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D6.1. Interactive web example showing one case study implementation

Dissemination level: **Public**

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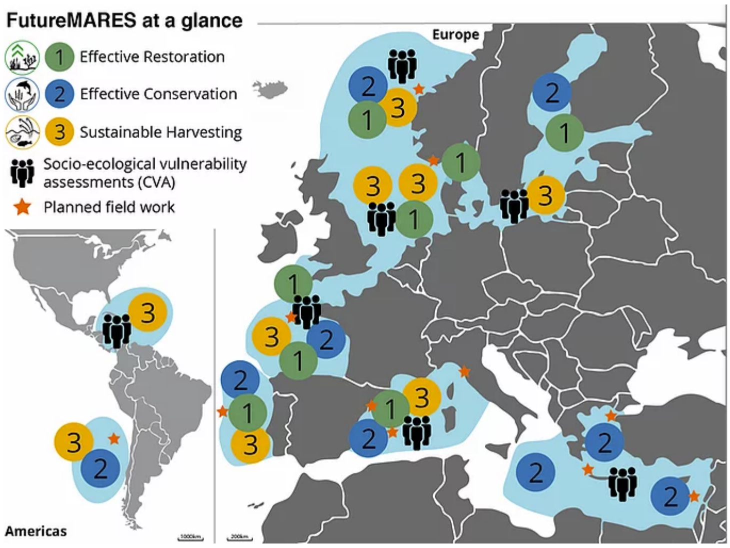
FutureMARES Project

FutureMARES - Climate Change and Future Marine Ecosystem Services and Biodiversity is an EU-funded research project examining the relations between climate change, marine biodiversity and ecosystem services. Our activities are designed around three Nature-based Solutions (NBS):

Effective Restoration (NBS1)

Effective Conservation (NBS2)

Nature-Inclusive Harvesting (NIH)



We are conducting our research and cooperating with marine organisations and the public in Case Study Regions across Europe and Central and South America. Our goal is to provide science-based policy advice on how best to use NBS to protect future biodiversity and ecosystem services in a future climate.

FutureMARES provides socially and economically viable actions and strategies in support of NBS for climate change adaptation and mitigation. We develop these solutions to safeguard future biodiversity and ecosystem functions to maximise natural capital and its delivery of services from marine and transitional ecosystems.

To achieve this, the objectives of FutureMARES defined the following goals:

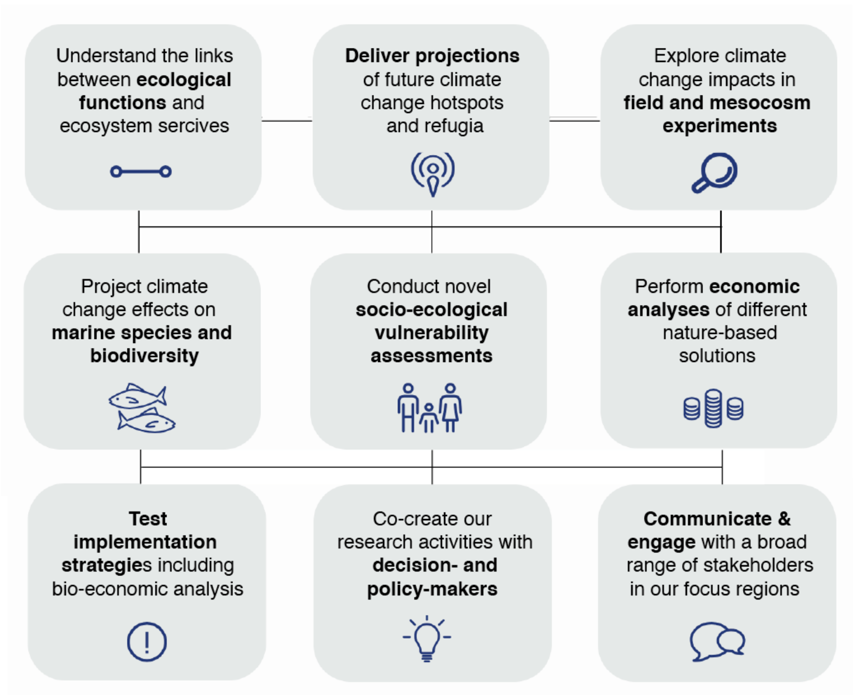


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Table of content

List of symbols, abbreviations, and a glossary

CC	Climate change
BN	Bayesian network
CES	Cultural ecosystem services
DST	Decision support tool
ES	Ecosystem service
EC	European Commission
MSY	Maximum sustainable yield
NBS	Nature-based solutions
PES	Provisioning ecosystem services
RES	Regulating ecosystem services
SBT	Sea bottom temperature
SST	Sea surface temperature
WP	Workpackage

Executive summary

Introduction

This document briefly describes how to access and use the decision support tool (DST) demo based on Bayesian network analysis. The DST is designed to visualize trade-offs between scenarios which do and do not implement Nature-based Solutions (NBS) or Nature-inclusive Harvesting (NIH). The Bay of Biscay is used as an example.

Defining the challenge

The implementation of NBS and/or NIS will have benefits, but also impacts since there are trade-offs among the different types of actions supporting such interventions. These trade-offs are complex to evaluate without graphical intuitive tools that allow one to simplify their exploration while considering the inherent uncertainties.

Approach

Bayesian networks (BNs) are used to produce a decision support system. BNs have the advantage of being easier to interpret and extract knowledge from other models due to their graphical representation and their principled probabilistic foundations in domains of high uncertainty.

Contribution to the project

The network shows trade-offs of ecosystem services (provisioning, regulating and cultural) in the Bay of Biscay under the FutureMARES scenarios. The Global Sustainability scenario, which corresponds to the implementation of NBS1 (habitat restoration), NBS2 (conservation such as marine protected areas) and NIH under maximum sustainable yield (MSY), shows higher chances of regulating economic value. In contrast, World Markets and National Enterprise show a higher likelihood of achieving higher values of provisioning and cultural services. However, this is just a demo of the potential of Bayesian networks (BNs) as decision support tools considering multiple trade-offs.

Dissemination and exploitation

The network demo is being exploited in the following ways:

1) Training examples for other Storylines and partners interested in this approach.
2) To show to stakeholders including policy makers in meetings and workshops.
3) Online for anyone to use or explore the possibilities of this approach.
4) Likely at least one scientific publication will be produced on the use of BNs as decision support tools within FutureMARES project.

1. Introduction

Climate change is impacting on pelagic and coastal biodiversity, reducing the services provided by nature (Chust et al. 2011, Chust et al. 2022, Garmendia et al. 2023, Murillas et al. 2023) as derived from WP1 work and deliverables (e.g. D1.1, D1.2, D1.3 and D1.5). In the Bay of Biscay (BoB), oceanographic conditions have changed over the last three decades (e.g., deepening of thermocline since 2007, Valencia et al. 2019) impacting on different pelagic species via spatial shifts in spawning habitats (Bruge et al. 2016) and changes on reproductive traits mediated by trophic links (Extramiana et al. 2019), among others. Moreover, climate change is affecting the distribution of species where the BoB plays an important role since it corresponds with the high and low latitudinal limit of the distribution of several species (Baudron et al. 2020, Fernandes et al. 2020; Erauskin-Extramiana et al. 2023).

Global model projections show that environmental change will be higher than previously forecasted (Lotze et al. 2019, Tittensor et al. 2021). Projections show a potential decline in productivity within the BoB in the lower trophic levels (Bindoff et al. 2019; Flombaum et al. 2020). As a result of temperature changes, faster initial growth of fish is also being induced with a decrease in weight- and size-at-age (Perry et al. 2005, Pauly et al, 2018), and this is expected to continue under climate projections (Queiros et al. 2018). This size decrease has been detected at a local scale in the BoB with European anchovy (*Engraulis encrasicolus)*, also impacted by the timing of reproduction with an earlier spawning rate of six days per decade (Erauskin-Extramiana et al. 2019). Large pelagic tuna species are changing to an earlier migration of 2.3 days per decade (Santiago 2004, Chust et al. 2019). All widely distributed species are showing shifts in distribution (Baudron et al., 2020), particularly small pelagic species (Fernandes et al., 2020). Mackerel is showing a northern distribution shift (Hughes et al. 2014, Bruge et al. 2016, Brunel et al. 2018). Climate variability affects the migration patterns of pelagic marine megafauna in the BoB, adjusted by optimal movement conditions and foraging (Louzao et al. 2015), while extreme events can increase seabird mortality (Louzao et al. 2019a). In terms of species at higher trophic levels, a great variety of marine mammals and seabirds are present in the BoB. The seabird community is of relevance during certain periods of the year through an important migratory flyway (Fort et al. 2012; Stenhouse et al. 2012). The migration of marine megafauna (i.e., cetacean, seabirds and large pelagic fishes) is highly influenced by early stages of pelagic fishes such as the European anchovy (García-Barón et al. 2019a, Louzao et al. 2019b, Lezama-Ochoa et al. 2010). Mammals are vulnerable to fishing bycatch, vessel collision, and pollution-related threats, whilst seabirds are particularly sensitive to oil spills, fishing bycatch and marine litter (García-Barón et al. 2019b, García-Barón et al. 2022, Zorrozua et al., 2023).

Here, we briefly describe how to access and use a decision support tool demo based on Bayesian network to see trade-offs between scenarios. This demo allows to explore ecosystem services trade-offs under FutureMARES climate, fishing and management scenarios considering the ecosystem services framework where services are the results of ecosystem functions that provide benefits to human well-being (Costanza et al., 2017). In particular, we considered the cultural, provisioning and regulating services (Haines-Young and Potschin, 2018). Cultural ecosystem services (CES) are defined within a wider framework of ecosystem services as benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experience (e.g., recreational fisheries, tourism). Provisioning ecosystem services (PES) are the products obtained from ecosystems (e.g., fish, protein, oils, genetic resources). Finally, regulating ecosystem services (RES) refer to the benefits obtained from the regulation of ecosystem processes (e.g., climate regulation, nutrient transportation). Supporting services are excluded from the valuation to avoid double counting. This double counting may occur when a service is valued at two different stages of the same process providing human welfare (Ojea et al. 2012).

2. Methodology

Classification models based upon probability theory, such as Bayesian Network (BN) classifiers, are especially useful for understanding and decision taking in highly uncertainty domains such as some marine social-ecological systems (Fernandes et al. 2010, Trifonova et al. 2015, Coccoli et al. 2018). In addition, supervised pre-processing methods can be combined with BNs to improve classifier performance and interpretability (Fernandes et al. 2010, Uusitalo, 2007). Data pre-processing is a key issue under conditions of high uncertainty, such as recruitment forecasting, where sparse and noisy data are common. Supervised pre-processing methods can also aid in the process of model interpretation and knowledge extraction (Fernandes et al. 2010, Fayyad et al. 1996).

Interpret and knowledge extraction from BNs is easier than other supervised classification models (Correa et al. 2009), due to their graphical representation and their principled probabilistic foundations in domains of high uncertainty (Sebastiani et al. 2005). 'Naive Bayes' (Duda et al. 2001), one of the simplest BN models for classification (Larrañaga et al. 2005), has been selected for this demo; this is due to its competitive performance, as it works well in many complex real-world problems (Domingos and Pazzani 1997, Zhang 2004). 'Naive Bayes' assumes that, given a target variable, all the rest of variables are independent between them. This assumption implies that a 'naive Bayes' classifier requires the specification of a small number of parameters, which leads to robust models and parameter estimation when few training data or noisy data are available. Further, it is a computationally fast model to be learnt (a computing time complexity of O (nk), where n is the number of training examples and k is the number of selected factors). Another advantage of the 'naïve Bayes' classifiers is that it not only gives a prediction, but also the estimated probability associated with each FutureMARES project scenarios.

To facilitate the use and interpretation of the BN model probabilistic classification models the variables can be discretized (Torgo and Gama 1997, Frank et al. 2000, Revoredo and Zaverucha 2004, Dreyfus-Leon and Chen 2007). Nevertheless, these methods might produce artificial boundaries without biological or management meaning. Therefore, discretization is undertaken often based on fisheries experts´ suggestions. However, sometimes insufficient information about the effects on the model performance is available for setting these boundaries (Uusitalo 2007). Therefore, information theory approaches are used here since these consider the reduction in uncertainty (Fayyad and Irani 1993, Fernandes et al. 2010). Fayyad and Irani's (1993) MDL Multi Interval Discretization (MID) method is a supervised method that searches for cut-off point sets, minimising the recruitment entropy given each factor (conditional entropy). Entropy is a measure of uncertainty (Shannon and Weaver 1963), whilst conditional entropy quantifies the discrimination power of factors, in relation to the fishing scenarios.

The decision support tool (DST) developed is called FutureBayes. It is an adaptation of a previously existing tool (Environmental Assessment and Marine Spatial Planning; VAPEM tool (https://aztidata.es/vapem/), which combines GIS with BNs to inform users about interactions between different ecosystem components and human activities to assess ecosystem services; the identification of suitable areas for the development of offshore energy projects; as well as for the assessment of potential conflicts between different marine activities. Some examples of the application of VAPEM platform could be found in Coccoli et al. (2018), Gacutan et al. (2019) and Pınarbaşı et al. (2019). FutureBAYES is an interactive web demo of the ecosystem services trade-offs among the FutureMARES scenarios. The deliverable first explains how to access the tool and the basics of its use for the BoB example. Then, it provides three case studies of how it can be used. The tool is based on shiny and bnlearn packages in R. FutureBayes simplifies the VAPEM interface and it has also improved user interactions and visualization on the networks under FutureMARES scenarios.

FutureMARES develops policy-relevant scenarios based on commonly used IPCC frameworks including SSPs and RCPs. These broad scenarios are regionalized based on stakeholder perspectives to guide activities such as model simulations, restoration plans and protected areas definition. Each of these scenarios has implications for the three NBS examined in this program (effective restoration, effective conservation, sustainable seafood harvesting):

Global Sustainability (RCP2.6, SSP1) - Low challenges to mitigation and adaptation

The world shifts gradually but pervasively to a more sustainable path, emphasising inclusive development that respects perceived environmental boundaries. Management of the global commons slowly improves, investments in educational and health accelerate lower birth and death rates, and the emphasis on economic growth shifts to an emphasis on human well-being. Societies increasingly commit to achieving development goals and this reduces inequality across and within countries. Consumption is oriented toward lower material growth, resource and energy intensity.

National Enterprise (RCP8.5, SSP3) - High challenges to mitigation and adaptation

A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to focus on domestic or regional issues. Policies shift to be oriented more on national and regional security. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. Population growth is low in industrialised countries and high in developing ones. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions.

World Markets (RCP8.5, SSP5) - High challenges to mitigation, low challenges to adaptation

The world increasingly believes in competitive markets, innovation and participatory societies to produce rapid technological progress and train and educate people for sustainable development. Global markets become more integrated and strong investments in health, education, and institutions are made to enhance human and social capital. The push for economic and social development is coupled with exploiting abundant fossil fuel resources and adopting resource and energy-intensive lifestyles around the world. All these factors lead to rapid growth of the global economy, while the global population peaks and declines in the 21st century. Local environmental problems like air pollution are successfully managed. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary.

The ecosystem service evaluation was made following the Common International Classification of Ecosystem Services (CICES) conceptual framework (Haines-Young and Potschin 2018). Three types of final services were evaluated PES, CES and RES (Prellezo et al. 2023). We used the benefit transfer of the estimated function to conduct a Willingness to Pay (WTP) assessment (Amuakwa-Mensah et al. 2018) to provide a CES value for threatened and endangered species by group. The groups considered were fishes, seabirds, invertebrates and marine mammals, where the threat and charisma have a positive effect on the WTP. The monetization of this carbon transport and content was made by transforming the carbon transport into CO_2 equivalents and using exchange prices of the existing CO_2 trade schemes and the social cost (Barage et al. 2017, Prellezo et al. 2023).

3. The evaluation of ecosystem services trade-offs

3.1. The Bayesian network as decision support tool

The FutureBayes tool is hosted in www.aztidata.es server (Fig. 1) and is freely accessible on https://aztidata.es/FutureBayes/. The link on the top left corner of the initial page (Ecosystem services trade-offs Bayesian network) allows to interact with the BoB trade-offs network. The credits link list all the contributors to the development of this tool and the financial support of FutureMARES is also included. A second spatial case study about *Zostera noltei* spatial planning is under development (*Zostera noltei* spatial model).

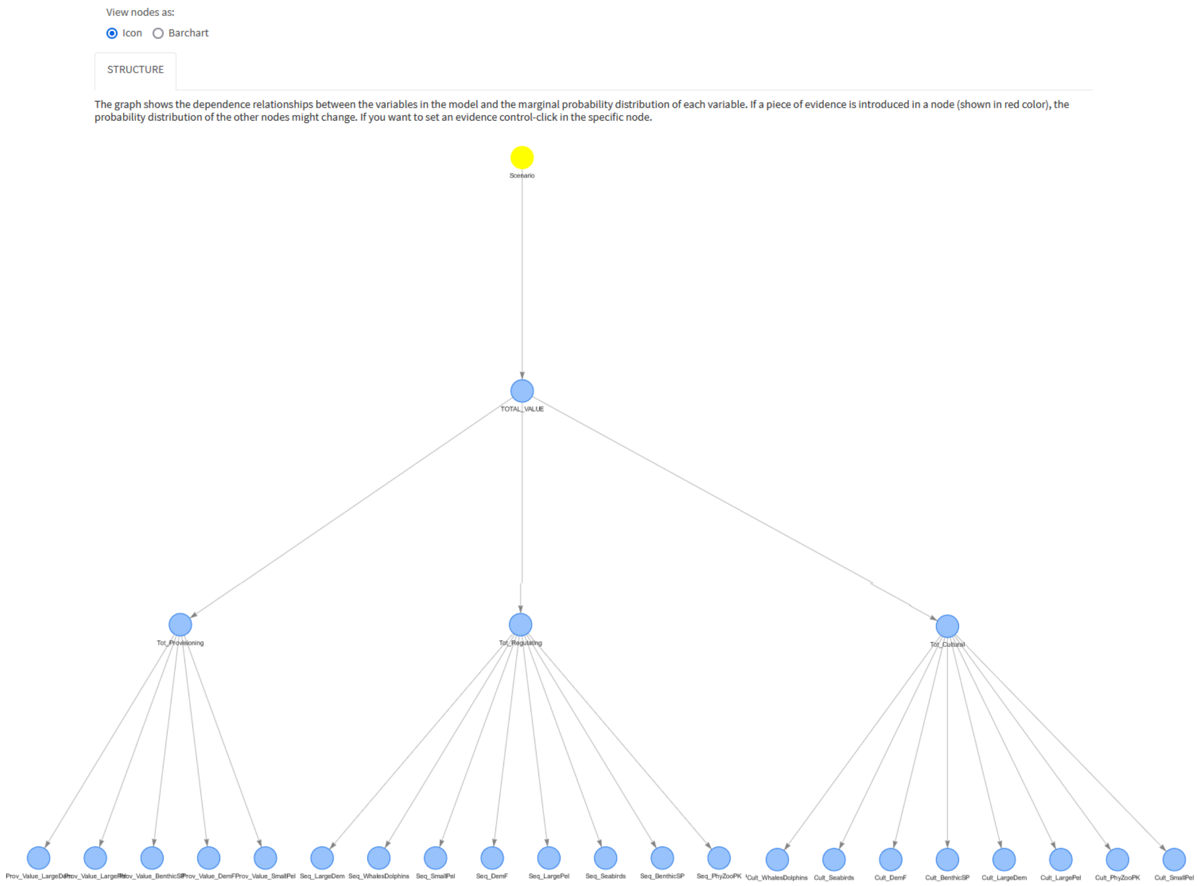

Figure 1. Structure of the network which can be navigated and interacted with.

This network page is divided into two parts: one fixed on the left and a right side where there are three selectable options or tabs. The fixed area has the title "STRUCTURE" (Fig. 1). The structure area shows all the variables (represented by a circular blue node) linked using a naïve Bayes structure (black arrows). The network can be zoomed in and out using the mouse wheel to see the nodes names. Moving the mouse over the nodes shows the probabilities distribution across its possible values. The top two nodes correspond to the scenario's nodes (s1oGS: Global sustainability, s2oWM: World markets, s3oNE: National enterprise). See Table 2 to see a complete list of the nodes with details of their meaning and the definition of values (shown in the tool as low, medium or high for easier visualization and interpretation). The information summarized in Table 1 can also be seen in the tool by selecting the "PARAMETERS" and "VARIABLES DESCRIPTION" tabs.

Table 1. Names of the nodes, description and values range.

Node name	Node description	Value (million euros)
Scenario	Scenario	s1oGS: Global sustainability s2oWM: World markets s3oNE: National enterprise
TOTAL_VALUE	TOTAL VALUE	Low: Less 4800 High: More 4800 to 16075
Tot_Provisioning	Total provisioning service	Low: Less 0.35 High: More 0.35 to 0.44
Tot_Cultural	Total cultural service	Low: Less 1560 High: More 1560 to 1770
Tot_Regulating	Total regulating service	Low: Less 3000 High: More 3000 to 14450
Prov_Value_LargeDem	Provisioning service value of large demersal fishes	Low: Less 19 High: More 19 to 27
Prov_Value_LargePel	Provisioning service value of large pelagic fishes	Low: Less 95 High: More 95 to 130
Prov_Value_BenthicSP	Provisioning service value of Benthic SP	Low: Less 390 High: More 390 to 625
Prov_Value_DemF	Provisioning service value of other demersal fishes	Low: Less 500 High: More 500 to 615
Prov_Value_SmallPel	Provisioning service value of small pelagic fishes	Low: Less 250 High: More 250 to 326
Cult_WhalesDolphins	Cultural service of marine mammals	Low: Less 600 High: More 600 to 650
Cult_Seabirds	Cultural service of sea birds	Low: Less 960 High: More 960 to 1050
Cult_DemF	Cultural service of other demersal fishes	Low: Less 5.7 High: More 5.7 to 6.5
Cult_BenthicSP	Cultural service of benthic species	Low: Less 22.3 High: More 22.3 to 23.6
Cult_LargeDem	Cultural service of large demersal fishes	Low: Less 0.52 High: More 0.52 to 0.59
Cult_LargePel	Cultural service of large pelagic fishes	Low: Less 3.4 High: More 3.4 to 4.4
Cult_PhyZooPK	Cultural service of phytoplankton and zooplankton	Low: Less 32 High: More 32 to 35
Cult_SmallPel	Cultural service of small pelagic fishes	Low: Less 13.8 High: More 13.8 to 18.2
Seq_LargeDem	Regulating service produced by large demersal fishes	Low: Less 270 High: More 270 to 1545
Seq_WhalesDolphins	Regulating service produced by marine mammals	Low: Less 180 High: More 180 to 925
Seq_SmallPel	Regulating service produced by small pelagic fishes	Low: Less 1100 High: More 1100 to 4950
Seq_DemF	Regulating service produced by demersal fishes	Low: Less 500 High: More 500 to 1960
Seq_LargePel	Regulating service produced by large pelagic fishes	Low: Less 220 High: More 220 to 1000
Seq_BenthicSP	Regulating service produced by benthic species	Low: Less 680 High: More 680 to 3690
Seq_Seabirds	Regulating service produced by seabirds	Low: Less 0.26 High: More 0.26 to 1.35
Seq_PhyZooPK	Regulating service produced by phytoplankton and zooplankton	Low: Less 156 High: More 156 to 672

When a node is clicked, its values and probabilities distribution across nodes are visualized in the right side (Fig. 2) under the “DETAILED PLOT” tab. Until now, the network is showing the prior data distribution without setting evidence. An evidence can be set to see how probabilities change under a selected scenario (“what if” in a certain scenario) using the scenario node. However, the evidence can be also introduced in other nodes for example simulating that the maximation of certain type of values (e.g. sequestration or cultural value is maximized or the provisioning value of specific species is maximized with trade-offs in other values). If an evidence or set of evidence are introduced (see next section), the introduced evidence is highlighted in red (Fig. 2) and the new probabilities distribution changes in all the variables are shown (without the evidence or in relation to the previous selection of evidence).

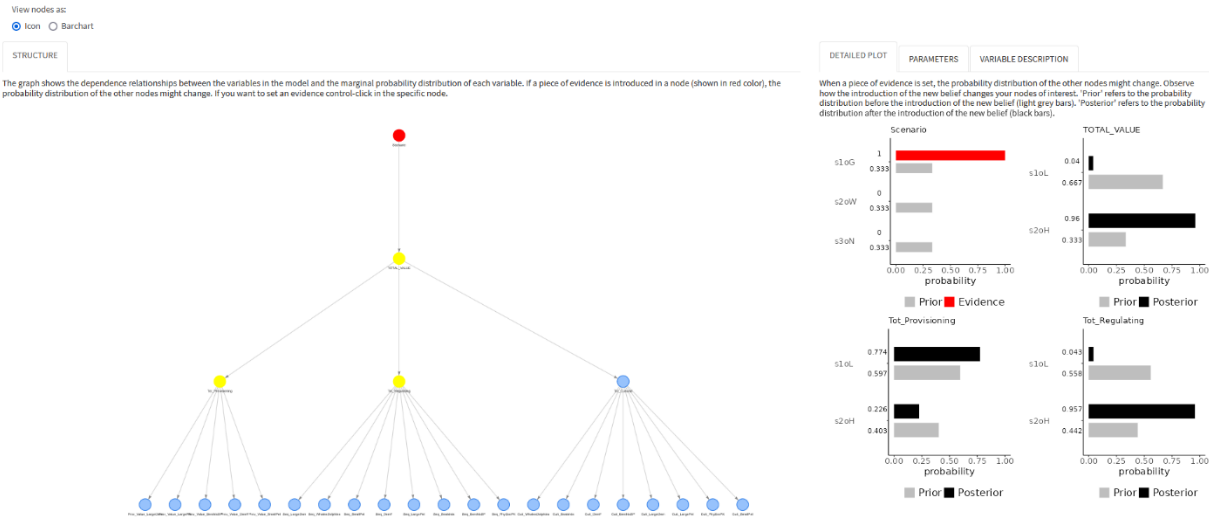

Figure 2. The left side shows selected nodes in red and yellow, whereas the right side shows the changes on probabilities given the provided evidences.

While pressing Ctrl key, click on a specific node to select or remove evidence (Fig. 3). The probability distribution of the other nodes will change accordingly. Probability distribution of nodes shows in this tab, but only for those nodes selected by the user. The introduction of evidence and its propagation is further explained with specific examples in next section.

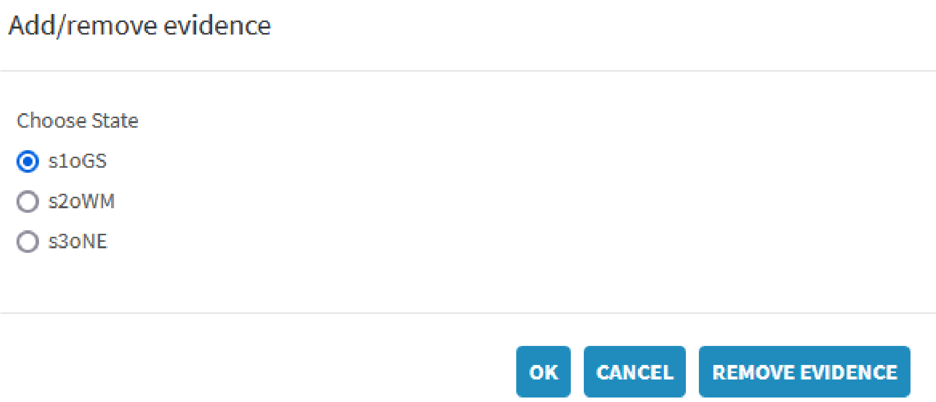

Figure 3. Setting and removing evidence with CTRL + Click (left mouse button).

3.2. *Climate and fishing scenarios exploration*

This case study of the use of the network shows the propagation of the evidence when exploring “what if” in each of the FutureMARES scenarios (Global Sustainability or GS, World Markets or WM, and National Enterprise or NE). For simplicity, only the scenarios and aggregated valuation nodes have been selected for visualization by clicking on each of them in the structure. Then, we start from the GS scenario as our prior state and as initial evidence by clicking on the fishing scenarios node while the CTRL key is pressed and selecting the s1oGS as evidence first (prior represented by the grey bars) and then set the evidence to WM (s2oWM) fishing (posterior represented by the black bars). In this scenario (Fig. 4), it can be observed that the likelihood of higher values of provisioning and cultural services increases, but with a lower likelihood of regulating services.

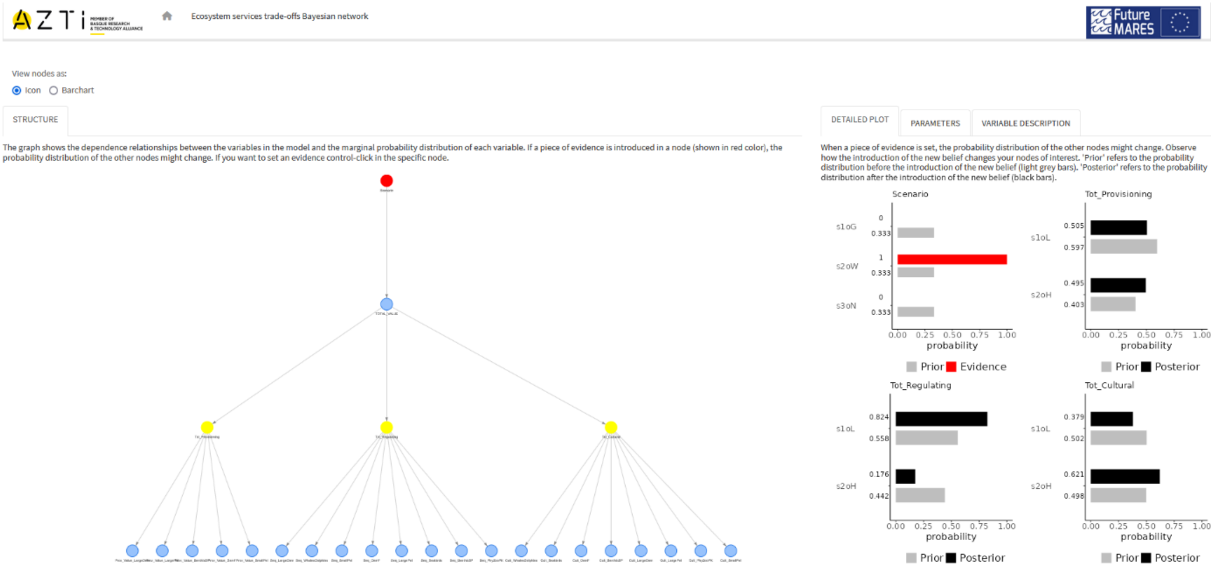

Figure 4. Exploring differences between Global Sustainability and World Markets.

In the GS comparison with NE (s3oNE) scenario (Fig. 5), a similar pattern can be observed with slightly higher chances of higher provisioning and cultural services.

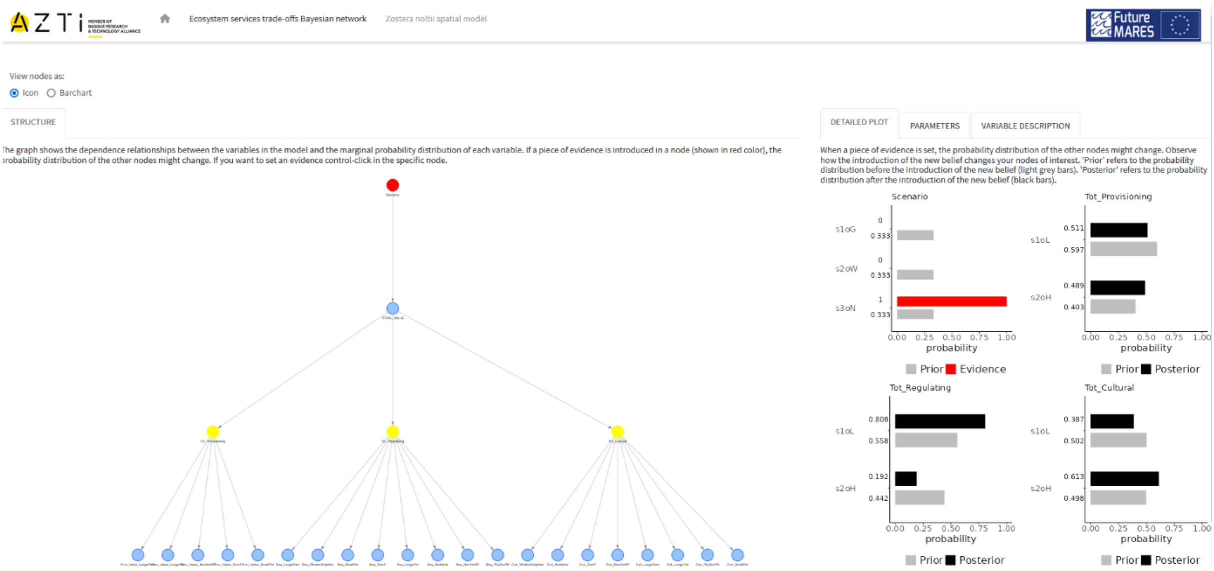

Figure 5. Exploring differences between Global Sustainability and National Enterprise.

3.3. Exploring trade-offs with what-if scenarios

In the previous section, the differences between scenarios were explored. However, the network allows also to explore bottom-up what-if scenarios. Here, we provide a couple of examples. In the first example, we can see that the maximization of the total value from all the ecosystem services requires of the Global Sustainable scenario with high weight of the regulating services (Fig. 6).

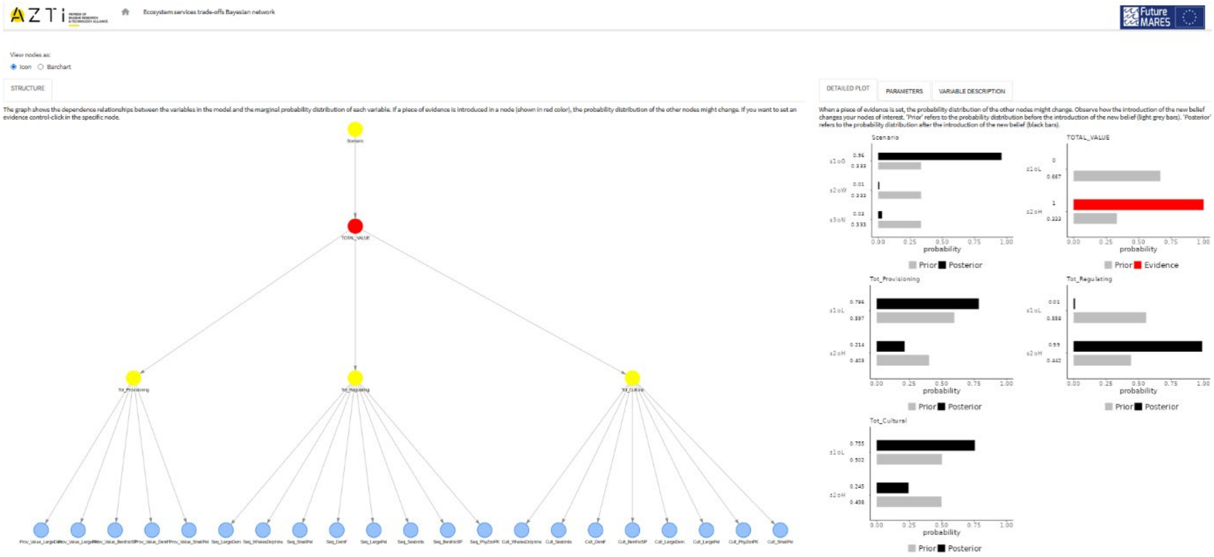

Figure 6. Most likely scenario for total ecosystem services values maximization.

In the second example, we can see the maximization of the value of provisioning and cultural services (Fig. 7). Under this what-if scenario, it can be observed that it is similarly accomplished in WM and NE scenarios with a low chance of high total value.

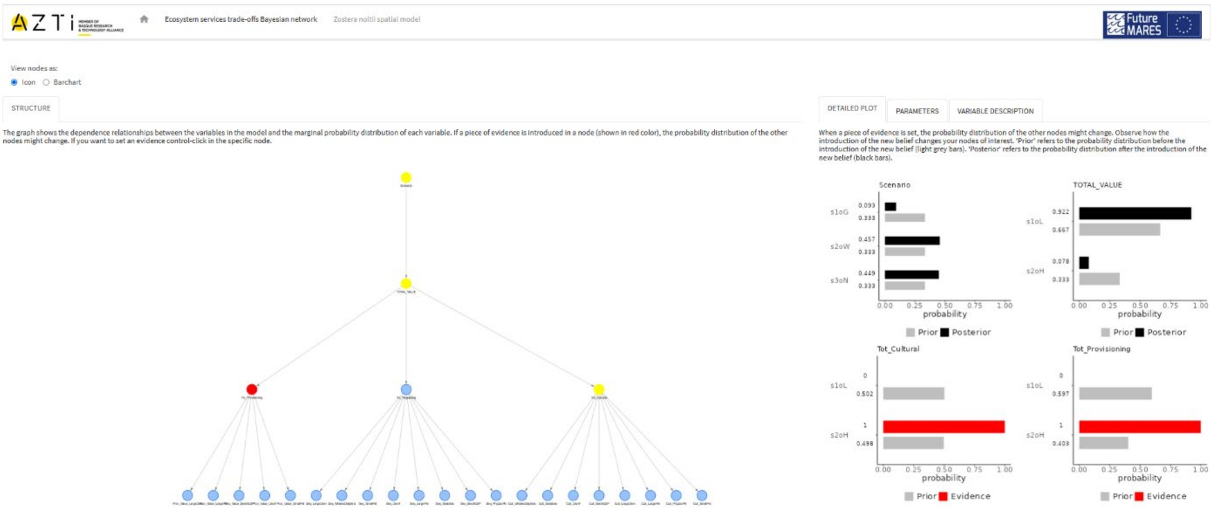

Figure 7. Scenarios likelihood when maximizing value from provisioning and cultural services.

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