

Drivers of Change and Pressures on Aquatic Ecosystems – Executive Summary[1]

Overview

Biodiversity is declining in Europe as well as globally. Affected mainly by human-induced activities, species are currently being lost 100 to 1 000 times faster than the natural rate, mainly due to ecosystem degradation and/or over-exploitation of natural goods and services. Even though there has been significant political progress to protect ecosystems and their biodiversity (e.g., the EU 2020 Biodiversity Strategy), and despite the positive effects of previous conservation and restoration efforts, biodiversity decline has neither stopped nor slowed yet. Therefore, it is essential to evaluate the consequences of those human-induced activities on biodiversity to halt biodiversity loss and to sustain the provision of goods and services provided by aquatic ecosystems.

AQUACROSS aims to promote ecosystem-based management (EBM) of aquatic systems to ensure both the protection of biodiversity and the sustainable provision of ecosystem services. This requires a comprehensive view on the system as a whole, accounting for internal and external interactions and flows. The first step towards managing a system as a whole, and thus practicing EBM, is through understanding the various linkages and interactions between ecological and societal systems. Although the flows and connections within the social-ecological systems have been captured by the AQUACROSS Concept and Assessment Framework (see Deliverables 3.1 and 3.2 respectively), the more detailed operationalisation of driver-pressure-state analysis requires a clear and common understanding of drivers, human activities and pressures across the aquatic realms and across involved research disciplines.

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[1] *This is the executive summary of AQUACROSS Deliverable 4.1 Drivers of Change and Pressures on Aquatic Ecosystems – Guidance on Indicators and Methods to assess Drivers and Pressures. The full version of this document can be found at www.aquacross.eu in project outputs.*

This report aims to deepen the understanding of which drivers and pressures are relevant across the aquatic realms, by which methods they can be analysed, and which indicators are adequate to be considered. Accordingly, this report brings policy-relevant information together, screens scientific literature, and identifies approaches and indicators to better understand the relationships between drivers, pressures and ecosystem components across the aquatic realms. This report and the more detailed information provided in Deliverable 4.1 (D4.1) will especially support the work of the AQUACROSS case studies and will help to operationalise the AQUACROSS Assessment Framework. In other words, the provided knowledge should help AQUACROSS practitioners to identify and analyse the drivers and pressures affecting ecosystem states, in particular, helping to highlight those that can induce loss of aquatic biodiversity and change sustainability of the supply of ecosystem services.

Transdisciplinary Science

Support for political decision-making should build upon science. In the case of AQUACROSS, which aims to provide consistent analyses across all aquatic realms (i.e., freshwater, coastal and marine), an advanced understanding of how ecological and socio-economic systems interact is necessary. Accordingly, this document broadens the transdisciplinary understanding across the aquatic realms and across socio-economic and ecological research. Subsequently, the presented work represents an advance of existing knowledge by overcoming the sectoral limitations and providing a solid foundation for the further work on drivers, pressures and ecosystem states across aquatic realms but also across research disciplines, such as socio-economy and ecology, and stakeholders.

Translating Policy

Drivers and pressures are deeply grounded in the existing environmental policies of the European Union. However, the existing views that are strongly linked to these political frameworks are highly fragmented and entail incompatible terminologies. Thus, the first essential step to overcome this fragmentation is an alignment of the terminologies and a broad understanding of the trade-offs needed to properly address drivers and pressures. A streamlined understanding will increase the implementation speed and quality of EBM approaches.

Promoting Innovation and Business

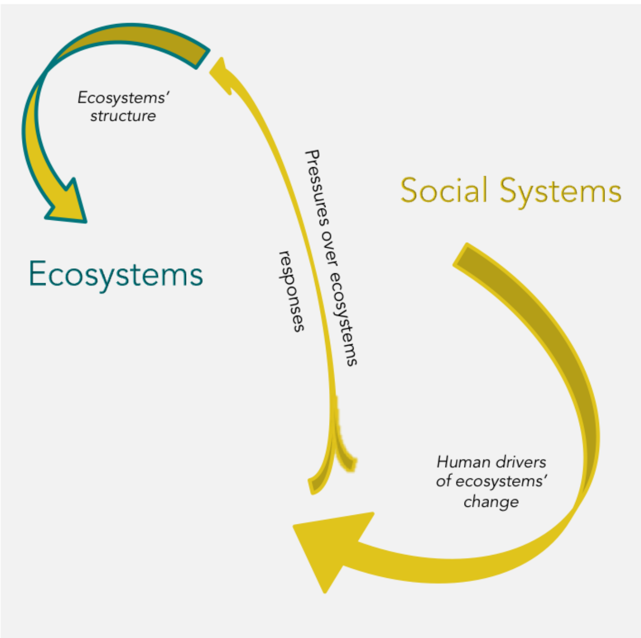
Despite the political dimension for sustainable management of aquatic ecosystems, the socio-economic systems and thus the business sector contain high potential to minimise the environmental consequences of human activities for aquatic biodiversity. Business in the broader sense, especially industry and the production sector, affect environmental change from the bottom. The identification of drivers and pressures across aquatic realms clearly underlines the need for and potentially stimulates innovation, creating space for new business solutions. More comprehensive information about the role of drivers and pressures will raise public awareness and, thus, strengthen the demand of environmentally friendly solutions. On the other hand, it allows the identification of areas where business solutions are not in place, opening the field for innovation.

1 Introduction

Biodiversity is generally declining in Europe as well as globally. This decline proceeds faster in aquatic than in terrestrial ecosystems. This trend is also reflected in the EU, where the current implementation of key environmental policies like the EU 2020 Biodiversity Strategy, the Birds and Habitats Directives, the Water Framework Directive (WFD), and the Marine Strategy Framework Directive (MSFD) are currently not seen as sufficient to effectively halt biodiversity loss. Despite shortcomings, such as the weak level of implementation or the need for better integration between policies, the societal demands on the environment have continuously increased in the last decades. Society depends on ecosystems in various ways, for example, to gain supply of materials (e.g., food, medicine, energy, shelter) or to provide space for recreational activities. This dependence of humans on natural systems has influenced ecosystems in all parts of the globe and in many different ways.

The AQUACROSS architecture as a whole is formed by two pathways linking the socio-economic and the ecological system. In more detail, the two pathways represent two sets of links: the first refers to how ecosystems are linked to human welfare; the second to how socio-economic systems shape and change ecosystems. From a societal perspective, these pathways can be named as the ‘supply side’ (i.e., ecosystems to society) and as the ‘demand side’ (i.e., society to ecosystems). The demand side explains how the drivers of ecosystems change and the responses to ecosystem challenges (the main outcomes of social systems) are linked to ecosystem structures. Thus, the analyses of drivers and pressures address the demand-side pathway (Figure 1), originating from the demand on ecosystem services and including the pressures on ecosystems. Social demand for ecosystem services and benefits manifest as drivers of ecosystem change. These drivers then create pressures within ecosystems by affecting the ecosystem structure, i.e. ecosystem state.

Figure 1: Demand-side relationships - use of ecosystem services by social systems



2 The AQUACROSS Project and D4.1

The AQUACROSS project, funded under the EU's Horizon 2020 Research and Innovation Programme, seeks to improve the management of aquatic ecosystems, thereby supporting the achievement of the EU 2020 Biodiversity Strategy and the Strategic Plan for Biodiversity 2011-2020. As part of Pillar 2 "Increasing Scientific Knowledge" of the AQUACROSS project, WP4 "*Drivers of change and pressures on aquatic ecosystems*" develops the drivers and pressures dimensions in more detail.

AQUACROSS Deliverable 4.1 - Drivers of Change and Pressures on Aquatic Ecosystems **deepens understanding of the Driver-Pressure-State (D-P-S) part of the Assessment Framework** by:

- Conceptualising how drivers, pressures and environmental states are intertwined in social-ecological systems;
- **Defining the drivers of ecosystem change, human activities and the resulting pressures** along the freshwater-marine continuum;
- Exploring the existing **qualitative and quantitative approaches** of D-P-S assessment systems;
- Characterising a suitable set of **pressure-sensitive indicators** across the different aquatic realms; and
- Proposing integrative indicators, especially for newly emerging drivers and pressures based on currently used cost-effective indicators.

3 Drivers and Pressures across Aquatic Realms

Although ecologically and socially linked, the different aquatic realms have mainly been investigated by autonomous research disciplines. This separation is further emphasised in high level EU environmental policies (e.g., WFD and MSFD). These different policies artificially divide the management of the aquatic realms and impede the implementation of integrative (ecosystem-based) solutions, thus also impeding the cessation of the loss of biodiversity.

The following hierarchy of elements forms the starting point to understand the drivers of ecosystem change. Firstly, **social processes** provide the basis to understand the demand of ecosystem services as well as the governance institutions in place. Furthermore, the **drivers of ecosystem change** refer to the decisions to utilise and transform ecosystem services within the market economy and the overall socio-economic system mediated by policy institutions, technology and social values. Finally, the **pressures** qualitatively and quantitatively describe how the socio-economic system affects the aquatic ecosystems.

Drivers - Pressures - States and beyond

In order to account for environmental changes in socio-ecological systems, conceptual frameworks have been employed that allow a categorisation of information to capture causes and the nature of change in ecosystem state, as well as the impacts of change on human welfare. In many cases, these frameworks have been based on the frequently used DPSIR (Driver-Pressure-State-Impact-Response) concept, a framework used to conceptualise interactions between society and the environment by formalising the relationships between drivers, resulting in pressures over ecosystem states through impacts propagating some kind of response. These relationships can be arranged by impact chains.

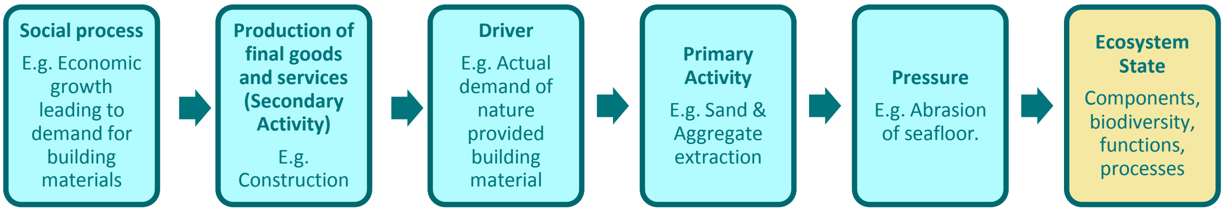
Even though the DPSIR framework is in widespread use, it has been substantially criticised for not being able to account for feedback processes, for only looking at one pressure and not accounting for multiple pressures, not explicitly linking to human welfare, not allowing consideration of trade-offs between natural use, conservation and enhancement and finally, for being reactive rather than proactive. Considering the broader AQUACROSS architecture (Figure 1), it is clear that the DPSIR framework does not encompass all necessary elements. Accordingly, AQUACROSS extends the concept to consider the social processes and the wider economic activities that explain the demand of nature-provided services that represent the actual drivers of change.

This goes beyond the 'Driving forces' covered in the classic DPSIR frameworks. Subsequently, drivers are defined as the demand of the supply of ecosystem services. This demand results from social processes, such as economic growth, and the production of final goods and services, which require ecosystem services and abiotic outputs from nature. As shown in Figure 2, we make a critical distinction between the activities devoted to the production of final goods and services (that may explain the demand of the services of natural capital, including all ecosystems services and abiotic outputs, that we consider the drivers of change), and the primary activities devoted to the co-production of nature-provided services in this expanded D-P-S framework. The higher level processes, such as population or economic growth, demographic and technological factors, are considered as the 'social' processes. These processes influence economic activities and the demand for ecosystem services. Furthermore, 'secondary activities' as the economic activities that produce final goods and services directly result in a demand for an ecosystem service that represents the 'driver'. Finally, the 'primary activities' are directly involved in the exploitation of ecosystem services and introduce 'pressures' to the ecosystem from which those services are supplied. These primary activities combine human effort and capital with natural capital to co-produce and convey to the social system the goods and services such as water, energy, fish, minerals, navigation, etc. to fulfil social demands. Indeed one primary activity may be the source of multiple pressures and any single pressure may be caused by more than one activity such as a many-to-many relationship in a relational database.

The physical, chemical and biological nature of Pressures

The term 'pressures' is strongly related to environmental policies and the application of the DPSIR concept into environmental assessment schemes is necessary to understand the relationships behind state changes. The wider perception of the term pressure mostly suggests a negative effect on the ecosystem. However, the effect of a pressure does not necessarily imply only negative effects for all parts of the ecosystem. Indeed, a pressure is a mechanism that has any kind of effect on the environment, respectively on ecosystem state. In the context of AQUACROSS, a pressure is always related to an anthropogenically induced effect on the state of an ecosystem. In turn, this does not explicitly exclude the consideration of natural factors from analyses as an impact is implied when the effect of a pressure alters an ecosystem component in such a manner that the change seen is beyond what would be expected due to natural variability. However, several pressures can interact in their effect on the ecosystem, implying that their combined effect is different to the simple addition of the single individual effects. Today, a complex mixture of physical, chemical and biological pressures exists that impair the functioning of ecosystems and can affect the provision of ecosystem services.

Figure 2: Relational chain from a social process through human activities and Pressures to a change in ecosystem State.



Relational chains, as used in the linkage framework developed in the ODEMM project, serve as an operational framework to characterise activities, pressures and ecosystem state components and their interrelationships, thus basically characterising the socio-ecological system and serving as a starting point for further analyses. Compiling information on the many relational chains interacting in a socio-ecological system, allows compounding multiple economic activities and various relevant social processes, resulting in the aggregate demand of specific services provided by a primary sector of the economy.

Linking Drivers and Pressures across aquatic realms

As AQUACROSS aims to use existing knowledge and generate a common assessment and management perspective to strengthen the linkages between existing policies relevant for aquatic ecosystems, a common understanding on drivers, human activities and pressures across aquatic realms and across the different disciplines within the socio-ecological system is much needed. This is not without difficulty because, as discussed above, the use of terminology and interpretation of what would count as a driver and pressure varies between the different policies and their associated typologies but also differs within the scientific community.

In order to create a common basis and to enable the identification of common drivers and pressures across the realms, common typologies of primary activities and pressures have been developed. These typologies are based on previous classifications including those from the WFD, the MSFD, the Habitats Directive (HD) and the statistical classification of economic activities (NACE). Furthermore, they consider existing knowledge found in the scientific literature. Even though the typologies here attempt to be more comprehensive, none of them can capture all of the relevant human activities and pressures for all aquatic ecosystems. However, in Table 1, we provide examples that attempt to be comprehensive, although fully exhaustive. These typologies enable a consistent work on drivers and pressures across all aquatic realms in the AQUACROSS case studies. Generally, the primary activities can fit within broad activity types Table 1, as the primary activities will be specific to a case study region or locality. Some primary activities can fit under more than one broad activity type, and this may depend on the secondary activity driving the primary activity. Subsequently, the primary activities can be linked to pressure categories and their associated pressures (Table 1).

Table 1: AQUACROSS Pressure categories, number of associated pressures, and broad categories for primary activity types

Pressure Categories		AQUACROSS Primary Activity Types	
	Biological disturbance Associated Pressures: 5		Agriculture & Forestry Aquaculture Fishing
	Chemical change, chemicals and other pollutants Associated Pressures: 8		Environmental Management Manufacturing (land-based)
	Physical change Associated Pressures: 16		Waste management Residential & Commercial Development
	Energy Associated Pressures: 4		Services (e.g. transport, utilities, water supply, defence) Mining, extraction of materials
	Exogenous/Unmanaged (e.g., due to climate change) Associated Pressures: 8		Non-renewable energy Renewable Energy Tourism, recreation & non-commercial harvesting

4 Approaches to investigate Drivers and Pressures

The investigation of drivers and pressures comprises firstly the analyses of social processes to explain the drivers of ecosystem change as outcomes of economic and social processes, secondly the analyses of the linkages between drivers and pressures and finally the linkage between pressures and ecosystem states. The basic purpose is to analyse how drivers and pressures can be connected to better understand the links between them. To do so, tools are required to analyse the relationships between drivers, pressures and ecosystem state. Furthermore, these tools enable the implementation of scenarios and storylines to explore the robustness of management strategies.

The identification, description and analysis of drivers of change should go beyond the usual comprehension (from the natural science side) of only interpreting drivers in terms of the human activities directly introducing pressures into the ecosystem. Firstly, the assessment of drivers must be purposely designed to contribute to two central objectives:

(1) Descriptively, the assessment must provide the elements to select from the multitude of ways how society triggers changes in nature by identifying those that result in significant ecosystem changes.

(2) Analytically, the assessment of drivers must be designed to provide the best possible understanding of societal choices about both, the demand for relevant ecosystem services and abiotic outputs, and the technology choices to meet those demands.

Thus, the assessment can be organised in two parts. The first one concerns the comprehensive description and representation of the drivers and pressures and compiles available information for its assessment, comparable to a screening approach. The second one refers to the analytical dimensions of the assessment and is linked to the analysis of the economic and social drivers on the demand side of ecosystems services and abiotic outputs.

Social and economic analysis for Driver assessment

The drivers of change in ecosystems are outcomes of social processes and are linked to both, the socio-economic activities that provide the final goods and services people care about, and the primary activities that co-produce and convey to the social system all the services and outputs provided by aquatic ecosystems. The analysis of drivers is then the equivalent to the study of these activities and social processes that result in the specific demands for ecosystems services and abiotic outputs. These analyses combine quantitative and qualitative approaches from social sciences in general, and from economic analysis in particular.

The definition of drivers as the demand for goods and services provided by nature, gives an important role to demand analysis, and therefore, to the analytical and empirical approaches to explain the demand for services and abiotic outputs from all relevant economic activities.

Qualitative approaches

The development of a linkage matrix, i.e. a matrix linking case study-relevant primary activities, pressures and ecosystem state characteristics based on a literature research, is recommended for each case study within AQUACROSS. An organised linkage framework approach enables the categorisation of information to capture multiple causes of change in ecosystem components and impact on human welfare. Adequate literature can be identified by search terms in scientific literature databases and based on a snowball principle. The linkage framework basically builds on the DPSIR approach, but goes beyond the limitations of DPSIR to fulfil the needs of EBM. It especially helps to identify and visualise the different system components and their manifold relationships and interlinkages as well as to provide decision support and to explore management options and can be used as the basis for exploratory analyses of the system, including simple network analyses. It also facilitates the consideration of feedback loops. Thus, the linkage framework provides an operational framework within the overall AQUACROSS architecture, by characterising the system.

By simply taking the linkage matrices, it is possible to examine the complexity and connectivity in the aquatic ecosystem. The developed matrix can then be used to frame detailed qualitative and quantitative analyses to investigate the relationships of drivers, activities, pressures and ecosystem states. This is accounted for through the consideration of ecosystem state characteristics, which will in turn facilitate the identification of pathways through which primary activity-pressure-ecosystem state characteristics link to ecosystem services. A primary activity that causes a pressure, which leads to a change in ecosystem state, can cause an impact on the supply of an ecosystem service, feeding back to the social system.

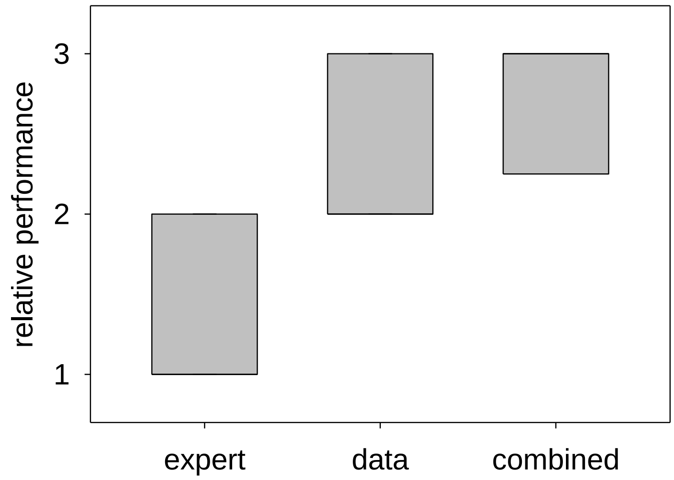
Thus, the linkages can be traced from the social, demand side to the ecological, supply side, and back to the social system.

Quantitative models and tools for analysis of Drivers and Pressures

The analysis of different approaches and modelling techniques allows the evaluation of their applicability and usability for the investigation of drivers and pressures. A review and meta-analysis of alternative quantitative and qualitative methods showed that model performance can vary substantially dependent on the structure of available data and information. Furthermore, model selection should be done on a case specific basis. The following trade-offs were identified leading to implications for the implementation of different methods in the case studies:

- Complexity versus interpretability (causality): Many machine learning and ensemble techniques (especially random forest, artificial neural networks or support vector machines) produce highly reliable models with excellent performance also under high dimensionality (high number of predictors and their possible interactions), but this advantage comes along with a low interpretability since those techniques have no simple way of graphical representation and are highly complex compared to simpler regression and machine learning techniques. If the results should be used as a communication tool for management, simpler methods with a good graphical representation and straight-forward interpretability (including generalised linear models or classification and regression trees) should be preferred, whereas for complex situations including interactions and hierarchical structure of drivers and pressures, complex methods may hold more advantages. A promising tool is Bayesian Belief Networks (BBNs), which are specific for their useful visual depiction and high potential to produce models of high accuracy also under high dimensionality, but quantitative applications of BBNs are so far not intensively tested against other methods.
- In-sample performance versus transferability: There is a known trade-off between in-sample accuracy and transferability in dependency of model complexity. If model results should be general and transferable to other systems, simpler model applications (such as linear models or generalised additive models) or less complex model structures (lower dimensionality) are better.
- Data versus expert knowledge: The quality of data driven models is highly dependent on the quality as well as quantity of the available data, likewise the reliability of expert driven models directly depends on the available expert knowledge in the field. Selection of methods should be done dependent on the available data and knowledge of a respective system. Combined approaches (e.g., by using Bayesian Believe Networks) often produce the most reliable, robust and interpretable models (Figure 3).

Figure 3: Relative performance of expert knowledge vs. data vs. combined modelling methods



Furthermore, analyses have shown that evaluation is essential for the development of reliable explanatory or predictive models, independent of whether the models are data or expert-based. Various strategies for model validation are available, including goodness-of-fit tests, cross-validation, using independent test date for validation, sensitivity analysis, expert knowledge (e.g., validation by stakeholders) or comparison against other models representing the same problem. Parallel or combined application of different modelling techniques (including qualitative and quantitative methods) to the same analytical problem is likely to increase robustness and importance of results.

5 Pressure-sensitive indicators

Ecological indicators are considered necessary to evaluate effect-oriented nature and environmental policy. Ecological indication is often considered to provide information by a limited set of measurable parameters to make an assessment of an entity that is not directly accessible. However, scientific and applied demands frame and define correctness and applicability of the indicator. Even though the term pressure-sensitive is rather broad, here we focus on how drivers, human activities and pressures are linked to ecosystem components, i.e. ecosystem states.

Characteristics and definitions of indicators

The term 'indicator' is widespread in use. In general, indicators provide aggregated information on specific targets, and try to depict qualities, quantities, states or interactions that are not directly accessible. Effective environmental management requires that the condition of complex environmental systems is captured in one or more simple figures or indicators understandable from policy- and decision makers to the general public. Hence, indicators are communication tools to supply information between science, policy, decision makers, stakeholders, as well as the broader public. A clear and common understanding of the concepts of indicators, indices and metrics is required. In AQUACROSS we will consider the following definitions:

- **Indicators** are variables that provide aggregated information on certain phenomena, acting as a communication tool facilitating a simplification of a complex process. An indicator relates to a component or process responsive to changes in the social-ecological system, but does not necessarily possess a measurable dimension, and therefore it is not an operational tool in itself.
- **Indices** are metrics whose final outcome should be easily interpreted by a non-specialist within a qualitative continuum. It can be a quantitative or qualitative expression of a specific component or process, to which it is possible to associate targets and to identify trends, and which can be mapped. It is how an indicator becomes an operational tool used within a management, regulatory or policy context.
- **Metrics** are quantitative, measured, calculated or composite measurements based upon two or more measurements that help to put a variable in relation to one or more other dimensions.

Further, there are scientific as well as applied demands on indicators. Scientific correctness comprises a clear representation of the indicandum by the indicator, a proven cause-effect relation, an optimal sensitivity of the representation, information on adequate spatio-temporal scales, transparency including a reproducible methodology, a high degree of validity and representativeness of the available data sources, an optimal degree of aggregation. The practical applicability of indicators is related to information and estimations of the normative loadings, high political relevance, high comprehensibility and public transparency, relations and responsiveness to management actions, an orientation towards environmental targets, a satisfying measurability, a high degree of data availability, a high utility for early warning purposes, and information on long-term trends of development. Finally, cost-effectiveness is also a crucial factor.

Integrative indicators

The AQUACROSS architecture evolves from the traditional DPSIR cycle by explicitly considering ecosystem functions and services, human well-being, and both social as well as ecological processes. To enhance the functioning of aquatic ecosystems and to preserve their inherent biodiversity, pressure-sensitive, integrative indicators are key to inform about and to identify primary activities and pressures that affect ecosystem components. Despite quantifying and indicating the primary activities and pressures themselves, the characterisation of ecosystem components by biological or abiotic descriptors (i.e., indicators, metrics as well as indices) that can be used to relate them to pressures and thus quantify impacts are widely in use.

The characterisation of biodiversity status and trends is inevitable to stop the loss of biodiversity. Even though the commitments taken by the EU have been reflected in the Convention on Biological Diversity in 2010, there is a much longer history in European indicators to characterise biodiversity, and respectively, to characterise the drivers and pressures that affect it. An exhaustive list of biodiversity-related indicators in Europe from 2003 already more or less contains all relevant issues that can be measured. Meanwhile, there are an enormous variety of indicators that have been developed to assess several aspects of biodiversity at different scales and extents covering local conditions, countries and continents.

The two major environmental policies relevant for aquatic ecosystems, the WFD and the MSFD, already aim to implement indicators that together describe the status of the ecosystem. Within the WFD the ecological status and the chemical status of a surface water body is the overall relevant indicator. The latter is mostly related to water quality measurements. The former expresses the quality of the ecological structure and functioning within the surface water body. The assessment of the ecological status is based on biological quality elements (BQEs) comprising fish, benthic invertebrates, phytoplankton as well as macrophytes and phytobenthos, i.e. these biological elements are used as indicator of the ecosystem state.

In contrast to the WFD, in the MSFD, marine ecosystems are divided into a set of process-based descriptors, including biological diversity, introduction of non-indigenous species, integrity of food-webs, eutrophication, and properties of marine litter or alteration of hydrographical conditions, which are recombined within a holistic framework and therefore explicitly address the detection of impacts from multiple human pressures. However, with an increasing number of pressures, the need for a greater understanding of the relationships between multiple human pressures and their effects on the ecosystem also increases to enable the development of robust strategies for the management of aquatic ecosystems and their ecosystem services.

Finally the identified indicators are integrated into the developed AQUACROSS concept for drivers, human activities, pressures and ecosystem state as well as in the developed concept of indicators, metrics and indices. A summary of the integrated indicators with examples of indicators is provided for human activities, pressures (Tables 2 and 3) and ecosystem state (Table 4) below. This set of indicators should enable the structuring and organisation of information needed to assess effects within and across different parts in the social-ecological system and to allow for the linkage between the demand side and supply side analyses.

Table 2: Examples of AQUACROSS primary activities and indicators

Broad category of primary activity	Primary activity	Indicators
Agriculture and Forestry	Cultivation Forestry activities Livestock	Agricultural area and intensity Area and intensity of forestry management Benefits from domesticated species
Aquaculture	Aquaculture total and per component	Aquaculture production per component
Fishing	Commercial fisheries per component	Capacity of commercial fisheries per component
Waste management	Sewage treatment	Proportion of population with sewage treatment
Services (e.g., transport, water supply)	Transport (terrestrial) Water use Urban development Shipping, total and per sector	Density of infrastructure network and traffic intensity Use of ground water Population density and built-up area Shipping intensity per sector
Non-renewable energy	Energy per sector and total	Energy per sector and total
Renewable Energy	Energy per sector and total	Use of renewable energy per sector
Tourism Recreation	Tourism intensity per sector and total	Benefits from tourism services, Tourism intensity per category

Table 3: Examples of AQUACROSS Pressures and proposed indicators

Pressure Category	Pressure	Indicator
Biological disturbance	Introduction of microbial pathogens	Introduction and distributions of aquatic pests and disease
	Introduction of IAS	Presence, numbers of invasive species
	Translocation of species	Genetic modification & translocation of indigenous species
	Selective extraction of species	Removal of target species or non-target species
Chemical change, pollution	Salinity change	Salinity status, Physical loss (to land or Freshwater habitat)
	Hazardous substances	Introduction of substances (solid, liquid or gas), contamination in critical points
	Emission of nutrient and organic substances	Deposition and emission of nutrients and organic substances per pathway
	Litter	Litter– Quantity, composition and distribution of litter
Physical change	Selective extraction non-living resources	Water abstraction and consumption
	Water flow rate change & abstraction	Water flow changes, hydrological alteration
	Visual disturbance	Visual disturbance, introduction of light
	Disturbance of substrate	Physical anthropogenic disturbance of substrate; Abrasion
	Barrier to species movement	Barrier to species movement, fragmentation
	Changes in siltation, Smothering	Smothering, siltation and sedimentation rate changes
	Conversion and destruction of habitat	Habitat loss and fragmentation due to human activities
	Death or injury by collision	Death or injury by collision
	Emergence regime change	Emergence regime changes – local, including tidal level change considerations
Energy	Electromagnetic changes	Electromagnetic changes
	Underwater Noise	Quantity and changes in (underwater) noise
	Thermal change	Thermal change of water bodies
Exogenous/Unmanaged	Emergence regime change	Trends in sea level
	Thermal change	Trends in air and water temperatures
	Water flow rate changes	Trends in flood and drough events
	pH changes	change in acidification
	Precipitation regime change	Change in precipitation and water balance

Table 4: Ecosystem State and indicators

	Chemical State	Biological State	Physical State
Indicators	pH, acidification status	Macrophytes	Disturbance of substrate
	Salinity status	Phytoplankton	Thermal conditions
	Conductivity	Plankton blooms	Change in wave exposure
	Hazardous substances	Benthic invertebrates	Alteration of morphology
	Nutrients and organic substances	Fish	Bottom sediment
	Water quality	Eutrophication	Hydrological regime
		Waterbirds	
		Mammals and reptiles	
		Habitat	

6 Conclusions

As the AQUACROSS project aims to support the achievement of the EU biodiversity targets and to promote the implementation of EBM across the aquatic realms, a deeper understanding on drivers and pressures is clearly needed. This deeper understanding includes an alignment of different views that are scattered through research disciplines and environmental policies. D4.1 summarises the cross-sectoral consensus on drivers, human activities and related pressures that are all relevant to understand changes in ecosystem state. Hence, it contributes to the discussion of links between drivers, human activities, pressures and ecosystem states and provides an essential basis to bridge different understandings as well as for the further work in the AQUACROSS case studies.

To develop and implement EBM solutions, it is necessary to consider the relationships and connections from the social to the ecological system. Thus, the analyses of the demand-side relationships of the AQUACROSS architecture must consider social processes including the economic sector. Based on the analyses of the socio-economic relationships it is possible to characterise the demand of goods and services provided by nature that ultimately drive the activities that enforce the pressures over the aquatic ecosystems. By this approach additional insights into DPSIR-based relationships (and moving beyond to ecosystem services) and especially on the relationships between the socio-economic and the ecological systems can be provided.

Common typologies have been developed that are in line with nomenclatures found in the existing environmental policies and represent the basis for consistent analyses across the aquatic realms and to populate the different aspects of the relational chains between society and ecosystems. It is recommended that linkage framework matrices linking case study-relevant primary activities, pressures and ecosystem state characteristics are developed for each case study under Task 4.2, also working through Task 5.2 to make sure that the links can be established to ecosystem services being studied in the case study systems. The linkage matrices and overall framework developed for each case study can then be used to recognise the full array of interactions and to help consider what approaches to use to evaluate each socio-ecological system. Thus, these matrices will provide a detailed view on the drivers and pressures in the aquatic realms. The mechanisms through which activities affect the ecosystem can be physical (e.g., abrasion), chemical (e.g., contamination) or biological (e.g., introduction of disease) in nature. In the context of AQUACROSS a pressure should always be related to an anthropogenically induced effect (from a human activity) on the state of an ecosystem.

The AQUACROSS case studies cover several types of aquatic ecosystems and a wide range of environmental conditions (from Northern Europe till the North-African coast). Accordingly, neither it is impractical to prescribe indicators, metrics or indices for the analyses in detail, nor it is possible to list all of them that are existing and potentially applicable. However, the indicators described can be easily integrated into the linkage framework and they are in line with the AQUACROSS definitions for indicators, indices and metrics.

In D4.1, we have described many of the conceptual and methodological issues required to explore drivers of change and their pressures acting in aquatic realms, highlighting the following points:

- Consistent terminologies across aquatic realms but also across scientific disciplines are essential
- A clear and common concept of indicators, metrics and indices builds the basis to extend the work on drivers-pressure-states to ecosystem services and functions
- Combined approaches integrating models based on data and expert-knowledge can provide robust results
- Requirements for a "good" indicators and modelling approaches must be considered to enable a robust communication between science, policy and stakeholders.

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

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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 the Conservation of Nature (IUCN)—Belgium

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Suggested Citation: Pletterbauer, F., Funk, A., Hein, A., Robinson, L., Culhane, F., Delacámara,G., Gómez, C.M., Klimmek, H., Piet, G., Tamis, J., Schlüter, M., Martin, R., 2016. "Drivers of change and pressures on aquatic ecosystems: Deliverable 4.1 Executive Summary." Report as part of the Horizon 2020 project AQUACROSS (Knowledge, Assessment, and Management for AQUAtic Biodiversity and Ecosystem Services aCROSS EU policies).