Modelling approaches for the assessment of projected impacts of drivers of change on biodiversity, ecosystems functions and aquatic ecosystems service delivery[1]

Overview

For sustainable ecosystem-based management (EBM), first the current status of the interplay between biodiversity, ecosystem functioning (EF) and ecosystem services (ESS) needs to be assessed. With this understanding, alternative pathways in terms of management scenarios can be explored, which evaluate the impacts and feedbacks to biodiversity, EF and ESS (as described in the AQUACROSS Assessment Framework). Such assessments can be achieved using simulations and modelling techniques, allowing the modification of specific factors, e.g. conservation or management targets and management costs, while controlling for other factors within the simulation and quantifying the uncertainty in the model predictions.

It is critical that biodiversity, EF and ESS are not considered independent when it comes to analysing and modelling the patterns within a study area. These components should be assessed together to: (1) get an overview of how they might potentially change when interlinked and (2) how one could possibly mediate the other. Only by accounting for these complementarities, the interaction between biodiversity, EF and ESS can be adequately analysed and used to predict potential changes and dependencies under alternative pathway scenarios. Such methods will ultimately help to promote ecosystem-based management (EBM) within AQUACROSS case studies (Figure 1 and Figure 2, Box 1).

[1] *This is the executive summary of AQUACROSS Deliverable 7.1: Modelling approaches for the assessment of projected impacts of drivers of change on biodiversity, ecosystems functions and aquatic ecosystems service delivery. The full version of this document can be found at www.aquacross.eu in project outputs.*

The aim of this Deliverable is to provide guidance on (i) how to jointly assess the dependency of biodiversity, EF and ESS using a linkage framework for qualitative analyses and results, and (ii) a spatially-explicit modelling framework that uses predictions of biodiversity, EF and ESS. While the qualitative modelling framework allows assessing general linkages and dependencies, the quantitative and spatially-explicit modelling framework allows pinpointing specific patterns and processes across the case study area, specifying the costs of the potential management alternatives. A central part of both frameworks is the consideration of scenarios and uncertainties given the assumptions and/or underlying data, allowing to iterate the models to meet and communicate stakeholders targets to yield sustainable EBM options (Figure 1). Finally, potential alternatives to the proposed modelling framework are given, as not all case study areas have the scope or the necessary data to perform a spatially-explicit assessment, respectively.

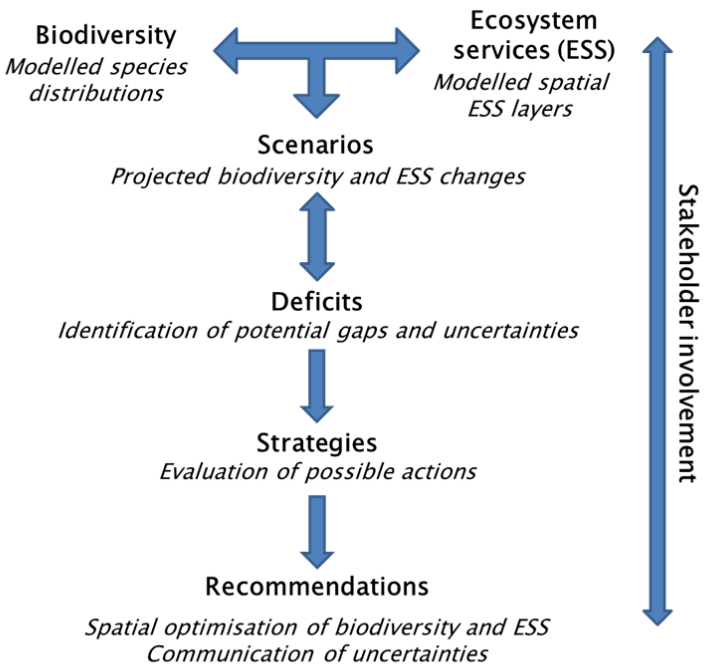

Figure 1: Generic workflow of the qualitative and quantitative (spatial) modelling workflow.

Note: text in *italics* describes the results of the proposed spatial modelling workflow after each step. See also Figure 2 for a detailed description of the quantitative (spatial) modelling workflow.

Source: Own elaboration

Promoting Integrative Science

This report directly helps advance integrative science across aquatic habitats and ecosystems, from freshwater to coastal and marine. Though understanding aspects of ecosystems is an important first step in characterising a management area, further analysis can provide additional insights that are important for decision makers. Modelling drivers of change and pressures (see Deliverable 4.1), and assessing causal flows between biodiversity, EF and ESS on aquatic ecosystems (see Deliverable 5.1) enables a baseline from which one can look into the future implications of different management options. Through integrating aspects across aquatic ecosystems, better management alternatives can be highlighted, which directly support the application of EBM.

Supporting Policy

Policy, like many fields, is dependent upon the quality of input to support the development of policies and management practices. As such, this report provides a workflow on how to evaluate scenario outcomes. It yields credibility and transparency, and the communication of potential uncertainties stemming from data, model algorithms, or from management scenario storylines and assumptions. Through heightened transparency and targeted policy options, management decisions can be informed by modelled scenarios and the impacts to biodiversity and ecosystems.

Opportunities for Innovation

Modelling can provide opportunities for innovation, mainly through the identification of relevant factors and indicators for biodiversity and ecosystem health. Jointly evaluating biodiversity and ESS/EF may allow the development of new and innovative processes and business solutions that balance environmental health with human well-being.

1 Qualitative Models: The Linkage Framework

The linkage framework, described in Deliverables 4.1 and 5.1, is a way of linking the demand side of the system (i.e., social processes, drivers, primary human activities and the pressures they cause on the ecosystem) with the supply side of the system (i.e., ecosystem processes and functions and the ESS they supply, leading to benefits for society). The framework consists of a series of connected matrices with typologies of activities, pressures, ecosystem components, and ESS that support policy objectives. Moreover, it acts as a central tool to organise, visualise and explore connections between different parts of the system, where linkages themselves can be analysed, as well as act as a starting point for subsequent modelling and analyses. These linkages and indicators will be provided by the ongoing work within AQUACROSS WP4 (relations from the demand side) and WP5 (modelled causal links on the supply side).

To answer specific questions, subsets of the linkages can be taken and considered under different contexts, such as:

- From an **ecological** perspective: what are the parts of the ecosystem most under threat and what are all the ways these components can be affected?; what are all the consequences of impacts on these components, such as a change in the supply of ESS?
- From an **economic** perspective: what are the most valuable activities occurring in the study area in terms monetary valuation of the demand side of ESS?; What impacts throughout the system do they have?; What are the social processes and drivers of these activities?
- From a **policy** perspective: what are the various relevant policies acting on different parts of the system?; In what ways might they interact or have consequences throughout the system?
- From a **stakeholder** perspective: what parts of the system are most socially relevant? How are these parts considered in the context of the wider network?

In this way, the framework can help to identify and visualise different system components and their manifold relationships and interlinkages, as well as provide decision support and explore management options.

2 Quantitative Models: A Spatially-explicit Modelling Framework

The linkage framework can be used as a stand-alone or exploratory tool to create the basis for using statistical and predictive models across space and time to allocate potential changes to biodiversity, EF and ESS. The suggested modelling framework encompasses simultaneous, spatial prioritisation assessment of biodiversity, EF and ESS within one workflow. It combines species distribution model (SDM) and ESS model outputs with the aim to spatially prioritise areas, allowing iteration with potential management scenarios (Figure 1, Box 1). Furthermore, it accounts for model uncertainties and how these potentially cascade throughout the modelling framework.

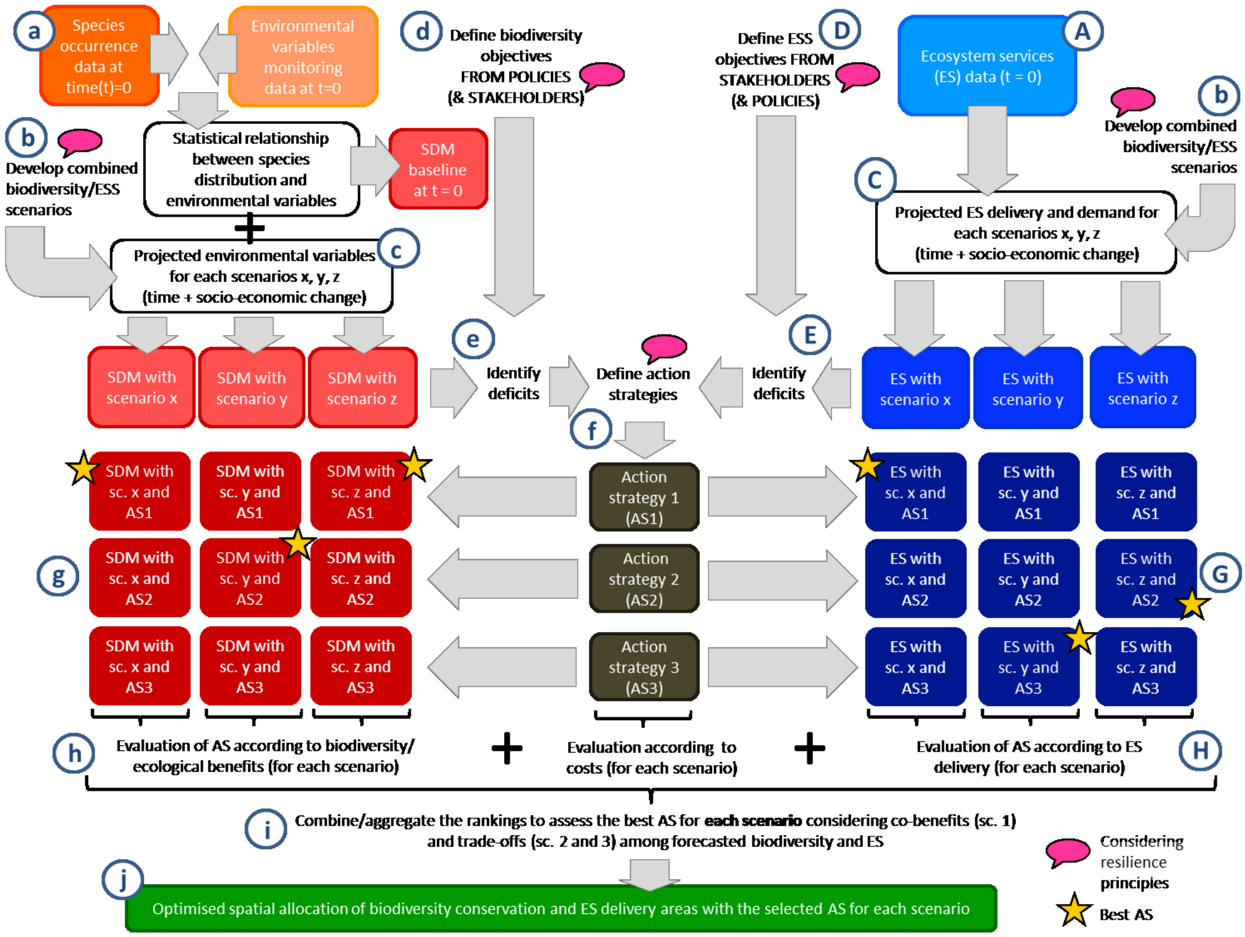

Figure 2: Detailed modelling workflow to evaluate action strategies and prioritise conservation and ecosystem services delivery areas for the application in the AQUACROSS case studies.

Note: the red shaded elements on the left hand side represent biodiversity models, whereas the blue shaded fields on the right represent ESS models. Grey fields indicate action strategies, and the green bar on the bottom represents the joint spatial prioritization of the biodiversity and ESS. See also Box 1 for an in-depth description.

Source: Own elaboration

Box 1: Detailed description of the single components of the proposed spatial modelling workflow as depicted in Figure 1.

The different consecutive steps (a-i and A-I, respectively) include **(a)** establishing a statistical relationship among species occurrence data, e.g. from monitoring campaigns or existing databases, and respective information for environmental variables. This relationship is used to model the current (t = 0) species distribution. Environmental variables are projected according to scenarios (x, y and z; defined by stakeholders **(b)**; scenario x being the baseline/business as usual scenario) and included in the statistical relationship to forecast species distribution for each of them **(c)**. Biodiversity objectives, i.e. targets, are identified according to respective policies **(d)**. Additional specific biodiversity targets that are particularly important to stakeholders independent of policies may be included here. Deficits can now be identified for each scenario, by comparing projected species distributions with biodiversity targets **(e)**. Parallel processes, tailored to ESS, are conducted **(A-E)**. With the deficits for biodiversity and ESS laid out, a set of potential action strategies (AS) to reach biodiversity and ESS targets, are defined **(f)**. AS have to be chosen in a way not to jeopardise ecosystem resilience. Species distributions and ESS delivery for each scenario are modelled considering the expected environmental changes from each AS **(g)**. Predicted consequences of each AS for biodiversity and ESS in each scenario are assessed, to identify the highest ranked AS for each scenario (marked with a yellow star) **(h/H)**. Biodiversity and ESS rankings and a third ranking of the costs of the individual AS are combined to find the optimal AS for each scenario **(i)**. Pre-cooked, spatially-explicit biodiversity and ESS data, derived from the best AS, are fed into *Marxan with Zones.*[2] *Marxan with Zones* is a planning tool (not to confuse with a decision support system) that optimises the spatial allocation of biodiversity conservation and ESS delivery areas across the whole area (e.g., a river basin, a basin plus an adjacent coastal zone, or a basin plus adjacent coastal and marine zones), while minimising cost and maximising targets for the management plan of an area **(j)**. These plans are discussed with the stakeholders and potentially refined, to eventually support decision making.

3 Modelling Framework Components

In practice, the spatial modelling framework consists of three components: biodiversity models, ESS models and joint prioritisation. All elements run spatially-explicitly, allowing to pinpoint locations and magnitude of overlap and dependency among the three components and any changes thereof:

- **Biodiversity models**: Species distribution models provide the basis. This model family, which constitutes a variety of model types and algorithms, create a standardised output regarding potential habitat suitability at a given location within the area. If using Bayesian Inference (given high-quality survey data), then the models can also provide the credible interval of the predictions that allow to quantify the uncertainty in the model output.

[2] *Marxan with Zones is available at http://marxan.net/. More information can be found under: Watts, Matthew E., Ian R. Ball, Romola S. Stewart, Carissa J. Klein, Kerrie Wilson, Charles Steinback, Reinaldo Lourival, Lindsay Kircher, and Hugh P. Possingham. 2009. "Marxan with Zones: Software for optimal conservation based land- and sea-use zoning." Environmental Modelling & Software 24 (12):1513-1521*

- **EF and ESS models**: The spatial layers can be computed using a variety of available tools, while each EF and ESS type has specific data requirements. EF and ESS layers can cover different types, including services that are compatible with conservation of biodiversity (e.g., regulation and/or cultural services) and services which might entail risks to the conservation of biodiversity and/or other services (e.g., provisioning services). Likewise to the biodiversity models, if the spatial EF and ESS layers are created in a Bayesian framework, the uncertainty can be quantified and communicated.
- **Spatial prioritisation**: The model coupling within a spatial prioritisation framework allows identifying priority areas for the conservation of aquatic biodiversity and different ESS related to marine, coastal and freshwater ecosystems within specific management zones. These different management zones include i) only conservation and compatible ESS zone (co-benefits zone) and ii) a zone for accessing provisioning services (trade-off zone). The software *Marxan with Zones* provides such a tool.
- **Alternatives**: Not all areas have the scope or the necessary data to perform a spatially-explicit assessment, respectively. A semi-quantitative risk-based approach, as well as a "light version" of the spatial modelling framework (e.g., using readily available data) can, nevertheless, provide first approximations of the interplay between biodiversity, EF and ESS under specific management scenarios.

4 Towards Ecosystem-based Management

The tools and techniques presented in this report provide an approach that allows (i) integrating the causal relationships identified in AQUACROSS WP4 and WP5 within one workflow, (ii) including scenario analyses, (iii) integrating stakeholder interactions by setting the targets as well as during the iteration of the modelling framework to (iv) ultimately achieve a greater transparency and credibility in the policy context and foreseeing biodiversity conservation and EBM in an area.

Moreover, the assessment of scenarios allows to confront stakeholders and institutions with the outcomes of their current decisions and to support collective decision-making to integrally manage ecosystems by comparing and assessing alternative courses of action. In summary, this approach supports a knowledge-based decision-making process, with increased relevance, credibility of social knowledge and legitimacy of policy decisions, all of which intends to inform and improve.

Depending on the aim (qualitative vs. data-driven), the linkage framework and/or the spatial modelling framework can be applied in various areas. Building on the knowledge of WP4 and WP5 (linkages and dependencies within and among biodiversity, EF and ESS) and given the data availability (quality and quantity), the quantitative (spatial) models can be used to develop information regarding the spatial patterns, the uncertainties involved in the data and models, and to assess the impact of various scenarios on biodiversity, EF and ESS as well as in a joint analysis.

These frameworks are planned to be tested within the AQUACROSS case study areas. All data and outcomes from the models in the case studies will be available on the Information Platform (dataportal.aquacross.eu/).

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