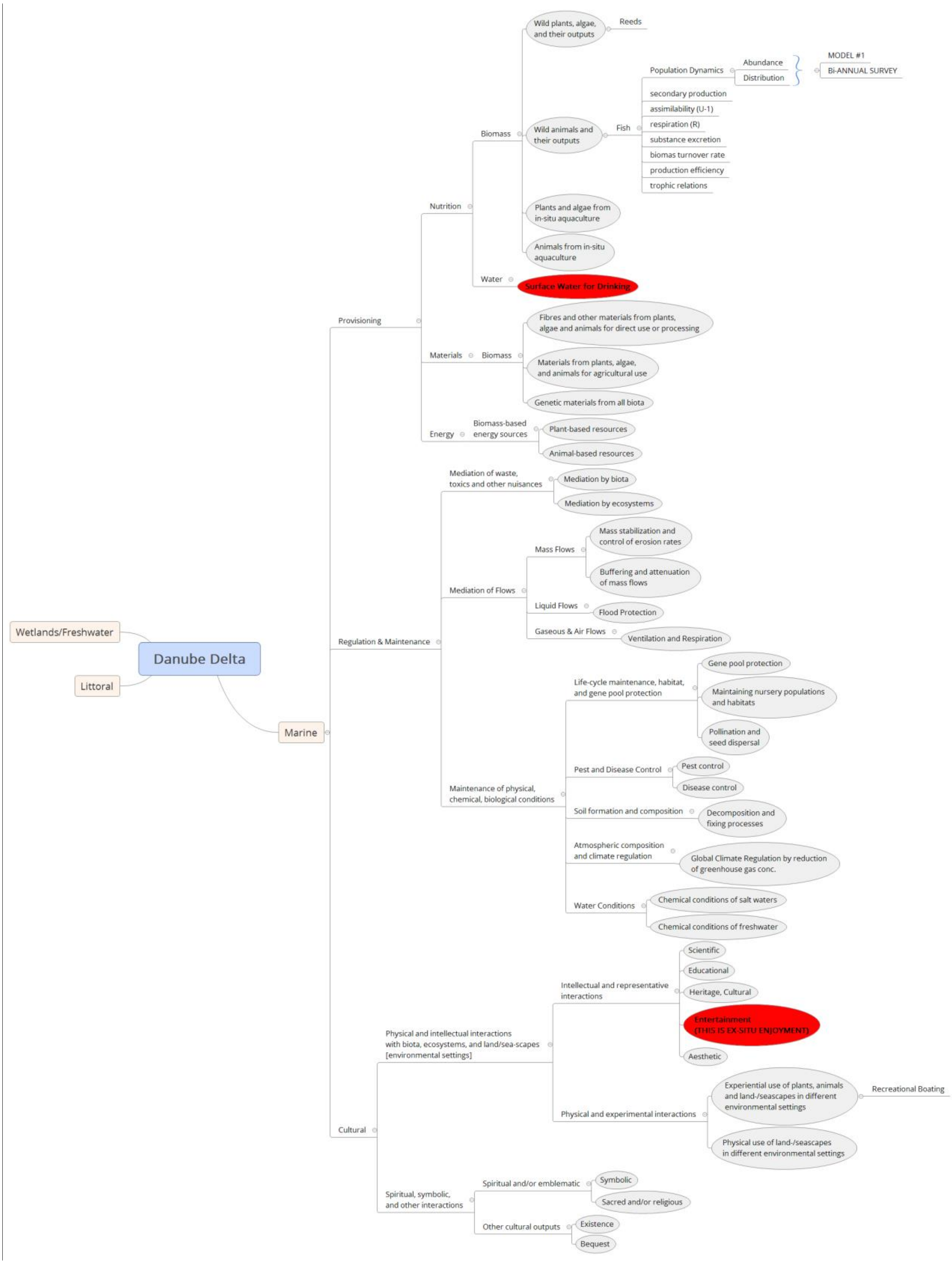


Figure 5.15: Mind Map for Danube Delta

In a second step we developed a BN for our case study focusing on exploring the link between aquatic ecosystem provisioning services and different types of tourists. We built a network of concepts using BN considering several variables influencing the quality/productivity of aquatic ecosystems (e.g. nitrogen phosphorous ratio, total suspended solids, phytoplankton, fish species, macrophytes, and benthos) and tourist attractions (e.g. habitat quality, fish productivity, bird density and accessibility) (Figure 5.16).

We found out that the BN is a useful environment to incorporate data and knowledge, test different scenarios and to capture stakeholder views as well as to identify the trade-offs between different ES.

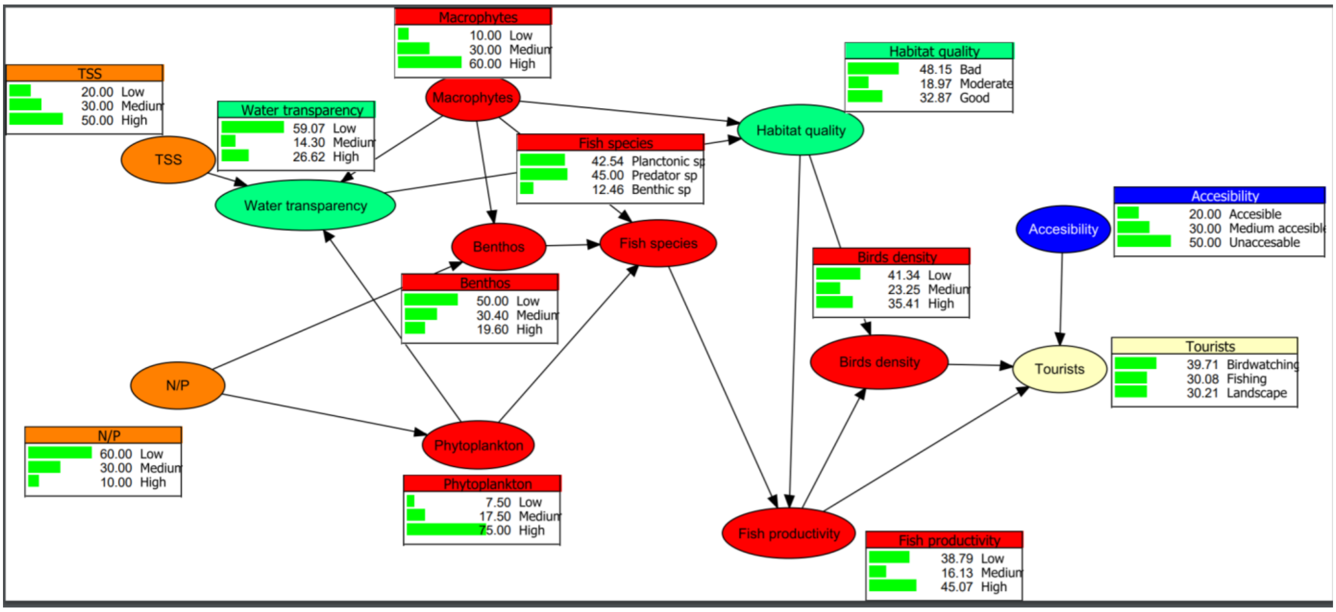


Figure 5.16: Bayesian Network Danube Delta

5.3 Arid

Dryland ecosystems are facing grand challenges of adaptation and reorganization in response to anthropogenic climate and land use changes worldwide (Peters, et al., 2006; Wiesmeier, 2015; Wilcox, et al., 2011). Although these water and nutrient-limited systems are characterized by low primary productivity and a low amount of standing biomass, they are nonetheless rich in ecosystem services, particularly regulating (Safriel, et al., 2005) and cultural services (Sagie, et al., 2013). Cultural services, in the form of informational, touristic, and spiritual benefits, are particularly prominent in drylands (Orenstein & Groner, 2014; Sagie, et al., 2013). Even the small amount of provisioning services were significant enough to define the cultural and livelihoods of societies. For example, arid regions have historically supported pastoralist societies who relied on the small amount of vegetation to support their herds (Finkelstein & Perevolotsky, 1990). Likewise, wild ungulate species specifically adapted for dryland environments depend on the existing vegetation (Henley & Ward, 2006).

5.3.1 Montado

Montado is a High Nature Value wood-pasture system characteristic of the Mediterranean Basin that is listed under the EU Habitats Directive (Habitat type 6310 “Dehesas with evergreen Quercus spp”). Despite their high nature value, the Montados are human dominated ecosystems, e.g., systems established for productive exploitation nowadays combining the exploitation of tree cover, namely cork, and undercover pastures for animal husbandry, namely cattle. The landscape originated by these combination of land uses, an open, savannah-type, evergreen oakland) provides also non-marketed ecosystem services. Indeed, landscape aesthetic enjoyment as well as habitat and diversity of species, are also (non-productive ecosystem) services provided by Montado. The demand for these ES have been demonstrated by several authors (Pinto-Correia & Sá-Sousa, 2011; Marta-Pedroso, et al., 2014) and their provision also relies on the maintenance of silvo-pastoral land use described above.

As a human dominated ecosystem, it is prone to change to the extension that management options might affect the ecosystem functions generating the above-mentioned flow of ES. Besides human-induced change other phenomena such as climate change might affect the ecological functioning of Montado and hence also affect societal wellbeing.

A fully understanding of the causal relationships between management, ecosystem structure and functioning and services provided calls for breaking down the complexity of the system. The breakdown of complexity has been first addressed in the PA storyline by adopting a DPSIR based approach to describe the PA. Despite the DPSIR framework based storyline construction a detailed further, the Task 7.2 aims at further define the possible drivers of change (and their related pressures/mechanisms) that would affect the ES provided by the PA and assess/quantify the associated uncertainties and to develop and to apply a DPSIR based conceptual framework to guide actions of enhancing protection levels in the focal protected areas. In pursuing this objective, for the case of Montado, a mind-mapping exercise have been carried out followed by an ES analysis as part of the adaptive DPSIR Cycle for the Montado. As motivated before, DPSIR does allow policy-makers to understand more easily the environmental problems although it does not allow per se addressing uncertainty. Hence as the DPSIR framework may appear as a deterministic and linear 'causal' description of environmental issues, which inevitably downplays the complexity of the environmental and socio-economic systems, BN have been introduced in the proposed framework to overcome such constraint. Based on the assumption that BN are a suitable tool for the structured analysis of complex systems as BNs can show relationships among variables graphically, allow the incorporation of uncertain and qualitative data and can be improved as more knowledge and data become available. Within Task 7.2 BNs development was restricted to a few PAs. The Montado does not include the group of PAs where BN have been tested to include uncertainty in the adaptive DPSIR cycle. Hereafter we report on mind mapping and we present our findings regarding the inclusion of ES in the DPSIR adaptive cycle for Montado. Regarding the involvement of the stakeholder (PA manager) it was restricted to the storyline narrative which is indeed the basis for the work reported under the task 7.2. In the corresponding section below we detailed how the stakeholder engagement evolved.

The mind mapping played a major role in understanding the system components and functioning and generated ES. The purpose of the mind map construction was not only depicting the complexity of the system but also provide a systematic way of linking such complexity with ES evaluation methods (evaluation is being carried out under Task 6.3 through process-based models). The mind map produced aims at reflecting the PA storyline and is organized around the three systems components/ levels (trees, pastures and landscape) that provided the key ES considered in the storyline: cork, meat, species and habitat diversity, and landscape aesthetic enjoyment. Additionally, other ES that are also attributable to each component have been listed though not being the focus of the analysis carried out. For listing ES, the CICES classification was adopted (Figure 5.17). Despite its important role in systematizing information, mind mapping is constrained by the level of information and complexity of systems components and the interlinkages among components that would have to be included. For instance, the inclusion of Drivers and Pressures was proven to be difficult as the reader would be getting tangled in the arrows network

Figure 5.18). Notwithstanding, mind mapping turned out as an efficient way of systematizing ecosystem components, services and flow of data/information needed to assess key ES.

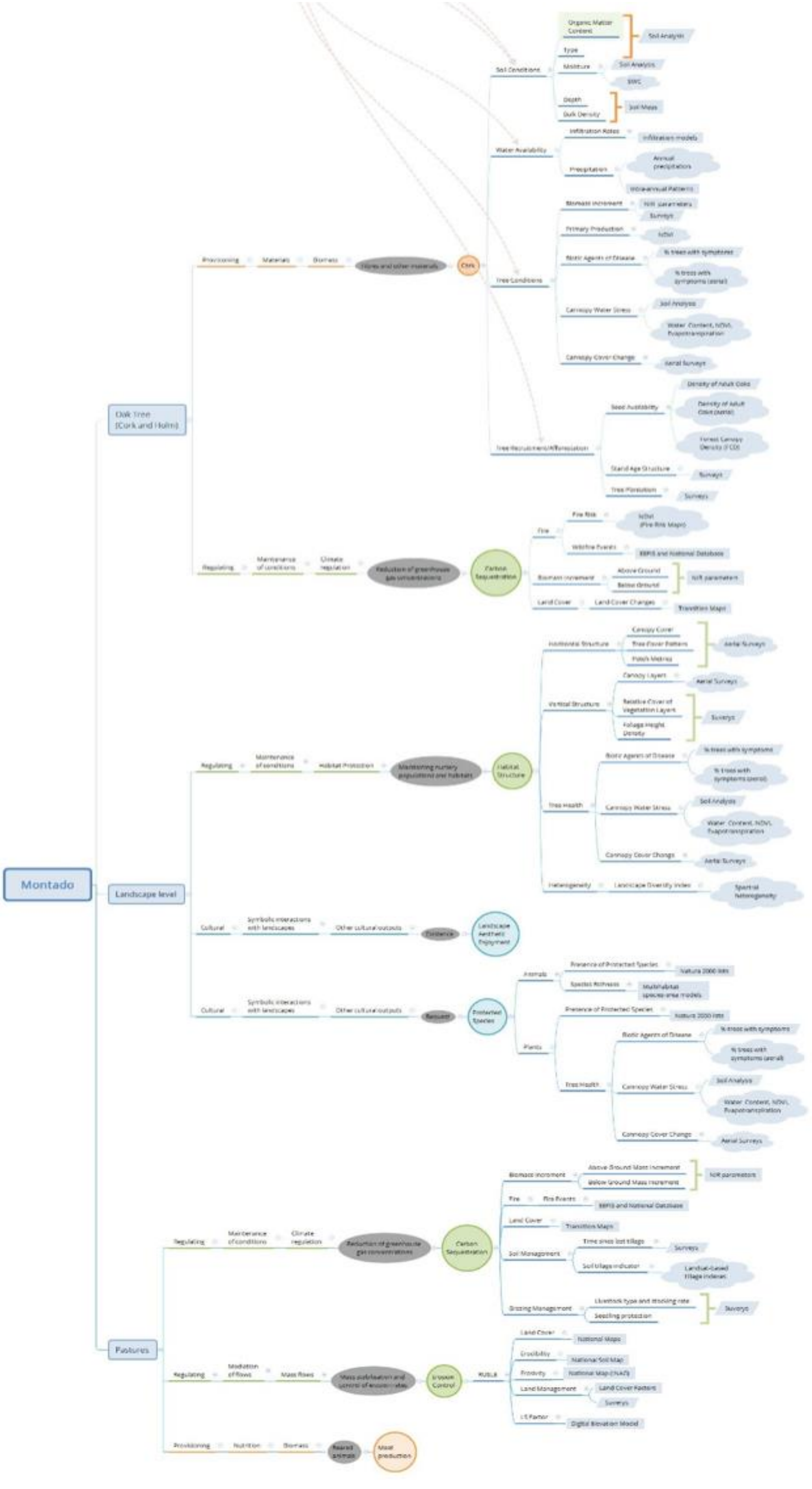


Figure 5.17: Mind map for Montado

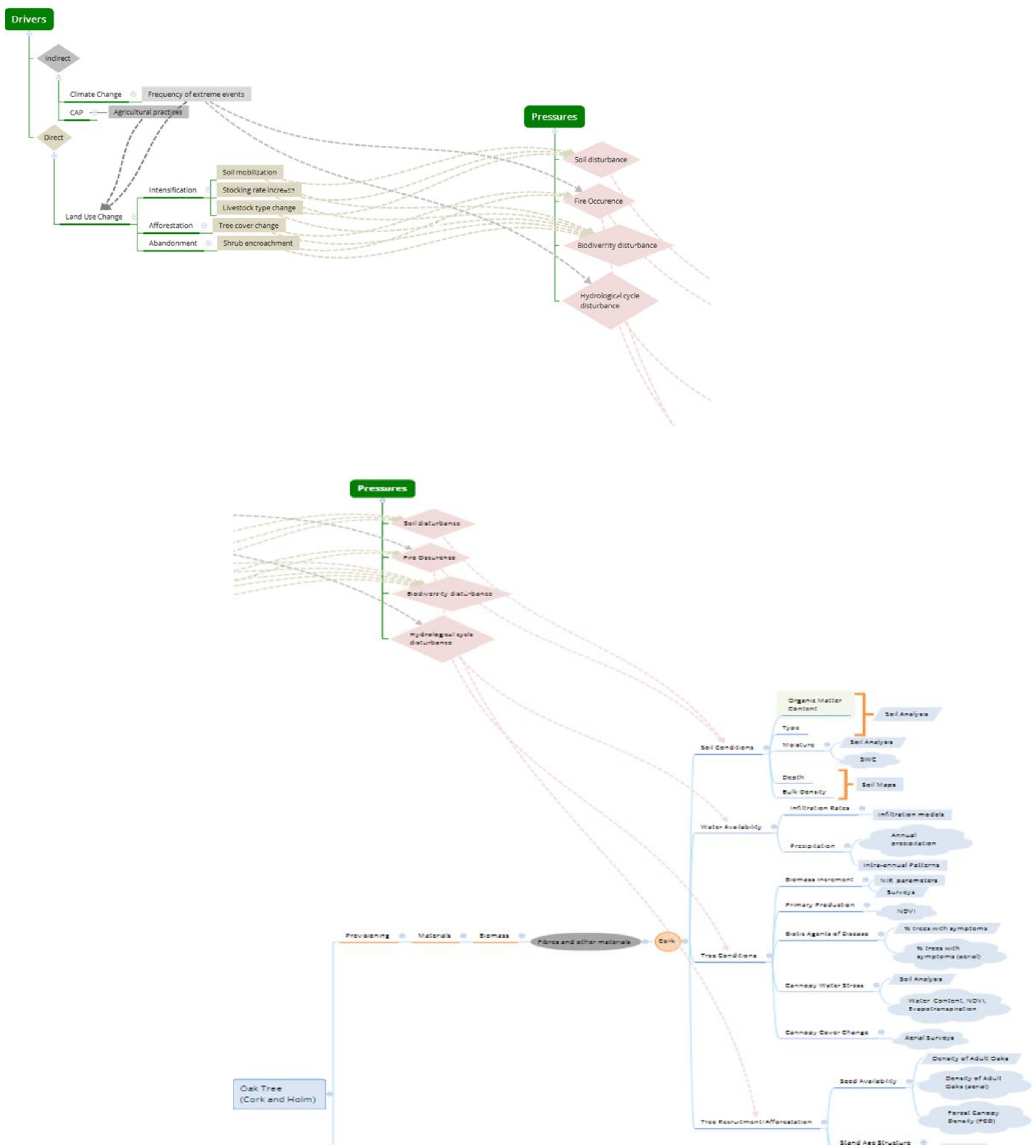


Figure 5.18: Partial shot of the mind map highlighting Drivers and Pressures (cut in two parts)

The DPSIR cycle inclusive of ecosystem services for the Montado presented here assume the provision of two key provisioning ecosystem services: cork - tree level and meat production – pasture level and two cultural ecosystem services: landscape aesthetic enjoyment and protected species – provided at landscape level. It is important to highlight that an appropriate scale is of utmost importance in carrying out ecosystem services assessment and for the case of Montado, given the combination of land uses, certainly the landscape level is the most appropriate. Notwithstanding a detailed analysis of the system and its components turns out as important since "tree decline" was identified as a major threat to landscape maintenance. Hereafter we detail the narrative constructed by ECOPOTENTIAL researchers in collaboration with stakeholders (ICNF and UNAC). Based on this a diagram including ecosystem services in a DPSIR cycle for the Montado is presented (Figure 5.19).

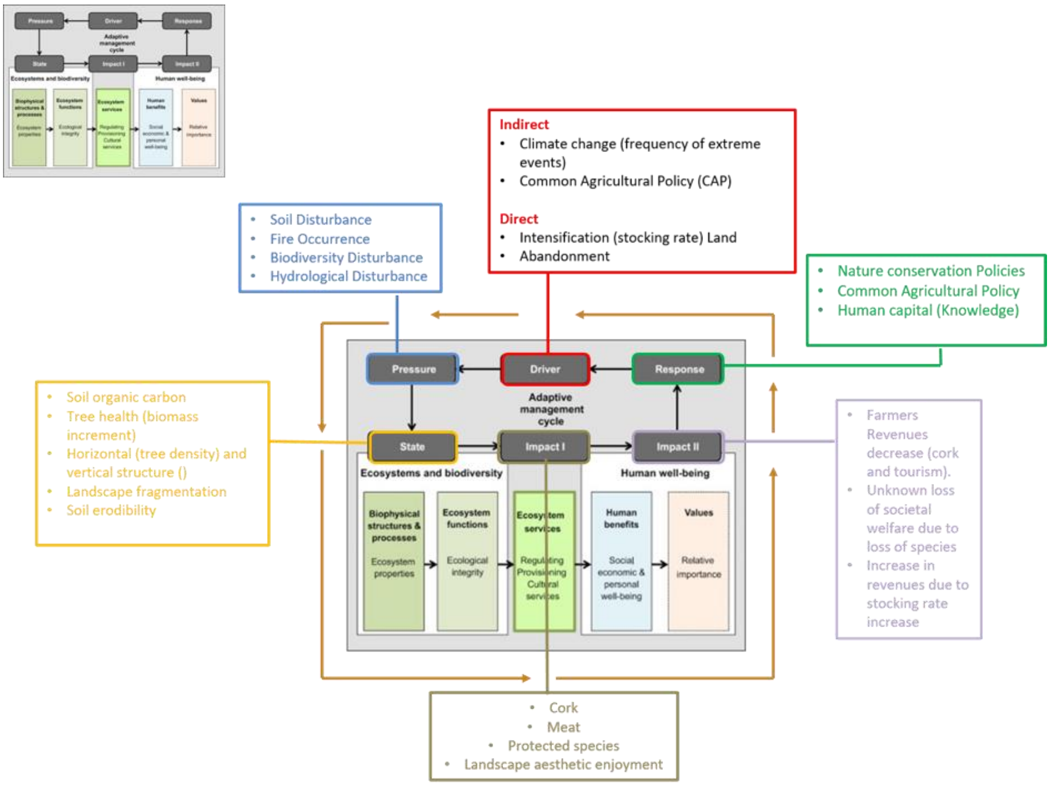


Figure 5.19: Ecosystem Services in a DPSIR cycle for the Montado

The long-term sustainability of the Montado ecosystem is currently threatened by declining trends in stand density caused by adult tree mortality and deficient tree recruitment ((Acácio & Holmgren, 2014; Almeida, et al., 2015). The Common Agricultural Policy (CAP) and market pressures have affected management practices, namely an increase in cattle density and grazing pressure, which leads to soil compaction, loss of vegetation cover, and a decline in natural regeneration (Bugalho, et al., 2011; Almeida, et al., 2015; Guerra, et al., 2016). At the same time, destructive soil tillage for pasture sowing and shrub control are contributing to soil degradation and also preventing natural regeneration (Pinheiro et al., 2008). Soil degradation also restricts soil water infiltration, thus aggravating the effects of a shift in precipitation regime and of more frequent droughts (Ramos, et al., 2015). The simultaneous increase in tree mortality and decline in recruitment not only affects cork production in the long term, but also causes changes in habitat structure with reduction of tree density, loss of tree cover and fragmentation of the system (Acácio & Holmgren, 2014; Almeida, et al., 2015). These structural changes can eventually lead to changes in ecosystem extent and distribution in the landscape, with impact on the abundance and distribution of threatened species. A focus on understanding plausible responses is of major importance for the future of PA establishment, namely for definition of management plans when multiple drivers are operating. Hereafter we present a specific response implemented in Portugal that covered the main drivers identified above and, definitely contributed to slowly (given the territorial implementation of the project and the number of farmers involved) the above-mentioned drivers of change for the Montado.

The project ExtEnSity (Environmental and Sustainability Management Systems in Extensive Agriculture) was a demonstration project financed by the Life Program (LIFE03 ENV/P/505). Project ExtEnSity was referred in the Millennium Ecosystem Assessment for Portugal (ptMA) as one example of a coherent set of responses (Pereira, et al., 2004; Pereira, et al., 2009). The project took place between November 2003 and February 2008, reaching 86 farmers and over 70 000ha spread throughout the country. The major thrust of ExtEnSity (Pereira, et al., 2006) was the creation of a prototype for “sustainable land use” in the agricultural sectors of extensive livestock production and arable crops, with three main components: (1) optimized irrigation, (2) no tillage, and (3) biodiverse, legume-rich pastures with increased animal stocking rates. Components 2 and 3 lead to increased soil organic matter, thereby reducing soil erosion and increasing water retention. All three components reduced water consumption and nitrate leaching, also leading to reduced soil erosion and reduced water pollution. Components 1 to 3 all lead directly to increased economic viability of agricultural activities, thereby promoting “sustainable land use” instead of afforestation, abandonment, and intensification. This transition was also promoted by compensating low human capital with technical support and information management. Additionally, the transition to “sustainable land use” was addressed by counteracting “reduced agricultural revenues” through two interventions associated with an increase in rewards for the private (food quality and safety) and public (other ecosystem services) goods provided by “sustainable land use.” The project directly increased the rewards for private goods by promoting the commercialization, at higher market prices, of the project farms’ products. This addressed the environmental attitudes component of the “environmental attitudes and legislation” driver. Increasing the rewards for public goods required a higher scale of intervention. Specific agri-environmental measures have been since implemented in Portugal based on the outcomes of ExtEnSity project (e.g., non-tillage and permanent pastures installation). ExtEnSity, had a strong multiscale, multi-user, multi-knowledge system approach and represented an example of an integrated response that addresses degradation of ecosystem services provided by Montado (though scalable to other agro-forestry ecosystems type). The entire and coherent set of responses mentioned above are shown in (Figure 5.20)

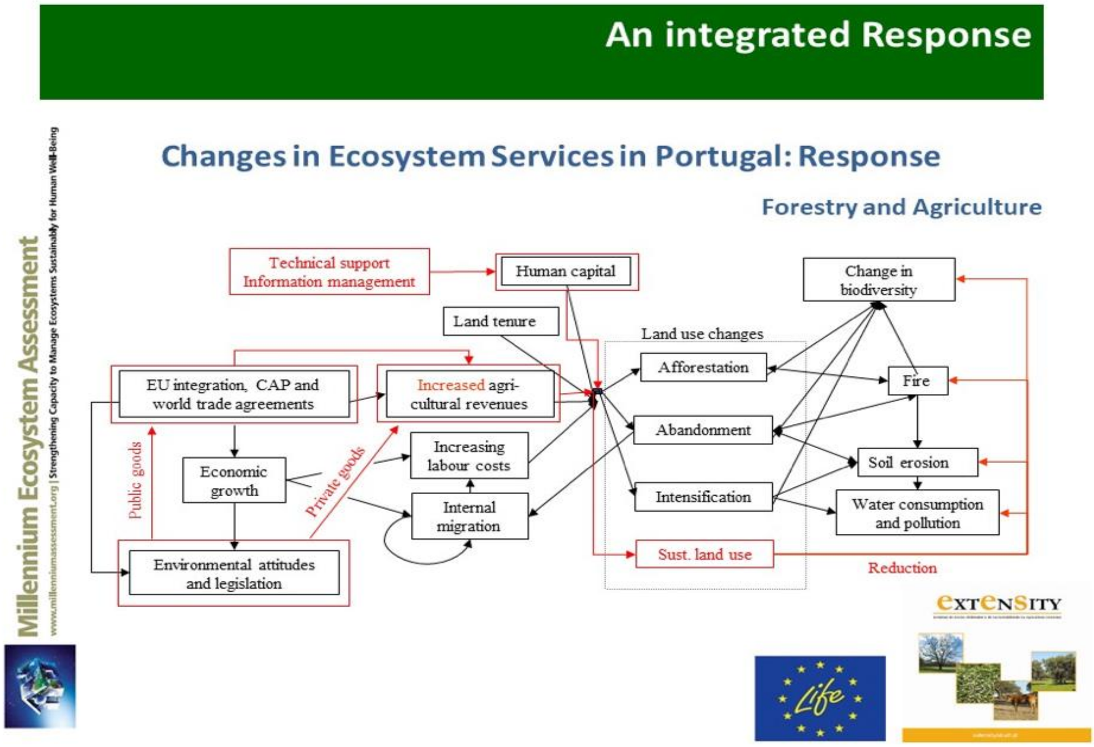


Figure 5.20: Schematic representation of responses on ecosystem services changes for Montado (Portugal)

Stakeholders involvement in the work carried out was promoted since the beginning of the project. The DPSIR based storyline, the cornerstone of the work developed within task 7.2, was developed by researchers, based on discussions with protected area managers, namely ICNF - Institute for Nature Conservation and Forests, the public entity responsible for the implementation of nature conservation and forestry policies in protected areas, and UNAC - Mediterranean Forest Union, an association of forest owners, and also supported by literature review.

From the point of view of the ICNF, the development of expedite methods that make use of Earth Observation tools and Remote Sensing technology in order to better characterize the state of Montado forests (e.g., density and age structure), is of utmost importance and hence collaboration was strengthened and flow of communication improved.

In May, 2017, the Director of the Department of Nature Conservation and Alentejo Forests accepted the invitation to participate in ECOPOTENTIAL workshop "Application of Earth Observation tools in Protected Areas in Europe and beyond - Establishing a community of practice", which took place in Pisa, Italy. As follow up of this participation connections with WP9 and WP11 were facilitated and last September researchers from both WP visited the Montado and collect information currently being processed.

6.3.2 Har HaNegev

Located in the heart of the Negev Desert in Israel, the Negev Highlands ("Har HaNegev") cover an area of 445 km^2. This protected area includes a national park, the UNESCO World Heritage Incense Route, and several national nature reserves established for their unique flora, fauna, water resources, geological features and archaeological values. The area also contains two urban settlements, several single-family agricultural farms, Bedouin settlements, as well as military bases and training areas.

Israel is one of the densest countries in the world, with the largest birth rate among the developed countries (Population Reference Bureau, 2016). The fast population growth rate in the country drives an increasing pressure for rapid residential development (Orenstein & Hamburg, 2009; Portnov & Safriel, 2004). The Negev, the southern arid part of Israel, is the largest land resource of the country, and government policy encourages redirecting growth to this region (Orenstein & Hamburg, 2009). Therefore, residential development is predicted to expand to this area; it is crucial to understand the effect of such settlement on the ecological integrity of the system. While the consequences of human residential development as a major land use change on ecological systems have been studied (Fox, 1998; Hansen, et al., 2005; McKenzie, et al., 2011), the effect of settlements on the fragile arid environment on the various levels of ecological organization and landscape scales is not well understood.

The first ECOPOTENTIAL activity for the Negev ECOPOTENTIAL team was a storyline writing workshop, which included the entire Israeli research team, including the primary investigators, research colleagues, Nature and Park Authority (NPA) staff scientists, and guest researchers from collaborating institutions in Europe. While the storyline writing ultimately produced a comprehensive document reflecting the complexity of arid ecosystems under heavy human impact and defining the ECOPOTENTIAL research agenda for the Negev Highlands Protected Area, there were fundamental differences in scientific approaches that had to be overcome. The stakeholder body, the NPA, which was integrated into ECOPOTENTIAL as a full partner, was primarily interested in biodiversity conservation and avoidance of destructive human impact on the ecosystem. Their representatives proposed questions that were practical in their orientation and focused primarily on conservation of certain target species. The principal scientific investigators, on the other hand, took an ecosystem perspective and focused on questions oriented to understanding flows of water, biomass, nutrients and species across the landscape, and the impacts of human interventions in these flows.

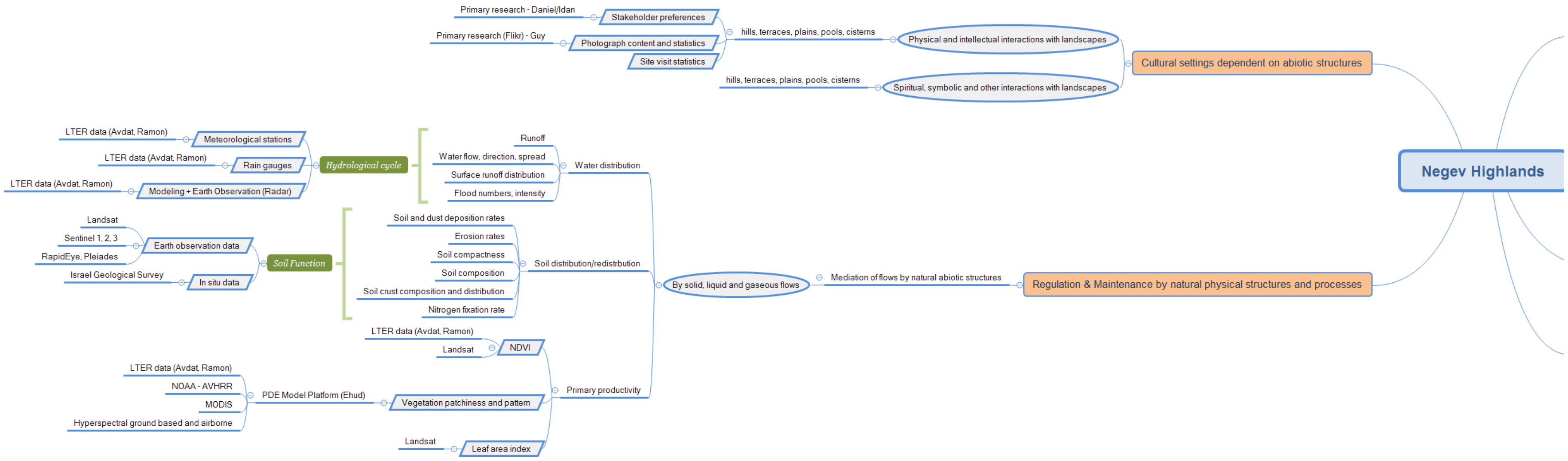
After two and a half days of discussion, a storyline document emerged entitled "Impact of Residential Settlements on the Life Supporting Capacity of Har HaNegev Arid Environment". As the title suggests, the participants chose to focus on modern residential settlement as a significant driver of ecosystem change - both from the perspective of ecosystem process and resultant ecosystem services, and from the perspective of biodiversity conservation. The two theoretical ecological approaches that influenced the storyline are reflected in the first two subsections of the report. The first is entitled "Main ecosystem services of interest for the storyline, and corresponding ecosystem characteristics / functions / processes that support them," and the focus was on habitat creation for biodiversity, which was then defined as a cultural ecosystem service. The second is titled, "Most important (abiotic and biotic) control factors of the ecosystem characteristics of interest and indicators of the state of the ecosystem characteristics," which focused on ecosystem processes embodied in feedbacks within and between the hydrological, pedological and energy and material system flows. So, both perspectives are presented and merge with the challenge of residential development.

Residential development and their associated infrastructure demands (e.g. electricity, water, and transportation networks) are defined as the main drivers of change in the storyline's DPSIR model for Har HaNegev, and key indicators for measuring the spatial extent and intensity of these drivers were defined. These include impact of settlement development, (e.g. land use/land cover change, population size, sewage/waste/noise/light pollution and invasive/pest species proliferation). These were considered to impact key ecosystem characteristics, functions and processes including habitat integrity, hydrological flow, soil function, geodiversity and biodiversity.

Three primary research programs were initiated following completion of the storyline. The first program, commensurate with the broader objectives of ECOPOTENTIAL, focused on the development of remote sensing technologies for ecosystem monitoring (e.g. (Oriani, et al., 2017; Paz-Kagan, et al., 2017a; Paz-Kagan, et al., 2017b). The second, in direct response to NPA concerns, focused on the aesthetic impact of residential and other forms of development in the Negev Highlands. Through the application of photo-based surveys, stakeholders – including residents and tourists – were queried regarding their landscape preferences (see below). Finally, the NPA is engaging in research around the topic of Onager reintroduction, including population monitoring, tracking of movement and assessing damage to agriculture.

In an effort to further define and crystallize the relations between Negev Highlands ecosystem services and the methodologies for quantifying and assessing them, the Negev research team assembled a mind map for three sub-ecosystem types within the PA (

Figure 5.21). This mind map characterized these relationships for wadi (dry-river bed) channels, slopes and plains. While the same ES are featured in all three sub-ecosystem types, the proportional representation of ES differ in each subsystem according to the patchy interaction of the hydrological, geological, pedological and ecological systems (see storyline for a complete description of these interactions).



Negev Highlands
Cultural settings dependent on abiotic structures
Physical and intellectual interactions with landscapes
Spiritual, symbolic and other interactions with landscapes
hills, terraces, plains, pools, cisterns
hills, terraces, plains, pools, cisterns
Stakeholder preferences
Photograph content and statistics
Site visit statistics
Primary research - Daniel/Idan
Primary research (Flikr) - Guy
Regulation & Maintenance by natural physical structures and processes
Mediation of flows by natural abiotic structures
By solid, liquid and gaseous flows
Water distribution
Runoff
Water flow, direction, spread
Surface runoff distribution
Flood numbers, intensity
Hydrological cycle
Meteorological stations
Rain gauges
Modeling + Earth Observation (Radar)
LTER data (Avdat, Ramon)
LTER data (Avdat, Ramon)
LTER data (Avdat, Ramon)
Soil distribution/redistrbution
Soil and dust deposition rates
Erosion rates
Soil compactness
Soil composition
Soil crust composition and distribution
Nitrogen fixation rate
Soil Function
Earth observation data
In situ data
Landsat
Sentinel 1, 2, 3
RapidEye, Pleiades
Israel Geological Survey
Primary productivity
NDVI
LTER data (Avdat, Ramon)
Landsat
Vegetation patchiness and pattern
PDE Model Platform (Ehud)
LTER data (Avdat, Ramon)
NOAA - AVHRR
MODIS
Hyperspectral ground based and airborne
Leaf area index
Landsat

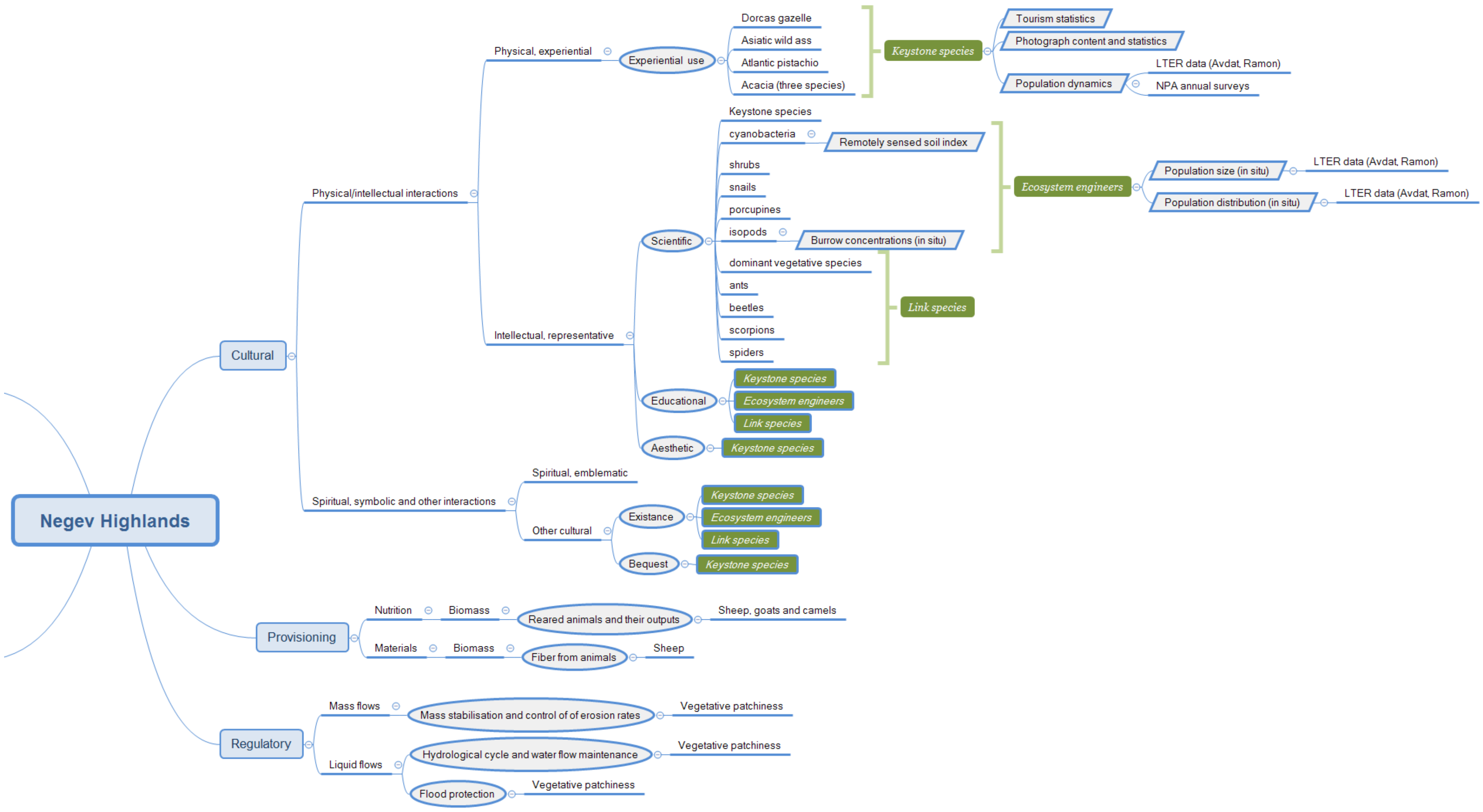


Figure 5.21: Negev Highlands Protected Area Mind Map

Stakeholder integration has been realized thus far through two channels. The first is the complete integration of the NPA as a partner into the ECOPOTENTIAL Project. In this way, the NPA was able to help set the research agenda, such that research would have direct relevance to the conservation challenges facing this management agency. Secondly, social research methods are applied in the form of a public landscape preference survey that was applied to 400+ residents and tourists to the area (). In this survey, at the request of the NPA, respondents were asked to look at 16 photographs of the region, each of the wadi landscape, but with varying degrees of human intervention, e.g. farms, afforestation, roads, electrical transmission lines, etc.). Preliminary analysis shows that the broad population has a strong preference for human intervention when it is in the form of adding vegetation to the landscape, but low preference when that intervention is in the form of residential or infrastructure development. Further, tourists have a higher preference for vegetation additions than local residents.

We intend to conclude the project with a public discussion of local stakeholders focused on the ECOPOTENTIAL research products with the goal of dissemination and validation of research results and of gathering stakeholder feedback regarding the relevance of the research and research products on local public lands policy and management.

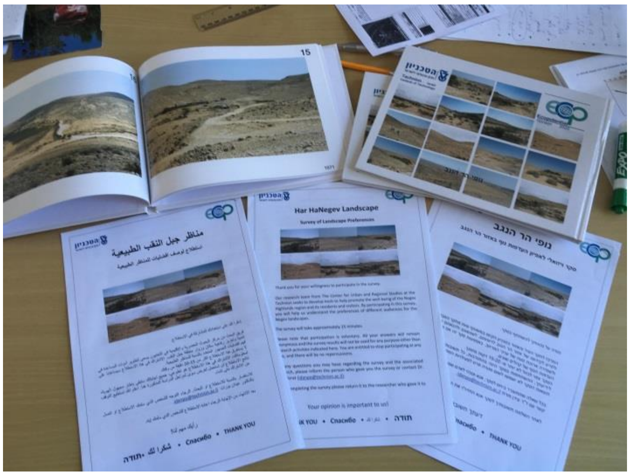


Figure 5.22: Questionnaire for querying public landscape preferences

6. Conclusions and Recommendations

The causal chain of the DPSIR framework as a tool to integrate knowledge from diverse disciplines has been widely adopted in environmental assessments but less applied in the context of PA management. Our findings indicate that DPSIR has potential to involve stakeholders in addressing the complexity of PA management given scenarios of future land use. Although we argue that the DPSIR framework is a relevant tool for structuring communication between scientists and end-users of environmental information, allowing policy-makers to understand more easily the environmental problems in place, it has to be completed by aspects addressing uncertainty. Without these, the DPSIR framework may appear as a deterministic and linear 'causal' description of environmental issues, which inevitably downplays the complexity of the environmental and socio-economic systems.

Gathering information into mind-maps works as a first step to the creation of a unified knowledge base, while Bayesian Network models allow for a better management of data uncertainty, commonly associated with the representation of complex models, as well as providing the possibility of creating future scenarios where assumptions can be tested. Indeed, although effective in systematizing information mind-maps might not be suitable to incorporate the system level of complexity desired.

The probabilistic structure of BNs is particularly useful in dealing with ecosystem services, where non-linear relationships between variables, threshold effects, and high uncertainties are common. When using ecosystem service maps to support management and resolve trade-offs between different services, these uncertainties need to be taken into account. This is especially important in natural hazard management, or when considering different scenarios of future change. Using BNs, we can identify the major knowledge gaps that contribute to uncertainty, which may help prioritize future research. Using sensitivity analyses on BNs can also determine the most important drivers or threats in a system (as in the Pelagos example). In further steps, such information should be used to evaluate and improve the model with experts or stakeholders, and may help to improve the understanding of the system on both sides.

Within the ECOPOTENTIAL project, PAs adopt particular approaches to their own management. The project advocates and coordinates the application of ES framework in participating PAs, but since the project also advocates partnering with local stakeholders, the ES framework may be disparaged in lieu of the biodiversity (species-specific) management approach. This has been, for example, the case with the Negev Highlands PA in Israel, where stakeholders (in this case, Nature and Parks Authority (NPA) scientists) pushed to focus on the status of endangered species as the management emphasis for the PA, while local ECOPOTENTIAL scientists promoted a focus on water, soil and primary productivity (i.e. ecosystem services) as the management emphasis. The conceptual frameworks applied by each group of scientists also led to distinctive management preferences, with NPA scientists preferring a minimum amount of human intervention in the ecosystem, and the university scientists advocating interventions such as restoration of ancient terraces in order to increase water retention and primary productivity in the system. As a de facto compromise, work proceeded on both fronts, with both groups continuing forward applying their own conceptual frameworks.

Applying the DPSIR framework as a tool to integrate knowledge from different disciplines in environmental assessment has been widely used. Applying the framework to PA management is not very common as its complexity has not completely been determined. Involving stakeholders by giving them future land use scenarios can potentially help to address this issue.

All in all, the DPSIR framework is a vital tool to structure communication between scientists and end-users of environmental information. This allows policy-makers to comprehend the environmental problems at place better. However, the aspect of uncertainty has to be addressed, when dealing these environmental problems. If uncertainty is not taken into consideration, the DPSIR may appear as deterministic and linear 'causal' description of environmental issues which inevitably minimise the complexity of the environmental and socio-economic systems.

Collecting information and developing mind maps is the first step to create a unified knowledge base. BNs models on the other hand allow for a better management of data uncertainty which are also commonly associated with the representation of complex models. Additionally, it is possible to create future scenarios where assumptions can be tested with BN models. Summarising, mind maps can effectively arrange information, however, they might not be suitable to incorporate the system level of complexity desired.

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