Assessment of causalities, highlighting results from the application of meta-ecosystem analysis in the case studies

Deliverable 5.2

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642317.

Authors

Heliana Teixeira, António J.A. Nogueira, Ana Lillebø (University of Aveiro)

Fiona Culhane, Leonie Robinson, (University of Liverpool)

Daniel Trauner, Florian Borgwardt, Andrea Funk, Thomas Hein (BOKU)

Mathias Kummerlen (EAWAG)

Ana Barbosa, Juan Arévalo-Torres, Alejandro Iglesias-Campos, Julian Barbière (IOC-UNESCO)

Hugh McDonald (Ecologic Institute)

Tim O'Higgins (University of Cork)

Jan Tjalling Van der Wal, Gerjan Piet (Wageningen Marine Research)

With contributions by:

Mariana Morgado, Ana Genua

With thanks to:

Manuel Lago (Ecologic Institute)

Project coordination and editing provided by Ecologic Institute.

Deliverable completed in September, 2018

This document is available on the Internet at: http://aquacross.eu/

Document title	Assessment of causalities, highlighting results from the application of meta-ecosystem analysis in the case studies – Synthesis report
Work Package	WP5
Document Type	Deliverable 5.2
Date	3 October 2018
Document Status	Draft version

Acknowledgments & Disclaimer

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 642317.

Citation: Teixeira, H., Lillebø, A., Culhane, F., Robinson, L., Trauner, D., Borgwardt, F., Kummerlen, M., Barbosa A., McDonald, H., Funk, A., O'Higgins, T., Van der Wal, T., Piet, G., Hein, T., Arévalo-Torres, J., Barbière, J., Nogueira, A.J.A., 2018. Assessment of causalities, highlighting results from the application of meta-ecosystem analysis in the case studies – Synthesis report. Deliverable 5.2, European Union's Horizon 2020 Framework Programme for Research and Innovation Grant Agreement No. 642317.

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List of abbreviations

AF	Assessment Framework
BD	Biodiversity
BEF	Biodiversity-Ecosystem Functioning
BES	Biodiversity-Ecosystem Services
CA	Consortium Agreement
CC	Consortium Committee
CS	Case Study
DOA	Description of Action
EBM	Ecosystem-Based Management
EF	Ecosystem Function
ES	Ecosystem Services
GA	Grant Agreement
MS	Member States
PCG	Project Coordination Group
PO	Project Office
SPBTT	Science-Policy-Business Think Tank
WP	Work Package

About AQUACROSS

Knowledge, Assessment, and Management for AQUAtic Biodiversity and Ecosystem Services aCROSS EU policies (AQUACROSS) aims to support EU efforts to protect aquatic biodiversity and ensure the provision of aquatic ecosystem services. Funded by Europe's Horizon 2020 research programme, AQUACROSS seeks to advance knowledge and application of ecosystem-based management (EBM) for aquatic ecosystems to support the timely achievement of the EU 2020 Biodiversity Strategy targets.

Aquatic ecosystems are rich in biodiversity and home to a diverse array of species and habitats, providing numerous economic and societal benefits to Europe. Many of these valuable ecosystems are at risk of being irreversibly damaged by human activities and pressures, including pollution, contamination, invasive species, overfishing and climate change. These pressures threaten the sustainability of these ecosystems, their provision of ecosystem services and ultimately human well-being.

AQUACROSS responds to pressing societal and economic needs, tackling policy challenges from an integrated perspective and adding value to the use of available knowledge. Through advancing science and knowledge; connecting science, policy and business; and supporting the achievement of EU and international biodiversity targets, AQUACROSS aims to improve ecosystem-based management of aquatic ecosystems across Europe.

The project consortium is made up of sixteen partners from across Europe and led by Ecologic Institute in Berlin, Germany.

Contact	aquacross@ecologic.eu
Coordinator	Dr. Manuel Lago, Ecologic Institute
Duration	1 June 2015 to 30 November 2018
Website	http://aquacross.eu/
Twitter	@AquaBiodiv
LinkedIn	www.linkedin.com/groups/AQUACROSS-8355424/about
ResearchGate	www.researchgate.net/profile/Aquacross_Project2

1 Background and objectives

The EU 2020 Biodiversity Strategy mid-term assessment emphasized the need to integrate the consequent devastating economic costs for society of failing to achieve its proposed targets. It is expected that mainstreaming the values of biodiversity (BD) and ecosystem services (ES) into decision-making will help increase awareness about the implications of the further degradation and loss of natural ecosystems on human well-being.

AQUACROSS investigates practical applications of the Ecosystem-Based Management (EBM) approach in aquatic ecosystems across Europe. For that, its researchers developed a concept as to what EBM means (Gomez et al. 2016a) (D3.1) and the types of assessment that are necessary for its full application (Gomez et al. 2016b) (D3.2). The AQUACROSS Assessment Framework (AF) offers a way of integrating complex information into a broader socio-ecological framework, which acknowledges the interdependencies of coupled human-natural systems.

The AQUACROSS Assessment Framework (AF) covers the whole Socio-Ecological System (SES) (Gomez et al. 2016a) (D3.1), and consists of the coupling of the ecological and the social dimensions, each with their own internal processes. These two systems are connected through supply-side connections, i.e. provision of ecosystem services from the ecological system into the social system (Nogueira et al. 2016) (D5.1), and demand-side connections, i.e. the allocation of human activities and pressures (Pletterbauer et al. 2016) (D4.1), as well as societal responses partially aiming at mitigating pressures (from the societal system on the ecological system).

The work here presented describes the SES relationships from the supply-side perspective (Teixeira et al. 2019), with focus on testing the AF developed in AQUACROSS (Gomez et al. 2016b) (D3.2). The supply-side assessment approach was developed by Nogueira et al. (2016) (D5.1) for explicitly integrating the provision of ecosystem services by aquatic systems into the socio-ecological framework, for use in EBM contexts. To support its implementation, a common classification for the supply-side was proposed (Nogueira et al. 2016) (D5.1), which identifies ecosystem components, ecosystem functions supported by such components and the associated ecosystem services (see section 2 for details). These chain elements are then linked to create linkage matrices for unravelling the multiple, direct and indirect, relationships between the various SES components.

The overall relationships in the supply-side were characterized based on the assessment of the relevant links between BD, functions (EF) and ES, as observed in the AQUACROSS case studies (Teixeira et al. 2019).

This deliverable synthetises the main findings of this research regarding:

- Main ES supported by aquatic systems, their dependence from BD, and the patterns of services supply across different aquatic realms along the freshwater/marine continuum;

  Related output: AQUACROSS scientific publication on the supply of ES by aquatic ecosystems (Teixeira et al. 2019);

- The comprehensive characterization of the flow linkages between BD, EF, and ES supply along the continuum of aquatic systems;

  Related output: linkages data generated by CSs integrated in the AquaLinksTool (under development), a tool for aquatic ecosystems in Europe that allows establishing connections between the social and the ecological systems, developed in AQUACROSS for supporting the implementation of EBM in practice (Box 2);

- The potential to link the supply and the demand sides of the SES system, based on the AQUACROSS Assessment Framework linkage matrices, enabling the assessment of the risk to ecosystem service supply;

  Related output: this contributed to an AQUACROSS scientific publication on the risk to the supply of ES (Culhane et al. 2019);

- Acknowledging the importance of the status and trends of aquatic ecosystems along the aquatic continuum to better understand the impact on the delivery of services;

  Related output: this originated a new index by AQUACROSS, the ES Supply Score (ESSs) presented in Teixeira et al. (2019);

- Testing the AQUACROSS AF for conducting exploratory analysis of the key linkages in each CS, and provide common criteria for the integration of the demand-side (WP4) with the supply-side components in real scenarios;

  Related output: this contributed to AQUACROSS Case Studies Reports (McDonald et al. 2018 (D9.2)) and several case-study specific scientific publications (AQUACROSS Special Virtual Issue on the topic *EBM in aquatic ecosystems* in the journal Science of the Total Environment).

Section 2 briefly describes the methodological approaches underlying the AQUACROSS AF supply-side implementation and analysis, along with the data used. Section 3 presents the main findings of this work regarding relationships between biodiversity and the supply of ecosystems services by aquatic ecosystems. Section 4 presents the main outcomes of testing of the supply-side of the AQUACROSS AF in the case studies. Section 5 concludes by discussing the potential of the AQUACROSS AF for integrating the complex relationships between BD and ES; and by collecting recommendations[1] for integrating the supply-side assessments on EBM plans, based on the experience of the case studies.

[1] Linking to project aims of evaluating the lessons learnt from this process, to be addressed in WP5 final task 5.3.

2 Supply-side of the Assessment Framework

AQUACROSS investigated practical applications of the EBM approach through eight case studies across Europe. This deliverable summarises the approach proposed (Nogueira et al. 2016) (D5.1) for implementing the AF supply-side in the case studies (McDonald et al. 2018 (D9.2)) with emphasis on recommendations for EBM assessments.

As part of the development of an EBM operational assessment framework, the social-ecological system was deconstructed into its major component parts (Elliott 2011; Smith et al. 2016; Gómez et al. 2016b D3.2). Previously, AQUACROSS (Nogueira et al. 2016) (D5.1) identified and defined the key points and links within the social-ecological system that are relevant for the stages of implementation of the AQUACROSS AF supply-side. As a result, we have proposed common approaches to assess it in similar ways across very diverse aquatic realms, from freshwaters to oceanic waters, including the very relevant water-land ecotones.

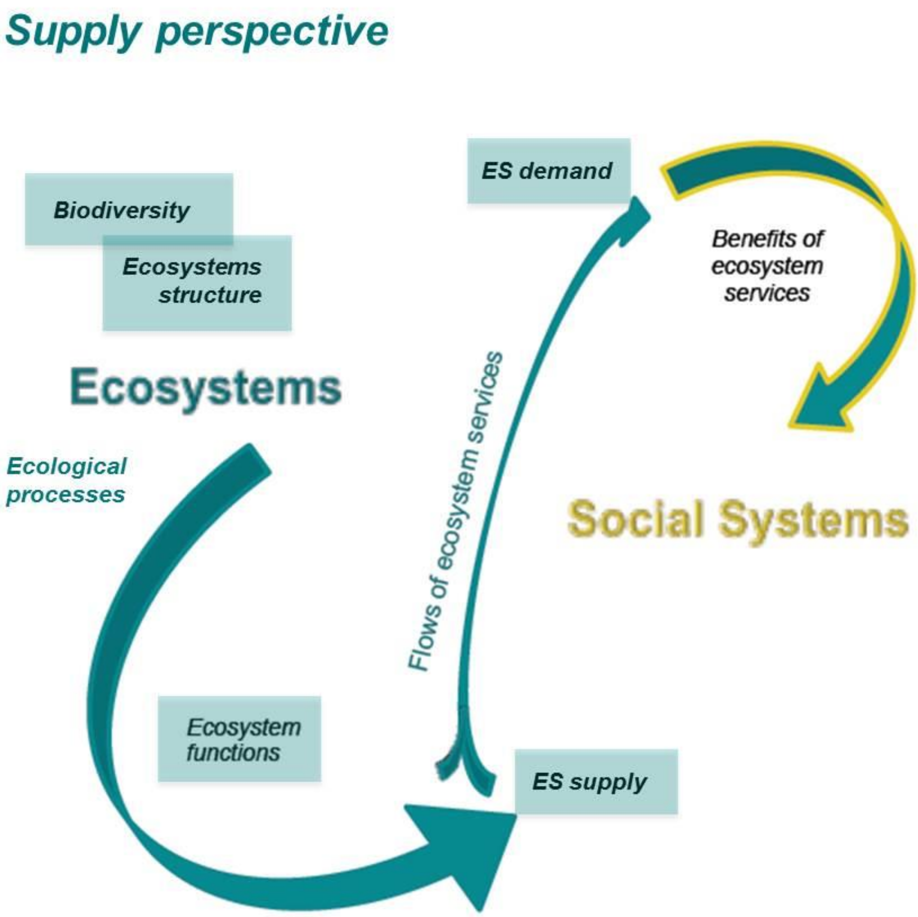
2.1 Supply-side linkages approach

2.1.1 Main features and components

A linkage framework approach formed the basis for characterising the ecological part of the studied socio-ecological systems (Figure 1). Prior to establish meaningful relationship links, a categorisation of ecosystem components within aquatic realms was undertaken, along with the identification and adoption of adequate ecosystem functions and services classification typologies (based on guidelines by Nogueira et al. 2016, previous D5.1).

Three typologies are the basis of the linkage framework developed: ecosystem components EC (Annex A), ecosystem functions EF (Annex B), and ecosystem services ES (Annex C); and were used to build habitat-function-service weighted matrices. Direct links were established between EC (i.e. habitats/ mobile biota) and EF and also between EC (habitats/ mobile biota) and ES, while indirect links were derived between EF and ES matrices. The linkages matrices aim at supporting analysis contributing to unravel the patterns and flow links between biodiversity and ecosystem services from freshwater to marine environments.

Figure 1: The supply-side of the AQUACROSS architecture



Source: Gómez et al. 2016b

Biodiversity was considered by taking its most relevant structural components (EC) as proxies, i.e. the main habitats and the most relevant mobile biotic groups. As pointed out in Nogueira et al. (2016; D5.1), this approach allows a comparable and comprehensive identification and assessment of parts of the ecosystem which, directly or indirectly, contribute to the delivery of ES in aquatic systems. Habitats distribution was mapped in eight case studies in Europe, using a hierarchical classification at different spatial scales from domain, to realm, to habitats. Three main domains were defined in a continuum from Freshwaters (FW), to Coastal waters (CW) and to Marine waters (MW) (Table 1). An additional domain was considered for Other (O) relevant habitats within or adjacent to the main aquatic domains, in the case studies' area. The domains considered in this study include habitats that have been grouped into 12 realms according to their specificities.

Table 1: AQUACROSS realms across different aquatic domains and correspondence with level 1of the EUNIS habitats classification

Domain	Realm	EUNIS level 1
Freshwaters (FW)	Lakes	C Inland surface waters
	Rivers	C Inland surface waters
	Riparian	E Grasslands and lands dominated by forbs, mosses or lichens; G Woodland, forest and other wooded land
	Wetlands	C Inland surface waters; D Mires, bogs and fens; E Grasslands and lands dominated by forbs, mosses or lichens
Coastal waters (CW)	Inlets & Transitional	A Marine habitats; J Constructed, industrial and other artificial habitats; X Habitat complexes
	Coastal Terrestrial	B Coastal habitat land
	Coastal	A Marine habitats
Marine waters (MW)	Shelf	A Marine habitats
	Oceanic	A Marine habitats
Other	Agricultural	I Regularly or recently cultivated agricultural, horticultural and domestic habitats; X Habitat complexes
	Terrestrial Natural	F Heathland, scrub and tundra; G Woodland, forest and other wooded land
	Urban	J Constructed, industrial and other artificial habitats

The realms considered extend beyond purely aquatic ecosystems, in order to understand the role of ecotones (land-freshwater, freshwater-marine, land-marine) in supporting EF and the provision of ES. The riparian realm was defined following Weissteiner et al. (2017) and, where present, was mapped using the Riparian Zones Delineation product available in Copernicus (EEA) (http://land.copernicus.eu/local/riparian-zones).

The European Nature Information System (EUNIS, 2012) habitat classification from the European Environment Agency (EEA) is applicable to all domains (Table 1). For this reason, it was adopted by all the case studies to ensure a harmonized approach for characterizing habitats across realms. The habitats were described up to the EUNIS level of highest resolution possible, although the EUNIS level 3 was the highest level used for analysis across case studies. This level of resolution was found to be the best available common denominator across all CSs that ensured comparability of the results (Teixeira et al. 2019). Nevertheless, within CSs higher resolution data was used when available.

Six mobile biotic groups, which are not particularly associated with a single habitat or that have dependencies on different habitats throughout their life cycle, were considered independently from the habitat categories within the ecosystem components of the linkage framework. This aims to facilitate the identification of EF or ES specifically associated with the mobile biota considered: Insects (adults); Fish & Cephalopods; Mammals; Amphibian; Reptiles and Birds.

The EF classification considered groups of 30 functions in three major categories: Production; Biogeochemical Cycles, related to the exchange component, i.e. the biotic and abiotic processes of, for example, mineralization of organic matter, evapotranspiration, biogeochemical processes, bioturbation, and others (see ecological processes list extracted from Nogueira et al. (2016, D5.1); and Mechanical-Physically structuring EF (Annex B). This classification establishes a clear distinction between functions and ecological processes, whereby an ecological process can be associated to several functions, and an EF may depend on several ecological processes (Nogueira et al. 2016) (D5.1).

The ES and Abiotic Outputs of the system (AbO) were considered from the supply-side perspective, i.e. those that the habitats and/or biotic components have the capacity to supply, whether or not used. The classification used in this study was selected to ensure consistency with the Common International Classification of Ecosystem Services CICES (Haines-Young and Potschin, 2013); where 1) Provisioning (P), 2) Regulating & Maintenance (R&M), and 3) Cultural (C) ecosystem services have been considered (Annex C). Despite that all classifications are artificial; this choice gathers great consensus among the scientific community regarding its adequacy, as demonstrated by many real case applications, moreover, it will ensure comparability with the approaches being followed across EU Member States. This ensures also that the AF here proposed can easily be adopted by future users in an European context. In this study, the ES are being treated at the CICES Group level equivalent. In our approach we have considered both the services dependent on biodiversity (i.e. biological mediated) as well as those reliant on purely physical aspects of the ecosystem (i.e. abiotic outputs), as also reflected in the more recent CICES V5.1.

2.1.2 Expert elicitation procedure

An elicitation procedure was conducted for identifying linkages between the ecosystem components (EC), which comprise both habitats and biota, and ecosystem functions (EF) and ecosystem services (ES). Linkages were assessed by expert judgement, involving researchers from the AQUACROSS case studies across different aquatic ecosystems in Europe. The expert judgement assignments followed a bottom-up approach and assumed a sound local knowledge of the experts on the respective case study (CS), where they identified and weighted the relevant links (0, 1, 2). The elicitation process is described in Box1. Further details are given in Teixeira et al. (2019).

Box 1: Expert judgement elicitation process for EF and ES linkages to Biodiversity

Round 1 Identified and signalled a linkage if the ecosystem component (habitat or biotic element) in the CS has the capacity to perform or sustain an EF or contribute to the supply of an ES or abiotic output, independently of the specific research questions addressed in each CS.

Linkages were added following a discriminating approach, excluding weak and potentially non-relevant effects of habitats/biotic elements, to avoid reporting trivial linkages which could compromise patterns and lead to misidentification of relationships.

The links evaluation was done within realm context, despite EUNIS habitat categories may be common across realms/domains. Only for mobile biotic groups an EF or an ES was directly associated. This means that when considering the contribution or role of a given Habitat, the role of its main associated communities (e.g. planktonic, sessile or sedentary species) was also considered, even if not explicitly mentioned in the habitat EUNIS category name.

Round 2 When identifying a linkage or reviewing previous linkages from first round (X) a further distinction was made between habitats or biotic groups with a relevant but weaker (1) role and those with a very important and stronger (2) role or contribution to perform or sustain a given function (EF) or provide a service (ES).

Round 3 The final review and consistency check across CSs was followed by a collaborative exchange process between all case studies. Actions to promote consistency during the elicitation procedure:

- common understanding of categories by clarification with examples provided;
- addressed specific questions /comments from CSs;
- final check, links were confirmed for relevance and not result of misinterpretation.

2.1.3 Weights

The information on the EC-EF and EC-ES linkage matrices was used in complementary ways based on the elicitation made by experts from seven out of the eight AQUACROSS case studies. The reported links and weighted valuation by the experts were used in twofold:

- Presence/absence of link (0; 1) non-weighted estimates, acknowledging only the existence (1) or not (0) of a link of an EC with a given function/service; and
- Average weight of links (range between 0 – 2) from an EC to a given function/service across all case studies reporting that EC (i.e. habitat assessment unit).

In a subsequent post-elicitation step, the expert valuations of services provided by habitats and of services provided by mobile biota were aggregated. For this, biota ES were only aggregated to habitat ES in those habitat assessment units assumed to be used by a given biotic group. This aggregated valuation was used to calculate several ES supply metrics presented in the following sections: the ES supply score by habitat; the ES supply potential at risk by anthropogenic threats; and the vulnerability of biodiversity structural components regarding the supply of ES.

2.2 Brief context of case studies

The estimates to build the AQUACROSS linkage framework were based on contributions gathered from real systems (CS) across diverse aquatic domains. Such case studies were also used for demonstrating the added value of such a framework for the practical implementation of EBM. Here we briefly introduce the AQUACROSS case studies to provide an overview of the diversity of aquatic ecosystems and of management contexts considered.

Covering a total area of approximately 615 000 km², from freshwaters to marine waters (Figure 2), eight case studies in Europe and Morocco described and mapped their habitats distribution (McDonald et al. 2018) (D9.2). Four of them are exclusively focused on freshwater, another two have a full coastal and marine focus, while the remaining two case studies encompass a gradient of aquatic realms from freshwaters to marine waters. In addition to the wide range of aquatic realms covered, each of the case studies also identified other relevant land uses associated with the aquatic environments or in the vicinity (Table 3).

Figure 2: Area of the aquatic realms* covered by AQUACROSS case studies

AQUACROSS CSs total area	615358	Km2			
DOMAINS		REALMS			
FW	18643	**Lakes** 4198	**Rivers** 4043	**Riparian** 6443	**Wetlands** 3960
CW	37389	**Inlets & Transitional** 25935	**Coastal Terrestrial** 3766	**Coastal** 7688	
MW	554486	**Shelf** 471129	**Oceanic** 83357		
Other	4839	**Agricultural** 3185	**Terrestrial Natural** 542	**Urban** 1112	

*Realms are grouped into the main domains considered: from freshwaters (FW) to coastal (CW) and marine waters (MW), and also by other type of ecosystems within the case studies area.

Besides the geographical differences, the case studies also differ with respect to their size, with areas ranging from 48 km² in an Irish Lake to the 547 224 Km² of the North Sea CS scope (Table 2). The purpose of selecting such wide range of systems, in terms of geographic cover and spatial scale, was to allow comparing patterns in the supply of aquatic ecosystem services over such gradients. Each CS is furthermore unique in that its socio-ecological context is very diverse, with distinct levels of pressure (Borgwardt et al. 2019; Costea et al. 2018 D4.2) or environmental protection statuses (Case Studies Report D9.2; AquaLinksTool database repository).

Table 2: AQUACROSS case studies area (km²) per realm occupied

Case study	Freshwaters				Coastal waters			Marine waters		Other		
CS area (km²)	Lakes	Rivers	Riparian	Wetlands	Inlets & Transitional	Coastal Terrestrial	Coastal	Shelf	Oceanic	Agricultural	Terrestrial Natural	Urban
1 North Sea 547224					25394	3304	7350	460098	51078			
2 IC Biosphere Reserve Med Spain 44099	61	1	267	262	129	41	14	10965	32219	84	60	1
2 IC Biosphere Reserve Med Morocco 3838	249	6	867	38	275	384				808	455	61
3 Danube River basin 19522	3808	3810	5169	3653						2157	15	1001
4 Lough Erne (IE) 48	34	0.44	10	2						1	0.12	0.07
5 Ria de Aveiro (PT) 512	4	2	7	2	137	37	148	66		83	12	25
6 Lake Ringsjön (SE) 155	41	2	51	3						45		13
7 Swiss Plateau Rivers 312		220	73							8		12
8 Azores Pico-Faial Channel (PT) 237							177		60			

The North Sea (CS1) is one of the busiest seas with many (often growing or newly emerging) sectors laying a claim to a limited amount of space. Although many competing activities co-occur in the area, the most important current activity, i.e. fisheries, and the main newly emerging activity, i.e. renewable energy, and thus the regional focus is applying an integrated, interdisciplinary perspective and an ecosystem approach when developing the knowledge base on how these relate to the achievement of the Biodiversity Strategy targets and related policy objectives.

The Intercontinental Biosphere Reserve of the Mediterranean (CS2) spans over two continents, Europe and Africa and the marine area of the Strait of Gibraltar. On both parts, the study area encompasses all types of aquatic realms. The economic activities in both the northern and southern sections of the case study area are based on agriculture, livestock, fisheries, and tourism, all of which are highly dependent on terrestrial and aquatic resources. The aquatic ecosystems provide a vital range of provisioning goods and services for sustaining human well-being (Barbosa et al. in 2019).

The Danube River Basin (CS3) has the second largest river in Europe and is the most international river basin, shared by 19 countries, as well as an example of a multiple-stressed, highly vulnerable riverine system, which still shows a high ecological potential despite its long-term exposure to socio-economic usage (Hein et al., 2018). Ongoing, partly conflicting demands within and among the different neighbouring countries, inconsistencies in legislation, and drivers of change aggravate the problem of a joint, sustainable management further, especially linking freshwater, coastal and marine environments.

The Lough Erne in Ireland (CS4) is a lake sustaining multiple primary activities each with different requirements from the system in terms of ecosystem services and biophysical abstraction. These heavily modified water bodies contain a range of non-native species with a very long history of introductions. Balancing the needs of competing uses while also meeting the additional legislative burden of the Invasive Alien Species Regulation requires consensus on ecosystem end-points as well as effective cross border cooperation.

The Southern European Ria de Aveiro is a Nature 2000 site (CS5) that covers the downstream area of the Vouga river until the Northeast Atlantic Ocean, encompassing all types of aquatic realms from freshwaters to marine waters (Lillebø et al. 2019). Due to its ecological complexity and diversity, it attracts very different types of socio-economic activities. Such natural richness is protected under several environmental policies, and regulatory competencies are shared by many institutions.

The Lake Ringsjön - Rönne å Catchment in Kattegat in Sweden (CS6) deals with the process of eutrophication and their implications for the provision of ecosystem services along the Rönne å catchment. Cross-sector collaboration is being pursued for achieving best-practice water governance, particularly focusing on engaging stakeholders. Under the WFD targets the aim is to seek best solutions for restoring water quality in lake Ringsjön.

The Swiss Plateau (CS7) corresponds to one of the biogeographical regions of Switzerland, located between the Alps and the Jura Mountains (Kuemmerlen et al. 2019). This area has historically concentrated most of the population and socio-economic activities of the country, influencing freshwater ecosystems strongly. While rigorous policies have driven the improvement of conditions, further efforts are underway to continue restoring freshwater ecosystems and these are widely supported by stakeholders and public in general.

The Marine Protected Area of the Pico-Faial Channel in the Azores Archipelago (CS8) encompasses coastal and marine realms. The Channel is bordered by the Faial and Pico islands, and managed by international, national, and local institutions and biodiversity protection agreements. The Channel's biodiversity supports ecosystem service flows highly valued by commercial and recreational fishers, as well as a swiftly growing eco-tourism sector.

The AF supply-side general approach was applied (section 4) on relevant and contextualised topics in each case-study. AQUACROSS CSs represent a wide spectrum of examples of how the complexity of aquatic systems can be integrated for a more effective EBM.

3 Biodiversity to services supply in aquatic ecosystems

3.1 Integration of linkages across aquatic ecosystems

The application of the linkage framework to the exploratory analysis of the socio-ecological systems offers the possibility to examine the complexity and the connectivity in the aquatic ecosystems. It also provides a framework for categorizing a problem domain along the cause-effect chain with great potential to be used as a policy-oriented tool, a crucial aspect as also recognized in recent studies (e.g. Patrício, Elliott, et al. 2016).

The characterization of how the activities and pressures, listed in Pletterbauer et al. (2016), affected a comprehensive list of aquatic and related habitat types (Borgwardt et al. 2019), was integrated with the relevant ecosystem functions and services provided by those same habitats, listed in Nogueira et al. (2016; D5.1) and assessed by Teixeira et al. (2019). This information is integrated, and will be made freely available, in a software application developed by AQUACROSS in the context of this work – the AquaLinksTool (Figure 3). This is a versatile tool to address causal links involving activities, pressures, biodiversity, ecosystem functions and services in aquatic ecosystems as described in Box 2. The linkage chain integrated in AquaLinksTool was developed using scientific knowledge, considering appropriate spatial scales, acknowledging the role of ecological integrity and biodiversity, coupling social-ecological systems, and acknowledging uncertainty. Therefore, this tool is well aligned with the AQUACROSS EBM components (as stated in Mattheiß et al. 2018 (D8.2)):

- EBM considers ecological integrity, biodiversity, resilience and ecosystem services;
- EBM is carried out at appropriate spatial scales;
- EBM develops and uses multi-disciplinary knowledge;
- EBM builds on social-ecological interactions, stakeholder participation and transparency;
- EBM supports policy coordination;
- EBM incorporates adaptive management.

Box 2: About AquaLinksTool

Human activities create pressures on habitats, their components and associated biota (responsible for ecosystem functions and services) and in this may compromise the sustainability of ecosystems and human well-being. AquaLinksTool was developed, in the framework of the EU H2020 AQUACROSS project, to support the implementation of Ecosystem-Based Management (EBM) in aquatic ecosystems (from freshwater to marine domains). Linkages between all these components are at the core of this tool. Such links were based on estimates from case studies across a wide geographic area and type of aquatic realms (see section 2 for case studies description). Those CS include from lakes in Sweden, Ireland and Portugal, alpine rivers in Switzerland, the entire Danube basin and small rivers in southern Europe, to coastal shores and marine areas in the North Sea, Spain, Morocco and in Portugal mainland and Azores islands in the mid of the Atlantic Ocean, to estuaries and deltas in Portugal and Romania.

The tool can thus be used to access the likelihood of a significant risk associated with linkage chains of activities-pressures-ecosystem components-ecosystem services and/or activities-pressures-ecosystem components-ecosystem functions, in all these types of aquatic environments and related land-water ecotones (e.g. wetlands, riparian areas). To achieve this goal for each chain an impact score and a supply score are derived from which a risk quotient is calculated. The scores are derived from the knowledge base produced within AQUACROSS with contributions and expertise from case-studies.

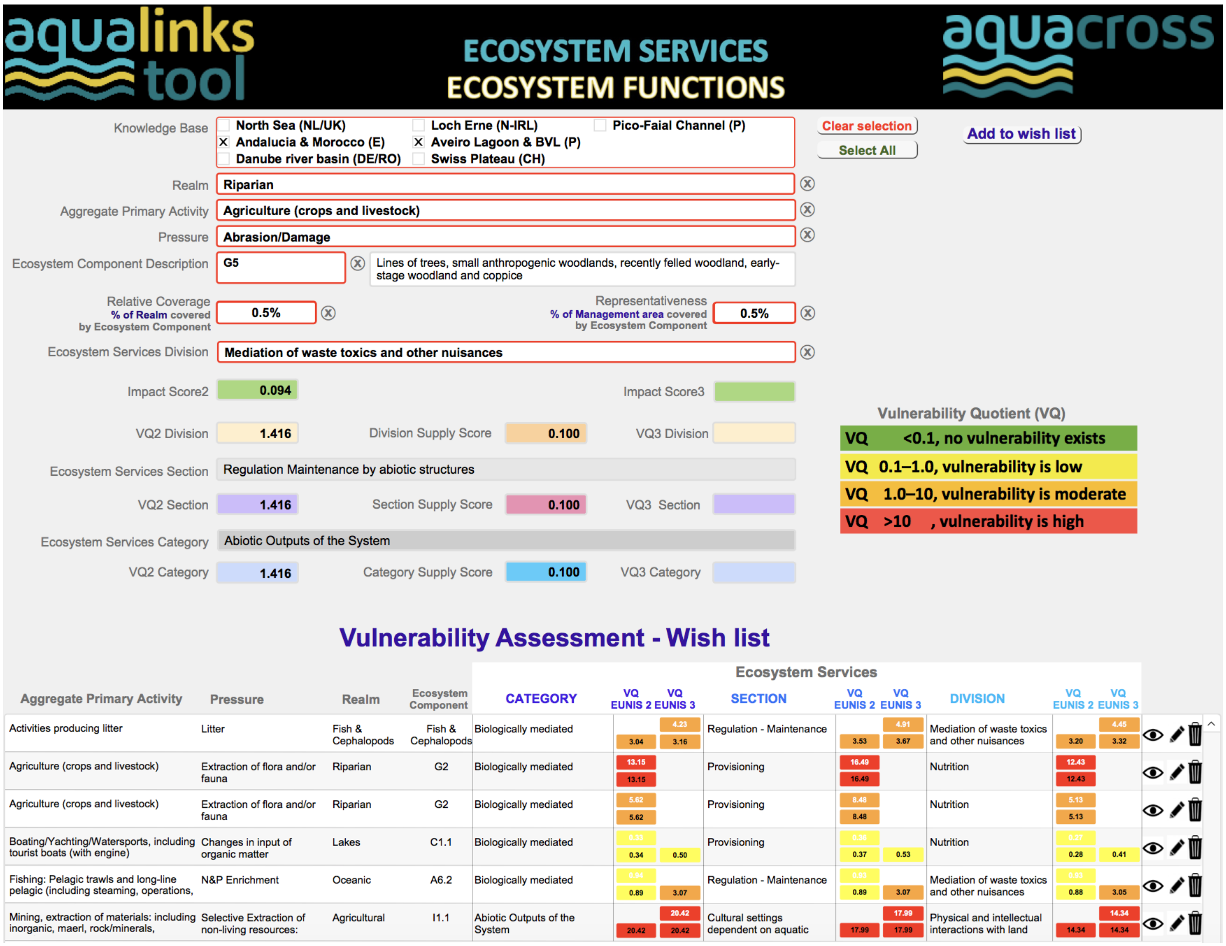
The information integrated in the AquaLinksTool allows the user to create suitable linkage chains to infer hazard risks of specific linkage in the form of risk quotients. The approach used will benefit the selection of suitable management options as it will be possible to identify which activities pose a greater risk to provisioning of ecosystem functions and services by a given ecosystem component. The knowledge built into the tool covers aquatic habitats (from freshwater to marine environments), land-water ecotones and other associated terrestrial interfaces as well as highly mobile biotic groups (mammals, birds, amphibians, reptiles, fish & cephalopods, and adult insects).

Examples of the application of the entire linkage chain to explore meaningful relationships at broad and local scales can be seen, respectively, in Culhane et al. 2019 (briefly introduced in section 3.3) and in a specific case study example by Lillebø et al. (2019). The first shows how the linkage framework can help identify

> *"the impacts of the pressures introduced by human activities and how this can lead to a change in the supply of ecosystem services"*

by aquatic ecosystems. The latter demonstrates, at a local scale application, the potential of the AquaLinksTool for revealing vulnerable habitats regarding ES supply in a Natura 2000 site (CS5) along a freshwater-marine continuum.

Figure 3: AquaLinksTool user interface of the AQUACROSS software application



3.2 A meta-ecosystem approach to services supply

As shown above, building on the estimates by the AQUACROSS case-studies, we derived general patterns of services supply across the main European aquatic systems and related ecotones. These general patterns can also be used to explore aquatic ES supply features from a **meta-ecosystem perspective** (Table 2), namely:

- the role of water interfaces on biodiversity and ecosystem resilience (key issue 9); and
- Identify feedbacks and impacts across multiple scales (key issue 10).

The meta-ecosystem framework allows simplifying complex ecosystems for studying spatial flows of both individuals and matter (Guichard et al. 2018) and, here we add also, of ecosystem services, in a broader spatial-ecological context. In AQUACROSS, analysing flow linkages from a meta-ecosystem approach revealed that water-land **ecotones** contributed with complementary ES and Abiotic Outputs of the system (Teixeira et al. 2019). These results strengthened the importance of considering the relationships between different realms, including between aquatic and terrestrial, for anticipating the role of such links and flows in biodiversity conservation and resilience.

As an example, we point out the role of **riparian** habitats, due to their strong contribution to regulation and maintenance services (Teixeira et al. 2019). Such riparian services (e.g. maintenance of water conditions, flood protection, stream bank stabilization) are relevant to keep the integrity of the aquatic systems themselves. On the other hand, biodiversity and ecosystem integrity of the non-aquatic habitats, such as riparian, wetlands, or coastal dunes, is highly dependent on hydrologic inputs and dynamics. The identification of **cross-ecosystem links** is crucial for targeting integrated management actions across spatial units and habitat types at different scales, in order to promote the provisioning of ecotone-related services. These results are also a contribution in support of the meta-ecosystem theory, which claims the significance of among-ecosystem spatial flows for ecosystem dynamics (Gounand et al. 2017). The demand-side of the AQUACROSS linkage framework showed clearly (in Borgwartd et al. 2019), that activities and pressures such as urban, agricultural and forest production land claim, are some of the threats to the riparian systems, as also pointed out by recent studies in riparian habitats at the European scale (Weissteiner et al. 2017). Complementarily, our supply-side analyses show that the general diminished ecological condition of European riparian habitats is compromising their full potential to provide such services, as measured by the **ES Supply score** in Teixeira et al. (2019). Our results indicate furthermore that when e.g. riparian areas are lost, the ES supply potential of the habitats that usually replace these natural water-land ecotones tends to be lower, representing an overall loss of ecosystem services.

The abovementioned results show that the linkage framework is also a relevant tool for identifying **feedbacks and impacts across multiple scales**. It also supports recent opinions that the inclusion of a social-cultural dimension to the meta-ecosystem framework would improve its predictive abilities and applicability (Renauld et al. 2018). This is well illustrated by modelling approaches implemented in several AQUACROSS case studies, as for example in the Swiss Plateau rivers (CS7). Kuemmerlen et al. (2019) identified connectivity as a crucial aspect to account for in river restoration planning and concluded that such actions would benefit from a catchment-scale approach (see also section 4.7).

3.3 Presenting an Ecosystem Services Supply score

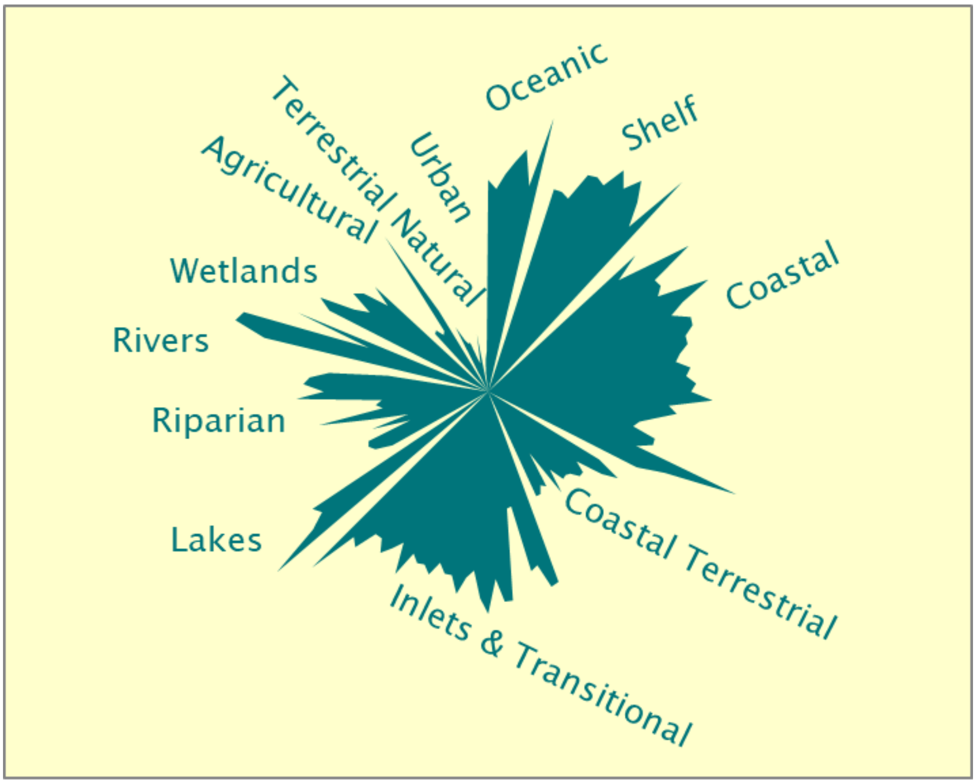
An **ES Supply score** [range 0-1], (Figure 4) is proposed by AQUACROSS (Teixeira et al. 2019), which is composed by three main dimensions:

- the potential to supply;
- the capacity to supply; and
- the condition to supply.

The ES **supply potential** refers to the importance of an ecosystem component (habitat and associated communities) to contribute to an ES, and is assessed based on a qualitative valuation attributed by expert judgement. The ES **supply capacity** refers to the actual contribution of the ecosystem component to an ES in a given location, and is assessed based on the area occupied, i.e. its representativeness. The rationale being that the area occupied by a given unit (e.g. habitat type) the greater the capacity to provide the ES dependent on that unit. The ES **supply condition** refers to the actual condition in terms of conservation status or environmental integrity of the ecosystem component, in a given location, and is assessed based on the habitat overall condition. The rationale behind is that the more disturbed the environment is, the weakest its capability of providing or supporting an ES.

The highest ES Supply score was observed in the habitat 'pelagic water column' in 'shelf marine waters' (ESS=0.803), while the lowest in 'urbanized areas', in particular in 'constructed, industrial and other artificial habitats' (ESS=0.051). In general, habitats in non-targeted realms have lower ESS supply scores than aquatic and related habitats (Figure 4).

Figure 4: Ecosystem services supply score (ESS) of the different habitats in each realm (range 0-1, max length observed in plot 0.8).



Source: adapted from Teixeira et al. 2019

Aquatic realms within the same domain are more similar regarding their ES supply patterns (see Table 1 for aquatic categories). However, the results of this work indicate a high turnover of ES provision across the habitats considered, with significant differences found across all realms, except for Lakes and Rivers (Teixeira et al. 2019).

In addition, we also found evidences of services with strong co-occurring patterns, i.e., that occur associated and are usually referred to as "bundles of ES" (Raudsepp-Hearne *et al.* 2010). The differences and spatial patterns of ES, across aquatic systems and associated ecotones, have important implications at the time of implementing EBM plan because the loss of specific habitats may lead to:

a) the loss of specific services; and

b) the loss of multiple related services (bundles).

In brief, the FW realms lakes and rivers were linked to the same bundle of ES (Group A in Figure 5). The pelagic water column habitats in marine to coastal waters emerged in this same group, as habitats associated with the co-occurrence of energy and water provisioning, cultural services related with both physical and intellectual or symbolic representations; and also, with regulating & maintenance services related with lifecycle maintenance and gene pool protection and pest and disease control (Group A). This group of ES presents similar patterns of occurrence across a wider type of habitats, covering almost all realms.

Marine and coastal waters' habitats appear more associated with cultural abiotic outputs; provisioning of biologically mediated nutritional substances and of both biotic and abiotic materials; abiotic mediation of flows and climate regulation; and waste mediation by biota (Group D).

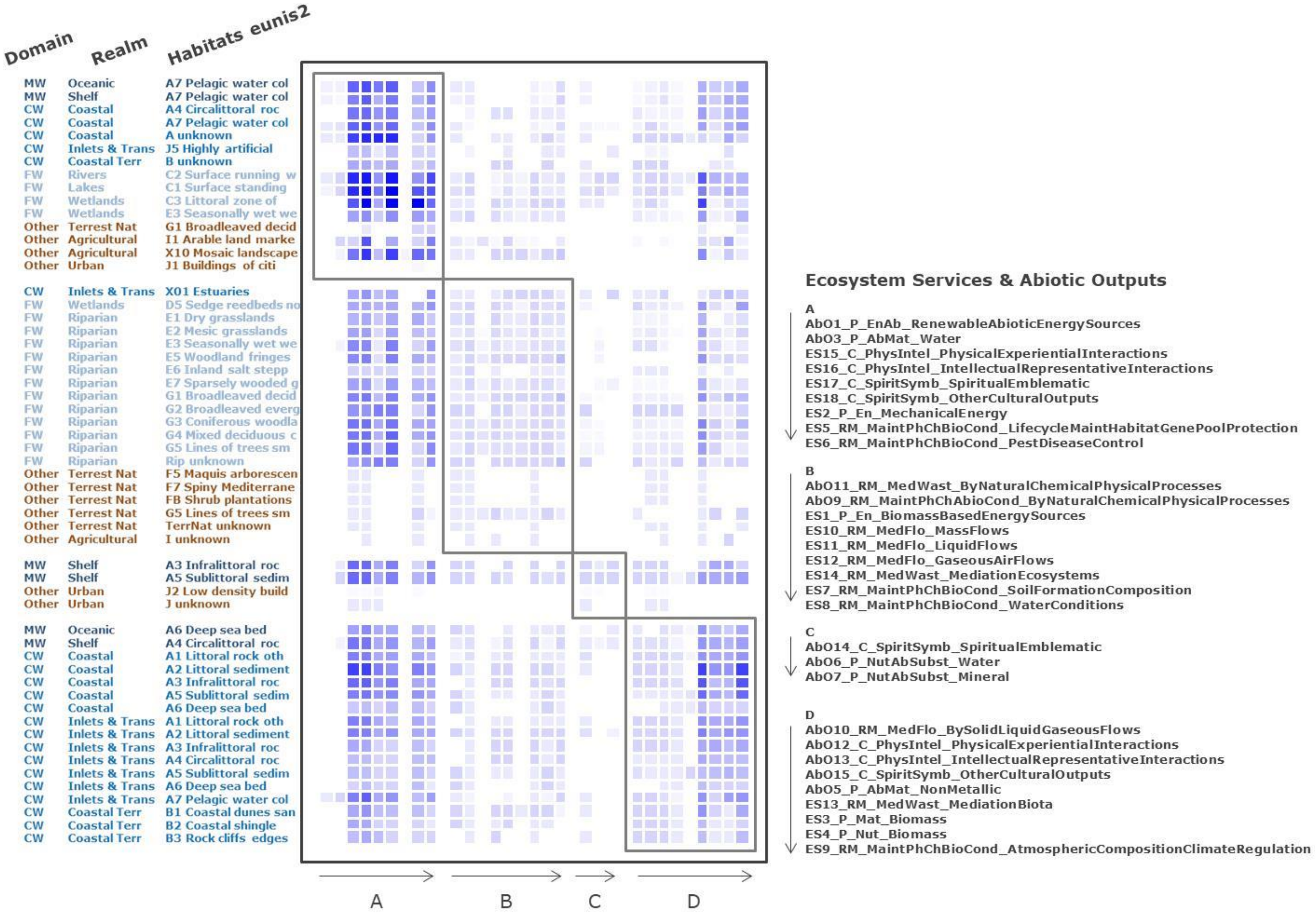
Group B services are essentially regulating and maintenance services, biologically mediated or not, on mediation of flows and waste, regulation of soil formation and water conditions, and maintenance of Physical-chemical conditions. Biomass energy provisioning is also included in this group of services that co-occur in estuarine habitats, riparian areas and terrestrial natural environments.

Finally, a group (Group C) of abiotic outputs such as water and mineral substances and also spiritual and emblematic services co-occurs in shelf marine waters and urbanized areas.

The ecosystem components in "Other" non-targeted realms, i.e. terrestrial natural habitats, agricultural, and urban, provide usually a lower number of services than the aquatic realms and associated ecotones.

Details in Teixeira et al. (2019).

Figure 5: ES spatial patterns, for 30 ES reported in 57 habitats at EUNIS 2, according to modularity analysis

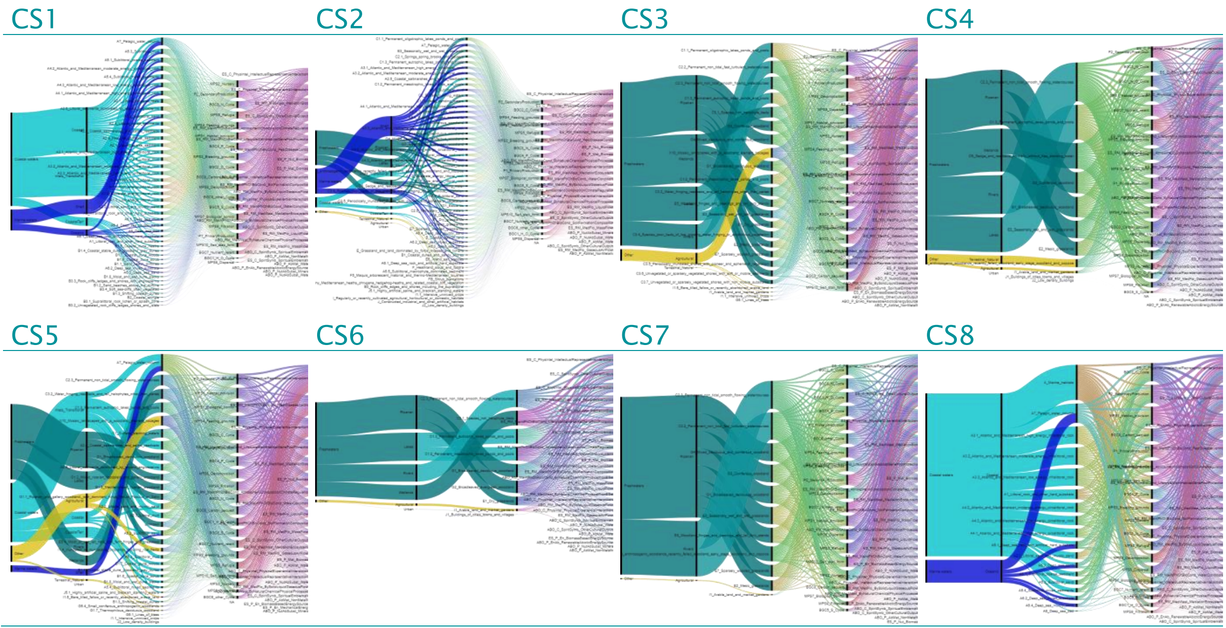


3.3.1 Potential application of ESS score in real scenarios

A comprehensive characterization of the supply-side of the AQUACROSS linkage framework in a given case study provides valuable information regarding the supply of ecosystem services, connecting the ecological system with the social system. This type of information may inform stakeholders on the consequences of their management choices, by revealing potential trade-offs and synergies on services provision. The full range of relationships can easily be overlooked or missed when focusing on specific sectoral topics or problems, as often occurs during management. A comprehensive linkage assessment is thus a powerful instrument for EBM.

(Assessing the implementation of the AF part I) In section 4, for each CS, we characterize their full ecological system based on the specific components reported and show the flow linkages from biodiversity to the ecological functions supported by each habitat and to the ES that the habitat is capable of providing. These links show the services to which the habitats most contribute, ranked e.g. by services with the highest ES Supply score as in Figure 6. Here, the links magnitude is based on the overall estimates of the potential of habitats to contribute to the supply of services as assessed across all CS, considering in addition the habitat representativeness in each CS and the respective ecological condition (section 3.3). The linkage flow of each CS is further detailed in section 4.

Figure 6: Overview of the supply-side of the AQUACROSS linkage framework in CS*



* More detailed information in D9.2 Case Study reports. Plots based on ESS score.

3.4 The risk to the supply of ecosystem services

The relevant ecosystem functions and services provided by a comprehensive list of aquatic and related habitat types, listed in Nogueira et al. (2016) (D5.1) and assessed by Teixeira et al. (2019), was integrated with information on the activities and pressures, listed in Pletterbauer et al. (2016) (D4.1), affecting those same habitats (Borgwardt et al. 2019). This integration of the various SES components, based on a series of linkage matrices from estimations of the AQUACROSS case studies, was explored by Culhane et al. (2019) to assess the risk to ecosystem service supply in aquatic ecosystems.

The approach by Culhane et al. (2019) uses the Services Supply Potential (Dimension 1 of the ESS score in section 3.2) and is particularly important for providing a general relative value of the importance to supply of different ecosystem components. They show, for example, which ecosystem components are exposed to the highest numbers of pressures and highlight the associated ecosystem services that, in consequence, are exposed to increased risk. It can also provide relevant information, for example, for scenarios testing, or for use within risk assessment contexts as demonstrated by Culhane et al. (2019).

Details in Culhane et al. (2018).

3.5 Assessing the vulnerability of ecosystem services

The ecosystem services valuation was included in the AquaLinksTool in a different perspective than that used to derive the ES Supply score by Teixeira et al. (2019). In the AquaLinksTool a vulnerability approach was preferred, and differs from the assumptions on the basis of which the ES Supply score is calculated (see previous section). The ES Supply score accounts for the actual state in terms of ecological integrity and environmental condition of the habitat at the local/regional scale, in order to provide a site-specific estimation of the supply of services. Instead, the vulnerability score in AquaLinksTool takes into account the global conservation status of European aquatic systems, as classified in the recent EU Red List habitats. The goal was to highlight which aquatic related ES could be disappearing in Europe, i.e. vulnerable, for being provided by natural habitats threatened at European scale.

The EU Red List of habitats was used to check for aquatic habitats in a threatened situation (i.e. CR, EN, V, NT) that were identified as occurring within AQUACROSS case studies, whenever EUNIS classification correspondence was available (Annex D). For this purpose, we assumed the most threatened category (CR: critically endangered; E: endangered; V: vulnerable; NT: near threatened) for a given habitat within the EU+28 area, independently of the habitat being or not locally threatened (i.e. in the CS area).

An example of the application of this score in an EBM process was conducted in CS5 by Lillebø et al. 2019 and is presented in section 4.5.

4 Contextualised analysis of supply-side linkages by case studies

Although general biodiversity conservation concerns were core to all of the case studies, each CS fits a particular management and policy context and, therefore, targets specific objectives set by one or several pieces of legislation or agreements: the EU Biodiversity Strategy, by EU Directives and regulations (such as the Marine Strategy, the Water Framework Directive, the Habitat and Birds Directives, the Common Fisheries Policy, and the EU Invasive Alien Species Regulation), or conservation objectives for areas under special protection (such as the Biosphere Reserves or the Natura 2000 sites) (O'Higgins et al. 2016) (D2.2).

Thus, while all case studies followed a minimum common approach for assessing ecosystem structure and biodiversity (key issue 1 identified[2] in Table 3), as well as habitat representativeness (habitats richness and relative coverage) (key issue 2), they also addressed case-specific topics using distinct indicators for measuring status, functions and services as relevant for their respective EBM context (key issues 3 to 8). So, while the influence of climate change (key issue 1), presently or in future scenarios, was considered by some case studies, the focus tended to be on the impacts of, for example, invasive species (key issue 7) or eutrophication (key issue 6) as done by CS4, CS6 or CS7; or of human activities, such as tourism, recreation or fisheries (key issue 4), as done in CS2 and CS4, in biodiversity. Other case studies focused on the management of sectoral conflicts through integrated management (key issues 5 and 10) (e.g. CS3, CS5, CS8), for promoting a sustainable exploitation of nature resources, and ensure the provisioning of different types of aquatic ES (e.g. CS1, CS2). However, frequently, several of these topics (Table 3) were tackled simultaneously by the case studies, reflecting the complex management context of aquatic ecosystems.

Commonalities and flexibility, to accommodate specificities of the case studies, were both foreseen while selecting the supply-side classifications suggested by Nogueira et al. (2016) (D5.1). Such CSs heterogeneity was crucial to ensure that the linkage framework proposed would be flexible enough for use in a wide range of EBM socio-ecological contexts, as will be demonstrated in the following sections for each CS implementation.

[2] These key issues reflect the most relevant topics identified in the AQUACROSS project DoA addressed by WP5 in Task 5.2.

Table 3: Case studies focus topics for testing the supply-side of the AQUACROSS AF

Key issues	CS1	CS2	CS3	CS4	CS5	CS6	CS7	CS8
1. Ecosystem structure and biodiversity	X	X	X	X	X	X	X	X
2. Density of habitats with different flow characteristics	X	X	X	X	X	X	X	X
3. Climate change adaptation (green/blue infrastructure) and mitigation (carbon sequestration/emissions)		X	X		X	X		
4. Tourism, recreation, fisheries (spawning and nursery grounds)	X	X	X	X		X	X	X
5. Protection status of aquatic habitats (e.g. included in Natura 2000 network, MPAs)	X	X	X		X			X
6. Implications of eutrophication/restoration management along catchment to ecosystem services		X	X	X	X	X	X	
7. Identification of indicator species (including invasive species) relevant for biodiversity and ES	X	X		X		X		X
8. Identification of relevant species for resilience (functional redundancy)	X		X		X	X		
9. Role of water interfaces on biodiversity and ecosystem resilience using meta-ecosystem approach *	X	X	X	X	X	X	X	X
10. Use meta-ecosystem approach to identify feedbacks and impacts across multiple scales *	X	X	X	X	X	X	X	X
Sources:		Barbosa et al. 2019			Lillebø et al. 2019; Martínez-López et		Kuemmerlen et al. 2019	

** See section 3.2*

The implementation of the supply-side of the AQUACROSS AF by the case studies is briefly presented around the major challenges identified regarding EBM by each of them. As highlighted in

Table 3, the eight case studies faced different challenges, with very specific objectives in distinct management contexts. Under the EBM umbrella, the principles though are shared and thus the AF was applied to each CS to showcase how it can support a more informed integration of the ecological system in an EBM approach. Below CSs are briefly[3] presented from their ecological system context, focusing on how they made use of the supply-side of the AQUACROSS AF to help implement their EBM plans.

Case studies highlighted how such challenges were facilitated by the integrative AF proposed by AQUACROSS (Assessing the implementation of the AF part II), for example:

- The link of the biophysical to the socio-economic dimension;
- The selection of relevant indicators;
- The spatialization of biodiversity and ES for prioritization approaches;
- The incorporation of supply-side information in advanced modelling;
- The identification of trade-offs.

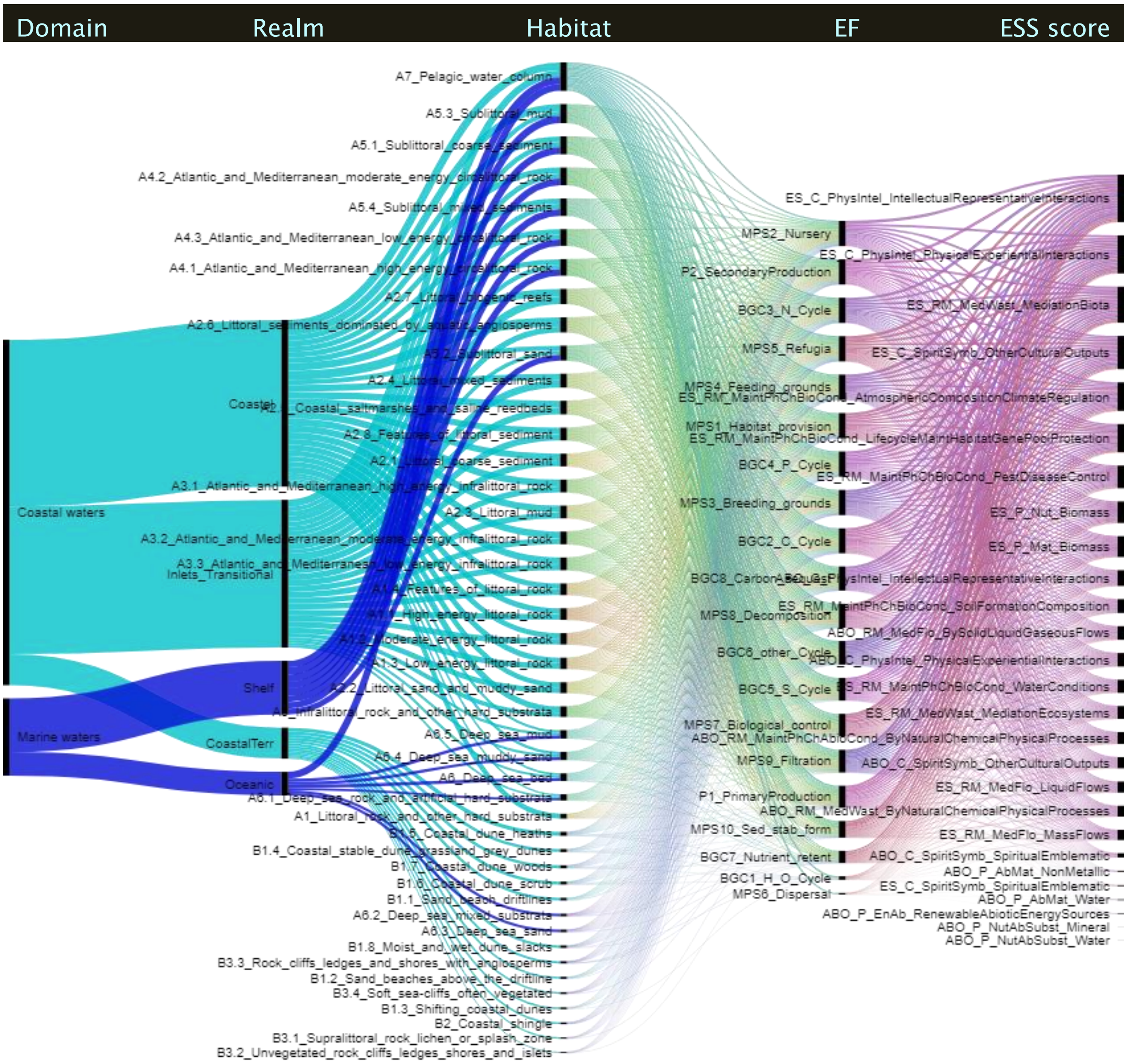
4.1 North Sea CS1

The EBM approach in CS1 focused on particular elements of the ecological system. Nevertheless, to ensure a holistic view, the full range of Biodiversity-Ecosystem Functioning-Ecosystem Services links was assessed as proposed in the AQUACROSS AF supply-side (represented by Figure 7). The outcomes were then used to rank all ecosystem components in the comprehensive SES based on their calculated service supply potential and the ecosystem components selected for the focal SES: sublittoral sediment habitats, demersal fish, mammals and birds. In terms of service supply potential covered by ecosystem components, the focal SES represents 24% of the total service supply potential found. This set of components is important in supplying Regulation and maintenance (e.g. waste treatment by benthic invertebrates) and Cultural services (e.g. intellectual representations from birds).

The two abovementioned services, particularly covered by the current EBM plan, are also some of the most relevant provided by the whole North Sea. They rank respectively as 1st and 3rd in the ecosystem services most strongly supplied, when the complete pool of habitats is considered. The AQUACROSS AF full linkage presented below (Figure 7) indicates the relative contribution of each habitat for the supply of ES (ESS score) in CS1. Here the ES contribution by the main mobile biotic groups is already reflected in the Supply score of the different habitats that support such biota (Teixeira et al. 2019). CS1 exemplifies how the AQUACROSS AF can be used to provide an overview of the links not directly targeted by specific management plans, while still accounting for the possible impacts of adopted measures in the ES supply balance of the entire system.

[3] Individual case study reports (D9.2) are all available at https://aquacross.eu/outputs

Figure 7: CS1 supply-side of the AQUACROSS linkage framework (ESS score)



Details in Piet et al 2018 (D9.2, CS1).

4.2 Intercontinental Biosphere Reserve of the Mediterranean CS2

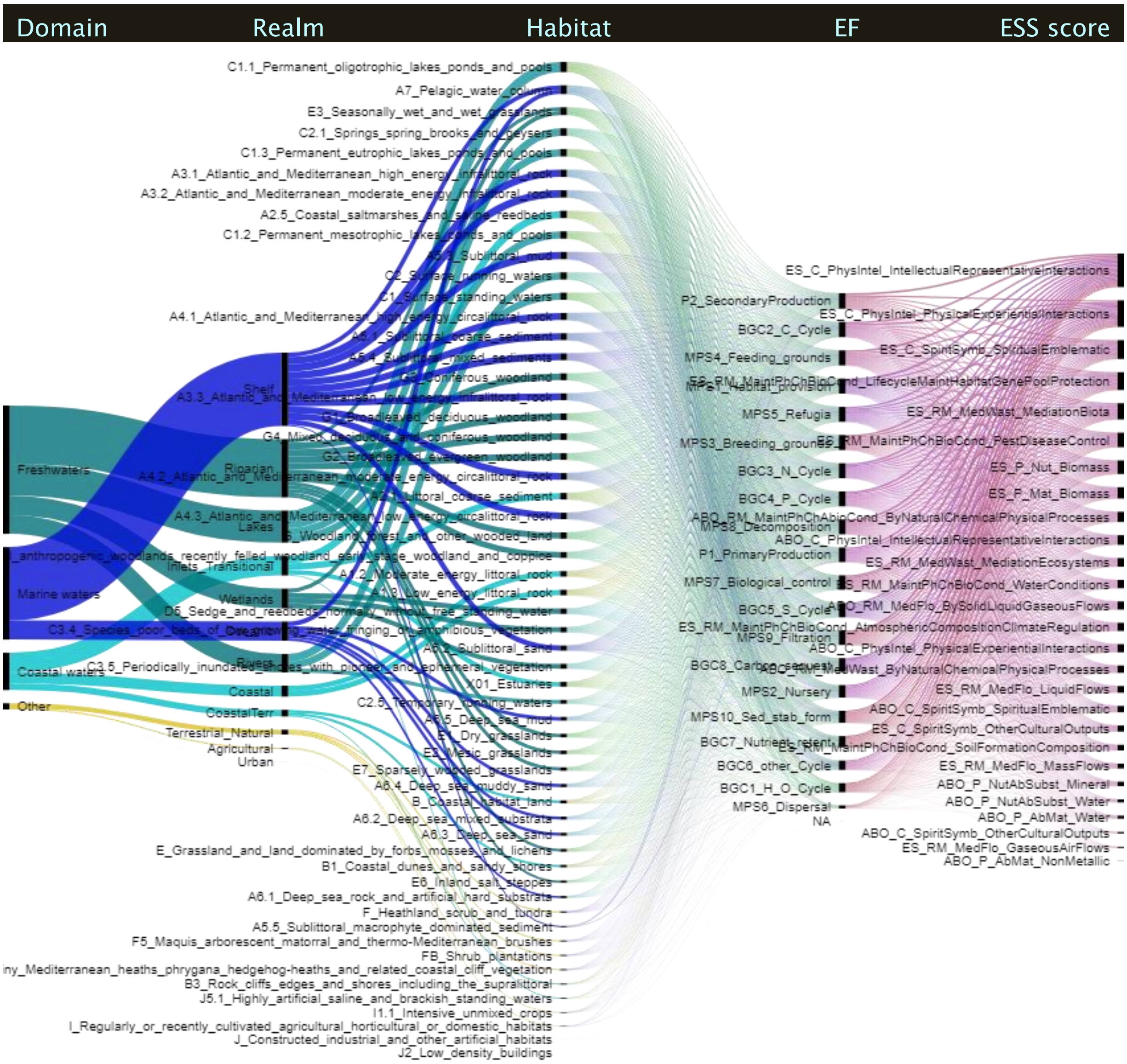
CS2 encompasses an area of several remarkable protected sites, high biodiversity richness and an important cultural heritage, whose final goal was to maintain, strengthen and restore ecosystems and the services they provide. In its EBM approach, CS2 made use of the AQUACROSS AF supply-side to map the overall supply of ecosystem services and identify key ecosystems. Where data was available, such services were further quantified with selected indicators, were not, the ES valuation provided by the AF was used as input to the models (based on expert judgment as described by Teixeira et al. 2019 and section 2). CS2 then used the ES spatial characterization to prioritize zones. The AF supply-side information supported the identification of zones according to:

- areas that best met conservation aims;
- areas to manage trade-offs between biodiversity conservation and maintenance of compatible and incompatible ecosystem services;
- and areas fitting EBM restoration objectives.

While the flow links below (Figure 8) present the rank of services supplied by CS2 based solely on a semi-quantitative expert judgement, it shows how the AQUACROSS AF links and estimations of the relative contribution of the different ecosystem components to services can be used to fulfill knowledge gaps. CS2 exemplifies how the AF was used to a) identify ES provided by each habitat and b) to provide estimations of ES supply potential for complementing assessments and models where regional data for calculating specific ES indicators was missing.

Details in Barbosa et al. 2018 (D9.2, CS2) and in Barbosa et al. in 2019.

Figure 8: CS2 supply-side of the AQUACROSS linkage framework (ESS score)



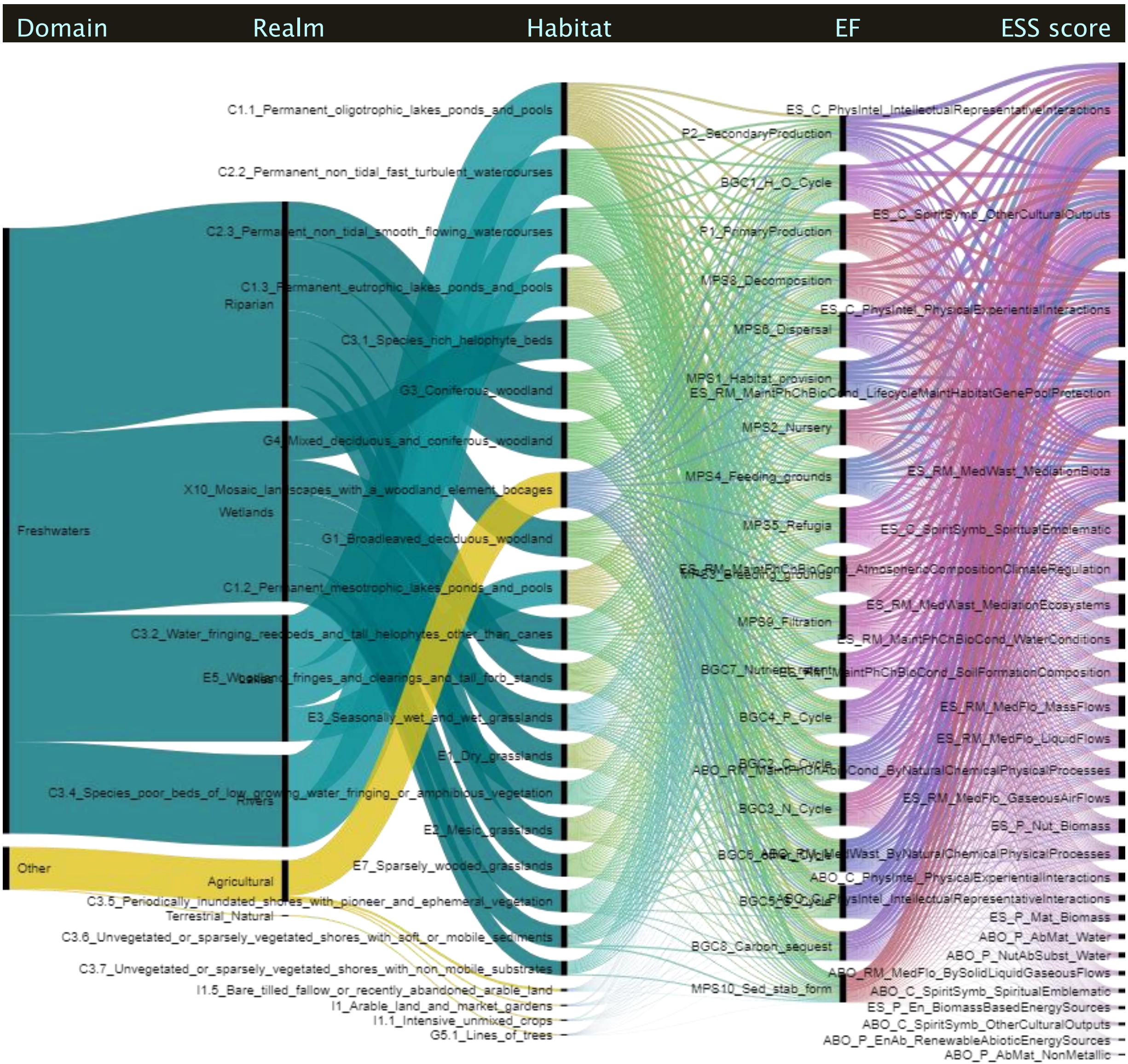
4.3 Danube River Basin CS3

In the Danube River Basin, an ongoing loss of habitat and biodiversity is being caused by hydro-morphological alterations. The hydro-morphological restoration of river-floodplain systems was thus considered important to conserve biodiversity at basin-wide scale. In this context, CS3 calculated status indicators of biodiversity (relevant for the Nature Directives, i.e. Habitats and Birds), as well as ecosystem services considered essential, such as flood retention, crop pollination, and recreation potential.

Acknowledging the multi-functionality of the systems related to biodiversity and ecosystem service, the AQUACROSS AF was applied in CS3 to identify habitats linked to the targeted ecosystem services (Figure 9) and support a spatial prioritization based on trade-off analysis to identify important areas for biodiversity and ecosystem service conservation and restoration potential.

Details in Funk et al. 2018 (D9.2, CS3).

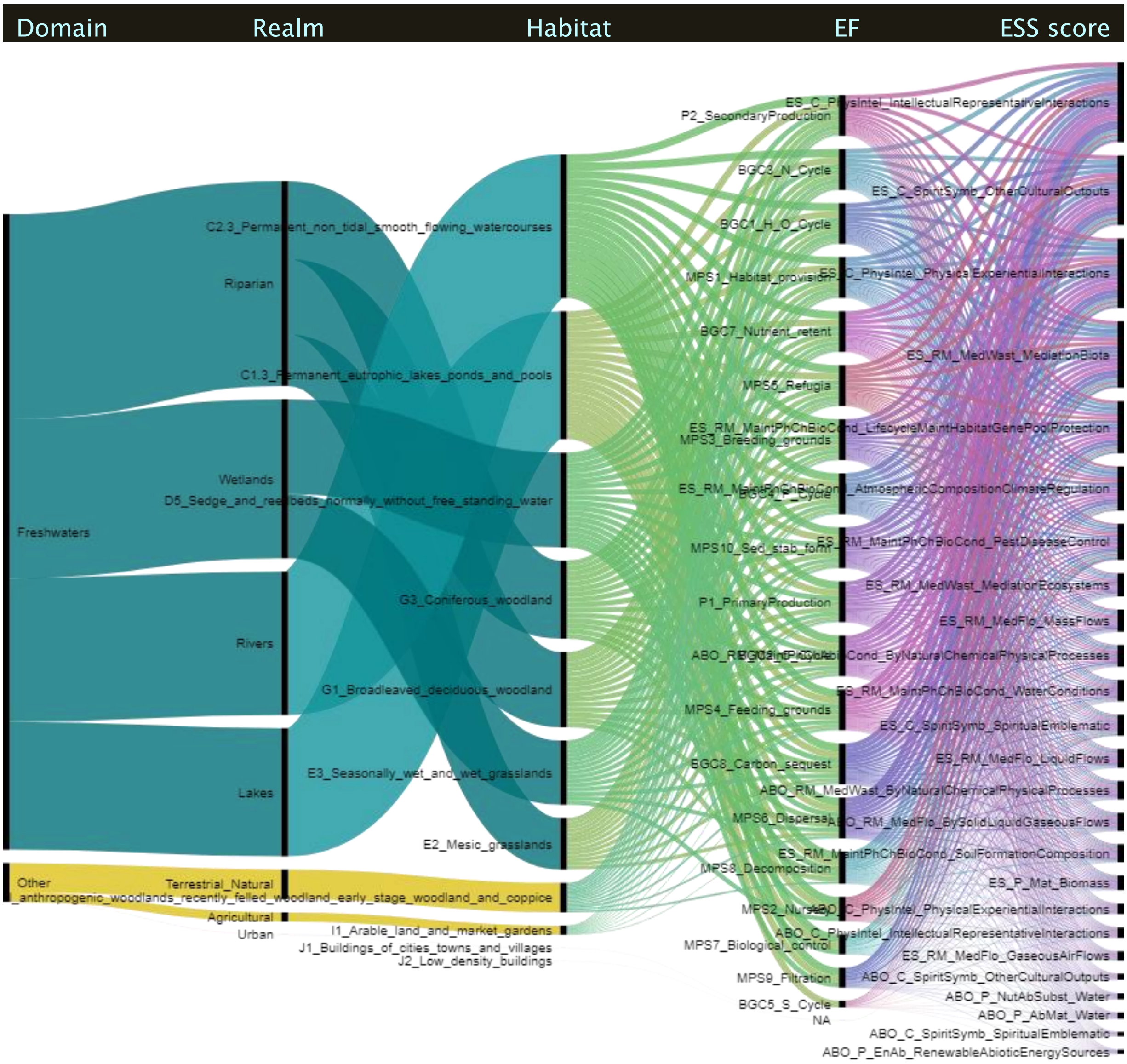
Figure 9: CS3 supply-side of the AQUACROSS linkage framework (ESS score)



4.4 Lough Erne CS4

Although Lough Erne is stage for innumerous activities, in CS4 the AQUACROSS AF was used in the specific context of the management of non-indigenous species in this lake. The supply-side of the AQUACROSS AF was applied to unravel relevant linkages that could highlight which ES are associated with habitats at risk by this pressure. The information derived from the linkage framework (Figure 10) highlighted that non-indigenous species potentially affect all habitats and associated biotic groups identified in this case study, and hence the related ES.

Figure 10: CS4 supply-side of the AQUACROSS linkage framework (ESS score)



Details in O'Higgins et al. 2018 (D9.1, CS4).

4.5 Ria Aveiro N2000 site CS5

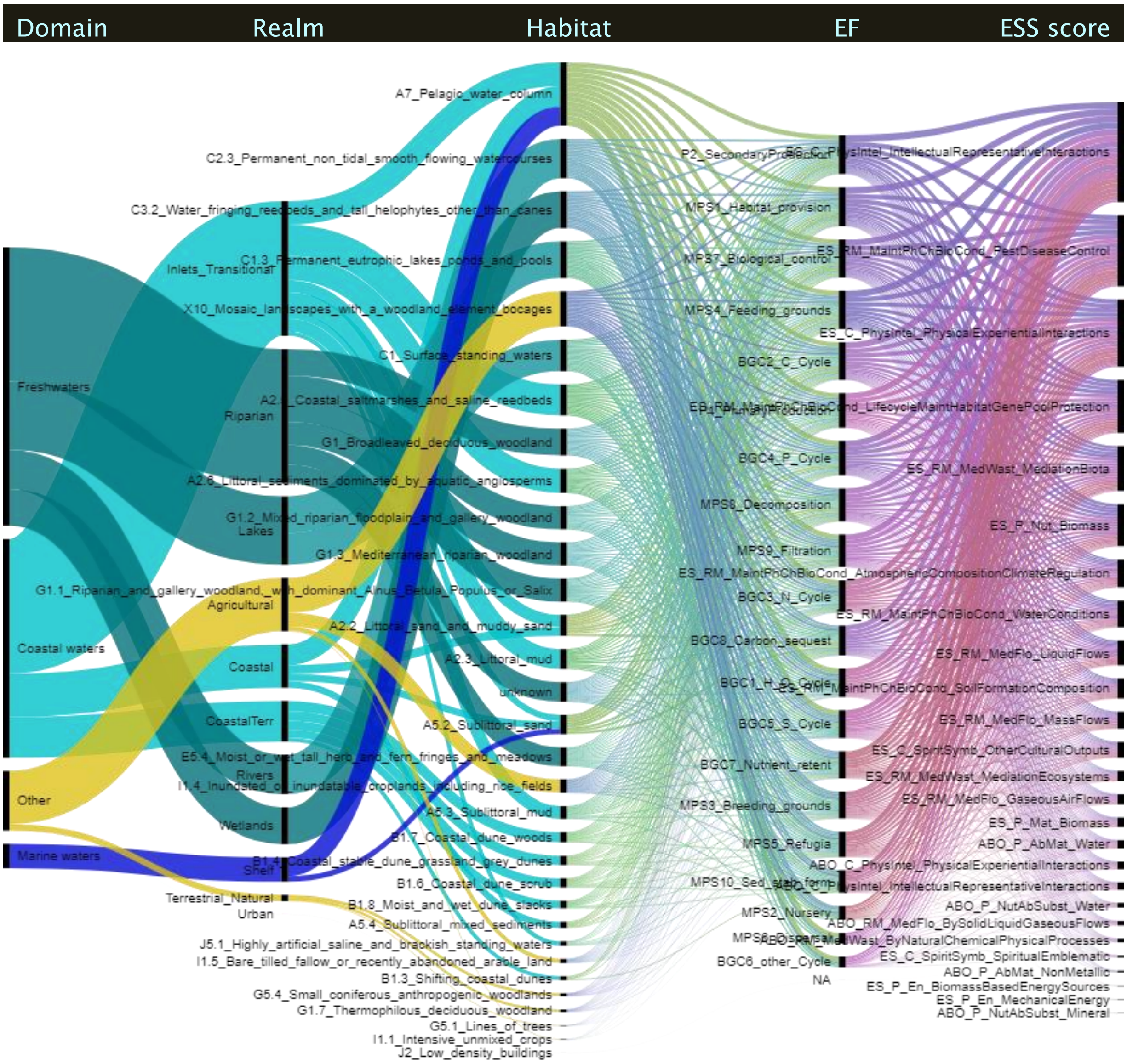
In this Nature 2000 site, the EBM was applied to integrate management at two spatial scales: the entire Natura 2000 area (Lillebø et al. 2019) and a smaller area at the confluence of Vouga river with Ria de Aveiro coastal lagoon, the Baixo Vouga Lagunar (Martínez-López et al. 2019). The AQUACROSS AF was used to inform on biodiversity and ES trade-offs at a broader scale for compensating for small-scale management options in specific areas within site. The drivers of environmental changes differ with scale, causing distinct pressures that affect local biodiversity. While wide-scale changes in the system hydrodynamics are causing the loss of sub-tidal *Zostera noltei* meadows; at local scales it is the dieback of saltmarshes, due to increased submerged period, and fragmentation of marshes at shoreline fringes of the lagoon that cause major concern. Saltmarshes habitats are at risk of being subdued due to the "coastal squeeze" effect.

CS5 characterized the full ecological system (habitats and biota) and identified links to all relevant ecosystem functions and services (Figure 11). Besides habitat mapping, the ES provided by such habitats were also spatialized based on the valuation obtained with the AQUACROSS AF links. The AF was a useful alternative to the use of ES specific indicators in the absence of standardized data for the current assessment. In a co-creation approach, the ES expert-based valuation together with stakeholders stated preferences for ES (Lillebø et al. 2019) were included in a spatial multicriteria analysis for identifying habitats and areas for prioritization. Local perceptions and environmental objectives, in particular those of the Water Framework and Nature Directives, were brought together to support future EBM scenarios for restoring habitats at risk and compensate for the loss of associated ES.

CS5 was also used to illustrate and test the AquaLinksTool, developed to integrate the socio and the ecological systems (Box 3).

Details in Lillebo et al. 2018 (D9.2, CS5), Lillebo et al. 2019, and Martinez-López et al. 2019.

Figure 11: CS5 supply-side of the AQUACROSS linkage framework (ESS score)



Box 3: CS5 Natura 2000 site as showcase for AquaLinksTool

The AquaLinksTool integrates the socio-ecological systems. It allows exploring causality in a linkage chain, relating Drivers/ Activities ► Pressures ► Biodiversity Status (structural components) ► Ecosystem functions ► Ecosystem Services provision as proposed in the AQUACROSS AF. The aim is to assess the vulnerability of ecosystem components threatening the provisioning of ES. By identifying the most vulnerable habitats regarding ES provision, the AquaLinksTool can support decision-making. To this end, in the scope of AQUACROSS WP5, the tool was tested with CS5 data. It showed that the habitats pinpointed by the tool clearly matched the environmental concerns reported by stakeholders (Lillebø et al. 2019). In CS5, the society perception and local knowledge match scientific estimates as integrated by the tool.

4.6 Lake Ringsjön CS6

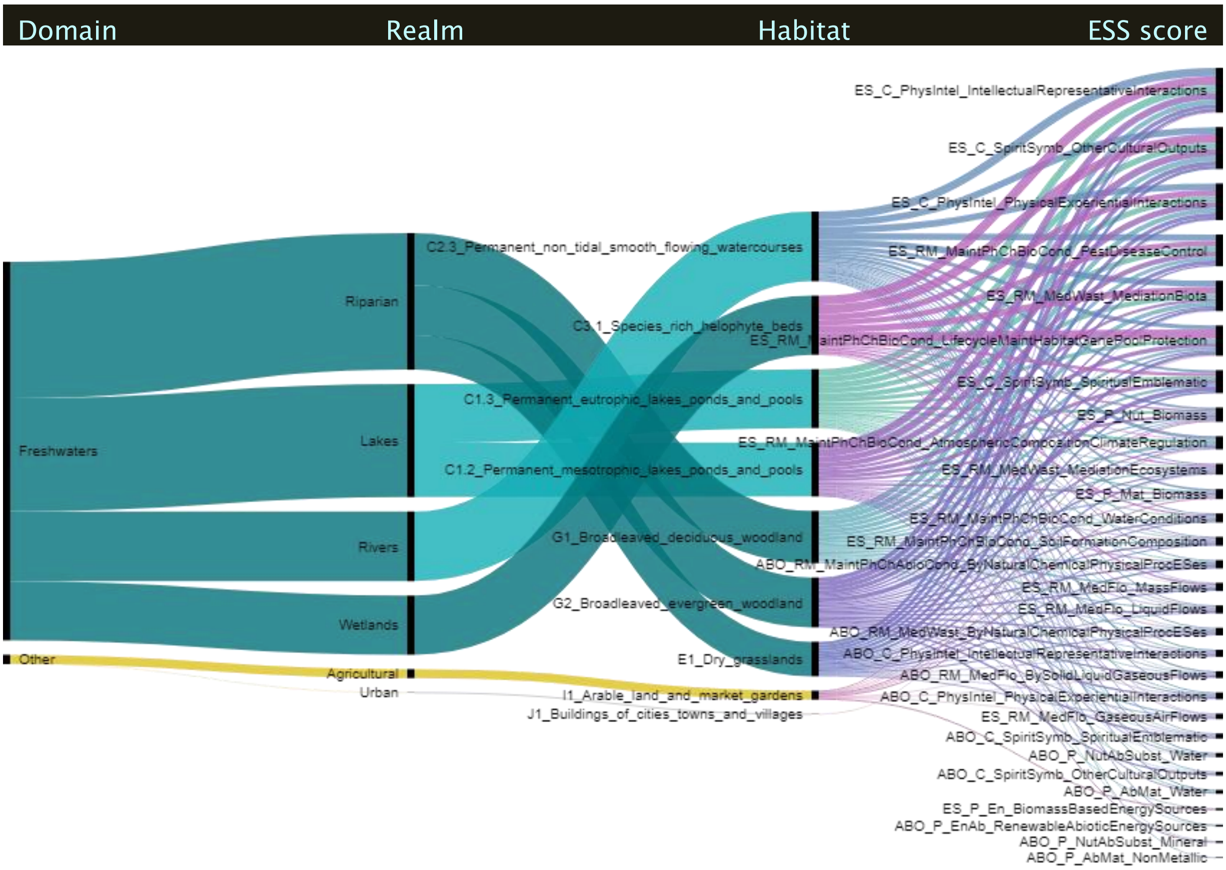
The Lake Ringsjön – Rönne å Catchment in Kattegat is a turbid lake prone to the occurrence of toxic algae blooms due to anthropogenic activities. With the target of restoring the system ecological integrity, CS6 proposed to increase the understanding of the social-ecological complexity and integrate it in current management "*through best-practices, multi-level governance and cross-sector collaboration*" (D9.2 CS6 Report). This integration was deemed *critical for addressing environmental problems, the provision of ecosystem services (ES) and maintenance of biodiversity*.

The Swedish case study investigated the water quality restoration process and its implications on the provision of tourism-related ES along the Rönne å catchment from a more sociological perspective. Therefore, it did not make a full use of the AQUACROSS AF, meaning that for the Lake Ringsjön no site-specific linkages were reported between its ecosystem components and the services they could deliver. In CS6, only biodiversity features (EC: habitats and biota) have been fully described (Annex A).

This system is thus an interesting test to the AQUACROSS AF, for using the overall estimates from across aquatic systems for characterizing the potential of CS6 habitats' for supplying specific ES. Based on the AQUACROSS AF supply-side links estimations, we derived CS6 specific supply score per habitat (Figure 12). These estimates can be used, for example, for setting expectations regarding the loss/recovery of tourism-related ES in future scenarios and compare those results with those derived with the alternative sociological approach used in CS6.

Details in Martin et al. 2018 (D9.2, CS6).

Figure 12: CS6 supply-side of the AQUACROSS linkage framework (ESS score)



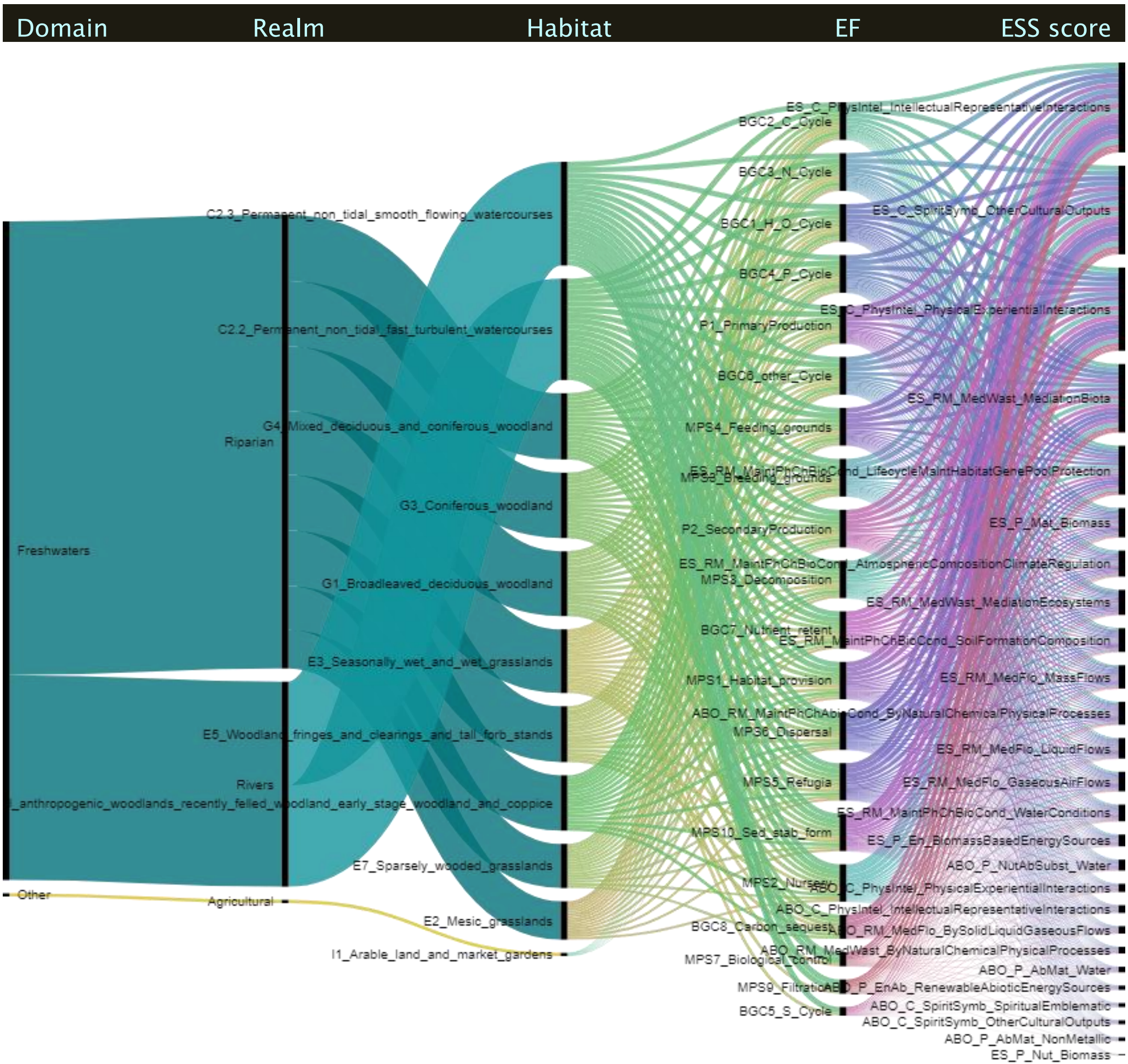
4.7 Swiss Plateau CS7

In the rivers of the Swiss Plateau, the complex relationships between the SES components of the AQUACROSS AF were considered with the aim of supporting spatial and temporal prioritisation of restoration areas. The main goal of CS7, considering specifically the ecological system perspective, was to optimise the overall ecological state at the catchment scale while ensuring a sustainable equilibrium between the supply and the demanded of services by the society, as well as taking into account societal constraints and budget limitations.

Despite that CS7 did not use the full linkage chain directly in their assessments, the characterization of the supply-side relationship was described (Figure 13). The derived estimations of the ES Supply score supported the identification of target and non-target ecosystem services that would benefit the most from alternative remedial measures for river restoration.

Details in Kuemmerlen et al. 2018 (D9.2, CS7), in Kuemmerlen et al. 2019, and Vermeiren et al., submitted.

Figure 13: CS7 supply-side of the AQUACROSS linkage framework (ESS score)



4.8 Azores MPA CS8

Biodiversity in the marine protected area of the Faial-Pico Channel, in the Azores case study, is affected by the human activities in the surrounding area, like fishing and tourism. The AQUACROSS AF was fully implemented in this CS8 to comprehensively identify and characterize the supply-side linkages (Figure 14). Then, based on research, expert and stakeholder input, the key ecological elements were identified: fish and rocky habitats. By applying the AQUACROSS AF linkages estimates, the ES supplied by the selected focal elements in the Channel Pico-Faial were identified and targeted:

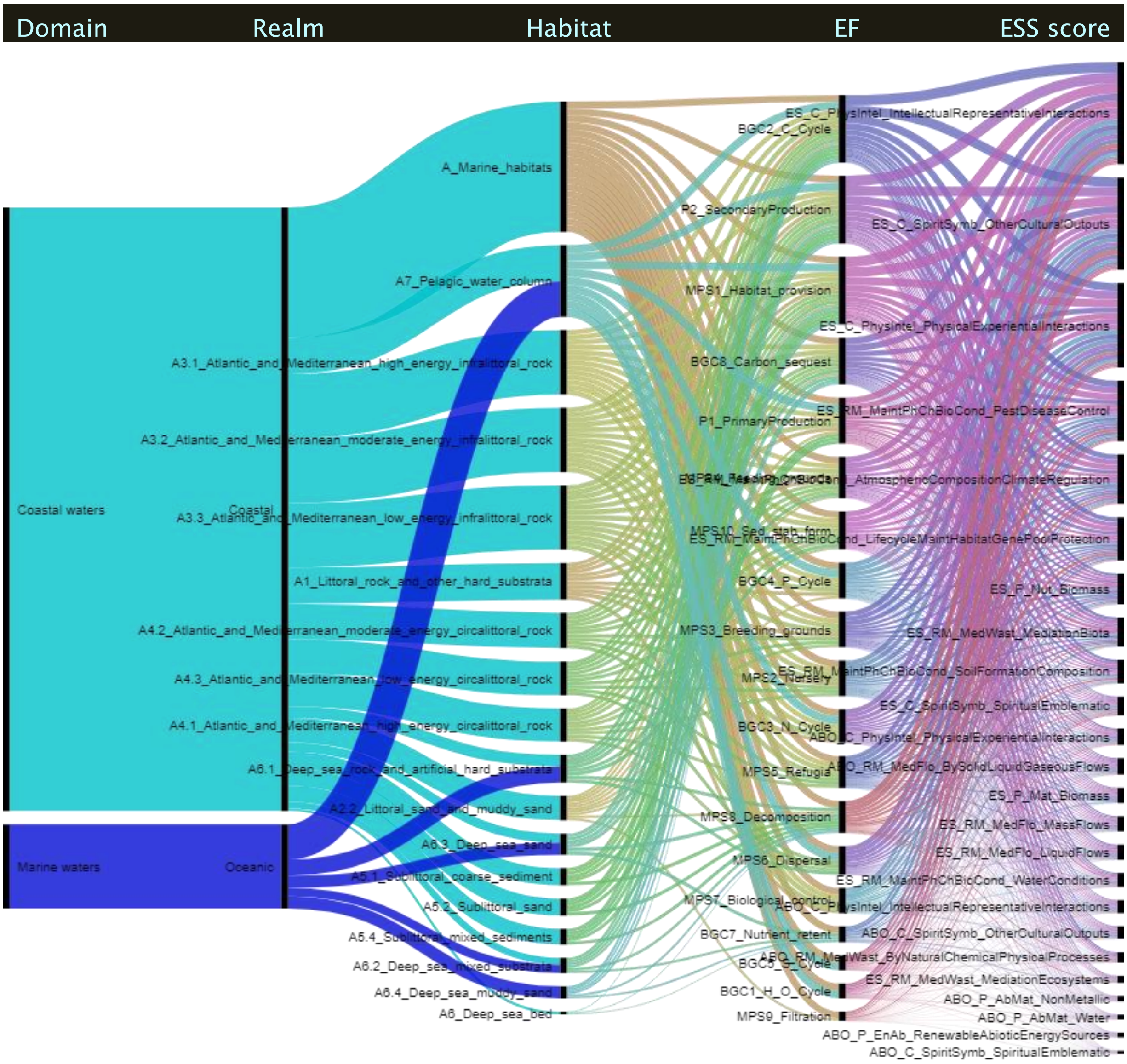
- Nutritional biomass (Fish);
- Physical and experiential interactions; and

- Other cultural values (existence/bequest).

CS8 aimed to understand this system and all of its complex interactions, including relevant stakeholders, for identifying the best options leading to sustainable exploitation of natural resources while halting biodiversity loss and protecting local ecosystems and the local communities depending on such resources.

Details in McDonald et al. 2018 (D9.2, CS8).

Figure 14: CS8 supply-side of the AQUACROSS linkage framework (ESS score)



5 Conclusions

The results of this work contribute to increase awareness about the importance of an holistic view when looking at the wide network of relationships between and within the SES components. While targeted ecosystem features or specific environmental and societal goals are usually the triggers of management, the AQUACROSS AF proved a useful tool for identifying potential conflicts, trade-offs and synergies, and thus support better informed decisions and management options.

A meta-ecosystem perspective increases the capacity to predict consequences of different activities and management options on biodiversity and hence on the provision of ecosystem services (Loreau et al. 2003). It was clearly demonstrated by several of our case studies and also by the overall BD-ES patterns analysis, that the AQUACROSS AF with its linkages approach is also a powerful tool for meta-ecosystems analysis. These findings point to promising contributions in the field of EBM.

The flexibility of the AF as an EBM tool is also crucial to accommodate different spatial management contexts across very different realms and geographies or even policy and social contexts. But its flexibility is even more relevant as tool capable of promoting and accompanying adaptive management within real situations and along temporal scales.

Finally, having failed 2010 targets, the EU2020 BD Strategy mid-term assessment stressed the importance of increasing dialogue with Member States and all relevant stakeholders, including socio-economic actors, for adoption of best practices for further integration of BD and trigger timely action towards accomplishing the 2020 targets. The lessons learnt from testing the AQUACROSS AF in eight real CS scenarios provide valuable recommendations on how to move forward implementing scientific-sound practices in EBM.

6 References[4]

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7 Annex

Annex A: AQUACROSS Habitats final list

Annex B: AQUACROSS Ecosystem Functions classification

Annex C: Ecosystem Services classification

Annex D: EU Habitats Red List classification correspondence

Annex A: AQUACROSS Habitats final list

Id	Domain	Realms & Biota	Habitats EUNIS 1	Habitats EUNIS 2	Habitats EUNIS 3	Case studies									Σ CS
						1	2 Sp	2 M	3	4	5	6	7	8	
H1	CW	Inlets Transitional	A_Marine_habitats	A1_Littoral_rock_and_other_hard_substrata	A1.1_High_energy_littoral_rock	1									1
H2	CW	Coastal	A_Marine_habitats	A1_Littoral_rock_and_other_hard_substrata	A1.1_High_energy_littoral_rock	1									1
H3	CW	Inlets Transitional	A Marine habitats	A1 Littoral rock and other hard substrata	A1.2 Moderate energy littoral rock	1									1
H4	CW	Coastal	A Marine habitats	A1 Littoral rock and other hard substrata	A1.2 Moderate energy littoral rock	1	1								2
H5	CW	Inlets Transitional	A Marine habitats	A1 Littoral rock and other hard substrata	A1.3 Low energy littoral rock	1									1
H6	CW	Coastal	A Marine habitats	A1 Littoral rock and other hard substrata	A1.3 Low energy littoral rock	1	1								2
H7	CW	Inlets Transitional	A Marine habitats	A1 Littoral rock and other hard substrata	A1.4 Features of littoral rock	1									1
H8	CW	Coastal	A Marine habitats	A1 Littoral rock and other hard substrata	A1.4 Features of littoral rock	1									1
H9	CW	Coastal	A Marine habitats	A1 Littoral rock and other hard substrata	unknown	1								1	2
H10	CW	Inlets Transitional	A Marine habitats	A2 Littoral sediment	A2.1 Littoral coarse sediment	1	1								2
H11	CW	Coastal	A Marine habitats	A2 Littoral sediment	A2.1 Littoral coarse sediment	1									1
H12	CW	Inlets Transitional	A Marine habitats	A2 Littoral sediment	A2.2 Littoral sand and muddy sand	1					1				2
H13	CW	Coastal	A Marine habitats	A2 Littoral sediment	A2.2 Littoral sand and muddy sand	1					1			1	3

Id	Domain	Realms & Biota	Habitats EUNIS 1	Habitats EUNIS 2	Habitats EUNIS 3	Case studies									Σ CS
						1	2 Sp	2 M	3	4	5	6	7	8	
H14	CW	Inlets Transitional	A Marine habitats	A2 Littoral sediment	A2.3 Littoral mud	1					1				2
H15	CW	Coastal	A Marine habitats	A2 Littoral sediment	A2.3 Littoral mud	1									1
H16	CW	Inlets Transitional	A Marine habitats	A2 Littoral sediment	A2.4 Littoral mixed sediments	1									1
H17	CW	Coastal	A Marine habitats	A2 Littoral sediment	A2.4 Littoral mixed sediments	1									1
H18	CW	Inlets Transitional	A Marine habitats	A2 Littoral sediment	A2.5 Coastal saltmarshes and saline reedbeds	1	1	1			1				4
H19	CW	Coastal	A Marine habitats	A2 Littoral sediment	A2.5 Coastal saltmarshes and saline reedbeds	1									1
H20	CW	Inlets Transitional	A Marine habitats	A2 Littoral sediment	A2.6 Littoral sediments dominated by aquatic angiosperms	1					1				2
H21	CW	Coastal	A Marine habitats	A2 Littoral sediment	A2.6 Littoral sediments dominated by aquatic angiosperms	1									1
H22	CW	Inlets Transitional	A Marine habitats	A2 Littoral sediment	A2.7 Littoral biogenic reefs	1									1
H23	CW	Coastal	A Marine habitats	A2 Littoral sediment	A2.7 Littoral biogenic reefs	1									1
H24	CW	Inlets Transitional	A Marine habitats	A2 Littoral sediment	A2.8 Features of littoral sediment	1									1
H25	CW	Coastal	A Marine habitats	A2 Littoral sediment	A2.8 Features of littoral sediment	1									1
H26	CW	Inlets Transitional	A Marine habitats	A3 Infralittoral rock and other hard substrata	unknown	1									1
H27	CW	Coastal	A Marine habitats	A3 Infralittoral rock and other hard substrata	unknown	1									1
H28	CW	Inlets Transitional	A Marine habitats	A3 Infralittoral rock and other hard substrata	A3.1 Atlantic and Mediterranean high energy infralittoral rock	1									1
H29	CW	Coastal	A Marine habitats	A3 Infralittoral rock and other hard substrata	A3.1 Atlantic and Mediterranean high energy infralittoral rock	1								1	2

Id	Domain	Realms & Biota	Habitats EUNIS 1	Habitats EUNIS 2	Habitats EUNIS 3	Case studies									Σ CS
						1	2 Sp	2 M	3	4	5	6	7	8	
H30	MW	Shelf	A Marine habitats	A3 Infralittoral rock and other hard substrata	A3.1 Atlantic and Mediterranean high energy infralittoral rock		1								1
H31	CW	Inlets Transitional	A Marine habitats	A3 Infralittoral rock and other hard substrata	A3.2 Atlantic and Mediterranean moderate energy infralittoral rock	1									1
H32	CW	Coastal	A Marine habitats	A3 Infralittoral rock and other hard substrata	A3.2 Atlantic and Mediterranean moderate energy infralittoral rock	1								1	2
H33	MW	Shelf	A Marine habitats	A3 Infralittoral rock and other hard substrata	A3.2 Atlantic and Mediterranean moderate energy infralittoral rock		1								1
H34	CW	Inlets Transitional	A Marine habitats	A3 Infralittoral rock and other hard substrata	A3.3 Atlantic and Mediterranean low energy infralittoral rock	1									1
H35	CW	Coastal	A Marine habitats	A3 Infralittoral rock and other hard substrata	A3.3 Atlantic and Mediterranean low energy infralittoral rock	1								1	2
H36	MW	Shelf	A Marine habitats	A3 Infralittoral rock and other hard substrata	A3.3 Atlantic and Mediterranean low energy infralittoral rock		1								1
H37	CW	Inlets Transitional	A Marine habitats	A4 Circalittoral rock and other hard substrata	A4.1 Atlantic and Mediterranean high energy circalittoral rock	1									1
H38	CW	Coastal	A Marine habitats	A4 Circalittoral rock and other hard substrata	A4.1 Atlantic and Mediterranean high energy circalittoral rock	1								1	2
H39	MW	Shelf	A Marine habitats	A4 Circalittoral rock and other hard substrata	A4.1 Atlantic and Mediterranean high energy circalittoral rock	1	1								2
H40	CW	Inlets Transitional	A Marine habitats	A4 Circalittoral rock and other hard substrata	A4.2 Atlantic and Mediterranean moderate energy circalittoral rock	1									1
H41	CW	Coastal	A Marine habitats	A4 Circalittoral rock and other hard substrata	A4.2 Atlantic and Mediterranean moderate energy circalittoral rock	1								1	2
H42	MW	Shelf	A Marine habitats	A4 Circalittoral rock and other hard substrata	A4.2 Atlantic and Mediterranean moderate energy circalittoral rock	1	1								2
H43	CW	Inlets Transitional	A Marine habitats	A4 Circalittoral rock and other hard substrata	A4.3 Atlantic and Mediterranean low energy circalittoral rock	1									1

Id	Domain	Realms & Biota	Habitats EUNIS 1	Habitats EUNIS 2	Habitats EUNIS 3	Case studies 1	2 Sp	2 M	3	4	5	6	7	8	Σ CS
H44	CW	Coastal	A Marine habitats	A4 Circalittoral rock and other hard substrata	A4.3 Atlantic and Mediterranean low energy circalittoral rock	1								1	2
H45	MW	Shelf	A Marine habitats	A4 Circalittoral rock and other hard substrata	A4.3 Atlantic and Mediterranean low energy circalittoral rock	1	1								2
H46	CW	Inlets Transitional	A Marine habitats	A5 Sublittoral sediment	A5.1 Sublittoral coarse sediment	1									1
H47	CW	Coastal	A Marine habitats	A5 Sublittoral sediment	A5.1 Sublittoral coarse sediment	1								1	2
H48	MW	Shelf	A Marine habitats	A5 Sublittoral sediment	A5.1 Sublittoral coarse sediment	1	1								2
H49	CW	Inlets Transitional	A Marine habitats	A5 Sublittoral sediment	A5.2 Sublittoral sand	1					1				2
H50	CW	Coastal	A Marine habitats	A5 Sublittoral sediment	A5.2 Sublittoral sand	1					1			1	3
H51	MW	Shelf	A Marine habitats	A5 Sublittoral sediment	A5.2 Sublittoral sand	1	1				1				3
H52	CW	Inlets Transitional	A Marine habitats	A5 Sublittoral sediment	A5.3 Sublittoral mud	1					1				2
H53	CW	Coastal	A Marine habitats	A5 Sublittoral sediment	A5.3 Sublittoral mud	1									1
H54	MW	Shelf	A Marine habitats	A5 Sublittoral sediment	A5.3 Sublittoral mud	1	1								2
H55	CW	Inlets Transitional	A Marine habitats	A5 Sublittoral sediment	A5.4 Sublittoral mixed sediments	1									1
H56	CW	Coastal	A Marine habitats	A5 Sublittoral sediment	A5.4 Sublittoral mixed sediments	1					1			1	3
H57	MW	Shelf	A Marine habitats	A5 Sublittoral sediment	A5.4 Sublittoral mixed sediments	1	1								2
H58	MW	Shelf	A Marine habitats	A5 Sublittoral sediment	A5.5 Sublittoral macrophyte dominated sediment		1								1
H59	CW	Inlets Transitional	A Marine habitats	A6 Deep sea bed	A6.1 Deep sea rock and artificial hard substrata	1									1
H60	CW	Coastal	A Marine habitats	A6 Deep sea bed	A6.1 Deep sea rock and artificial hard substrata	1								1	2
H61	MW	Oceanic	A Marine habitats	A6 Deep sea bed	A6.1 Deep sea rock and artificial hard substrata	1	1							1	3

Id	Domain	Realms & Biota	Habitats EUNIS 1	Habitats EUNIS 2	Habitats EUNIS 3	Case studies 1	2 Sp	2 M	3	4	5	6	7	8	Σ CS
H62	CW	Coastal	A Marine habitats	A6 Deep sea bed	A6.2 Deep sea mixed substrata									1	1
H63	MW	Oceanic	A Marine habitats	A6 Deep sea bed	A6.2 Deep sea mixed substrata	1	1							1	3
H64	CW	Coastal	A Marine habitats	A6 Deep sea bed	A6.3 Deep sea sand									1	1
H65	MW	Oceanic	A Marine habitats	A6 Deep sea bed	A6.3 Deep sea sand	1	1							1	3
H66	CW	Inlets Transitional	A Marine habitats	A6 Deep sea bed	A6.4 Deep sea muddy sand	1									1
H67	CW	Coastal	A Marine habitats	A6 Deep sea bed	A6.4 Deep sea muddy sand	1									1
H68	MW	Oceanic	A Marine habitats	A6 Deep sea bed	A6.4 Deep sea muddy sand	1	1							1	3
H69	CW	Inlets Transitional	A Marine habitats	A6 Deep sea bed	A6.5 Deep sea mud	1									1
H70	CW	Coastal	A Marine habitats	A6 Deep sea bed	A6.5 Deep sea mud	1									1
H71	MW	Oceanic	A Marine habitats	A6 Deep sea bed	A6.5 Deep sea mud	1	1								2
H72	CW	Inlets Transitional	A Marine habitats	A6 Deep sea bed	unknown	1									1
H73	CW	Coastal	A Marine habitats	A6 Deep sea bed	unknown	1								1	2
H74	MW	Oceanic	A Marine habitats	A6 Deep sea bed	unknown	1									1
H75	CW	Inlets Transitional	A Marine habitats	A7 Pelagic water column	unknown	1					1				2
H76	CW	Coastal	A Marine habitats	A7 Pelagic water column	unknown	1					1			1	3
H77	MW	Shelf	A Marine habitats	A7 Pelagic water column	unknown	1	1				1				3
H78	MW	Oceanic	A Marine habitats	A7 Pelagic water column	unknown	1	1							1	3
H79	CW	CoastalTerr	B Coastal habitat land	unknown	unknown			1							1
H80	CW	CoastalTerr	B Coastal habitat land	B1 Coastal dunes and sandy shores	B1.1 Sand beach driftlines	1									1
H81	CW	CoastalTerr	B Coastal habitat land	B1 Coastal dunes and sandy shores	B1.2 Sand beaches above the driftline	1									1
H82	CW	CoastalTerr	B Coastal habitat land	B1 Coastal dunes and sandy shores	B1.3 Shifting coastal dunes	1					1				2
H83	CW	CoastalTerr	B Coastal habitat land	B1 Coastal dunes and sandy shores	B1.4 Coastal stable dune grassland grey dunes	1					1				2

Id	Domain	Realms & Biota	Habitats EUNIS 1	Habitats EUNIS 2	Habitats EUNIS 3	Case studies									Σ CS
						1	2 Sp	2 M	3	4	5	6	7	8	
H84	CW	CoastalTerr	B Coastal habitat land	B1 Coastal dunes and sandy shores	B1.5 Coastal dune heaths	1									1
H85	CW	CoastalTerr	B Coastal habitat land	B1 Coastal dunes and sandy shores	B1.6 Coastal dune scrub	1					1				2
H86	CW	CoastalTerr	B Coastal habitat land	B1 Coastal dunes and sandy shores	B1.7 Coastal dune woods	1					1				2
H87	CW	CoastalTerr	B Coastal habitat land	B1 Coastal dunes and sandy shores	B1.8 Moist and wet dune slacks	1					1				2
H88	CW	CoastalTerr	B Coastal habitat land	B1 Coastal dunes and sandy shores	unknown		1								1
H89	CW	CoastalTerr	B Coastal habitat land	B2 Coastal shingle	unknown	1									1
H90	CW	CoastalTerr	B Coastal habitat land	B3 Rock cliffs edges and shores including the supralittoral	unknown		1								1
H91	CW	CoastalTerr	B Coastal habitat land	B3 Rock cliffs edges and shores including the supralittoral	B3.1 Supralittoral rock lichen or splash zone	1									1
H92	CW	CoastalTerr	B Coastal habitat land	B3 Rock cliffs edges and shores including the supralittoral	B3.2 Unvegetated rock cliffs ledges shores and islets	1									1
H93	CW	CoastalTerr	B Coastal habitat land	B3 Rock cliffs edges and shores including the supralittoral	B3.3 Rock cliffs ledges and shores with angiosperms	1									1
H94	CW	CoastalTerr	B Coastal habitat land	B3 Rock cliffs edges and shores including the supralittoral	B3.4 Soft sea-cliffs often vegetated	1									1
H95	FW	Lakes	C Inland surface waters	C1 Surface standing waters	C1.1 Permanent oligotrophic lakes ponds and pools		1		1						2
H96	FW	Lakes	C Inland surface waters	C1 Surface standing waters	C1.2 Permanent mesotrophic lakes ponds and pools		1		1			1			3
H97	FW	Lakes	C Inland surface waters	C1 Surface standing waters	C1.3 Permanent eutrophic lakes ponds and pools		1		1	1	1	1			5
H98	FW	Lakes	C Inland surface waters	C1 Surface standing waters	C1.4 Permanent dystrophic lakes ponds and pools										0
H99	FW	Lakes	C Inland surface waters	C1 Surface standing waters	unknown			1			1				2
H100	FW	Rivers	C Inland surface waters	C2 Surface running waters	C2.1 Springs spring brooks and geysers		1								1

Id	Domain	Realms & Biota	Habitats EUNIS 1	Habitats EUNIS 2	Habitats EUNIS 3	Case studies									Σ CS
						1	2 Sp	2 M	3	4	5	6	7	8	
H101	FW	Rivers	C Inland surface waters	C2 Surface running waters	C2.2 Permanent non tidal fast turbulent watercourses				1				1		2
H102	FW	Rivers	C Inland surface waters	C2 Surface running waters	C2.3 Permanent non tidal smooth flowing watercourses				1	1	1	1	1		5
H103	FW	Rivers	C Inland surface waters	C2 Surface running waters	C2.5 Temporary running waters		1								1
H104	FW	Rivers	C Inland surface waters	C2 Surface running waters	unknown			1							1
H105	FW	Wetlands	C Inland surface waters	C3 Littoral zone of inland surface waterbodies	C3.1 Species rich helophyte beds				1			1			2
H106	FW	Wetlands	C Inland surface waters	C3 Littoral zone of inland surface waterbodies	C3.2 Water fringing reedbeds and tall helophytes other than canes				1		1				2
H107	FW	Wetlands	C Inland surface waters	C3 Littoral zone of inland surface waterbodies	C3.4 Species poor beds of low growing water fringing or amphibious vegetation		1		1						2
H108	FW	Wetlands	C Inland surface waters	C3 Littoral zone of inland surface waterbodies	C3.5 Periodically inundated shores with pioneer and ephemeral vegetation		1	1	1						3
H109	FW	Wetlands	C Inland surface waters	C3 Littoral zone of inland surface waterbodies	C3.6 Unvegetated or sparsely vegetated shores with soft or mobile sediments				1						1
H110	FW	Wetlands	C Inland surface waters	C3 Littoral zone of inland surface waterbodies	C3.7 Unvegetated or sparsely vegetated shores with non mobile substrates				1						1
H111	FW	Wetlands	D Mires bogs and fens	D5 Sedge and reedbeds normally without free standing water	unknown		1			1					2
H112	FW	Riparian	E Grassland and land dominated by forbs mosses and lichens	unknown	unknown			1							1
H113	FW	Riparian	E Grassland and land dominated by forbs mosses and lichens	E1 Dry grasslands	unknown		1		1			1			3

Id	Domain	Realms & Biota	Habitats EUNIS 1	Habitats EUNIS 2	Habitats EUNIS 3	Case studies									Σ CS
						1	2 Sp	2 M	3	4	5	6	7	8	
H114	FW	Riparian	E Grassland and land dominated by forbs mosses and lichens	E2 Mesic grasslands	unknown		1		1	1			1		4
H115	FW	Wetlands	E Grassland and land dominated by forbs mosses and lichens	E3 Seasonally wet and wet grasslands	unknown		1		1	1					3
H116	FW	Riparian	E Grassland and land dominated by forbs mosses and lichens	E3 Seasonally wet and wet grasslands	unknown		1						1		2
H117	FW	Riparian	E Grassland and land dominated by forbs mosses and lichens	E5 Woodland fringes and clearings and tall forb stands	E5.4 Moist or wet tall herb and fern fringes and meadows						1				1
H118	FW	Riparian	E Grassland and land dominated by forbs mosses and lichens	E5 Woodland fringes and clearings and tall forb stands	unknown				1				1		2
H119	FW	Riparian	E Grassland and land dominated by forbs mosses and lichens	E6 Inland salt steppes	unknown		1								1
H120	FW	Riparian	E Grassland and land dominated by forbs mosses and lichens	E7 Sparsely wooded grasslands	unknown		1		1				1		3
H121	Other	Terrestrial Natural	F Heathland scrub and tundra	unknown	unknown			1							1
H122	Other	Terrestrial Natural	F Heathland scrub and tundra	F5 Maquis arborescent matorral and thermo Mediterranean brushes	unknown		1								1
H123	Other	Terrestrial Natural	F Heathland scrub and tundra	F7 Spiny Mediterranean heaths phrygana hedgehog heaths and related coastal cliff vegetation	unknown		1								1

Id	Domain	Realms & Biota	Habitats EUNIS 1	Habitats EUNIS 2	Habitats EUNIS 3	Case studies 1	2 Sp	2 M	3	4	5	6	7	8	Σ CS
H124	Other	Terrestrial Natural	F Heathland scrub and tundra	FB Shrub plantations	unknown		1								1
H125	FW	Riparian	G Woodland forest and other wooded land	unknown	unknown			1							1
H126	FW	Riparian	G Woodland forest and other wooded land	G1 Broadleaved deciduous woodland	G1.1 Riparian and gallery woodland, with dominant *Alnus Betula Populus* or *Salix*						1				1
H127	FW	Riparian	G Woodland forest and other wooded land	G1 Broadleaved deciduous woodland	G1.2 Mixed riparian floodplain and gallery woodland						1				1
H128	FW	Riparian	G Woodland forest and other wooded land	G1 Broadleaved deciduous woodland	G1.3 Mediterranean riparian woodland						1				1
H129	Other	Terrestrial Natural	G Woodland forest and other wooded land	G1 Broadleaved deciduous woodland	G1.7 Thermophilous deciduous woodland						1				1
H130	FW	Riparian	G Woodland forest and other wooded land	G1 Broadleaved deciduous woodland	unknown		1		1	1	1	1	1		6
H131	FW	Riparian	G Woodland forest and other wooded land	G2 Broadleaved evergreen woodland	unknown		1					1			2
H132	FW	Riparian	G Woodland forest and other wooded land	G3 Coniferous woodland	unknown		1		1	1			1		4
H133	FW	Riparian	G Woodland forest and other wooded land	G4 Mixed deciduous and coniferous woodland	unknown		1		1				1		3
H134	Other	Terrestrial Natural	G Woodland forest and other wooded land	G5 Lines of trees small anthropogenic woodlands recently felled woodland early stage woodland and coppice	G5.1 Lines of trees				1		1				2
H135	Other	Terrestrial Natural	G Woodland forest and other wooded land	G5 Lines of trees small anthropogenic woodlands recently felled woodland early stage woodland and coppice	G5.4 Small coniferous anthropogenic woodlands						1				1

Id	Domain	Realms & Biota	Habitats EUNIS 1	Habitats EUNIS 2	Habitats EUNIS 3	Case studies									Σ CS
						1	2 Sp	2 M	3	4	5	6	7	8	
H136	FW	Riparian	G Woodland forest and other wooded land	G5 Lines of trees small anthropogenic woodlands recently felled woodland early stage woodland and coppice	unknown		1						1		2
H137	Other	Terrestrial Natural	G Woodland forest and other wooded land	G5 Lines of trees small anthropogenic woodlands recently felled woodland early stage woodland and coppice	unknown					1					1
H138	Other	Agricultural	I Regularly or recently cultivated agricultural horticultural or domestic habitats	unknown	unknown			1							1
H139	Other	Agricultural	I Regularly or recently cultivated agricultural horticultural or domestic habitats	I1 Arable land and market gardens	I1.1 Intensive unmixed crops		1		1		1				3
H140	Other	Agricultural	I Regularly or recently cultivated agricultural horticultural or domestic habitats	I1 Arable land and market gardens	I1.5 Bare tilled fallow or recently abandoned arable land				1		1				2
H141	Other	Agricultural	I Regularly or recently cultivated agricultural horticultural or domestic habitats	I1 Arable land and market gardens	unknown				1	1		1	1		4
H142	Other	Urban	J Constructed industrial and other artificial habitats	unknown	unknown			1							1
H143	Other	Urban	J Constructed industrial and other artificial habitats	J1 Buildings of cities towns and villages	unknown				1	1		1	1		4
H144	Other	Urban	J Constructed industrial and other artificial habitats	J2 Low density buildings	unknown		1		1	1	1				4

Id	Domain	Realms & Biota	Habitats EUNIS 1	Habitats EUNIS 2	Habitats EUNIS 3	Case studies 1	2 Sp	2 M	3	4	5	6	7	8	Σ CS
H145	CW	Inlets Transitional	J Constructed industrial and other artificial habitats	J5 Highly artificial man made waters and associated structures	J5.1 Highly artificial saline and brackish standing waters		1				1				2
H146	Other	Agricultural	X Habitat complexes	X10 Mosaic landscapes with a woodland element bocages	unknown				1		1				2
H147	CW	Inlets Transitional	X Habitat complexes	X01 Estuaries	unknown		1								1
H148	FW	Riparian	unknown	unknown	unknown						1				1
H149	CW	Inlets Transitional	unknown	unknown	unknown										0
H150	CW	Coastal	A Marine habitats	unknown	unknown									1	1
H151	MW	Shelf	unknown	unknown	unknown										0
H152	Other	Agricultural	I Regularly or recently cultivated agricultural horticultural or domestic habitats	I1 Arable land and market gardens	I1.4 Inundated or inundatable croplands including rice fields						1				1
B1	Biota	Insects (*adults*)	Insects (*adults*)	Insects (*adults*)	Insects (*adults*)		1	1	1	1	1	1	1		7
B2	Biota	Fish & Cephalopods	Fish & Cephalopods	Fish & Cephalopods	Fish & Cephalopods	1	1	1	1	1	1	1	1	1	9
B3	Biota	Mammals	Mammals	Mammals	Mammals	1	1	1	1	1	1	1	1	1	9
B4	Biota	Amphibian	Amphibian	Amphibian	Amphibian		1	1	1	1	1	1	1		7
B5	Biota	Reptiles	Reptiles	Reptiles	Reptiles	1	1	1	1		1	1	1	1	8
B6	Biota	Birds	Birds	Birds	Birds	1	1	1	1	1	1	1	1	1	9

Annex B: AQUACROSS Ecosystem Functions classification

Function category	Ecosystem Function (EF)	EF code
Production	1.1. Primary production	P1_PrimaryProduction
	1.2. Secondary production	P2_SecondaryProduction
Biogeochemical Cycles	2.1. Hydrological cycling (O and H)	BGC1_H_O_Cycle
	2.2. Carbon cycling (C)	BGC2_C_Cycle
	2.3. Nitrogen cycling (N)	BGC3_N_Cycle
	2.4. Phosphorus cycling (P)	BGC4_P_Cycle
	2.5. Sulfur cycling (S)	BGC5_S_Cycle
	2.6. other element cycling	BGC6_other_Cycle
	2.7. Nutrient retention	BGC7_Nutrient_retent
	2.8. Carbon sequestration	BGC8_Carbon_sequest
Mechanical-Physically structuring	3.1. Habitat provision	MPS1_Habitat_provision
	3.2. Nursery function	MPS2_Nursery
	3.3. Breeding grounds	MPS3_Breeding_grounds
	3.4. Feeding grounds	MPS4_Feeding_grounds
	3.5. Refugia	MPS5_Refugia
	3.6. Dispersal	MPS6_Dispersal
	3.7. Biological control	MPS7_Biological_control
	3.8. Decomposition (mechanical & chemical)	MPS8_Decomposition
	3.9. Filtration	MPS9_Filtration
	3.10. Sediment stability & formation	MPS10_Sed_stab_form

Annex C: **Ecosystem Services classification** adapted from CICES

Category (C) Ecosystem Services	Section (S)	Division (D)	Group (G)	ES code
Biotic	Provisioning	Energy	Biomass-based energy sources	ESS_P_En_BiomassBasedEnergySources
			Mechanical energy	ESS_P_En_MechanicalEnergy
		Materials	Biomass	ESS_P_Mat_Biomass
		Nutrition	Biomass	ESS_P_Nut_Biomass
	Regulation & Maintenance	Maintenance of physical chemical biological conditions	Lifecycle maintenance, habitat and gene pool protection	ESS_RM_MaintPhChBioCond_LifecycleMaintHabitatGenePoolProtection
			Pest and disease control	ESS_RM_MaintPhChBioCond_PestDiseaseControl
			Soil formation and composition	ESS_RM_MaintPhChBioCond_SoilFormationComposition
			Water conditions	ESS_RM_MaintPhChBioCond_WaterConditions
			Atmospheric composition and climate regulation	ESS_RM_MaintPhChBioCond_AtmosphericCompositionClimateRegulation
		Mediation of flows	Mass flows	ESS_RM_MedFlo_MassFlows
			Liquid flows	ESS_RM_MedFlo_LiquidFlows
			Gaseous / air flows	ESS_RM_MedFlo_GaseousAirFlows
		Mediation of waste toxics and other nuisances	Mediation by biota	ESS_RM_MedWast_MediationBiota
			Mediation by ecosystems	ESS_RM_MedWast_MediationEcosystems
	Cultural	Physical and intellectual interactions with biota ecosystems and land seascapes environmental settings	Physical and experiential interactions	ESS_C_PhysIntel_PhysicalExperientialInteractions
			Intellectual and representative interactions	ESS_C_PhysIntel_IntellectualRepresentativeInteractions
		Spiritual symbolic and other interactions with biota ecosystems and land seascapes environmental settings	Spiritual and/or emblematic	ESS_C_SpiritSymb_SpiritualEmblematic
			Other cultural outputs	ESS_C_SpiritSymb_OtherCulturalOutputs

Category (C) Ecosystem Services	Section (S)	Division (D)	Group (G)	ES code
Abiotic	Abiotic Provisioning	Energy abiotic	Renewable abiotic energy sources	ABO_P_EnAb_RenewableAbioticEnergySources
			Non-renewable abiotic energy sources	ABO_P_EnAb_NonRenewableAbioticEnergySources
		Abiotic materials	Water	ABO_P_AbMat_Water
			Metallic	ABO_P_AbMat_Metallic
			Non-metallic	ABO_P_AbMat_NonMetallic
		Nutritional abiotic substances	Water	ABO_P_NutAbSubst_Water
			Mineral	ABO_P_NutAbSubst_Mineral
			Non-mineral	ABO_P_NutAbSubst_NonMineral
	Regulation Maintenance by abiotic structures	Maintenance of physical chemical abiotic conditions	By natural chemical and physical processes	ABO_RM_MaintPhChAbioCond_ByNaturalChemicalPhysicalProcesses
		Mediation of flows by natural abiotic structures	By solid (mass), liquid and gaseous (air) flows	ABO_RM_MedFlo_BySolidLiquidGaseousFlows
		Mediation of waste toxics and other nuisances	By natural chemical and physical processes	ABO_RM_MedWast_ByNaturalChemicalPhysicalProcesses
	Cultural settings dependent on aquatic abiotic structures	Physical and intellectual interactions with land seascapes physical settings	Physical and experiential interactions	ABO_C_PhysIntel_PhysicalExperientialInteractions
			Intellectual and representative interactions	ABO_C_PhysIntel_IntellectualRepresentativeInteractions
		Spiritual symbolic and other interactions with land seascapes physical settings	Spiritual and/or emblematic	ABO_C_SpiritSymb_SpiritualEmblematic
			Other cultural outputs	ABO_C_SpiritSymb_OtherCulturalOutputs

Annex D: EU Red List Conservation Status only aquatic habitats considered (threatened categories CR: critically endangered; E: endangered; V: vulnerable; NT: near threatened).

Habitat EUNIS level 3	Critically Endangered	Endangered	Vulnerable	Near Threatened	Data Deficient
A1.2_Moderate_energy_littoral_rock					
A1.3_Low_energy_littoral_rock					
A2.1_Littoral_coarse_sediment					X
A2.5_Coastal_saltmarshes_and_saline_reedbeds			X		
A3.1_Atlantic_and_Mediterranean_high_energy_infralittoral_rock					
A3.2_Atlantic_and_Mediterranean_moderate_energy_infralittoral_rock					
A3.3_Atlantic_and_Mediterranean_low_energy_infralittoral_rock					
A4.1_Atlantic_and_Mediterranean_high_energy_circalittoral_rock					
A4.2_Atlantic_and_Mediterranean_moderate_energy_circalittoral_rock					X
A4.3_Atlantic_and_Mediterranean_low_energy_circalittoral_rock					
A5.1_Sublittoral_coarse_sediment			X		
A5.2_Sublittoral_sand		X			X
A5.3_Sublittoral_mud		X	X	X	
A5.4_Sublittoral_mixed_sediments			X	X	X
A5.5_Sublittoral_macrophyte_dominated_sediment			X		
C1.1_Permanent_oligotrophic_lakes_ponds_and_pools			X		
C1.2_Permanent_mesotrophic_lakes_ponds_and_pools					
C1.3_Permanent_eutrophic_lakes_ponds_and_pools					
C2.1_Springs_spring_brooks_and_geysers					
C2.5_Temporary_running_waters					X
C3.4_Species_poor_beds_of_low_growing_water_fringing_or_amphibious_vegetation			X		
C3.5_Periodically_inundated_shores_with_pioneer_and_ephemeral_vegetation				X	

AQUACROSS PARTNERS

Ecologic Institute (ECOLOGIC) | Germany
Leibniz Institute of Freshwater Ecology and Inland Fisheries (FVB-IGB) | Germany
Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO) | France
Stichting Dienst Landbouwkundig Onderzoek (IMARES) | Netherlands
Fundación IMDEA Agua (IMDEA) | Spain
University of Natural Resources & Life Sciences, Institute of Hydrobiology and Aquatic Ecosystem Management (BOKU) | Austria
Universidade de Aveiro (UAVR) | Portugal
ACTeon – Innovation, Policy, Environment (ACTeon) | France
University of Liverpool (ULIV) | United Kingdom
Royal Belgian Institute of Natural Sciences (RBINS) | Belgium
University College Cork, National University of Ireland (UCC) | Ireland
Stockholm University, Stockholm Resilience Centre (SU-SRC) | Sweden
Danube Delta National Institute for Research & Development (INCDDD) | Romania
Eawag – Swiss Federal Institute of Aquatic Science and Technology (EAWAG) | Switzerland
International Union for Conservation of Nature (IUCN) | Belgium
BC3 Basque Centre for Climate Change (BC3) | Spain

Contact aquacross@ecologic.eu
Coordinator Dr. Manuel Lago, Ecologic Institute
Duration 1 June 2015 to 30 November 2018

Website http://aquacross.eu/
Twitter @AquaBiodiv
LinkedIn www.linkedin.com/groups/AQUACROSS-8355424/about
ResearchGate www.researchgate.net/profile/Aquacross Project2