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# Introducing the H2020 AQUACROSS project: Knowledge, Assessment, and Management for AQUAtic Biodiversity and Ecosystem Services aCROSS EU policies

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## HIGHLIGHTS

- We describe the aims and approaches of the EU-funded Horizon 2020 project AQUACROSS, its conceptual framework and case studies.
- AQUACROSS aims to demonstrate practical applications of the Ecosystem Based Management concept.
- AQUACROSS considers the management of aquatic ecosystems as a continuum, from freshwater to marine through coastal areas.
- The project addresses multiple interactions between socio-economic and ecological systems in aquatic ecosystems
- It includes eight case studies across Europe, all with different scales (temporal, spatial, at different levels of ecosystem organization).

## GRAPHICAL ABSTRACT


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ABSTRACT

The AQUACROSS project was an unprecedented effort to unify policy concepts, knowledge, and management of freshwater, coastal, and marine ecosystems to support the cost-effective achievement of the targets set by the EU Biodiversity Strategy to 2020. AQUACROSS aimed to support EU efforts to enhance the resilience and stop the loss of biodiversity of aquatic ecosystems as well as to ensure the ongoing and future provision of aquatic ecosystem services. The project focused on advancing the knowledge base and application of Ecosystem-Based Management. Through elaboration of eight diverse case studies in freshwater and marine and estuarine aquatic ecosystem across Europe covering a range of environmental management problems including, eutrophication, sustainable fisheries as well as invasive alien species AQUACROSS demonstrated the application of a common framework to establish cost-effective measures and integrated Ecosystem-Based Management practices. AQUACROSS analysed the EU policy framework (i.e. goals, concepts, time frames) for aquatic ecosystems and built on knowledge stemming from different sources (i.e. WISE, BISE, Member State reporting within different policy processes, modelling) to develop innovative management tools, concepts, and business models (i.e. indicators, maps, ecosystem assessments, participatory approaches, mechanisms for promoting the delivery of ecosystem services) for aquatic ecosystems at various scales of space and time and relevant to different ecosystem types.


## 1. Introduction

Aquatic ecosystems are rich in biodiversity and home to a diverse array of species and habitats. These ecosystems are vital to economic and social well-being, including through contributing to socio-economic security and human health, supplying clean water, preventing floods, producing food, and providing energy, among others. Around Europe, as in the rest of the world, many of these valuable ecosystems are currently at significant risk of being irreversibly damaged by human activities and by the numerous pressures these create, including pollution, contamination, invasive species, and overfishing, as well as climate change (Rockström et al., 2009; EEA, 2010, 2014). Current and forecasted trends of biodiversity loss in aquatic ecosystems raise substantial concern not only on grounds of environmental impacts and loss of ecosystem processes and functions, but also in terms of their effects on human well-being through the provision of ecosystem services (Maes et al., 2013). Aquatic biodiversity is declining worldwide at an alarming pace (WWF, 2016), forcing scientists and policymakers to act together to identify effective policy solutions.

Internationally action has been promoted under the Convention on Biodiversity (CBD, 1992) via a number of protocols (e.g. Cartagena Protocol on Biosafety; Nagoya Protocol on Access to genetic resources and the fair and equitable sharing of benefits arising from their utilization) and conventions (e.g. Convention on International Trade in Endangered Species (CITES, 1973); Bonn Convention on Migratory Species (CMS, 1983); Bern Convention on the conservation of European wildlife and natural habitats (COE, 1979). In parallel, the EU is taking action on multiple fronts to safeguard the status of aquatic ecosystems. These international goals and commitments are also reflected within the EU through a range of policies, regulations and directives these include the Birds and Habitats Directives (EC, 1992; EC, 2009) the Water Framework Directive (WFD, EC, 2000), the Marine Strategy Framework Directive (MSFD, EC, 2008), the Blueprint to Safeguard Europe's Water Resources (European Commission, 2012), and more recently the EU Biodiversity Strategy to 2020 (EC, 2011).

To date, despite these many environmental initiatives EU directives have been unable to halt and reverse the trend of declining biodiversity of aquatic ecosystems, the EU biodiversity strategy is at risk of failing. In the EU, the lack of success is the result, among other things, of a static view towards EU policies, their fragmented design and implementation, and the divisions in governance between the public and private sectors (European Commission (EC), 2015). In practical terms a better understanding of aquatic ecosystems state (and functioning), the services they deliver, the pressures that impact them, and the causes of these pressures (economic and social drivers), including their thresholds and tipping points when impacted by changing drivers and pressures, is required (Borja, 2014 and Barbier et al., 2010) and the need for more holistic approaches to environmental management has been widely recognised.

Two promising approaches to work towards meeting these challenges include Ecosystem Based-Management (EBM), which explicitly considers the full range of ecological and human interactions and processes necessary to sustain ecosystem composition, structure and function (Tallis et al., 2010) and integrates the connections between land air water and all living things including human beings and their institutions (Mee et al., 2015), and the (related) Ecosystem Services Approach, which enables integration of the many different types of benefits derived from biodiversity into the management of environmental resources for society and the economy (Millennium Ecosystem Assessment, 2005).

Both EBM and the incorporation of ecosystem services have been widely championed in academic research and through a variety of major EU research projects (e.g. Ostrom, 2009; O'Higgins, 2017) and the language of EBM and of Ecosystem services is included within many of the EU environmental Directives, yet these more holistic, integrative approaches to management have proved difficult to put into practice.

Recognizing the many parallel environmental management efforts at play stemming from diverse EU directives and regulations, the AQUACROSS (Knowledge, Assessment, and Management for AQUAtic Biodiversity and Ecosystem Services aCROSS EU Policies) research project aimed to develop mechanisms for harmonized implementation of environmental management directives and regulations and expand the empirical as well as practical basis for application of the Ecosystem-based Management concept for all aquatic ecosystems along the freshwater, coastal, and marine water continuum. At its core, the project aimed to be of direct policy-relevance, in particular for supporting the timely achievement of the targets set out by the EU Biodiversity Strategy to 2020 (EC, 2011) and its strategic plan 2012–2020 by promotion of ES and EBM concepts in the statutory management process set out under EU regulations. This paper presents the context, approaches and objectives of the AQUACROSS project, and describes its strongly integrative and transdisciplinary approach, highlighting the major project outputs and providing context for the individual project components which have contributed to this dedicated special issue. To this end, we reflect on the state of the art of ecosystem-based management and the ecosystem services approach prior to AQUACROSS's inception (Section 2). We then outline AQUACROSS's key objectives and outputs (Section 3) before describing the AQUACROSS approach (Section 4). Section 5 concludes by emphasising the project's promotion of EBM to generate tangible real world examples of EBM application.

## 2. Context

AQUACROSS was designed to advance knowledge in three particular fields of research relating to both the social and ecological components of social-ecological systems:

i) the application of EBM for the management of aquatic ecosystems, including through the development of an holistic conceptual framework to integrate social and ecological components of research and to provide a loosely standardized protocol for conducting EBM
ii) the understanding of the biodiversity - ecosystem services causality chain (i.e. linkages between ecosystem composition, structure, and function, with ecosystem services) e.g. Culhane et al. this issue, to understand the risks posed by human activities to ecosystem components and habitats and the services they provide, across different aquatic ecosystem types (lakes, rivers, estuaries and marine waters)
iii) Methods and mechanisms to develop and promote socially, politically and economically acceptable EBM solutions into local management.

### 2.1. Ecosystem-based management

EBM can be defined as an integrated approach to management that considers the entire ecosystem, including humans. The goal is to maintain ecosystems in a healthy, clean, productive and resilient condition, so that they can provide humans with the services and benefits upon which we depend (McLeod and Leslie, 2009; Mee et al., 2015). Management decisions should not adversely affect ecosystem functions and productivity, so that the provisioning of aquatic ecosystem services (and subsequent economic benefits) can be sustained in the long term. EBM is also relevant to maintain and restore the connection between social and ecological systems. Indeed, EBM now encompasses a whole range of decision-making support tools (see for example the EBM Tools Network[1]), and has in that context permeated scientific and policy practice related to the management of aquatic ecosystems (Nobre and Ferreira, 2009) and the language of EBM and of ES for example is present within many of the newer EU directives and regulations (see Rouillard et al., 2017 and O'Higgins, 2017 for reviews).

A major challenge nevertheless remains in the establishment of an operational framework that links the assessment of biodiversity and ecological processes and their full consideration in public and private decision-making (Rockmann et al., 2015). EBM implementation remains limited in particular regarding i) the lack of explicit consideration of the ecosystem services concept (Jordan et al., 2012), which would critically help link ecological assessments with the achievement of human well-being, thereby enhancing the relevance of achieving biodiversity targets for a range of public and private actors; ii) a primary focus on ecological dimensions which may limit the acceptability of EBM as relative to a more truly holistic consideration of social-ecological processes (Berkes, 2012), which would also enhance our integrated understanding of relevant dynamics and feedbacks between society and environment; iii) the lack of attention to trade-offs, uncertainties, and thresholds inherent in the management of (aquatic) ecosystems (Curtin and Prellezo, 2010); and, iv) standardized methodologies and approaches (Sarda et al., 2014). In this context AQUACROSS developed an analytical framework to enable a common approach to Ecosystem Based Management across ecosystems and management contexts (Delacámara et al., this issue).

### 2.2. The biodiversity – ecosystem services causality chain

Better understanding the links between biodiversity and ecosystem functions and services and how natural and anthropogenic drivers and pressures alter these relationships, is essential to inform decision-making to support achievement of biodiversity targets. Knowledge regarding these linkages has progressed rapidly since the early 1990s (Lecerf et al., 2009). Substantial evidence indicates the positive influence of biodiversity on freshwater and marine ecosystem functions (Song et al., 2014), the provision of ecosystem services (Cadotte et al., 2011) and overall ecosystem resilience (Griffen et al., 2010). The relationship between biodiversity and ecosystem functions has in particular been studied, with evidence that these relationships vary depending on the relative contribution of dominant and minor species (Emmerson et al., 2001), environmental context (Lecerf et al., 2007), and density dependence and species interactions (O'Connor and Crowe, 2005). In parallel, significant efforts have been made on building modelling capacities, to test key causal links between biodiversity and ecosystem functions and to increase our ability to forecast future dynamics.

However, the whole biodiversity causality chain remains poorly understood. Insufficient evidence exists to determine the modifying effects of environmental factors, such as nutrient concentration, altered physical structures, or elevated $CO_2$ on biodiversity and community dynamics and, subsequently, ecosystem properties (Balvanera et al., 2006). Most studies fail to find tangible links between structure, diversity and dynamics of natural communities and their ability to deliver ecosystem services that directly affect human well-being (Cardinale et al., 2012). In addition, current modelling predictions remain very limited. For example, few studies have explicitly incorporated structuring abiotic (environmental heterogeneity) and biotic (movement, dispersal) features that are key to species co-existence and vital for the maintenance of species diversity (Loreau et al., 2003). While more advanced dynamical modelling approaches have been developed (e.g. Boumans et al., 2002; Villa et al., 2009), their complexity has led to limited practical application. Models usually only cover selected ecosystem functions and are rarely able to link them to targets of biodiversity conservation and to socio-economic variables. They also have largely neglected the coupling of social-ecological systems and often exhibit significant weaknesses regarding the complex and adaptive nature of these systems, such as assuming linear response kinetics, ignoring regime shifts, uncertainty, and uncertainties of human responses to policies and management decisions and environmental change (Schlueter et al., 2012). Under such conditions of uncertainty, risk based approaches may provide a useful practical basis for incorporating what is known about system behavior into specific management strategies and several AQUACROSS outputs based on these causality chains are described in detail in this special issue (e.g. Culhane et al.; Borgwardt et al.; Teixiera et al., this issues).

### 2.3. Putting EBM into practice

EU policies on water, the marine environment, nature and biodiversity, together form the backbone of environmental protection of Europe's aquatic ecosystems and their services. One of the biggest challenges for the implementation of the EU Biodiversity Strategy to 2020 is to take advantage and reduce conflicts between these policy fields, and to effectively leverage activities harmful for the protection and sustainable management of aquatic ecosystem (O'Higgins, 2017; Rouillard et al., 2017). It is widely recognised that effective streamlining and coordination of EU environmental policy cannot only be supported by developing innovative concepts and methods, and tackling knowledge gaps, but also requires the involvement of society in policy design and research activities (Quevauviller et al., 2005 and Martini et al., 2013). Participation may have both an instrumental role (e.g. enhancing the quality and durability of decisions, creating ownership, resolving tradeoffs) and additionally a normative one (e.g. promoting democracy, citizenship and equity – Reed, 2008). In view of building resilience, stakeholder engagement is also a key process that helps build the capacity of actors to mobilise knowledge and resources for action and promote social learning by changing actors' relationships, understanding, values and norms (Olsson et al., 2006 and Pahl-Wostl, 2009).

While the benefits of stakeholder engagement are established in theory (Reed, 2008; Pahl-Wostl, 2009), limited attention is paid to the

[1] http://www.ebmtools.org/about_ebm.html.

"policy demand" of such processes in practice. In many participatory research initiatives, stakeholders and decision-makers often play a purely advisory and observer role, with minor influence on the research carried out (European Commission, 2017). As a result, and despite an increasing number of dissemination events targeting stakeholders and policy makers in past and on-going research activities, the impact of research results continues to remain limited, which reduces the scope for evidence-based policy-making and hinders the potential uptake of identified solutions.

## 3. Objectives of the AQUACROSS project

The overall aim of the AQUACROSS project has been to support the coordinated implementation of the EU 2020 Biodiversity Strategy and international biodiversity targets, and by doing so to ensure improved functioning of aquatic ecosystems as a whole (from rivers to seas). More specifically, AQUACROSS has had the following research goals:

1) To explore, advance and support the implementation of the EBM concept across aquatic ecosystems in the EU and beyond for the purposes of enhancing human well-being;
2) To specifically identify and test robust, cost-effective and innovative management and business models and tools for seizing all the opportunities offered by aquatic ecosystems services that correspond to the objectives and challenges faced by stakeholders, businesses, and policy makers; and
3) To mobilise policy makers, businesses, and societal actors at global, EU, Member State, and case-study levels in order to learn from real-world experiences, aligned with EU policy implementation, and to co-build and test assessment frameworks, concepts, tools, management approaches, and business models, to ensure end-users' uptake of project results

AQUACROSS has focused its research activities on identifying synergies and overcoming barriers between policy objectives, concepts, knowledge, data streams, and management approaches for freshwater, coastal, and marine ecosystems (Fig. 1). To do so, AQUACROSS applied end-user driven processes and social innovation.

The first two goals described above were supported by two specific sub- objectives:

A) To Provide an interdisciplinary assessment framework to support an EBM approach built both on exploring the evidence of links between biodiversity and aquatic ecosystem functions and services, as well as between drivers and pressures, changes in the status of biodiversity and the delivery of biophysical flows of ecosystem services, and linking this to the future impacts these will have in turn on human well-being.
B) Overcome knowledge gaps on evaluating the effects of biodiversity change on ecosystem services by providing assessments of how ecosystem functions cascade into service supply, delivery, and value, moving beyond ideal experimental conditions to realistic management scenarios in which services are actually delivered to society at large.

While the 3rd goal was supported by the specific objective of developing a network of interdisciplinary, adaptive, and participatory EBM experiments that cover a gradient of landscapes and seascapes, as well as a diversity of socioeconomic contexts. Here, demand-driven approaches were central to ensuring that AQUACROSS research addressed issues that were important to stakeholders, taking their needs and knowledge into account, providing opportunities for co-learning, and feeding into public and private decision-making.

## 4. The AQUACROSS approach

In this section, we introduce how AQUACROSS has set out to achieve its objectives. Given the integrative and interdisciplinary nature of the project, guiding concepts and an overarching theoretical framework were essential to enable parallel collaborative works strands, these are summarised in Section 4.1. Application of the theoretical framework is outlined in Section 4.2. This application was built around four pillars: 1 – real world testing, 2 – giving direction, 3 – improving scientific knowledge, and 4 – improving management. Given their central role as a practical testing ground for AQUACROSS concepts and as source of insights and conclusions, Section 4.3 introduces each of the eight case studies in the AQUACROSS project.

### 4.1. Key concepts of the AQUACROSS project

Integration as well as inter- and trans-disciplinary research were central to the project, and the application of these approaches to the

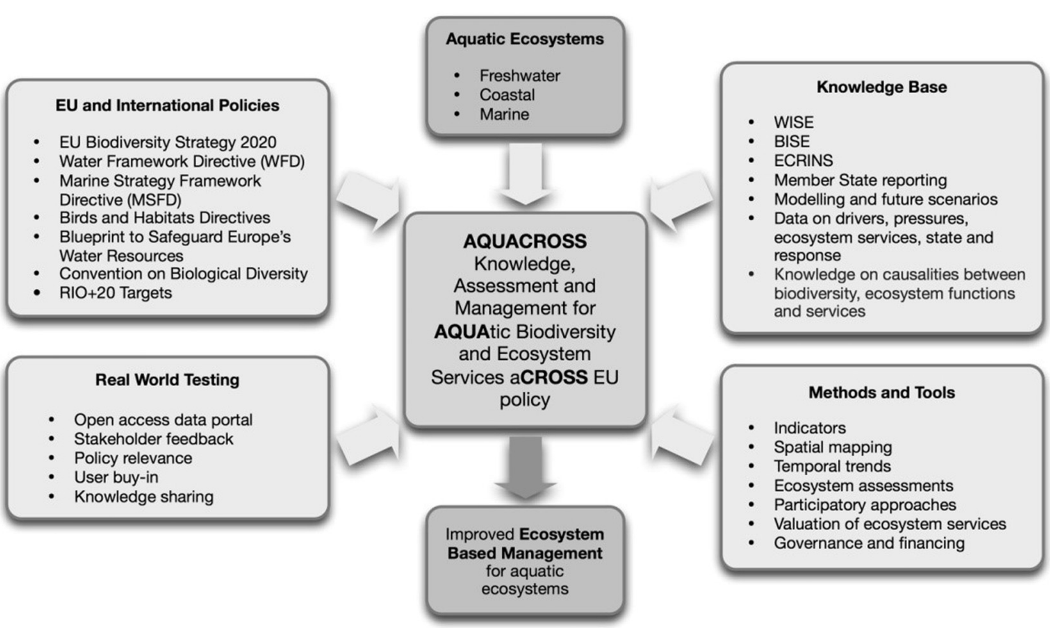


**Fig. 1.** AQUACROSS links science, stakeholders, policy, knowledge, data, and management.

challenges of EBM across aquatic ecosystems were its main innovation. AQUACROSS combined scientific analyses to develop an integrative understanding of drivers, pressures, state of ecosystems, ecosystem services, and impacts on aquatic ecosystems based on an adaptation of the well-known DPSIR analytical framework (see Delacámara et al., this issue for more detail on the AQUACROSS Assessment Framework). At the outset and throughout, the project incorporated stakeholder and end-user engagement into the assessment of causal links between ecosystems and the services they provide. This integration is illustrated by the way AQUACROSS addressed both the harmonisation and streamlining of environmental policies under the overall framework of the EU Biodiversity Strategy to 2020; in the coordination of policies in transitional and coastal waters, where different policy directives apply, and through the integration of relevant information for the assessment of aquatic ecosystems across the freshwater-saltwater continuum. By addressing and integrating across all aquatic ecosystems (freshwater, coastal, and marine), the project mobilised biologists, ecologists, chemists, eco-toxicologists, hydrologists, oceanographers, environmental scientists, physicists, economists, IT-experts, and other social scientists in a truly transdisciplinary process.

At its core, AQUACROSS developed and tested an Assessment Framework (AF) that aimed to enable the practical application of EBM in aquatic ecosystems through relevant indicators, data, models and guidance protocols. AQUACROSS recognised EBM as a way to address uncertainty and variability in dynamic ecosystems in an effort to embrace change, learn from experience and adapt policies throughout the management process. As EBM measures needs to be supported by an effective policy and governance framework that enables their adoption among a wide range of actors from public authorities to businesses, civil society organisations and citizens, this aspect also featured in the Assessment Framework (Delacámara et al., this issue). The AQUACROSS AF integrates ecological and socio-economic aspects in one analytical approach to EBM, building on well-established frameworks currently in application to assess biodiversity, ecosystem functions and services, for example, MAES, CICES, TEEB, MA and ARIES, as well as INSPIRE, SEIS and the GEOSS Data Sharing Principles (see Fig. 1). The AQUACROSS AF applied and extended the widely used DPSIR cycle (Keble et al., 2013; Elliott et al., 2017; EEA, 2010; Rouillard et al., 2017) addressing Drivers (D), Pressures (P), States (S), Ecosystem Goods and Services (EGS), Impacts (I) and Responses (R) for the assessment of aquatic ecosystems (DPS-EGS-IR). The DPS-EGS-IR approach, which includes the causal relationships relevant to inform management decisions, allows for addressing multiple interactions between socio-economic and ecological systems in aquatic ecosystems (see further insights in Culhane et al., this issue; Borgwardt et al., this issue).

AQUACROSS emphasised the role of feedback loops, critical thresholds of ecosystems and coupled social-ecological systems that behave as complex adaptive systems as illustrated by the "Butterfly diagram" (Delacámara et al., this issue) which is central to the AF. For this, the project enriched its analyses with the current debates and practical applications of Resilience Thinking (Folke et al., 2010). Resilience is defined as the ability to cope with alterations induced by the presence of multiple stressors or with unpredictable or non-directional environmental change (Rockström et al., 2014). A system is resilient when it retains or returns to its essential features and functions after its elements, processes and structures are subjected to pressure. In AQUACROSS, resilience was not only considered on conceptual grounds but also from a practical perspective to facilitate the integration of knowledge on ecosystem functions and services with values, needs and preferences of stakeholders to develop sustainable solutions. Processes of knowledge production through participation aimed to support social learning and lead to management and governance approaches that were more capable of coping with uncertainty and are more suitable to enhance the resilience of social-ecological systems.

Finally, AQUACROSS took the Meta-Ecosystem Approach (Largaespada et al., 2012) to better understand feedbacks and impacts across multiple scales and the emergent properties that arise from spatial coupling of local ecosystems, such as global source–sink constraints, biodiversity–productivity patterns, stabilisation of ecosystem processes and indirect interactions at local or regional scales. The meta-ecosystem approach is a useful and powerful theoretical and conceptual tool i) to integrate the perspectives of community ecology, ii) to provide novel fundamental insights into the dynamics and functioning of ecosystems from local to global scales, and iii) to increase our ability to predict the consequences of drivers and pressures on biodiversity and the provision of ecosystem services to human societies (Loreau et al., 2003). The meta-ecosystem approach recognises the distinctive spatial distribution of ecosystems, describing abiotic and biotic components based on interaction, connection or movement rates, e.g. of nutrients or long distance migratory organisms. This approach is widely seen as theoretical, and it has been rarely applied in practice to aquatic ecosystems. Being scale independent, this approach enables a focus on ecosystem diversity (rather than on species diversity solely), which renders outputs more operational for EBM (i.e. an ecosystem can be a single habitat or the entire North Sea depending on the unit that will be managed).

### *4.2. The AQUACROSS workflow*

The project built on existing knowledge to generate innovative responses to policy coordination challenges by developing integrative tools and concepts with relevant stakeholders. The AQUACROSS approach was built around four interconnected pillars of work (Fig. 2), enabling an integrated work programme throughout the project. In addition, eight different case studies supported the development and testing of the AQUACROSS AF as well as the wider suite of innovative and applicable AQUACROSS management tools for aquatic ecosystems, which together served to best enhance, through conservation of biodiversity, the socio-ecological resilience of the ecosystem and its capacity to deliver services to society.

#### *4.2.1. AQUACROSS Pillar 1 - real-world testing*

AQUACROSS placed stakeholders and policy demands first to ensure research was framed in terms of real policy, stakeholder, and business needs, and to accelerate and broaden the uptake of projects' results. This required not only a sound understanding of prevailing policy, scientific and management paradigms, values and perceptions for each policy area (Pillar 2, see below), but also effective engagement mechanisms within the project. Pillar I involved the development of guidance on stakeholder engagement to the case studies, the creation of interactive platforms for discussion, advice and consultation on the main questions relevant for AQUACROSS research, and the communication and dissemination of AQUACROSS findings and outputs. To ensure relevance to policy and business, AQUACROSS used a science-policy-business interface focused at two levels: local, through the case studies (through stakeholder groups); and generically, through a project guidance board, the Science-Policy-Business Think Tank (SPBTT). The SPBTT membership was a balanced mix of individuals with backgrounds in science, policy and business. This, combined with local stakeholder representation contributed to the identification of common research and policy challenges to elucidate policy and business solutions, and their extrapolation to wider areas/issues, along with the identification of their pre-conditions (e.g. regulatory changes) necessary for implementation.

#### *4.2.2. AQUACROSS Pillar 2 - giving direction*

Pillar 2 was based around two research activities: Policy Orientation and the AQUACROSS AF. Policy Orientation (Fig. 2) investigated the demands that arise from "policy implementation in practice". It identified the main international, European and Member State-level policy drivers affecting biodiversity conservation targets (negatively or positively) at different scales of application through a top-down/bottom-up approach (see Rouillard et al., 2017 and O'Higgins, 2017 for detailed analysis).

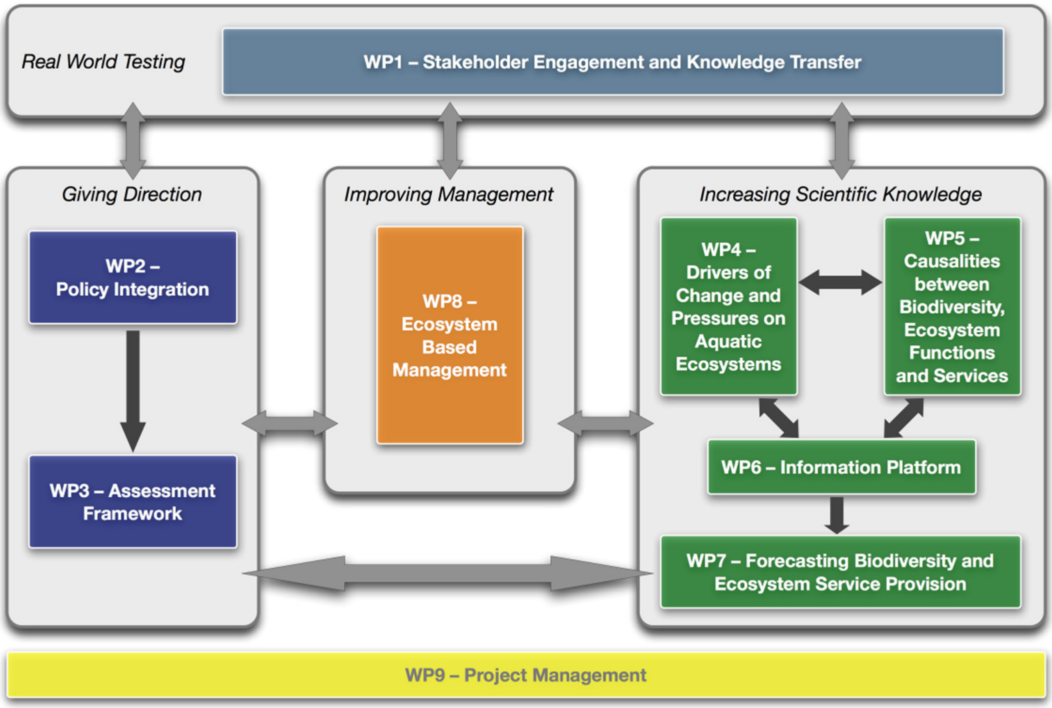


**Fig. 2.** The AQUACROSS workflow, featuring the four AQUACROSS pillars.

Synergies, opportunities and barriers were identified between the specific operational features of existing environmental and related sectoral policies in Europe that are relevant for the protection of aquatic ecosystems (e.g. Birds and Habitats directives, Water Framework Directive, Marine Strategy Framework Directive, Common Agricultural Policy, Common Fisheries Policy, among others). This analysis enabled a fuller understanding of the extent to which existing and planned EU policies may support or hinder the achievement of EU and international biodiversity targets. Finally, the analysis synthesised the insights gained from AQUACROSS to provide policy-relevant information guiding EBM implementation for the achievement of the EU biodiversity targets in aquatic ecosystems in all regions of Europe, and beyond (through a series of widely disseminated business and policy briefs).

The Assessment Framework (Delacámara et al., this issue) (Fig. 2) developed a common framework focused on concepts, tools and methods for the assessment of aquatic ecosystems and application in the project case studies. Within the project, it built a joint understanding, facilitating the integration of social and natural scientific disciplines. The AQUACROSS AF followed the DPS-EGS-IR causal framework, and identified critical linkages between the different elements of the project: analysis of drivers and pressures; the assessment of causalities between biodiversity and ecosystem functions and services; the impact of direct, indirect and emerging drivers on the status and trends of biodiversity, ecosystem functions and services; as well as facilitating the design and implementation of EBM approaches to enhance the status of aquatic ecosystems and achieve policy objectives. The AF integrates crosscutting issues such as resilience thinking, uncertainty, issues of varying spatial and temporal scales, and data and metrics for indicators. The AF highlights key areas or "nodes" where indicators are essential for capturing the state and dynamics of biodiversity and ecosystem services, as well as the adaptive capacity and resilience of aquatic ecosystems. Finally, the framework was further refined and updated based on feedback from its implementation in case studies to develop an ecosystem based management handbook to enable more widespread practical implementation of EBM.

*4.2.3. AQUACROSS Pillar 3 - increasing scientific knowledge*

The AQUACROSS AF was used to assess drivers of change and pressures for different aquatic ecosystems and ecosystem components along a freshwater – marine continuum, including transitional (estuarine) waters, and addressing ecological and socio-economic factors in eight case studies (see Section 4.3). Pillar 3 consisted of four separate but interlinked research activities based on the DPS-EGS-IR approach of the AQUACROSS AF.

Drivers of change and pressures on aquatic ecosystems (Fig. 2) examined existing knowledge and global projections of direct, indirect and emerging drivers and resulting pressures on aquatic ecosystems to be faced at different spatial scales. It extends the AF through guidance on indicators and methods to assess drivers and pressures affecting aquatic ecosystems. Further, it tested the suitability of indicators and applicability of methods in the case studies (see Section 4.3). Analyses on drivers and pressures, and their complex interactions, are based on a meta-analysis of the current state of knowledge on drivers and pressures, taking into consideration finalised and ongoing research projects (see for example, Hering et al., 2013; Stendera et al., 2012; Hering et al., 2015; Knight et al., 2013). Additionally, it also assessed the existing indicators addressing the driver-pressure relationship including different biodiversity indices. Drivers were considered both at global and local scales (e.g. case studies). Similarly, the temporal (dynamic) dimension was factored in (e.g. expected urban sprawl, shift in tourism flow trends, stable or declining agriculture, expansion towards new fishing grounds) (Burgwardt et al., this issue).

Causalities between biodiversity, ecosystem functions and services (Fig. 2) increases knowledge on the relationship between biodiversity, ecosystem functions and ecosystem services across the three aquatic realms. Assessments on the causality links between biodiversity and ecosystem functions and services not only considered species richness but also the functional trait composition of biological assemblages using multimetric biodiversity indices. This work built on previous literature, including outcomes of finalised and ongoing research projects (Van Dijk et al., 2018; Hering et al., 2015). In addition, multivariate modelling approaches were used to consider the multidimensional nature of causality relationships. Generalised dissimilarity modelling and diversity-interactions models were used to derive biodiversity and ecosystem functions and services across large regions (Lopez et al., this issue). Derived causality functions were integrated into the Artificial Intelligence for Ecosystem Services (ARIES – Villa et al., 2009; Martinez-Lobez, this issue) modelling platform, using mapping explicit techniques, to increase forecasting ability of ecosystem services. Additionally, AQUACROSS considered how biodiversity-related causal links are affected during disturbance and recovery.

The third research activity, the development of an Information platform (http://dataportal.aquacross.eu/) involved the construction of a software platform based on the Comprehensive Knowledge Archive Network (CKAN) architecture to make possible the cataloguing, interrogation, analysis, and visualisation of diverse datasets on aquatic ecosystems and biodiversity using a range of selection criteria. Data and information were acquired from within the project and external sources. The platform was implemented as a network of interoperable databases including an ingestion module, in charge of data acquisition from external service providers, e.g. WISE, BISE, OBIS, EMODnet, other EU initiatives (e.g. Freshwater Information Platform) in addition to GEOSS, COPERNICUS and other initiatives led by the European Space Agency (ESA), among others. The open-access information and dissemination platform integrates inputs from the three aquatic realms and contain modules for: (i) overview of data and metadata (including links to data repositories); (ii) AQUACROSS indicators and tools; (iii) technical documentation and guidelines; (iv) geospatial exploration and visualisation of the collected data (e.g. case studies) with various levels of access to the stored data; and (v) a user management module to administer user accounts, data access and processing rights.

Forecasting biodiversity and ecosystem service provision (Fig. 2) established novel predictive capacities for key indicators of aquatic biodiversity, ecosystem function, and service provision with greatest relevance to EU environmental policy. A key scientific challenge was to provide robust evidence for expected trends that considered effects of ecosystem resilience and connectivity, effect thresholds, climatic extremes, socio-economic trends and uncertainties. A special effort was also dedicated to optimisation modelling on the effects of the spatial arrangement of various ecosystem types. Depending on case studies, the work was based on semi-quantitative models (i.e. robust linkage models, output models), quantitative deterministic or statistical models, and qualitative social-ecological models co-developed with stakeholders. Social-ecological models in particular aimed to bridge the gap between ecological modelling and policy paradigms, values and perceptions of stakeholders. This supported a joint learning process and contributed to the science-policy interface of Pillar 1. This work supported more robust scenarios, more integrated management approaches and policies, and maximisation of the delivery of multiple ecosystem services.

#### 4.2.4. AQUACROSS Pillar 4 - improving management

To close the DPS-EGS-IR cycle, Pillar 4 identified, developed and assessed impacts and responses for innovative management of aquatic ecosystems building on scientific evidence and a strong stakeholder involvement. Pillar 4 was strongly framed by Pillar 2 (Giving Directions) but drew on evidence built within Pillar 3 (Increasing Scientific Knowledge). Pillar 4 involved the development of EBM management responses, and policy instruments, that can ensure the cost-effective provision of ecosystem services so as to contribute to the objectives of marine, freshwater and biodiversity policies. Particular attention was given to the link between well-being and human responses for the conservation of biodiversity and sustainable management of ecosystem services.

### 4.3. AQUACROSS case studies

The eight AQUACROSS case studies (Fig. 3) were of key importance to the AQUACROSS project forming a major source for information and data, co-created concepts and developed products, shared experiences with implementing policy and respective management responses, as well as providing critical feedback on project outputs, including the AQUACROSS AF. The large-scale observational case studies not only benefited from the collaborative science-policy-business activities, but they also provided different and complementary insights into the development of indicators, methods and tools to assess the links between aquatic biodiversity and ecosystem services. These case studies were specifically selected to 1) showcase specific elements of the objectives of the EU 2020 Biodiversity Strategy relevant for the management of aquatic ecosystems; 2) understand the most relevant challenges surrounding the protection of aquatic biodiversity; and 3) maximise the lessons learnt in order to up-scale results.

The eight case studies include:

*Case Study 1*: *Development of the knowledge base for more informed decision-making and the implementation of ecosystem-based management aimed at achieving Biodiversity Strategy targets in the North Sea.*

The North Sea is one of the busiest seas with many (often growing or newly emerging) sectors laying a claim to a limited amount of space. The need for Integrated Ecosystem Assessments (IEAs), Marine Spatial Planning (MSP) and Ecosystem-based Management (EBM) is therefore rapidly increasing and an appropriate scientific knowledge base is becoming a key requirement for more informed decision-making. This case study focused on what a focal point of North sea policy, food security, clean energy and nature conservation. This involved the most important current activity, i.e. fisheries, and the main newly emerging activity, i.e. renewable energy (or more specifically offshore wind farms), to showcase how EBM (which includes marine spatial planning) can contribute to the achievement of the societal goals (but with a focus on the Biodiversity Strategy targets and related policy objectives) centred around the conservation of the seabed habitats. This case study started with an integrated risk-based assessment of all the human activities and their pressures in the study area in order to frame the focal point of this case study, i.e. the food-energy-conservation nexus, into the wider context required for integrated EBM. This risk-based assessment guided the further development of more detailed models which were then applied to evaluate different management strategies, e.g. spatial closures, technical measures, based on trade-offs between e.g. policy objectives or the supply of specific ecosystem services in the study area.

*Case Study 2*: *Analysis of transboundary water ecosystems and green/blue infrastructures in the Intercontinental Biosphere Reserve of the Mediterranean Andalusia (Spain) – Morocco.*

This case study uncovered best practice examples of nature-based solutions for aquatic ecosystems through the development of direct recommendations to increase the establishment of green and blue infrastructures in the management and planning of transboundary water ecosystems within natural protected areas. The study focused on the Intercontinental Biosphere Reserve of the Mediterranean: Andalusia (Spain) – Morocco which spans two continents, Europe and Africa. The one million hectare reserve passes through the Strait of Gibraltar and includes river basins, coastal and marine waters. The case study identified major drivers and pressures of the study site, which include water management and planning, transboundary fragmentation of water bodies, pollution, water uses, water prices, illegal extraction, and drought and water scarcity. A set of indicators was identified to assess the provision of ecosystem services across the reserve, which can be applied to the 20 diverse natural protected sites in both Andalusia and Morocco and cover the three water realms. Data on case study characterisation and water bodies, statistics, uses, prices, plans and strategies was collected and modelled to forecast the future provision of aquatic ecosystem services over time. Lastly, the case study further

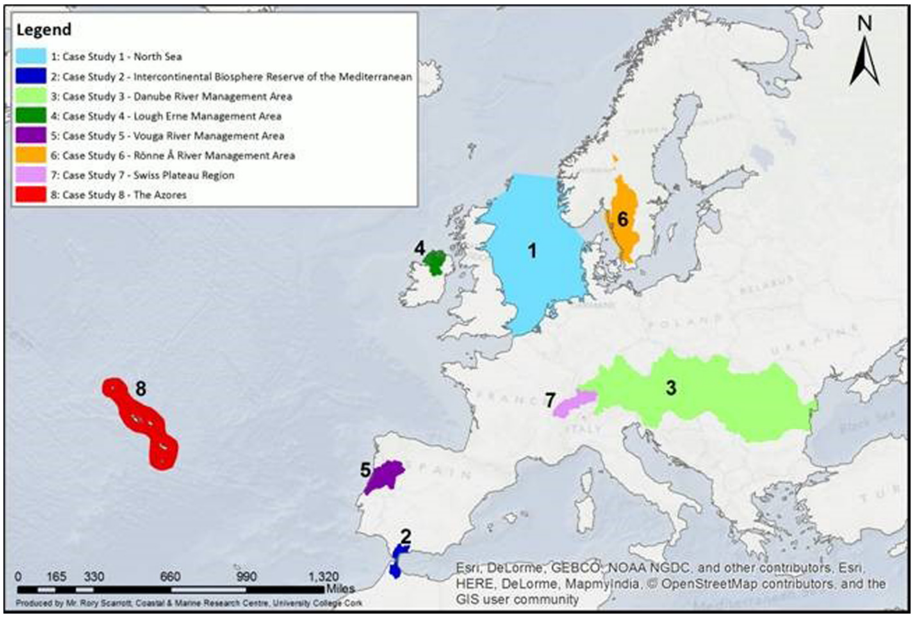


**Fig. 3.** Location of AQUACROSS case studies.

extends these models to examine green/blue infrastructures as nature-based management solutions in the Mediterranean context. Further detail is provided in Barbosa et al., this issue).

*Case Study 3*: *Danube River Basin - harmonising inland, coastal and marine ecosystem management to achieve aquatic biodiversity targets.*

This case study identified the impacts of significant water management issues of the Danube River Basin (ICPDR, 2016) on its aquatic biodiversity. These management issues included organic, hazardous substances and nutrient pollution, and hydromorphological alterations. Major drivers and pressures of the study area are identified, including land use change, pollution, hydropower, navigation, eutrophication, and habitat loss and degradation. The focus at the river basin scale was to assess effects of hydromorphological alterations, e.g. hydropower development in the network of tributaries and the conservation and restoration potential of floodplains along the Danube River by considering mechanisms for enhancing the integration between different policies (EU WFD, EU Biodiversity Strategy, Habitats and Birds Directives –HBD) and human activities. A set of indicator species, such as those based on outcomes of historical analyses within the FP7 project MARS, was identified as well as floodplain characteristics, status of protected areas (Natura 2000 sites) and biodiversity indices at different scales. The study assembled data on biodiversity, historical records of indicator species occurrences, and specific data on floodplains as well as analyses on ecosystem services. This data were used to forecast the future development of aquatic ecosystems under changed environmental conditions and management schemes. These forecasting models were extended to identify management options to address hydromorphological alterations as one of significant water management issues, while taking into account better integration with other EU water policies (Kuemmerlen et al., this issue, Domisch et al.., this issue).

*Case Study 4*: *Management and impact of Invasive Alien Species in Lough Erne in Ireland.*

This case study investigated the management protocols in place for invasive alien species (IAS) in a transboundary (catchment) context and assessed where institutional arrangements could be improved or refined to better serve biodiversity conservation needs, and advance an ecosystem-based approach to management. The study focussed on IAS in Lough Erne (Republic and Northern Ireland); specifically, the aquatic weed *Nuttall's Pondweed*. As IAS are largely considered an environmental pressure, the study examined the drivers of this particular pressure within the study site and management options to alleviated the negative effects of IAS on recreational activities within the Lough. Additionally, the study examined the ecological impacts of these species, as well as the impact on (protected) habitats, other species and human activities. This stage provides information and data on the links/relationships between IAS and affected ecosystem services and/or biodiversity. This information on the impacts was combined with scientific data on species distribution, monitoring and historical establishment of species, as well as information from stakeholder engagement processes regarding the current management regimes dealing with (directly or indirectly) the impacts of IAS. This data were then used to develop a Fuzzy Cognitive Map, a qualitative model on the effects of IAS and forecast the potential future changes in the Lough based on the relationships between existing activities and ecosystem components.. These forecast models help identify possible opportunities to incorporate EBM approaches within current or emerging plans to address IAS impacts on ecology, social and economic systems in the study area.

*Case Study 5*: *Improving integrated management of Natura 2000 sites in the Vouga River, from catchment to coast, Portugal.*

In the context of environmental (e.g. Natura 2000 network; Biodiversity Strategy) and water related (e.g. WFD; MSFD) policies and the Integrated Coastal Zone Management recommendation, this case study aims to contribute to the improvement of integrated management of aquatic Natura 2000 sites, from catchment to coast, involving the concepts of Science-policy-stakeholders interface. Special attention is given to investigate causalities involving biodiversity, ecosystem functions and services in relation to spatial flows (biotic and abiotic) and how they affect ecosystem resilience using a meta-ecosystem approach. The study area includes a downstream section of the Vouga river (Baixo Vouga Lagunar), the Vouga river estuary, which is part of Ria de Aveiro coastal lagoon, the lagoon adjacent coastal area, and the freshwater wetland Pateira de Fermentelos classified as Ramsar site. It includes several habitats integrated in the Natura 2000 network, classified as Special Protection Area (SPA) and/or as Site of Community Importance (SCI), contributing significantly to the maintenance of biological diversity within this biogeographic region and its provision of ecosystem services. Initially, the case study promotes actions for engagement of stakeholders at different levels, reviews the current laws and policies governing the environmental management of the area. The study then identifies the main drivers and pressures in the considered area, which include agriculture, fishing, population growth, tourism and recreational activities, uncoordinated management, and associated economic drivers and pressures. A causalities analysis is conducted to explore and identify links to biodiversity, ecosystem functions and services in Natura 2000 aquatic habitats. All data collected on ecosystem service indicators is used in GIS-based models applied to environmental and socio-economic scenario analysis. Lastly, the case study develops innovative management instruments, including participatory initiatives, which set out conservation objectives for biodiversity and preservation of ecosystem services, as well as restoration measures for Natura 2000 sites. Further detail is provided in Libello et al., this issue).

*Case Study 6*: *Understanding eutrophication processes and restoring good water quality in Lake Ringsjön - Rönne å Catchment in Kattegat, Sweden.*

This case study aims to identify key structural elements and processes in the social and ecological subsystems and their interactions that determine the capacity of a social-ecological system in a catchment to adapt to change and transition to new management approaches. Specifically, the case study examines the process of eutrophication and restoration of good water quality and their implications for the provision of ecosystem services along the Rönne å catchment and Lake Ringsjön. An initial assessment of drivers and pressures takes into account both ecological (nutrient inflow from agriculture and sewage, climate change, reduction of fish) and social (historical housing traditions, regulation on sewage treatment, development of ecotourism, etc.) perspectives. Links between these drivers and pressures and changes in biodiversity and provision of ecosystem functions and services utilise identified indicators, such as habitat characteristics attractive to tourists, support drinking water purification, fisheries, etc. Data is collected on spatial distribution of habitats for water plants, fish and birds; historical land use; fishing pressure; climate change impacts; eutrophication history of the catchment; relevant local and regional policies; socio-economic statistics; and spatial data on ecosystem services perception and use. This information is used in participatory socio-ecological models to specify and explore scenarios of catchment use and restoration, and to address conceptual questions of resilience. Lastly, the study explores possible future trajectories under different management settings through scenario projection and analysis considering responses to climate change, WFD requirements, integrated catchment management and improved (or worsened) water quality.

*Case Study 7*: *Biodiversity Management for Rivers of the Swiss Plateau.*

This case study predicts the development of biodiversity of invertebrates and fish in the rivers of the Swiss Plateau between the Jura and the Alp mountains as a function of climate change, land use and population growth scenarios and of suggested management strategies. Identification of main drivers and pressures, such as river canalisation, chemical pollution and modification of hydrologic regimes by hydropower plants, is conducted in conjunction with the identification of indicator species, such as invertebrates and fish. Information on (general) cause-effect relationships is formalised in the structure and quantification of a probability network model. Additionally, site-specific information is used to specifically condition this model to the investigated river networks. Forecasting of aquatic biodiversity in the rivers is done by applying the conditioned probability network model. Lastly, management alternatives is evaluated for their effectiveness using a multi-criteria decision analysis approach. The study estimates the changes from different management alternatives and thus, jointly with the value function formulating the societal preferences, allowing us to valuate management alternatives.

*Case Study 8*: *Ecosystem-based solutions to solve sectoral conflicts on the path to sustainable development in the Azores.*

Case Study 8 considers the richly biodiverse Faial-Pico Channel, a 240 $km^2$ Marine Protected Area (MPA) in the Azores, an EU Outermost Region. Despite international, Azorean, and local protection for the area, biodiversity in the MPA continues to be lost. Commercial and recreational fishing as well as swiftly growing tourism place pressures on the Channel ecosystem. This in turn threatens the biodiversity and sustainability of the Channel on which these sectors rely, and lead to increasing conflict over the Channel's scarce resources. Given this context, the case study collaborates with local stakeholders and policy makers to identify cooperative ecosystem-based solutions to ensure long-term sustainability. To do so, we analyse current biodiversity-relevant EU and local policies to identify policy objectives and gaps. Stakeholder objectives are collected and analysed through interviews and stakeholder workshops. To understand relationships between the sociological and ecological aspects of the ecosystem, we characterise the Channel in terms of key drivers, pressures, ecosystem state, ecosystem functioning, and ecosystem service flows, using a qualitative linkage tool and available quantitative data. Scenario analysis with stakeholders draws on this policy, stakeholder, and sociological-ecological system characterisation to identify and evaluate ecosystem-based management measures that ensure a sustainable future for the Channel and its inhabitants.

## 5. Final remarks

AQUACROSS emphasises the integration of existing ideas and approaches to provide innovative outcomes and products relevant for the sustainable management of aquatic ecosystems at different scales of application. At its core, AQUACROSS outcomes are aimed at problem solving and responding to pressing societal and economic needs. It applies a policy- and user- led research approach, where science is furthered through the co-creation of knowledge between practitioners and stakeholders. AQUACROSS brings together traditionally fragmented research traditions between biodiversity, freshwater, coastal, and marine components, and thereby contributes to integrating knowledge, concepts, information, methods, and tools across multiple research fields in an inter-disciplinary way. In particular, the consolidated outlook on EU policy for biodiversity and aquatic ecosystems (i.e. objectives, terminology, concepts) will help build shared values, perceptions, and views. A coherent set of EBM assessment methods and models that cover the further developed DPS-EGS-IR cycle for freshwater, coastal and marine waters will be produced. More specifically on monitoring, combined indicators as called for in Resource Efficient Europe 2020 are advanced for freshwater, coastal, and marine waters. A direct support is provided to the achievement of biodiversity targets, and the implementation of river basin management in the ongoing second (2015–2021) and third (2021–2027) cycle of the WFD and for marine management in the second cycle of the MSFD (2018). A structured information platform integrates generated knowledge and provides a consistent framework for collection of existing and improved data to ensure quality, comparability, and availability of water-related environmental information.

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## References


Balvanera, P., et al., 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecol. Lett. 9, 1146–1156.

Barbier, E.B., et al., 2010. The value of estuarine and coastal ecosystem services. Ecol. Monogr. 81, 169–193.

Berkes, F., 2012. Implementing ecosystem-based management: evolution or revolution? Fish Fish. 13 (4), 465–476.

Borja, A., 2014. Grand challenges in marine ecosystem ecology. Mar. Ecosyst. Ecol. 1, 1.

Boumans, R., Costanza, R., Farley, J., Wilson, M.A., Portela, R., Rotmans, J., Villa, F., Grasso, M., 2002. Modeling the dynamics of the integrated earth system and the value of global ecosystem services using the GUMBO model. Ecol. Econ. 41, 529–560.

Cadotte, M.W., et al., 2011. Beyond species: functional diversity and the maintenance of ecological processes and services. J. Appl. Ecol. 48, 1079–1087.

Cardinale, B.J., et al., 2012. Biodiversity loss and its impact on humanity. Nature 486, 59–67.

CBD, 1992. Convention on Biodiversity 1992. Available from: https://www.cbd.int/.

CITES, 1973. Convention on International Trade in Endangered Species of Wild Fauna and Flora, March 3rd, 1973. 993. U.N.T.S., p. 243.

CMS, 1983. Convention on migratory species. Available at https://www.cms.int/.

COE, 1979. Bern Convention on European Wildlife and Natural Habitats. https://www.coe.int/en/web/bern-convention.

Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the EEC. 1992; L206/7 1.

Curtin, R., Prellezo, R., 2010. Understanding marine ecosystem based management: a literature review. Mar. Policy 34 (5), 821–830.

EEA, 2010. 10 Messages for 2010 Freshwater Ecosystems.

EEA, 2014. Marine Messages, Brochure No 1/2014.

Elliott, M., Burdib, D., Atkins, J.P., Borja, A., Cormier, R., de Jonge, V.N., Turener, R.K., 2017. "And DPSIR begat DAPSI(W)R(M)!" - a unifying framework for marine environmental management. Mar. Pollut. Bull. 15, 27–40.

Emmerson, M.C., et al., 2001. Consistent patterns and the idiosyncratic effects of biodiversity in marine ecosystems. Nature 411, 73–77.

European Commission, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community actions in the field of water policy. Off. J. Eur. Communities L327 (1.22.12.2000).

European Commission, 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for Community actions in the field of marine environmental policy (Marine Strategy Framework Directive). Off. J. Eur. Communities L164, 19 (25.06.2008).

European Commission, 2011. The EU Biodiversity Strategy to 2020. European Commission.

European Commission, 2012. COM (2012). p. 673.

European Commission (EC), 2015. Mid-term Review of the EU Biodiversity Strategy to 2020 Brussels: EC.

European Commission, 2017. Results of Horizon Stakeholder Interim Evaluation of Horizon 2020. Accessed online. http://ec.europa.eu/research/evaluations/pdf/archive/h2020_evaluations/h2020_stakeholder_consultation_042017_web.pdf.

European Community Directive 2009/147/EC of the European Parliament and of the council of 30 November 2009 on the conservation of wild birds (codified version) Official Journal of the European Union. 2009; L20/7.

Folke, C., et al., 2010. Resilience thinking: integrating resilience, adaptability and transformability. Ecol. Soc. 15 (4), 20.

Griffen, B.D., et al., 2010. Moving species redundancy toward a more predictive framework. In: Kemp, P.F. (Ed.), Eco-DAS VIII Symposium Proceedings. ASLO, pp. 30–46.

Hering, D., Borja, A., Carvalho, L., Feld, C.K., 2013. Assessment and recovery of European water bodies: key messages from the WISER project. Hydrobiologia 704, 1–9.

Hering, D., Carvalho, L., Argillier, C., Beklioglu, M., Borja, A., Cardoso, A.C., Duel, H., Ferreira, T., Globevnik, L., Hanganu, J., Hellsten, S., Jeppesen, E., Kodes, V., Lyche Solheim, A., Nõges, T., Ormerod, S., Panagopoulos, Y., Schmutz, S., Venohr, M., Birk, S., 2015. Managing aquatic ecosystems and water resources under multiple stress - an introduction to the MARS project. Sci. Total Environ. 503-504, 10–21.

ICPDR, 2016. The Danube River Basin District Management Plan. ICPDR — International Commission for the Protection of the Danube River, p. 164. https://www.icpdr.org/main/sites/default/files/nodes/documents/drbmp-update2015.pdf (Vienna).

Jordan, S.J., et al., 2012. Ecosystem services of coastal habitats and fisheries: multiscale ecological and economic models in support of ecosystem-based management. Mar. Coast. Fish. 4 (1), 573–586.

Keble, C.R., Loomis, D.K., Lovelace, S., Nuttel, W.K., Ortner, P.B., Fletcher, P., Cook, G.S., Lorenz, J.J., Boyer, J.N., 2013. THE EBM-DPSER conceptual model: integrating ecosystem services into the DPSIR framework. PLoS One https://doi.org/10.1371/journal.pone.0070766 (eCollection).

Knight, M., Koss, R.A., Robinson, L., 2013. Identifying common pressure pathways from a complex network of human activities to support ecosystem based management. Ecol. Appl. 23, 755–765.

Largaespada, C., et al., 2012. Meta-ecosystem engineering: nutrient fluxes reveal intraspecific and interspecific feedbacks in fragmented mussel beds. Ecology 93 (2), 324–333.

Lecerf, A., et al., 2007. Decomposition of diverse litter mixtures in streams. Ecology 88, 219–227.

Lecerf, A., et al., 2009. Biodiversity-ecosystem function research: insight gained from streams. River Res. Appl. 26 (1), 45–54.

Loreau, M., et al., 2003. Meta-ecosystems: a theoretical framework for a spatial ecosystem ecology. Ecol. Lett. 6 (8), 673–679.

Maes, J., et al., 2013. Mapping and Assessment of Ecosystems and Their Services. An Analytical Framework for Ecosystem Assessments Under Action 5 of the EU Biodiversity Strategy to 2020. Publications office of the European Union, Luxembourg.

Martini, F., et al., 2013. Science–Policy Interface in Support of the Water Framework Directive: CIS-SPI Activity Report 2010–12.

McLeod, K., Leslie, H. (Eds.), 2009. Ecosystem-based Management for the Oceans. Island Press, Washington, DC.

Mee, L., Cooper, P., Kannen, A., Gilbert, A.J., O'Higgins, T., 2015. Sustaining Europe's seas as coupled social–ecological systems. Ecol. Soc. 20 (1), 1. https://doi.org/10.5751/ES-07143-200101.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington.

Nobre, A.M., Ferreira, J.G., 2009. Integration of ecosystem-based tools to support coastal zone management. J. Coast. Res. SI56, 1676–1680.

O'Connor, N.E., Crowe, T.P., 2005. Biodiversity loss and ecosystem functioning: distinguishing between number and identity of species. Ecology 86, 1783–1796.

O'Higgins, T.G., 2017. You can't eat biodiversity: agency and irrational norms in European aquatic environmental law. Chall. Sustain. 5 (1), 43–51. https://doi.org/10.12924/cis2017.05010043.

Olsson, P., et al., 2006. Shooting the rapids: navigating transitions to adaptive governance of social-ecological systems. Ecol. Soc. 11 (1), 18.

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science 325, 419–422.

Pahl-Wostl, C., 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Glob. Environ. Chang. 19 (3), 354–365.

Quevauviller, P., et al., 2005. Science-policy integration needs in support of the implementation of the EU Water Framework Directive. Environ. Sci. Pol. 8 (3), 203–211.

Reed, M.S., 2008. Stakeholder participation for environmental management: a literature review. Biol. Conserv. 141, 2417–2431.

Rockmann, C., van Leeuwen, J., Goldsborough, D., Kraan, M., Piet, G., 2015. The interaction triangle as a tool for understanding stakeholder interactions in marine ecosystem based management. Mar. Policy 52, 155–162.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., et al., 2009. A safe operating space for humanity. Nature 461 (7263), 472–475. https://doi.org/10.1038/461472a.

Rockström, J., et al., 2014. Water Resilience for Human Prosperity. Cambridge University Press.

Rouillard, J., Lago, M., Abhold, K., Röschel, L., Kafyeke, T., Klimmek, H., Mattheiß, V., 2017. Protecting and restoring biodiversity across the freshwater, coastal and marine realms: is the existing EU policy framework fit for purpose? Environ. Policy Gov. J. Available online: https://doi.org/10.1002/eet.1793.

Sarda, R., O'Higgins, T.G., Cormier, R., Diedrich, A., Tintore, J., 2014. Proposal of a marine ecosystem-based management system: linking the theory of environmental policy and practice of environmental management. Ecol. Soc. 19 (3).

Schlueter, M., et al., 2012. New horizons for managing the environment: a review of coupled social-ecological systems modelling. Nat. Resour. Model. 25 (1), 219–272.

Song, Y., et al., 2014. Relationships between functional diversity and ecosystem functioning: a review. Acta Ecol. Sin. 34 (2), 85–91.

Stendera, S., Adrian, R., Bonada, N., Canedo-Arguelles, M., Hugueny, B., Januschke, K., Pletterbauer, F., Hering, D., 2012. Drivers and stressors of freshwater biodiversity patterns across different ecosystems and scales: a review. Hydrobiologia 696, 1–28.

Tallis, H., et al., 2010. The many faces of ecosystem-based management: making the process work today in real places. Mar. Policy 34 (2), 340–348.

Van Dijk, Jiska, Dick, Jan, Harrison, Paula, Jax, Kurt, Saarikoski, Heli, Furman, Eeva, 2018. Special Issue: Synthesizing OpenNESS. vol. 29, Part C. Ecosystem Services, pp. 411–608.

Villa, F., et al., 2009. ARIES (Artificial Intelligence for Ecosystem Services): a new tool for ecosystem services assessment, planning, and valuation. Proceedings of the 11th Annual BIOECON Conference on Economic Instruments to Enhance the Conservation and Sustainable Use of Biodiversity, Venice, Italy, September, 2009.

WWF, 2016. Living Planet Report.