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

Overview

Aquatic ecosystems are rich in biodiversity and home to a diverse array of species and habitats, providing numerous economic and societal benefits to people. Despite progress in defining conservation goals to protect ecosystems and their biodiversity (e.g. the EU 2020 Biodiversity Strategy), biodiversity is declining due to strong anthropogenic activities and over-exploitation of natural goods and services. Evaluating the consequences of anthropogenic impacts on biodiversity, and subsequently the ecosystem functioning and ecosystem services provided by aquatic ecosystems, is an important step within ecosystem-based management (EBM) approaches. Therefore, it is crucial to better understand the interplay and dependencies between biodiversity, ecosystem functioning and ecosystem services. Based on this understanding, alternative pathways in terms of management scenarios can be explored, which evaluate the impacts and feedbacks to biodiversity, ecosystem functioning and ecosystem services (as described in the AQUACROSS Assessment Framework). The potential outcome of management scenarios can be assessed 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, ecosystem functioning and ecosystem services are assessed together when it comes to analysing and modelling the patterns within a study area in order to: (i) get an overview of how they might potentially influence change in one another and (ii) how one could possibly mediate the other. Only by accounting for these complementarities, the interaction between

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[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.*

biodiversity (BD), ecosystem functioning (EF) and ecosystem services (ESS) can be adequately analysed and used to predict potential changes and dependencies in alternative scenarios.

The aim of the report is to provide guidance for the case studies on (i) how to jointly assess the dependency of BD, EF and ESS using a linkage framework for qualitative analyses and results, and (ii) a spatially-explicit modelling framework that uses predictions of BD, EF and ESS. While the qualitative modelling framework allows the assessment of general linkages and dependencies, the quantitative and spatially-explicit modelling framework allows the identification of specific patterns and processes across the case study area, thereby specifying the costs of the potential management alternatives. Central to both frameworks is the consideration of scenarios and uncertainties, given the assumptions and/or underlying data, allowing the iteration of the models to meet and communicate stakeholders' targets. This step is crucial to achieve the yielding of 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 spatially-explicit assessments, respectively.

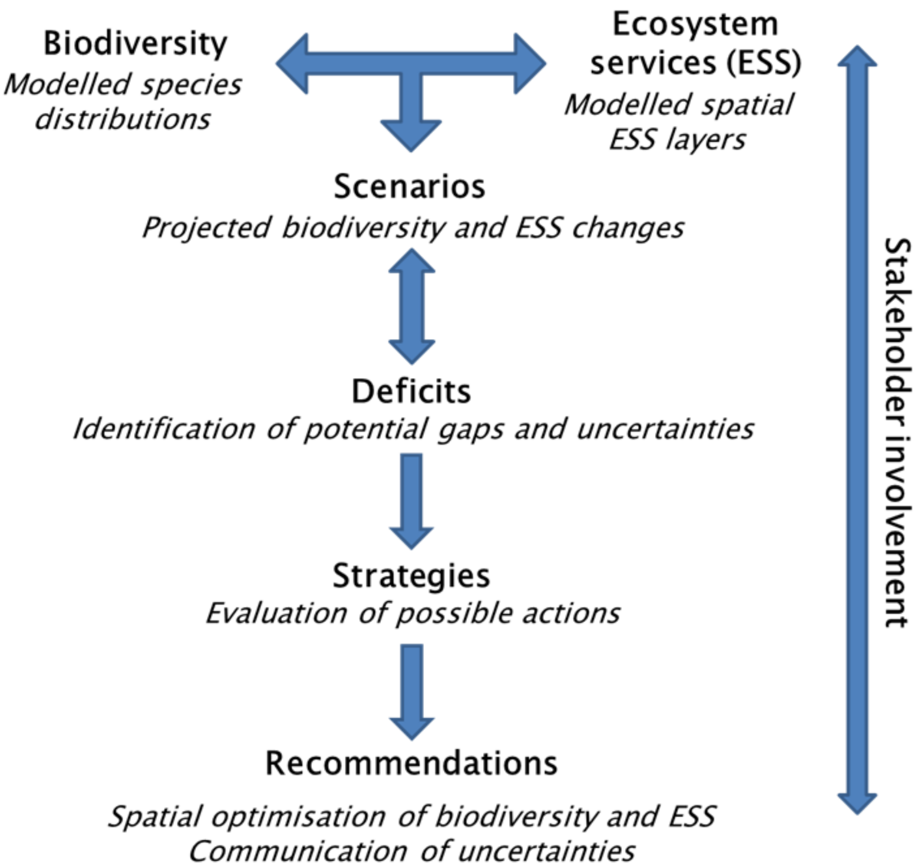

Figure 1: Generic workflow of the qualitative and quantitative (spatial) modelling framework.

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 deliverable supports the advancement of 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 analyses can provide additional insights that are important for decision makers. Modelling drivers of change and pressures (see Deliverable 4.1), and assessing causal links between BD, EF and ESS on aquatic ecosystems (see Deliverable 5.1) enables a baseline, from which decision makers can look into the future implications of different management options. Through integrating certain aspects across aquatic ecosystems, better management alternatives can be highlightedthat directly support the application of EBM.

Supporting Policy

Policy, like many fields, is dependent upon the quality of input to support the development of management practices. As such, Deliverable 7.1 provides a workflow on qualitative and quantitative (spatial) modelling of different scenarios targeted at policy options. It yields credibility and transparency, e.g. by communicating potential uncertainties that stem from different sources such as inaccuracies in the BD and ESS data, through inter-model variability derived from a variety of modelling algorithms, or from model forecasting according to management scenario storylines and assumptions. Through heightened transparency and considering policy options, management decisions can be informed by modelled scenarios and the impacts to BD, EF and ESS.

Opportunities for Innovation

Modelling can provide opportunities for innovation, mainly through the identification of relevant factors and indicators for BD and ecosystem health. Jointly evaluating BD and EF/ ESS may allow the development of new and innovative processes and business solutions that balance environmental health with human well-being. Key sectors could for instance be the agriculture, aquaculture, fisheries, food supply chains, water industry and environmental consultancy.

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, EF 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. Moreover, they 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 parts of the ecosystem are most under threat and in what ways can these components be affected?; what consequences do these impacts have 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 do they have throughout the system?; 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 over time to analyse potential changes of BD, EF and ESS. The suggested modelling framework encompasses simultaneous, spatial prioritisation assessment of BD, EF and ESS within one workflow. For each of these three elements an own model environment is suggested, and the output from the BD and ESS models serves as the input in the joint spatial prioritisation of BD and ESS. The **BD models** consist of Species Distribution Models (SDMs) that use species geographic occurrences and environmental factors at those locations to simulate the range-wide potential habitat suitability across a study area. Applying this technique to a variety of species within a given study yields an approximation of the BD and indicates possible hotspots given the species that are used in the models. The **ESS models** developed with the ARtificial Intelligence for Ecosystem Services (ARIES) infrastructure present the service flow as ecosystem potential on the one hand, and the service demand on the other hand, the latter mainly based on population density maps so far. Ecosystem potential and demand then generate together the relative service. The ESS under consideration cover different types of services, including services that are *compatible* with conservation of biodiversity (e.g., regulation and/or cultural services), and *incompatible* services which might entail risks to the conservation of biodiversity and/or other services (e.g., provisioning services). These predictions of BD, ESS supply and demand – all as spatial maps – **are then used to spatially prioritise different management zones according to the BD and ESS.** This will be done to demonstrate how to maximise co-benefits between the maintenance of some ESS and conservation of BD (e.g., there could be benefits for BD conservation by promoting flood regulation), while minimising potential trade-offs (e.g., reducing potential negative effects of granting access to provisioning services on conservation of BD and the maintenance of other ESS as much as possible). Hence, these different management zones will include i) a conservation-only and compatible ESS zone (co-benefits zone) and ii) a zone for accessing provisioning services (trade-off zone). In a subsequent step, potential management scenarios can be included, allowing an iteration of the spatial prioritisation with altered management targets. The proposed modelling workflow accounts for uncertainties in the modelling approach, and allows for uncertainties that potentially cascade throughout the modelling framework to be traced back.

3 Modelling Framework Components

In practice, the spatial modelling framework consists of three components: BD models, ESS models and joint prioritisation. All elements run spatially-explicit, 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 comprises a variety of model types and algorithms, create a standardised output i.e., a habitat suitability map of a species at a given location within the area. Various SDM algorithms can be used to jointly build a statistical model, each emphasizing different aspects. The resulting ensemble prediction reduces the uncertainty and is considered more robust than when using a single algorithm. Creating the BD models in a Bayesian framework (using probability) allows for the quantification of uncertainty in the model output.
- **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 of ecosystem services, including services that are compatible with conservation of BD (e.g., regulation and/or cultural services) and services which might entail risks to the conservation of BD and/or other services (e.g., provisioning services). Similarly to the BD 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 makes it possible to identify priority areas for the conservation of aquatic BD and different ESS related to marine, coastal and freshwater ecosystems within specific management zones. These different management zones include i) a conservation-only and ESS compatible zone (co-benefit zone) and ii) a zone for accessing provisional services (trade-off zone). The software *Marxan with Zones* provides this type of tool.
- **Alternatives**: Not all case studies have the scope, or are limited in the necessary data (i.e., either BD or ESS) in terms of the quality and quantity needed to perform a spatially-explicit assessment. Nevertheless, approximate estimates can be derived either by (i) a semi-quantitative risk-based approach through network analyses of the above mentioned Linkage Framework, as well as (ii) through a “light version” of the spatially-explicit modelling framework (e.g., using readily available data), to provide insights into the interplay between BD, EF and ESS under specific management scenarios.

4 Towards Ecosystem-based Management

The tools and techniques presented in the report provide an approach that allows (i) integrating the causal relationships identified in previous project workwithin 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 advancing EBM in an area. Moreover, assessing scenarios makes it possible to not only confront stakeholders and institutions with the outcomes of their potential decisions but also 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 EBM.

Depending on the aim (qualitative vs. spatial, data-driven), the linkage framework and/or the spatial modelling framework can be applied in various areas. Building on the knowledge gained in AQUACROSS on linkages and dependencies within and among BD, 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 of BD and ESS, to identify the uncertainties involved in the data and models, and to assess the impact of various scenarios on BD, EF and ESS independently and in a joint analysis.

These frameworks are scheduled 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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