

Assessment of Causal Flows between Biodiversity, Ecosystem Functions and Ecosystem Services in Aquatic Environments [1]

Overview

Global initiatives have been increasingly focusing on making nature's values visible and mainstreaming the values of **biodiversity (BD)** and **ecosystem services (ESS)** into decision-making at different levels of application. This AQUACROSS report summarises the current knowledge on the causalities between BD (directly measured or as captured by the state of ecosystems) and the ecological processes that ensure critical **ecosystem functions (EF),** enabling the supply of ESS. Based on a detailed review of literature, this work aims to provide guidance to the AQUACROSS case studies, proposing ways of identifying patterns across BD-EF-ESS, measuring those relationships, and integrating that complex information into a broader socio-ecological framework, which acknowledges the complexity and interdependencies of coupled social and ecological systems.

The reflections and recommendations in this deliverable focus specifically on the assessment of BD, EF and ESS, which are crucial stages in the supply-side of the socio-ecological system (**Error! Reference source not found.**), described in the AQUACROSS Assessment Framework (AF). Central to the AQUACROSS AF is the interaction between natural aquatic ecosystems and societal systems. Therefore, the recommendations laid herein take into account the need to link the ecological components of the supply-side stages to the demand for ESS that drives the pressures over ecosystems and subsequent changes in their structure and functioning.

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[1] *This is the executive summary of AQUACROSS Deliverable 5.1: Guidance on Methods and Tools for the Assessment of Causal Flow Indicators between Biodiversity, Ecosystem Functions and Ecosystem Services in the Aquatic Environment. The full version of this document can be found at www.aquacross.eu in* [*project outputs*]

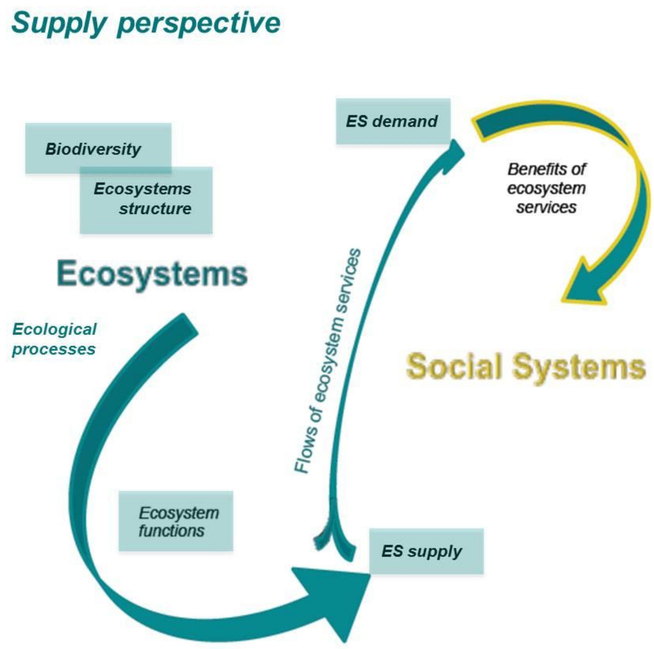

Figure 1: The supply-side perspective of the AQUACROSS architecture.

Major international agreements and European and national policies, including the EU 2020 Biodiversity Strategy, have recently been implemented to tackle global declines in biodiversity. However, despite these efforts, targets are far from been achieved in aquatic ecosystems. In order to reverse current trends, it is necessary to not only understand the mechanisms that drive on-going biodiversity loss but to also identify where existing policies can either hinder or support biodiversity conservation efforts.

The main goal of this Deliverable is to support integrated ecological assessments that account for these socio-economic feedbacks with nature by enabling flow linkages both to pressures affecting the ecosystems and to the demand of ESS. This report and the associated outputs of the Deliverable (i.e., a database with BD-EF-ESS classification schemes and associated indicators, and a set of modelling approaches for establishing the BD-EF-ESS causal links) are expected to address the needs of the different stakeholders engaged in local and regional environmental management actions across European aquatic realms (i.e., the scientific community, environmental managers, local authorities, and socio-economic actors).

Integrating Science

The guidance provided for assessing causal links between biodiversity and ecosystem structure, biodiversity ecosystem functioning, and the supply of ecosystem services will be tailored to be applicable across all types of aquatic ecosystems, from freshwaters to the marine realm, at different temporal and spatial scales, and across the EU. The aim is to establish a common baseline for identifying and analysing the factors influencing aquatic biodiversity loss, how these factors interact, and contribute to select adequate management options to ensure robust and healthy aquatic ecosystems, capable of providing ESS. Such a harmonised approach will be ensured by the application of the AQUACROSS AF to different scenarios across eight case studies. The ultimate goal is to allow the revealing of general BD-EF-ESS patterns and to promote a more efficient transfer of knowledge across aquatic, geographic, and scientific domains. This knowledge is essential for bridging the gap between ecological and socio-economic management.

Supporting Policy Implementation

This Deliverable intends to address the need of scientific knowledge to support the identification, the effective design and the successful implementation of EBM responses to current environmental challenges. Within this context, AQUACROSS seeks to facilitate the development of **Ecosystem-based Management (EBM)** approaches to aquatic ecosystems. EBM is recognised as an efficient management alternative to integrate and advance towards the comprehensive implementation of the different objectives of EU environmental policy, namely the Nature Directives (Birds and Habitat), the Water Framework Directive and the Marine Strategy Framework Directive, and the EU 2020 Biodiversity Strategy (in particular its Action 5 on Mapping and Assessment of ESS). Member States' obligations towards international agreements and relevant legislation must be coherently integrated in the AQUACROSS AF, and available information should contribute, if possible, to those assessments. This Deliverable brings together different BD assessment perspectives, which is the most widely covered aspect by these policies; it proposes a structured approach to deal with EF, which is the least addressed aspect by these policies; and develops on existing ESS approaches that are, to date, poorly integrated into environmental policies, although receiving increasing attention, with several initiatives and research efforts in place to operationalise their assessment.

Lessons learnt in AQUACROSS regarding the causal links between BD, EF and ESS, and regarding best approaches for their assessment, will ultimately provide inputs and feedback into environmental polices acting in the field of aquatic ecosystems, towards adaptation and a better implementation of these legal requirements in practical management scenarios.

Fostering Innovation

The use of integrated modelling approaches for implementing the AQUACROSS AF in real case scenarios will act as proof of the concept that an integration of the socio-ecological systems into current environmental management practices is feasible and a more effective approach. Clarifying the supply-side chain of events with the use of specific indicators promotes transparency at the time of characterising all the factors operating within and at the frontiers of ecological systems with the socio-economic system. Our aim is to advance management by increasing knowledge on BEF and BES relationships and contributing to include the causal links of this supply side into modelling tools. This will make the benefits of ecosystem conservation and protection more visible and will contribute to develop more effective models, for supporting negotiations that meet both conservation goals and stakeholders' expectations, increasing synergies and regulating trade-offs in responsible and sustainable ways.

1 Biodiversity, Ecosystem Functions and Ecosystem Services Relationships

Concern has grown over the past decades about the rate at which biodiversity is declining and its consequences for the functioning of ecosystems and, subsequently, the services they provide.

Due to the inherent multidimensional nature of biodiversity (BD), which spans genes and species, functional forms, habitats and ecosystems, as well as the variability within and between them, it is often taken to be an abstract ecological concept. BD is usually considered as a measure of the complexity of a biological system, but a difficult one to operationalise. On the other hand, to offer a consistent theory about the functioning of the ecosystems, their complexity needs to be accounted for. But, because of such complexity, there is still not a clear understanding of the underlying role that BD plays, nor of the impacts of its decline on EF and in ESS provision in general. The challenge for AQUACROSS, regarding BD, is to propose meaningful approaches to measure it, taking advantage of existing Member States' monitoring and obligations towards EU environmental policies already in place, while promoting the advance of knowledge for establishing **biodiversity-ecosystem functioning (BEF)** and **biodiversity-ecosystem services (BES)** relationships in aquatic ecosystems.

The vast number of currently existing experimental and observational BEF studies, and meta-analyses of data generated by these studies, tested the hypothesis that ecosystems with species-poor communities are functionally poorer, less resistant (capacity to resist change) and less resilient (capacity to recover from change) to disturbance than systems with species-rich communities.

Ecosystem functions (EF), however, were not traditionally incorporated in applied environmental management. Hence, the definition of EFs and, in particular, the indicators used for measuring them, do not gather great consensus. The term 'function' has been used in different ways within environmental science, and in particular within the field of ecology and in the ESS context. In ecology, *functions* research has privileged a contextual and relational aspect, i.e. 'causal role' of functions, over an evolutionary perspective. In an EBM context, central to the AQUACROSS AF, attributing functions to biotic and abiotic components of ecosystems facilitates the purpose of analysing processes of an ecosystem in terms of the causal contributions of its parts to some activity of an ecosystem, for example in relation to ESS. However, the evolutionary perspective can add an extra dimension to the study of BEF relationships, namely in the relationship between BD and ecosystem stability and resilience. This is particularly important in a fast changing world, in face of increasing anthropogenic disturbances and global climate change, with huge relevance for conservation and management purposes.

It is of paramount importance to consider ESS both from the **supply side**, considering the capacity of the ecosystem to supply services, and from the **demand side**, understanding their importance for human welfare, for economic activities and for the whole social system. The supply side is the potential or capacity of the ecosystem to supply services, whether or not they are used, whilst the demand side is the services people ask from the ecosystems, whether they are actually provided or not. Moreover, a 'supply side' assessment based on ecosystem capacity considers how the state of the ecosystem is affected (structure and functioning) by the ESS demand and how it is, thus, affecting the generation of the actually used services, and the potential to provide more and better services for present and future generations.

In AQUACROSS, we aim to promote comprehensive assessments of the services and the benefits people get from nature. Thus, we include both the services dependent on BD (i.e., biological mediated), as well as those reliant on purely physical aspects of the ecosystem (i.e., abiotic outputs). Furthermore, both biotic and abiotic ESS can have implications for spatial planning, management and decision-making.

The provisioning of services should reflect changes to the ecosystem state, i.e. a change in state of the ecosystem must result in a change in the supply of a service. This is true for biologically-mediated services; for example, a change in abundance of commercial fish populations has an impact on the supply of seafood, while a change in the wetland heath status (e.g., fragmentation) has an impact on the supply of clean water. However, a change or a difference in abiotic conditions can also lead to a change in the supply of abiotic services. For example, a change in sand natural deposits, including beaches, due to a high energy storm event has an impact on mining of sand for construction or industrial uses, or even an impact on recreational activities on the beach.

Whilst the capacity of the ecosystem to supply services is tightly linked to the state of the ecosystem (BD and ecosystem processes and functions), the demand and actual use of services can be decoupled from the state of the ecosystem, as they result from social processes. Also, a change in ecosystem state and BD can lead to a change in the supply of services but not in the demand of services.

This report reviewed the current state of knowledge on links between BD, EF and ESS in aquatic realms (i.e., freshwater, coastal and marine). It focuses on scientific evidence gathered for understanding the underlying BEF mechanisms, the shape of aquatic BEF relationships reported in the literature, understanding whether BEF relations are ecosystem-specific or whether they are interchangeable, and the current research limitations and needs in related aquatic studies. It also summarises the current knowledge on BES relationships, indicating some of the better-established links, while highlighting the aspects hampering the further establishment of other BES relationships and accurately characterising them.

Underlying biodiversity-ecosystem functioning mechanisms

Several mechanisms have been denoted to explain the influence of compositional diversity on ecosystem functioning, of which *complementary niche partitioning*, *density-dependent effects*, *facilitation and identity effects* are the most documented and accepted. Essentially, they go by the following assumptions, respectively: several species coexist at a given site and complement each other spatially and temporally in their patterns of resource use; species assemblage at a given site establish species-specific interactions; and the density of a specific species assemblage will determine the expected prevailing processes, namely niche partitioning or competition, and the magnitude of the ecosystem response; activities of some species enhance or facilitate activities of others and, in turn, ecosystem process rates; where particular species have a disproportionate functional role, and may subsequently also generate positive BEF relationships, also known as sampling or selection effects.

BEF research has also explored multiple hypotheses on how organisms promote EFs, among which the *diversity hypothesis* and the *mass ratio hypothesis* gather greater scientific evidences. The first considers mechanisms including niche complementarity and insurance (compensatory dynamics through space and time); the second considers that functional traits of dominant species chiefly promote EFs (i.e., identity effects). Ultimately, both hypotheses are due to trait expression and a combination of both species richness and identity may evidently play an important role.

Evaluating taxonomic changes is not sufficient to study BEF relationships since species composition can change without concomitant functional changes (e.g. due to functional redundancy), and functioning can change even when species are unaffected, e.g. through changed interactions or behaviours.

Shape of aquatic biodiversity-ecosystem functioning relationships

After hypothetical associations between BD and EF were proposed in the 1980s and 1990s, several experimental studies were put in place to unravel the shape and function of the BEF relationship. Nevertheless, caution was advised, since experimental studies fail to reveal the positive role of ecological interactions, by e.g. forcing species to compete or interact. The contrasting results between experimental and observational studies can be explained by three hypotheses:

- The use of functional richness instead of species richness;
- An increased production efficiency of species in producing biomass when more ecological interactions are present; and
- The fact that communities are likely assembled in an ordered succession of species from low to high ecological efficiency.

Thus, different experimental designs will result in different BEF relationship results, influenced, for example, by the duration of the experiments, the environmental complexity and spatial heterogeneity, and the diversity of traits accounted for. Nevertheless, some studies have found consistent causal effects in marine BEF relationships between experiments performed in the laboratory, in mesocosms and in the field. In addition to the above-mentioned factors, the disturbance level in place also interferes with the BEF relationship. In sum, and regardless of the experimental design applied, BEF relationships appear to be best approximated by a power function, where the shape and strength of the BEF relationships are variable and depend on the factors mentioned above. This heterogeneity is reflected in the wide range of values reported for the constants determining the BEF curve.

Biodiversity-ecosystem functioning relationships in aquatic ecosystems

Striking levels of generality have been reported in diversity effects on ecosystem functioning across terrestrial, freshwater, and marine ecosystems, and among organisms as divergent as plants and predators. Experimental design and approach, rather than inherent differences between marine and terrestrial ecosystems, appear to be the underlying cause of contrasting responses among systems. But despite the non-ecosystem specificity of BEF relationships, marine and terrestrial realms differ significantly in terms of their phylogenetic diversity at higher levels. Aquatic ecosystems are also characterised by greater propagule and material exchange, often steeper physical and chemical gradients, more rapid biological processes and, in marine systems, higher metazoan phylogenetic diversity. These differences may limit the potential to extrapolate conclusions derived from terrestrial experiments to aquatic ecosystems.

In addition, as the nature of BEF linkages can be highly context-dependent (regarding, for example, abiotic and climatic controls, disturbance and management), it is often suggested that a focus on within-ecosystem type studies is crucial.

The mechanisms behind BEF relationships seem also to differ between ecosystem types. Hence, although BEF relationships may not directly extrapolate across ecosystems, BEF relations established in a certain ecosystem type may provide indications for further studies and/or additional evidence for their existence in other ecosystem types.

Biodiversity-ecosystem services evidence

There is firm evidence demonstrating the importance of BD to ecosystem functioning, but less research is available on whether BD has the same pivotal role for ESS. Whether protection of ESS will protect BD, and vice versa, is valuable scientific knowledge to turn the concept of ESS into a practical conservation tool in the formulation of day-to-day policies on a national or regional scale.

The key role of biodiversity for regulating services has been observed in several studies. Additionally, studies focusing on cultural and provisioning ESS services gathered evidence of the positive role of BD, even though the pattern is not consistently observed in all types of services (e.g. BD negative effect on water provisioning). When addressing BES it is also crucial to look at relationships between ESS to minimize undesired trade-offs and enhance synergies as they can create confounding effects. Synergistic relationships tend to dominate relationships among regulating services and among cultural services, whereas provisioning services often imply trade-off relationships.

ESS are generated from numerous interactions occurring in complex systems, and BD can have direct and/or indirect effects in ESS provisioning. BD-ESS relationships seem to also differ among ESS, and depend on methods of measuring BD and ESS, as well as on approaches to link them (spatially, management linkage, and functional linkage).

In addition, BES relationship can be affected by trade-offs between ESS, thus resulting in weaker evidences. There is evidence that synergistic relationships dominate within different regulating services and within different cultural services, whereas regulating and provisioning services often imply trade-off relationships.

Research gaps in BEF and BES

Understanding which part of the ecosystem (which ecosystem state components) is impacted by pressures can help to lead to an understanding of how the ecosystem's capacity to supply services may be impacted. However, the way a pressure affects ecosystem state and the way that this is measured may not align with what needs to be known to assess the ecosystem's capacity to supply a service. If EBM is to be successful, there is a need for BES research to look towards underlying BEF-linkages. However, the connections between these areas of research remain weak, and its implementation follows very diverse approaches.

AQUACROSS proposes linkage matrices[2] that highlight all possible relational links between pressures and ecosystem state components, and state components with EFs and ESS, will help to provide a framework for exploring analyses across the whole socio-ecological system (*see also AQUACROSS Deliverable 4.1*).

AQUACROSS work will focus to contribute to solve a few of the aspects hampering establishing BEF and BES relationships, such as those highlighted in the table below.

Table 1: Issues hampering establishing BEF and BES relationships and relevant research topics.

BEF relationships	BES relationships
Consider multiple EF relationships	Consider multiple interconnected ESS and activities
Rare species and ecosystem connectivity	Type of ESS considered
Random vs. realistic species losses	Consider the demand-side
Spatio-temporal scale	Spatio-temporal scale
Trophic levels	Influence of climate change
Role of environmental conditions	Consider social-ecological systems and

[2] *That use the classifications and typologies proposed within AQUACROSS.*

	stakeholders
Trait-based evaluations	Selection of relevant indicators

See Deliverable 5.1 full report for details in each point.

2 Assessment of Flow Indicators

In the process of implementing an EBM approach, it is essential that the measures of ecosystem functioning can be correlated both with measures of BD of ecosystems and with measures of ESS. There are many different potential classifications and indicators that can be selected to illustrate the state, and change in state, of BD, EF and ESS. Considering these classifications and lists of possible indicators helps to establish the overall socio-ecological system in which we may consider evaluation of particular issues, which can be formalised in a set of linkage matrices that describe the possible network of interactions relevant to a given ecosystem.

Classification for the supply-side assessment

The field of BD valuation is rather heterogeneous, regarding both valuation objects and valuation methods. Conservation and environmental management programmes have had different goals and approaches through time and have, therefore, selected different components to be assessed, thus leading to different classifications. A BD assessment that would support establishing causal flows between BD-EF-ESS needs to adopt classifications used by different approaches, in an attempt to broadly encompass and facilitate the identification of parts of the ecosystem which, directly or indirectly, contribute to the delivery of ESS. Once the ESS providers have been identified, these can be the focus for identifying further indicators of the EF and ESS (and ultimately benefits),[3] while maintaining a strong link with the state of the ecosystem and BD. The ecosystem state/BD components also form the common link between the demand side and the supply side. Therefore, a typology of ecosystem components also facilitates the assessment of changes in ecosystem state due to drivers and pressures, by linking it upstream to a typology of drivers and pressures (*see AQUACROSS Deliverable 4.1*).

EFs and related indicators are usually divided into three main categories: (1) Production, (2) Biogeochemical cycles and (3) Structural (i.e., directly mediated by ecosystem structural components), although terminology may differ slightly depending on the source. Several EFs (e.g., decomposition, production, nutrient cycling) relevant in aquatic ecosystems have been identified under these main categories, along with the different ecological processes (e.g., bioturbation, photosynthesis, nitrification) that ensure these EFs. In the proposed classification, an ecological process can be associated to several EFs and an EF may depend on several ecological processes. The latter facilitate linking organisms and the environmental features relevant for sustaining specific EFs, and hence support the selection of relevant indicators.

Regarding ESS, to ensure consistency with the Common International Classification of Ecosystem Services (CICES), the indicators and metrics were classified using the EU MAES ESS categories, which builds on the latest version (V4.3) of CICES, in which 1) Provisioning, 2) Regulating & Maintenance and 3) Cultural ecosystem services have been considered. In addition, we adjusted this

[3] *Assessment of Benefits and Values not in the scope of the present report.*

classification to also include the ESS reliant on purely physical aspects of the ecosystem. This choice will ensure comparability with the approaches being followed by EU Member States.

The use of indicators in the supply-side assessment

The complexity of the ecological systems, where structure and processes will combine in a myriad of ways to perform ecosystem functions and secure ecosystem services supply, makes the selection of indicators a difficult process in practice. The choice of indicators of BD-EF-ESS should be influenced by consideration of both how the pressure effect on ecosystem state is measured, and how any contributions to capacity to supply linked ecosystem services are measured. Assessing BD and evaluating the state of ecosystems requires suitable indicators for tracking progress towards environmental goals, for quantifying the relation between BD and function, and for establishing links with ecosystem provision.

Potential lists of indicators, indices and associated metrics have been collated, accounting for indicators outlined by key legislation identified in the project and identified in relevant scientific literature. For each main theme in the supply side of the AQUACROSS AF (**Error! Reference source not found.**) (i.e., BD, EF, and ESS, both ESS supply and ESS demand) the possible sources and examples of indicators were listed.[4] However, these are not intended to be prescriptive indicator lists, and each case study should select the indicators deemed most appropriate for the context and purpose of study (i.e., the aquatic realm, the ecosystem features, the scale(s) of study, the identified pressure(s), the ESS being scrutinised).

This guidance additionally aims to promote consistency throughout the case studies, so that a standardised approach may ultimately allow a comparison of BEF and BES relations identified across aquatic realms, contributing to the understanding of whether they are interchangeable or ecosystem-specific.

Finally, the selection of sound and relevant indicators has been topic of prolific research, with several established criteria for identifying and testing the quality of indicators largely recognised as essential for building more robust assessments. AQUACROSS acknowledges the importance of ensuring the robustness of the assessments, especially in complex integrated frameworks, where cumulative error can amplify uncertainty in the predictions. In this sense, criteria for selecting and testing the quality of indicators will be adopted across AQUACROSS case studies. Criteria such as *policy relevance*, *stakeholder relevance*, *ecosystem relevance*, *scientific basis*, *possibility of setting targets*, or *cost-efficiency* may be of wide importance, although some more for the supply side.

3 Methods for Analysing Causal Links

Ecological and biological systems dynamics are often governed by nonlinear interactions of environmental factors. Interactions between environmental variables can be so complex that the whole system achieves a broader functionality that cannot be deduced by considering individual environmental factors. Thus, an analysis of these complex relationships requires the use of models and statistical tools capable of dealing with large datasets of environmental and biological variables.

[4] *Available as supporting material in Deliverable 5.1 Annex I.*

The classifications proposed in AQUACROSS, and potential associated indicators, will help to establish the overall socio-ecological system in which we may consider evaluation of particular issues. This, in turn, can be formalised in a set of linkage matrices that describe the possible network of interactions relevant to a given study system. All this complex and multidimensional information can then be incorporated into integrated modelling approaches.

Integrated models could highlight priorities for the collection of new empirical data, identify gaps in our existing theories of how ecosystems work, help develop new concepts for how BD composition and EF interact, and allow predicting BEF relations and its drivers at larger scales. Integrated models are models which simulate and project simultaneous changes in BD composition and EF over space and time for large regions, incorporating interactions between composition and function. Such models could also form components within larger 'integrated assessment models', improving consideration of feedbacks between natural and socio-economic systems. Ultimately, this would aim at better informed management, as is seen in the framework underlying the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES).

Meta-analysis

Meta-analyses are useful to provide an integrated view of dispersed experiments and knowledge. They are also a powerful approach for statistically testing hypotheses linked with multi-scale spatial and temporal patterns of dynamic populations, communities and ecosystems. In the past decade, several meta-analyses on data obtained from manipulative experimental BEF experiments have been conducted to attain evidence for BEF relationships.

Meta-analysis and validation of modelling approaches based on existing data, provided that they carefully consider the aspects discussed in the present report (spatio-temporal scale, number of EFs considered in the studies used, etc.), appear to be a good way forward to enable the operationalisation of BEF (and eventually also BES) research. Numerous examples of meta-analyses can be found in literature involving different aspects of the causal flows involved in the chain of processes-BD-EF-ESS-benefits.[5]

Modelling approaches

Among the multitude of mathematical tools and approaches available, four of them can be used to assess causal links and environmental flows in case studies: discriminant analysis, generalised dissimilarity models, generalised diversity-interactions models, and tools integrating Bayesian approaches like ARIES. The choice of methodology will ultimately depend on the objective of the study, and on the amount and quality of the available data. Below, we briefly introduce the main features of these four approaches:

- **Discriminant Analysis** also known as Canonical Variate Analysis or Linear Discriminant Analysis is a multivariate approach to pattern recognition and interpretation that has been used extensively in ecological investigations, e.g.: fish distributions, freshwater habitat selection, temporal patterns linked with physico-chemistry and the biology in aquatic systems, and linking trophic guild with functional traits. Discriminant analysis is generally appropriate in problems with aggregated multivariate data, and ecologists have applied it in areas as diverse as geographical

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[5] *An example of outputs from a Meta-analysis is detailed in Deliverable 5.1, and a list of relevant scientific literature providing further relevant examples for AQUACROSS case studies was compiled in Annex II.*

ecology, social behaviour, niche structure, and organism morphology and physiology. This technique allows the classification of sites into classes or clusters using data from species composition, and how it differs among sites of different classes.

- **Generalised Dissimilarity Models** are statistical techniques for analysing and predicting spatial patterns of turnover in community composition (beta diversity) across large regions. The approach extends matrix regression to accommodate two types of nonlinearity commonly encountered in large-scaled ecological data sets: (1) the curvilinear relationship between increasing ecological distance, and observed compositional dissimilarity, between sites; and (2) the variation in the rate of compositional turnover at different positions along environmental gradients. Thus, generalised dissimilarity models address the spatial variation in BD between pairs of geographical locations to make predictions (in both space and time) and map biological patterns by transforming environmental predictor variables.
- **Generalised Diversity-Interactions Models** aim at unifying existing approaches to BEF relationships by providing a common framework within which to explore the effects of environment, space and time on ecosystem properties. The unification of several approaches within a single model is probably the most important outcome of their work. Generalised diversity-interactions models follow the general equation when we consider an interaction between pairs of species.
- **ARIES - ARtificial Intelligence for Ecosystem Services**, aims at improving conceptual detail and representation of ESS dynamics in support of more accurate decision-making in diverse application contexts. By using computer learning and reasoning, model structure may be specialised for each application context without requiring costly expertise. For these reasons, ARIES can be a powerful tool in the context of AQUACROSS, and case study modelling and scenarios testing. ARIES is assisted by model integration technologies that allow the assemblage of customised models from a growing model base. The interdisciplinarity required for the study of ESS is best tackled using integrated modelling tools that are able to represent the wide variety of interactions that happen within socio-ecological systems, such as those based on behaviour, market prices, local vs. global economy, etc. It currently integrates various techniques, such as Geographical Information Systems, Bayesian Belief Networks, Social Network Analysis, System Dynamic and Agent-Based Modelling.

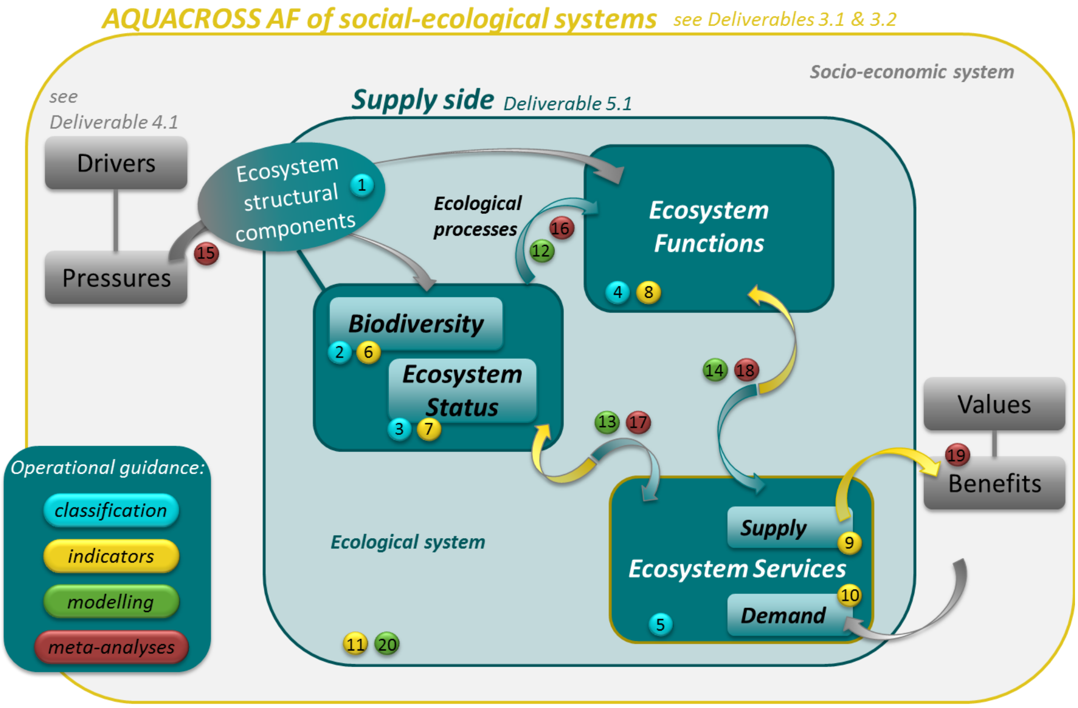
4 Guidance and Recommendations

This report establishes a common understanding and highlights key points for the implementation of the AQUACROSS AF when assessing the supply side in the case studies, and eventual case scenarios beyond the project scope.

To facilitate effective assessments, it identifies **main challenges** for operationalising the AQUACROSS AF and provides an overview of the **supporting information** and **resources available** at specific stages of the **supply side** (**Error! Reference source not found.**). In addition, by identifying the main links of the ecological system with the socio-economic system, it promotes a fully integrated assessment.

The AQUACROSS AF will be tested in eight case studies in conjunction with stakeholders. Potentially relevant steps of the supply-side conceptual assessment and respective available resources have been identified for each of the case studies, attending to their main focus and objectives. Such suggestions are not exhaustive and intend to illustrate the concept applicability.

Figure 2: Conceptual guidance for assessing ecosystems' integrity and ESS supply.



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