aquacross

Drivers of change and pressures on aquatic ecosystems

Guidance on indicators and methods to assess drivers and pressures

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

Authors

Florian Pletterbauer, Andrea Funk, Thomas Hein (BOKU)

Leonie Robinson, Fiona Culhane (ULIV)

Gonzalo Delacámara (IMDEA) , Carlos M. Gómez (UAH)

Helen Klimmek (IUCN)

GerJan Piet, Jacqueline Tamis (IMARES)

Maja Schlüter, Romina Martin (SRC)

With thanks to:

Daniel Hering (UNIDE; AQUACROSS Science-Policy-Business Think Tank);

Manuel Lago, Katrina Abhold and Lina Roeschel (ECOLOGIC)

Project coordination and editing provided by Ecologic Institute.

Manuscript completed in November, 2016, revised version January, 2017

Document title	Guidance on indicators and methods to assess drivers and pressures
Work Package	WP 4
Document Type	Deliverable
Date	13th January 2017

Acknowledgments & Disclaimer

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

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: AQUACROSS Deliverable 4.1”, European Union’s Horizon 2020 Framework Programme for Research and Innovation Grant Agreement No. 642317.

Table of Contents

About AQUACROSS 2

1 Background and Objectives 3

2 Introduction 5

2.1 Conceptual framework: DPSIR and beyond 6

2.2 Definitions and constraints on the expanded D-P-S part of AQUACROSS 10

2.3 Summary 13

3 Drivers and Pressures Along the Freshwater-marine Continuum 14

3.1 Drivers and pressures from the policy perspective 14

3.2 The drivers of change in ecosystems 20

3.2.1 Newly emerging drivers 25

3.2.2 Summary 26

3.3 Pressures and the primary activities that introduce them 27

3.3.1 Common typologies of pressures and primary activities 28

3.3.2 Representing and quantifying pressure effects 32

3.3.3 Summary 32

3.4 A framework approach to linking drivers and pressures, ecosystem states (and services) across aquatic realms 33

3.4.1 Uses of the linkage frameworks developed 34

3.4.2 Potential for extension of the linkage framework developed 36
3.4.3 Summary 36
4 Approaches to Investigate Drivers and Resulting Pressures 38
4.1 Social and economic analysis for the assessment of drivers 39
4.2 Quantitative approaches to assess the links between drivers, pressures and ecosystem components 40
4.3 Meta-analysis of strategies for quantitative model fitting 47
4.4 Model validation 49
4.5 Comparison of quantitative models 49
4.5.1 Methods 49
4.5.2 Results 51
4.5.3 Discussion 52
4.5.3.1 Quantitative, qualitative or both 53
4.6 Summary 55
5 Pressure-sensitive Indicators 57
5.1 Characteristics of indicators 57
5.1.1 Uncertainty associated with indicators 59
5.2 Identification of currently used and cost-effective indicators 59
5.2.1 Indicators related to biodiversity 60
5.2.2 Indicators related to the Water Framework Directive 62
5.2.3 Indicators related to the Marine Strategy Framework Directive 64
5.2.4 Further examples of indicators in use for the marine environment 67

5.3 Integrative indicators 68

5.3.1 Integrative indicators for primary activities, pressures and ecosystem components 68

6 Conclusion 82

6.1.1 Guidance to identify drivers of change 82

6.1.2 Guidance to identify pressures 83

6.1.3 Guidance on linkage framework 83

6.1.4 Guidance on modeling approaches 84

6.1.5 Guidance on indicators 85

6.1.6 Final thoughts 86

7 References 87

8 Annexes 110

List of Tables

Table 1: Pressure categories and single pressures listed in the MSFD 17

Table 2: Pressures according to the WFD 19

Table 3: Proposed Aquacross Activity types and (non-exhaustive) examples of more specific primary activities within those types, that co-produce nature based goods and services, which can directly cause pressures in the ecosystem. 29

Table 4: Proposed Aquacross Pressures categories relevant to aquatic realms identified from the alignment of threats and pressures from the HD, MSFD, WFD 31

Table 5: Description of available quantitative methods (alphabetical order) with references for method details and examples for D-P-S application. 43

Table 6: Correlation analysis between relative performance of nine models 50

Table 8: Overview of the biodiversity-related indicators per sector 60

Table 9: Position in the DSPIR cycle of the 37 EEA core set indicators 61

Table 10: Overview of WFD state indicators 63

Table 11: Percentage of metric types used in freshwater bio-assessment 64

Table 12: Overview of the MSFD descriptors 66

Table 13: Proposed set of integrative indicators describing activities 70

Table 14: Proposed set of integrative indicators describing pressures. 73

Table 15: Proposed set on integrative indicators describing state/ecosystem components. 80

List of Figures

Figure 1: The AQUACROSS Architecture 4

Figure 2: The DPSIR (Driver-Pressure-State-Impact-Response) cycle 7

Figure 3: DPSIR adapted to Driver-Pressure-State(change)-Welfare(change)-Response (DPSWR) 8

Figure 4: A further iteration of DPSIR to DAPSI(W)R(M) 9

Figure 6: Single relational chain from a social process through human activities to pressures that lead to a change in ecosystem state. 10

Figure 7: The six targets of the Biodiversity Strategy 15

Figure 8 Share of pressure types in freshwater ecosystems based on Stendera et al (2012); N=353 28

Figure 9 Multiple impact chains 35

Figure 11: Relative performance of ten statistical model types 51

Figure 12: Relative performance of the three model types data-driven, expert-based and combined. 55

Figure 14: Relative portion of the SEBI 2010 indicators in the DPSIR categories. 62

Figure 15: Comparison of status assessment between WFD and MSFD 65

List of Boxes

Box 1: Definition of Indicators, Index, Metric and Measure in the context of AQUACROSS 58

List of Annexes

Annex 1: Studies included in the meta-analysis on quantitative and qualitative model applications 110

Annex 2: List of all biodiversity-related indicators (EEA, 2003b) 112

Annex 3: The Streamlining European Biodiversity Indicators 2010 with focal areas of the Convention on Biological Diversity plus an assignment of the position in the DPSIR cycle 144

Annex 4: Marine Strategy Framework Directive indicators (S=state, I=impact, P=pressure) (EC, 2011b) 146

Annex 5 Integration table, linking state characteristics to pressures through impacts (EC, 2011b) 150

Annex 6: United Kingdom pressure benchmarks (from Tillin and Tyler-Walters, 2015) 151

Annex 7: Common indicators of OSPAR 154

Annex 8: Additional OSPAR common indicators for Regions 155

Annex 9: Pressure indicators of the MARMONI project (Martin et al. 2014) 156

List of Abbreviations

AF	Assessment Framework
AIC	Akaike Information Criterion
BBN	Bayesion Belief Network
BD	Birds Directive
BIC	Bayesian Information Criterion
CART	Classification and regression tree
CBD	Convention on Biological Diversity
CICES	Common International Classification of Ecosystem Services
D-P-S	Driver-Pressure-State
DPSIR	Driver-Pressure-State-Impact-Response
EBM	Ecosystem Based Management
EC	European Commission
EEA	European Environment Agency
EU	European Union
GBM	Generalised boosting method
HD	Habitats Directive
MARS	Multivariate adaptive regression spline model
MSFD	Marine Strategy Framework
NACE	Statistical classification of economic activities in the European Community
OECD	Organisation for Economic Co-operation and Development
RBMP	River Basin Management Plan
RF	Random forest
RMSE	Root-mean-squared error
SDM	Species distribution modeling
SEBI	Streamlining European Biodiversity Indicators
SEM	Structural equation modeling
SVM	Support vector machines
WFD	Water Framework Directive
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 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 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.

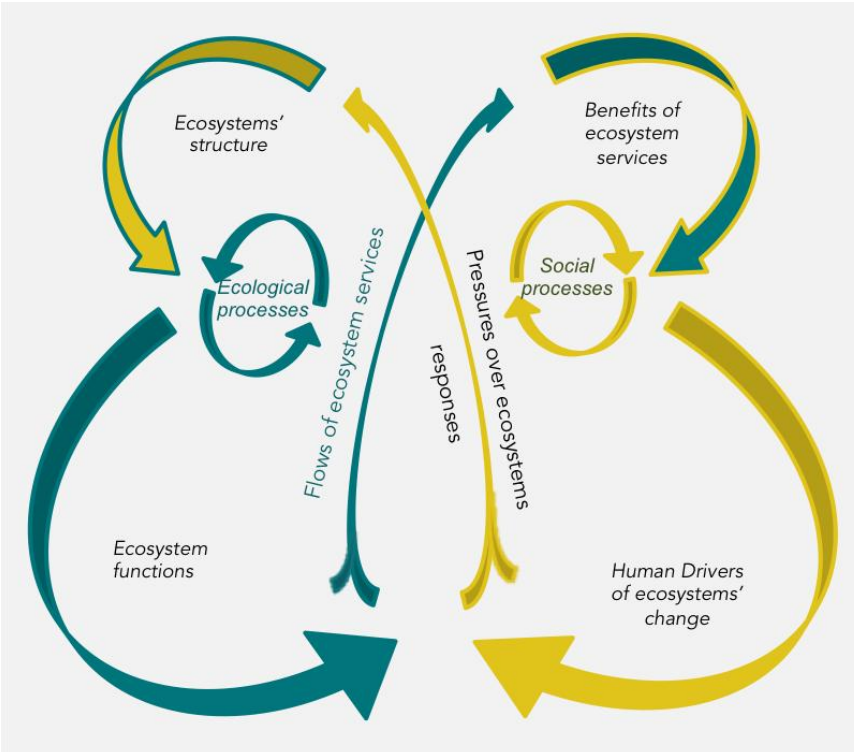
According to the structure of the AQUACROSS project, Work Package (WP) 4 builds on and forms part of the Assessment Framework (AF) developed in WP3. Task 4.1 builds the basis for the analysis of drivers of change and pressures on aquatic ecosystems (WP4) and should provide guidance for the analyses performed within the case studies. Hence, this Deliverable (D4.1) aims at the AQUCROSS consortia partners, in order to help guide their work going forward under Task 4.2. Within this deliverable, the following objectives are addressed:

- Conceptualise how drivers, pressures and environmental states are interwoven across the aquatic realms and in relation to complex social-ecological systems
- Define the role of drivers that directly or indirectly act on different levels, the interacting effects of these drivers, related human activities and the resulting pressures along the freshwater-marine continuum
- Deepen the understanding of the Driver-Pressure-State (D-P-S) part of the AF by exploring the existing qualitative and quantitative approaches of D-P-S assessment systems
- Identify the most suitable set of pressure-sensitive indicators, including indicators for ecosystem state
- Propose integrative indicators especially for newly emerging drivers and pressures based on currently used cost-effective indicators

The AQUACROSS Innovative Concept (Gómez et al., 2016) considers social (including economic) and ecological systems as being complex, adaptive, and mutually interdependent. To understand both systems and their connections, the AQUACROSS Architecture (Figure 1) considers two interrelated sets of linkages between the ecological system and the socio-economic system: the supply-side perspective, which describes the capacity of the ecological system to deliver services to the social system, contributing to human welfare, and the demand-side perspective, through which the socio-economic system affects the ecosystem. Task 4.1 addresses the relationships described by the demand-side perspective, to investigate how driving forces of the social systems, i.e. human sectors, cause pressures, which may impact the ecological system.

A broad review of existing knowledge will explain how drivers, pressures and the state of ecosystems are defined, described and linked across the different aquatic realms. This will consider, on the one hand, the information gained during the development of the AF in WP3, which reviewed basic concepts and knowledge on drivers and pressures, and, on the other hand, information gained through other EU-funded projects (e.g., ODEMM, MARS, BioFresh, Devotes). Accordingly, this deliverable will essentially contribute to an aligned and common understanding of drivers and pressures across the aquatic realms and across the disciplines represented in AQUACROSS. The disambiguation of terms and the precise definition of drivers and pressures across the aquatic realms are a quintessential requirement for the work within the AQUCROSS case studies. Furthermore, recommendations on assessment concepts and analytical approaches for D-P-S relationships will be made to guide the identification of drivers and related pressures as well as their effects on ecosystem states in the case studies. Finally, basic principles of indicators will be highlighted and pressure-sensitive indicators will summarised and described.

Figure 1: The AQUACROSS Architecture



Source: Gómez et al. (2016)

Task 4.1 reviews the concepts, data and analyses that are relevant for evaluating and understanding demand-side relationships, i.e. those aspects covered by the larger yellow arrows in the figure (e.g., human drivers, pressures and ecosystem responses).

2 Introduction

Biodiversity is threatened or declining across all aquatic realms and biogeographical regions globally, with pressures related to human activities well documented in driving these changes (Dudgeon et al., 2006; Vörösmarty et al., 2010). Most aquatic ecosystems are currently used and affected by human purposes (Millennium Ecosystem Assessment, 2005; also see a review of major threats to aquatic realms in AQUACROSS Deliverable 2.1). Therefore, it is essential to evaluate the consequences of human-induced disturbances on biodiversity. Disturbances induced by socio-economic systems are summarised under the terms 'drivers' and 'pressures'. Around 660 million people live in catchment areas in Europe (EU and non-EU countries), which have the potential to influence European fresh- and marine-waters under EU jurisdiction (EEA, 2015). Driven mainly by human disturbances, species are currently being lost 100 to 1 000 times faster than the natural rate: according to the Food and Agriculture Organisation of the United Nations (FAO), 60% of the world's ecosystems are degraded or used unsustainably; 75% of fish stocks are over-exploited or significantly depleted and 75% of the genetic diversity of agricultural crops has been lost worldwide since 1990 (FAO, 2010).

In particular, land use changes, non-native species invasions, nutrient enrichment, and climate change are often considered some of the most ubiquitous and influential pressures associated with global biodiversity loss and ecosystem change (Vitousek et al., 1997; Chapin et al., 2000; Butchart et al., 2010). It is essential to understand the mechanisms by which human-induced pressures influence biodiversity, ecosystem processes and ecosystem services to anticipate further changes.[1] Despite the positive effects of conservation and restoration efforts, biodiversity declines have not slowed (Butchart et al., 2010). Thus, further investigation of *how* and *which* drivers and pressures lead to change in ecosystems; as well as how the effects of drivers and pressures can be altered by the interactions between them (cumulative effects, which can be additive, synergistic or antagonistic, e.g. Piggott et al., 2015), is needed to develop robust management strategies.

The EU Biodiversity Strategy to 2020[2] aims to halt the loss of biodiversity by 2020 as well as to restore biodiversity as far as feasible. However, ecosystems are under multiple threats. Freshwater ecosystems are thought to be the most altered ecosystems across any terrestrial or aquatic realm, with degraded water quality and loss of connectivity in wetlands, while in coastal and marine systems, there has been widespread degradation of the sea bed, declines in fish abundance and degradation of coral reefs and mangroves worldwide (MEA, 2005).

[1] In Deliverable 5.1 the understanding of how change in biodiversity relates to ecosystem functions, processes and services is discussed in more detail.

[2] http://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm

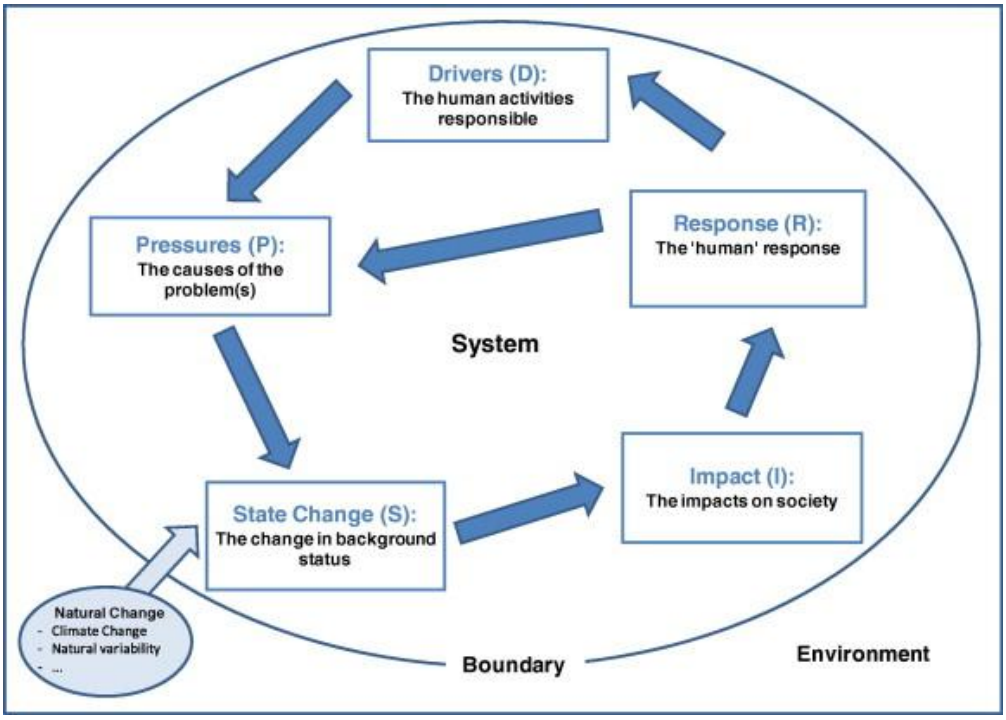
More than half of the freshwaters in Europe are in a degraded state and are affected by pollution and modifications to water courses (EEA, 2012). Human activities that introduce these pressures come from agriculture, urban areas, energy production, transport, commercial fishing, the waste sector, tourism, species trade, flood protection, etc. (Rouillard et al., 2016; EEA, 2012). Meanwhile, European marine systems are known to have been profoundly altered since historical times, and the level of human-induced change has greatly increased in recent decades (EEA, 2015; Steffen et al., 2015). These changes are evident in alterations in marine biodiversity and the distribution of species. Continued, increasing human activities are further driving these changes through the pressures that they introduce (EEA, 2015). Some of the main pressures effecting Europe's seas include physical disturbance to the seafloor, the selective extraction of commercial fish species, introduction of invasive species, pollution and input of energy such as noise, and these pressures are introduced through activities such as fishing, water abstraction, impoundment diversion, dredging, mining, shipping, land occupation, and waste treatment (Rouillard et al., 2016; EEA, 2015). Coastal areas are additionally impacted through activities related to urbanisation and coastal protection (EEA, 2012).

Multiple and interacting social processes and drivers of change mean that it is often not possible to elucidate causal chains with changes in ecosystem state and the supply of services (MEA, 2005). Most studies to date attempt to deal with how single pressures may cause a change in ecosystem state, such as nutrient enrichment (e.g., Donohue et al., 2009) or resource use such as fishing (e.g., Daskalov et al., 2007). More recently, attempts have been made to consider multiple pressures and their cumulative or interacting effects on ecosystem state (Schinegger et al., 2012, 2016), but cumulative effects assessment is a relatively novel area with much work still to do, in particular in the area of understanding *how* pressure effects interact with one another (Judd et al., 2015).

2.1 Conceptual framework: DPSIR and beyond

In order to account for changes in socio-ecological systems, conceptual frameworks have been employed that allow a categorisation of information to capture multiple causes and the nature of change in ecosystem state, and the impacts of change on human welfare (Cooper, 2013). In many cases, these frameworks have been based on the frequently used DPSIR (Driver-Pressure-State-Impact-Response) concept (for a summary of work on how DPSIR has evolved see Cooper, 2013). DPSIR formalises the relationships between drivers that result in direct pressures over ecosystems and the environment as interacting causal chains of links (see Figure 2) and frameworks based around its principles have been widely used across freshwater (e.g., Friberg, 2010) and marine and coastal realms (Borja et al., 2006, 2016; Atkins et al., 2011; Cooper, 2013; Smith et al., 2016) to organise information for ecosystem assessments.

Figure 2: The DPSIR (Driver-Pressure-State-Impact-Response) cycle



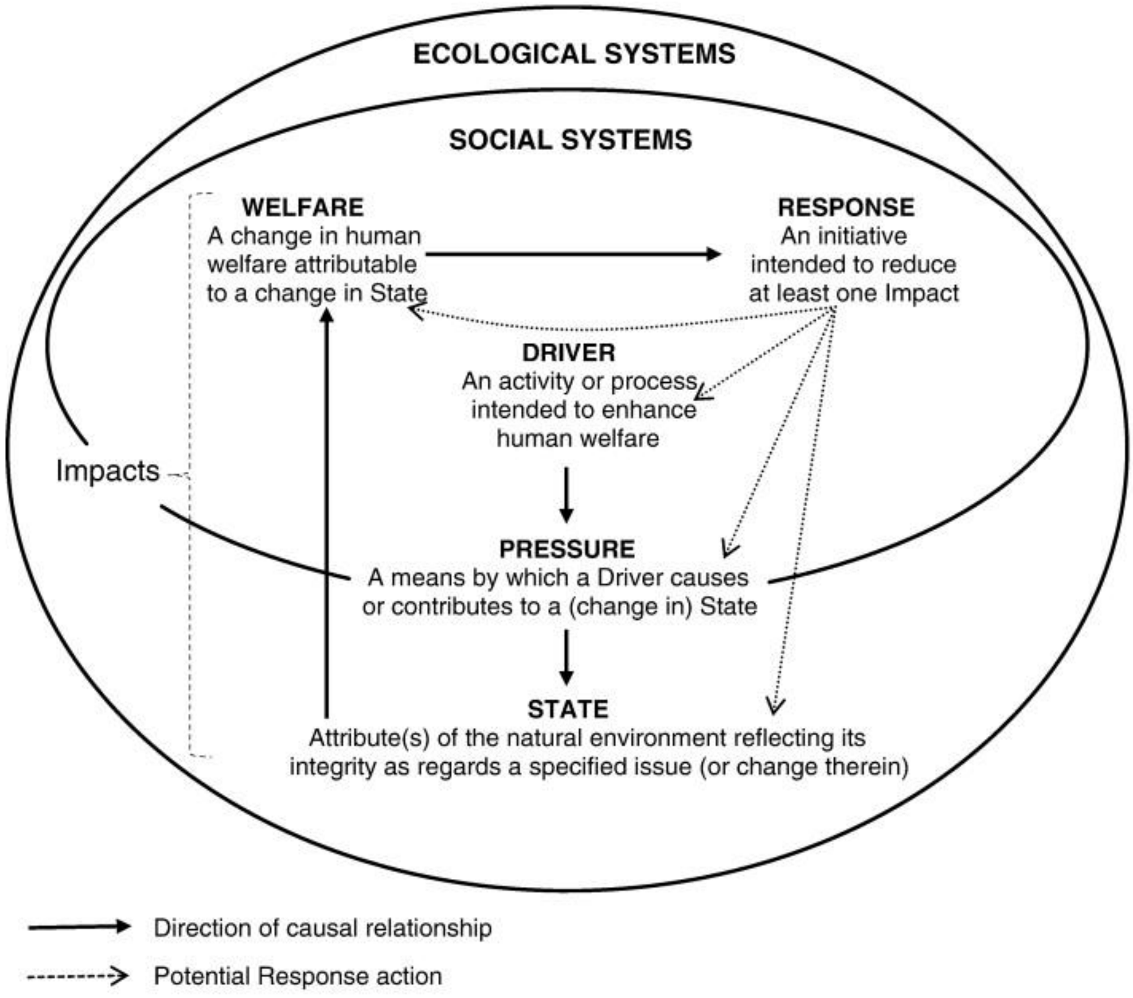
Source: Atkins et al., 2011

Even though the DPSIR framework is widely used, it has been substantially criticised for not being able to account for feedback processes or multiple pressures; lacking explicit links to human welfare; not allowing consideration of trade-offs between natural use, conservation and enhancement; and finally, for being reactive rather than proactive (Gomez et al., 2016). However, as discussed further below, more recent developments of the framework have addressed some of these issues (Cooper, 2013; Borja et al., 2016) allowing for a more comprehensive application of the concept. Furthermore, it represents a well-known approach that is comprehended by a wide field of disciplines, thus facilitating an easy communication across them, and it can be placed within a broader conceptual framework (such as that provided by AQUACROSS) to allow incorporation of feedbacks and multiple pressures.

As the use of the DPSIR conceptual framework has evolved, different groups have placed emphasis on clarification of particular aspects. For example, Cooper (2013) introduced the need to highlight that impacts should be understood in terms of being a change in welfare for society, by specifically exchanging the element 'Impact' for 'Welfare' (Figure 3). DPSWR (Driver-Pressure-State-Welfare-Response) emphasises that impacts should be considered in terms of being an impact on human welfare.

Subsequently, Borja et al. (2016) introduced the need to separate drivers from activities (Figure 4), to highlight that the drivers are, in fact, societal demands on nature (e.g., the need to provide building aggregates), whilst activities are sectoral actions taken to fulfil those demands (i.e., dredging for aggregates). This so-called DAPSI(W)R(M) (Drivers-Activities-Pressures-State-Impacts(Welfare)-Responses(Measures)) framework adapts DPSIR so that the difference between drivers and activities is added. Most of the iterations show that human responses can directly act on drivers (and activities) and/or pressures, but Cooper (2013) also recognised they can act directly on State variables (e.g., through restoration activities - see Figure 3).

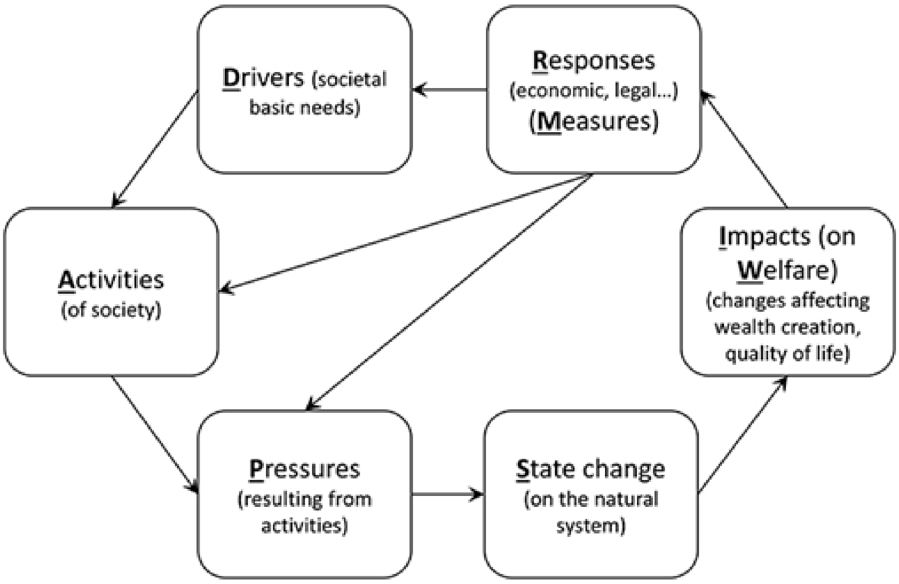
Figure 3: DPSIR adapted to Driver-Pressure-State(change)-Welfare(change)-Response (DPSWR)



Source: Cooper (2013)

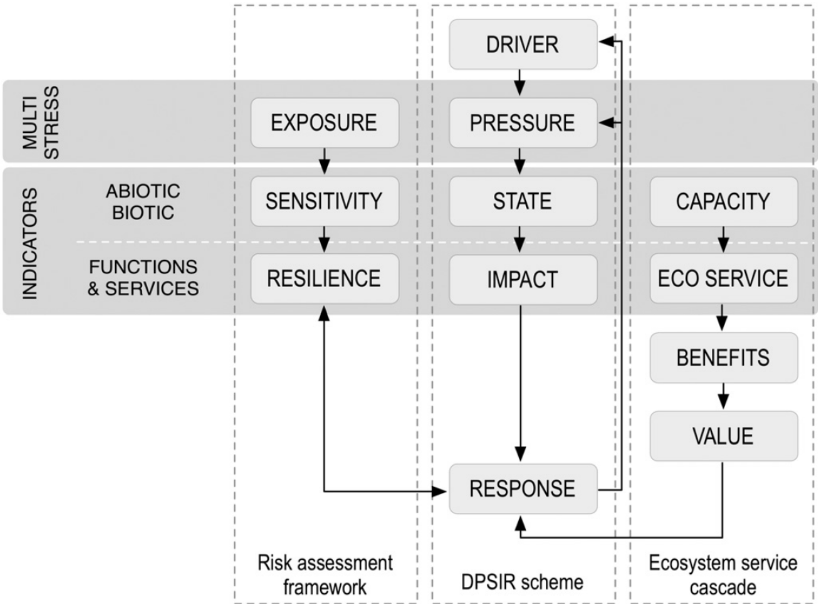
Recently, Hering et al. (2015) introduced the MARS model (Figure 5). In this conceptual assessment framework, the DPSIR cycle itself is not adapted or changed but supplemented by a risk assessment framework and an ecosystem service cascade. The three parts of this model, namely risk, status and ecosystem services, are linked through indicators of a water body's sensitivity or resilience to stressors, its status and the capacity to provide services. This approach aims to support management decisions and scenario-testing through the ecosystem services paradigm by examining interactions between the structure and functioning of ecosystems, and benefits for human well-being.

Figure 4: A further iteration of DPSIR to DAPSI(W)R(M)



Source: Borja et al. (2016) introduced by Wolanski and Elliott (2013)

Figure 5: Conceptual model of MARS for an integrated assessment framework



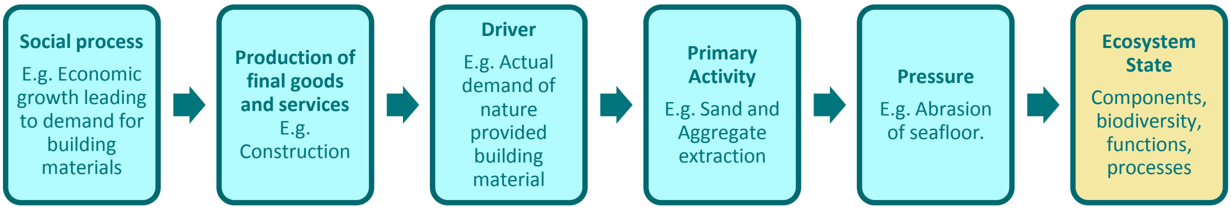
Legend: This conceptual model integrates the three parts of a risk assessment framework, the DPSIR scheme and an ecosystem service cascade by indicators and response decisions that are relevant for all three parts.

Source: Hering et al. (2015)

2.2 Definitions and constraints on the expanded D-P-S part of AQUACROSS

Considering the broader AQUACROSS Architecture (Figure 1), it is clear that the DPSIR framework, even when modified as described above, does not encompass all that is envisaged by AQUACROSS. In particular, AQUACROSS extends the concept to consider the social processes and the wider economic activities that explain the demand of nature-provided services; the actual drivers of change. This extends out from the Driving forces covered in the classic DPSIR frameworks as shown by the added elements on the left hand side of Figure 6 below. In this expanded D-P-S framework, we make a critical distinction between **activities devoted to the production of final goods and services** (the 'secondary activities', that may explain the demand of the services of natural capital, including all ecosystems services and abiotic outputs, and that we consider the **drivers** of change), and **primary activities** devoted to the co-production of nature-provided services. These primary activities combine human effort and capital with natural capital to co-produce and convey to the social system goods and services, such as water, energy, fish, minerals, navigation, etc., to fulfil social demands.

Figure 6: Single relational chain from a social process through human activities to pressures that lead to a change in ecosystem state.



Legend: This expands the D-P-S part of the classic DPSIR concept, such that Drivers are the demand for the supply of ecosystem services, resulting from social processes, such as economic growth, and the production of final goods and services, which require ecosystem services from nature. Primary activities are directly involved in the exploitation of ecosystem services and, thus, can directly cause Pressures on ecosystem State. The interaction with Impacts on Welfare and Responses to this (the I-R elements of DPSIR) are not shown here. This relational chain fits within the demand side of the AQUACROSS Innovative Concept[3] as shown by the yellow arrows in Figure 1. For definitions of each of the six elements represented above, see further detail under section 2.2.

[3] Deliverable 3.1 The AQUACROSS Innovative Concept
http://aquacross.eu/sites/default/files/D3.1%20Innovative%20Concept.pdf

We call higher-level processes, such as population or economic growth, demographic and technological factors, 'social' processes. These processes influence economic activities and the demand for ecosystem services. We identify 'secondary activities' as the economic activities that produce final goods and services directly resulting in a demand for an ecosystem service. For example, construction may lead to a demand for building materials; this demand is the 'driver' (Figure 6). This driver leads to a 'primary activity' (sand and aggregate extraction, that is the proximate activity directly causing a pressure in the ecosystem.

A literature review of existing definitions of the elements included in DPSIR conceptual frameworks from studies related to freshwater, marine and coastal ecosystems was conducted in WP2 to refine the terms. Following this review, we have proposed specific and precise definitions of 'production of final goods and services', 'drivers', 'primary activities', 'pressures', and 'state' to allow for a more cohesive application of the AQUACROSS architecture and heuristics, adapting existing DPSIR frameworks, across aquatic realms that can be consistently used within AQUACROSS (please see D2.1[4] and D3.2 for more information). Within *this* deliverable, we emphasise the definitions of 'drivers', 'pressures' and 'state' as they are most relevant for the aims of this WP. These definitions are an essential part to align sectoral views across the aquatic realms and the research disciplines represented in AQUACROSS. Following the structure shown in Figure 6 above, the sequential definitions adopted within the AQUACROSS framework (based on D3.2) are as follows:

- **Production of final goods and services**: *These are all economic activities requiring the inputs of any good and service provided by the natural capital for the production of any final goods for human use (consumption goods and services) or for the replacement and enlargement of the productive capacity of the economy (capital goods).* Understanding these economic activities, the resources they use with the technology in place and within the institutional system in place is essential to understand the demand of nature-provided goods and services that drive change in ecosystems. The scale, composition, productivity and other relevant characteristics of these activities depends on different factors, such as location, abundance or scarcity of natural resources, comparative advantages in the global economy, technology, availability of infrastructures and human capital, etc., and the governance institutions in place. At a sectoral level, each activity is influenced by the regulatory and market conditions in which they operate. At a higher macroeconomic level, all these economic activities can only be explained as part of social processes, including institutional decisions, technology development and innovation, adaptive response to climate change and all kinds of resource constraints, etc. Using well-established economic accounting

[4] http://aquacross.eu/content/deliverable-21-synergies-and-differences-between-biodiversity-nature-water-and-marine-1

methods, these activities can be defined and classified among economic sectors, such as agriculture, energy, manufacturing, financial services, etc. (EC, 2006).

- **Drivers of change**: *These are represented by the effective demand on the goods and services provided by natural capital, including ecosystems goods and services and abiotic outputs.* In this way, drivers can be represented and measured relying on the standard classifications of ecosystems services, abiotic outputs and other goods and services provided by natural capital (CICES, 2016).

- **Primary activities**: *These are the particular economic activities devoted to the co-production and conveyance to the social system of the goods and services provided by natural capital, in combination with human work and capital, so as to fulfil the demand of these services for the production of final goods and services*. These primary activities include, for instance, the extraction and transport of water, any kind of water impoundment and diversion, the point and diffuse disposal of pollutants, the capture of fish and other living species, mining, hydropower and the production of energy from tides, dredging of rivers to enhance their potential for navigation, the construction and operation of harbours and all other activities that may result in detrimental pressures over aquatic ecosystems (EC, 2006).

- **Pressures**: *These result from human sectoral activities and are the mechanisms through which drivers have an effect on the environment*. Pressures can be of a physical, chemical or biological nature, and include for example, the extraction of water or aquatic species, emissions of chemicals, waste, radiation or noise, or the introduction of invasive alien species.

- **State (change in)**: *State refers to the environmental condition of an ecosystem as described by its physical, chemical and biological parameters*. Physical parameters encompass the quantity and quality of physical phenomena (e.g., temperature, light availability). Chemical parameters encompass the quantity and quality of chemicals (e.g., atmospheric CO_2 concentrations, nitrogen levels). Biological parameters encompass the condition at the ecosystem, habitat, species, community, or genetic levels (e.g., fish stocks, biodiversity).

It is the change in State parameters caused by human drivers of change that then links to any Impacts on welfare that result from a change in the supply of ecosystem services. These Impacts on welfare then lead to Responses that can be used to target any aspect of the relational chain described in Figure 6 (see Deliverables 3.2 and 5.1).

Finally, it is important to specify that we focus here on the manageable endogenous drivers of change in AQUACROSS. As argued in the AQUACROSS AF (Deliverable 3.2) broadening the definition of drivers to encompass all possible causes of ecosystem change at various scales from global to local, at any possible timeframe from long to the very short term, being inclusive of both manageable and non-manageable exogenous drivers, weakens the precision of the concept itself, and reduces its potential usefulness for analytical purposes.

2.3 Summary

The revised DPSIR framework described above fits within the AQUACROSS Architecture (Figure 1, Gomez et al. 2016). In WP4, the focus lies on the D-P-S part of the framework and, thus, the demand-side relationships. From this starting point, it is our aim that, through work completed in the case studies under Task 4.2, it will be possible to identify drivers and pressures across the aquatic realms that are most relevant for ecosystem state in the case studies, and therefore for impacts on aquatic biodiversity and its capacity to support ecosystem services (Task 5.2). As the description under section 2.2 above should illustrate, 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 (the primary activities of Figure 6); the economic activities that require input from the nature-provided services and deliver final goods and services to society should also be considered (and have often been more of the focus in economic/social science approaches). These activities lead to the demand of ecosystem services from the environment and, without accounting for them, it is impossible to understand what can cause changes in drivers acting on the ecosystem. Furthermore, the social processes (exogenic and endogenic) that lead to variability in demand must also be considered to fully evaluate the demand-side.

Under chapter 3 of this report, we go forward to explain in more detail how the drivers of change and pressures can be fully represented and explained, considering both academic and policy-driven perspectives on this across aquatic realms. We describe a consistent typology of drivers and pressures that can be used to bridge the gaps and inconsistencies between existing nomenclatures, where those differences mostly stem from the aims and objectives of different policies. This should facilitate the generation of comparable results and outcomes across the different case studies and their aquatic realms in AQUACROSS and we make a number of recommendations on how this can be used in guiding the case study analyses under Task 4.2.

3 Drivers and Pressures Along the Freshwater-marine Continuum

AQUACROSS addresses all aquatic realms, from freshwater to marine. Thus, the relationships to nearly all types of human uses can be relevant in the context of drivers and pressures along the continuum of freshwater to marine realms. In WP2, the effects of drivers, human activities and pressures on aquatic biodiversity were summarised under the term ‘threat’. Even though it facilitates the description of consequences of human alterations to ecosystems, the identification of the specific impact pathway (threat) that has caused change in ecosystem state is not always possible. However, to develop and implement ecosystem-based management (EBM) solutions, it is necessary to consider the relationships and connections of the different parts along the impact pathway.

Although ecologically and socially linked, the different aquatic realms have mainly been investigated by autonomous research disciplines, and this separation is further emphasised in high level policies such as the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD). Those different policies artificially divide the management of the realms and impede the implementation of integrative (ecosystem-based) solutions. Furthermore, the perceptions of natural and social scientists on how human uses and ecosystems are related are based on mismatching terminologies. Although, the AQUACROSS Innovative Concept and AF generally formalised the flow and connections within the social-ecological systems, the operationalisation of the concepts needs a common understanding of drivers, human activities and pressures. In this chapter, the different perspectives that originate from the divided discipline views will be aligned to one common AQUACROSS view to build a common basis for the analyses in the case studies under Task 4.2. We start by reviewing the approach taken under the most relevant policy drivers (Chapter 3.1) and then go on to describe what we believe should be covered in AQUACROSS, for drivers of change and their associated economic activities (Chapter 3.2), primary activities and pressures (Chapter 3.3). Finally we describe a linkage framework approach that can be used to provide the setting in which analyses can be explored linking within the AQUACROSS framework, focusing on the demand-side perspective (Chapter 3.4).

3.1 Drivers and pressures from the policy perspective

Management and conservation efforts of aquatic ecosystems are strongly related to different environmental policies in the EU. These policies aim to improve ecosystem conditions through the achievement of pre-defined ecosystem or environmental status objectives. In this context, drivers and pressures are often key elements in the policies because it is acknowledged that achievement of such status objectives will be difficult, or impossible, without an understanding of the drivers and pressures acting on affected ecosystems. Accordingly, chapter 3.1 highlights how drivers and pressures are perceived in these legislative frameworks.

Drivers and pressures in the Biodiversity Strategy

The EU Biodiversity Strategy to 2020 (EC, 2011), as part of the commitment to the Convention on Biological Diversity (CBD; UN, 1992), aims to halt the loss of biodiversity and ecosystem services as well as to improve the state of species, habitats and ecosystems in the EU and to help stop global biodiversity loss by 2020 through six targets. The six inter-dependent targets should address the main drivers of biodiversity loss (Figure 7). Even though the Biodiversity Strategy picks up terms such as drivers, indirect drivers and pressures, a clear definition is lacking.[5] For example, the official document postulates: “Growing pressures on Europe's biodiversity: land-use change, over-exploitation of biodiversity and its components, the spread of invasive alien species, pollution and climate change have either remained constant or are increasing.” Or “Indirect drivers, such as population growth, limited awareness about biodiversity and the fact that biodiversity's economic value is not reflected in decision making are also taking a heavy toll on biodiversity.”

Figure 7: The six targets of the Biodiversity Strategy

Target 1	Target 2	Target 3
· Conserving and restoring nature through better application of the Birds and Habitats Directives with the goal of halting biodiversity loss and restoring biodiversity by 2020.	· Maintaining, enhancing and restoring (15% as minimum by 2020) ecosystems and their services, by integrating green infrastructure into land-use planning.	· Ensuring the sustainability of agriculture and forestry through enabling existing funding mechanisms to assist in the application of biodiversity protection measures.
Target 4	**Target 5**	**Target 6**
· Ensuring sustainable use of fisheries resources by 2015 with the goal of achieving MSFD targets by 2020.	· Combating invasive alien species.	· Addressing the global biodiversity crisis and meeting international biodiversity protection obligations.

Source: D2.1 Executive Summary[6]

[5] As explained under chapter 2.2, we reserve the concept of “driver” for the effective demand of goods and services provided by aquatic ecosystems. Then the so called indirect drivers (a term we systematically avoid) is the equivalent of social processes and economic activities devoted to the production of goods and services.

[6] http://aquacross.eu/content/deliverable-21-synergies-and-differences-between-biodiversity-nature-water-and-marine-1

Drivers and pressures in the Birds and Habitats Directive

The Birds and Habitats Directives (jointly referred to as the Nature Directives) require EU Member States to establish a strict protection regime for all wild European bird species and other endangered species, and to contribute to the development of coherent ecological network of nature areas, known as the Natura 2000 Network. Together, they form the cornerstone of Europe's nature conservation policy and make a fundamental contribution to the EU Biodiversity Strategy.

The directives (Article 17 of the HD and Article 12 of the BD) oblige EU Members States to assess and report to the European Commission on the threats and pressures to habitats and species both within and outside the Natura 2000 Network. Under both directives, pressures are considered to be factors which are acting now or have been acting during the reporting period, while threats are factors expected to be acting in the future.[7]

While there is no explicit mention of 'drivers' within either directive, the 'list of threats and pressures',[8] which serve as a basis for reporting, include human activities that produce an environmental impact such as agriculture, forestry, urbanisation, etc., as well as the resulting pressures on the environment (e.g., pollution, invasive species, waste). The directives, therefore, do not seem to distinguish between activities associated with drivers and their resultant pressures as defined by AQUACROSS, but instead groups them under the umbrella term 'threats and pressures'.

Drivers and pressures in the Marine Strategy Framework Directive

The aim of the European Union's MSFD is to protect more effectively the marine environment across Europe. More specifically, the MSFD aims to protect and preserve the marine environment, prevent its deterioration and where practicable, restore that environment in areas where it has been adversely affected (Provision 43, MSFD). The MSFD does not provide an explicit definition of 'drivers'. However, Provision 24 obliges Member States across a marine region or subregion to "*undertake an analysis of the features or characteristics of, and pressures and impacts on, their marine waters, identifying the predominant pressures and impacts on those waters, and an economic and social analysis of their use and of the cost of degradation of the marine environment*."

Annex III of the MSFD lists a number of 'pressures' to guide these assessments, including: physical loss, physical damage, physical disturbance, interference with hydrological processes, contamination by hazardous substances, systematic and/or intentional release of

[7] Assessment and reporting under Article 17 of the Habitats Directive Explanatory Notes & Guidelines for the period 2007-2012 https://circabc.europa.eu/sd/a/2c12cea2-f827-4bdb-bb56-3731c9fd8b40/Art17%20-%20Guidelines-final.pdf

[8] http://bd.eionet.europa.eu/activities/Reporting/Article_17/reference_portal

substances, nutrient and organic matter enrichment and biological disturbance (Table 1). The pressures in its Annex refer to activities such as commercial or recreational fishing, boating and dredging. Such activities could be understood to be covered under the broader term drivers as defined by the DPSIR framework, though they are not explicitly defined as such in the MSFD.

Table 1: Pressure categories and single pressures listed in the MSFD

Presure category	Single pressure
Physical loss	Smothering (e.g., by man-made structures, disposal of dredge spoil)
	Sealing (e.g., by permanent constructions)
Physical damage	Changes in siltation (e.g., by outfalls, increased run-off, dredging/disposal of dredge spoil)
	Abrasion (e.g., impact on the seabed of commercial fishing, boating, anchoring)
	Selective extraction (e.g., exploration and exploitation of living and non-living resources on seabed and subsoil)
Other physical disturbance	Underwater noise (e.g., from shipping, underwater acoustic equipment)
	Marine litter
Interference with hydrological processes	Significant changes in thermal regime (e.g., by outfalls from power stations)
	Significant changes in salinity regime (e.g., by constructions impeding water movements, water abstraction)
Contamination by hazardous substances	Introduction of synthetic compounds (e.g., priority substances under Directive 2000/60/EC which are relevant for the marine environment such as pesticides, antifoulants, pharmaceuticals, resulting, for example, from losses from diffuse sources, pollution by ships, atmospheric deposition and biologically active substances)
	Introduction of non-synthetic substances and compounds (e.g., heavy metals, hydrocarbons, resulting, for example, from pollution by ships and oil, gas and mineral exploration and exploitation, atmospheric deposition, riverine inputs)
	Introduction of radio-nuclides
Systematic and/or intentional release of substances	Introduction of other substances, whether solid, liquid or gas, in marine waters, resulting from their systematic and/or intentional release into the marine environment, as permitted in accordance with other Community legislation and/or international conventions
Nutrient and organic matter enrichment	Inputs of fertilisers and other nitrogen — and phosphorus-rich substances (e.g., from point and diffuse sources, including agriculture, aquaculture, atmospheric deposition)
	Inputs of organic matter (e.g., sewers, mariculture, riverine inputs)
Biological disturbance	Introduction of microbial pathogens
	Introduction of non-indigenous species and translocations
	Selective extraction of species, including incidental non-target catches (e.g., by commercial and recreational fishing)

Drivers and pressures in the Water Framework Directive (WFD)

The economic analyses required under the WFD include the development of a baseline scenario, which assesses forecasts of all significant water-related social processes and economic activities and the drivers likely to influence pressures and thus water status. The key objective of the WFD is to achieve good status for all water bodies by 2015. This includes the objectives of good ecological and chemical status for surface waters and good quantitative and chemical status for groundwater. The WFD indirectly addresses all social processes, economic activities and drivers, which put water bodies at risk of failing good ecological status. While the term 'driver' is not defined in the legal text of the WFD, guidance documents define a driver as "an anthropogenic activity that may have an environmental effect (e.g., agriculture, industry)",[9] which relates to the AQUACROSS definitions of primary activities, (activities leading to) production of final goods and services, and the drivers that link both kinds of activities due to the demand for nature-provided goods and services (See 2.3).

The list of drivers to report on, as indicated in the 2016 WFD reporting guidance documents, include all the economic activities with significant impact over water bodies (Art. 5 of the WFD and Wateco Guidelines), within the river basin (agriculture, energy -hydropower and non-hydropower-,fisheries and aquaculture, forestry, industry, tourism and recreation, transport and urban development), along with adaptive social processes (demography, climate change, technology development, sectoral policies, flood control, drought management, etc.).[10].

Similarly, while 'pressures' are mentioned in the legal text of the WFD, a definition is not provided. However, the guidance document on the 'Analysis of Pressures and Impacts'[11] defines a pressure as "the direct effect of the driver (for example, an effect that causes a change in flow or a change in the water chemistry)", which also aligns with the DPSIR framework. The WFD defines seven coarse pressure categories with 47 detailed pressures (see table 2).

In summary, while the EU Nature Directives, MSFD and WFD, all refer to terms such as drivers, pressures and impacts, clear definitions for these are not always provided. Furthermore, terms such as 'threats' and 'pressures' are sometimes used interchangeably (e.g., HD and BD). DPSIR definitions are explicitly adopted/referred to within guidance documents for some (e.g., MSFD, WFD) but not all (e.g., HD and BD) directives. Going forward in Chapters 3.2 and 3.3, we explain the AQUACROSS approach to representing and explaining drivers of change, activities and pressures that should be taken forward in the case studies under Task 4.2.

---

9 https://circabc.europa.eu/sd/a/7e01a7e0-9ccb-4f3d-8cec-aeef1335c2f7/Guidance%20No%203%20-%20pressures%20and%20impacts%20-%20IMPRESS%20%28WG%202.1%29.pdf

10 https://circabc.europa.eu/sd/a/cffd57cc-8f19-4e39-a79e-20322bf607e1/Guidance%20No%201%20-%20Economics%20-%20WATECO%20(WG%202.6).pdf

11 https://circabc.europa.eu/sd/a/7e01a7e0-9ccb-4f3d-8cec-aeef1335c2f7/Guidance%20No%203%20-%20pressures%20and%20impacts%20-%20IMPRESS%20(WG%202.1).pdf

Table 2: Pressures according to the WFD

Level1	Level2
1 Point Source pollution	1.1 Urban waste water 1.2 Storm overflows 1.3 IPPC plants (EPRTR) 1.4 Non IPPC 1.5 Other
2 Diffuse Source pollution	2.1 Urban runoff 2.2 Agricultural 2.3 Transport and infrastructure 2.4 Abandoned industrial sites 2.5 Release from facilities not connected to sewerage network 2.6 Other
3 Water Abstraction	3.1 Agriculture 3.2 Public water supply 3.3 Manufacturing 3.4 Electricity cooling 3.5 Fish farms 3.6 Hydro-energy 3.7 Quarries 3.8 Navigation 3.9 Water transfer 3.10 Other
4 Water flow regulations and morphological alterations of surface waters	4.1 Groundwater recharge 4.2 Hydroelectric dam Manufacturing 4.3 Water supply reservoir 4.4 Flood defence dams 4.5 Water flow regulation 4.6 Diversions 4.7 Locks 4.8 Weirs
5 River management	5.1 Physical alteration of channel 5.2 Engineering activities 5.3 Agricultural enhancement 5.4 Fisheries enhancement 5.5 Land infrastructure 5.6 Dredging
6 Other morphological alterations	6.1 Barriers 6.2 Land sealing
7 Other Pressures	7.1 Litter/Fly tipping 7.2 Sludge disposal to sea 7.3 Exploitation/removal of animals /plants 7.4 Recreation 7.5 Fishing 7.6 Introduced species 7.7 Introduced disease 7.8 Climate change 7.9 Land drainage 7.10 Other

3.2 The drivers of change in ecosystems

Water-related ecosystems provide a wide array of goods and services that are essential for human life, indispensable for eventually all economic activities and necessary for the maintenance of the aquatic ecosystems themselves. Subsequently, they are essential for the continuous provision of the services and abiotic outputs they provide to society, people and their economic activities. The demand for these goods and services are the actual drivers of change in ecosystems (see definition under chapter 2.3). Thus, the first basic approach to describe and explain the drivers of change in ecosystems consists of a systematic analysis of economic activities that link goods and services provided by aquatic ecosystems to human well-being. Below, we describe some of the ways in which this can be approached. We argue that it will be necessary to consider the different types of approaches in order to fully evaluate the drivers of change acting on case study ecosystems, but it is also anticipated that not all aspects may be equally well explored across all case studies due to both data and time constraints. As such, it will be important to consider how the aspects that cannot be captured may affect uncertainty in the socio-ecological systems modelled within each case study.

Linking drivers with economic activities

At the case study level, the activity analysis under Task 4.2 may go through the following sequence of basic steps:

1. A first step consists in **identifying the economic activities that benefit from the current provision of water-related ecosystems services** for the production of final goods and services (such as irrigated agriculture, tourism, energy, transport, mining, power, timber, tourism, etc.). Such activities can be characterised by the value added they produce and by the employment opportunities they provide both directly and indirectly through relations with other economic sectors (for instance, agriculture and the fishing industry can be connected to food production, transport and trade creating value and inducing employment creation through a wider value chain).
2. A second step consists of the **identification of the particular goods and services provided by ecosystems** followed by characterising and measuring these demands which are actually the drivers of change in ecosystems; see, for instance, Schaldak, et al. (2012) for methods to characterise demand for irrigation in the EU, Gaudard et al. (2014) for hydropower, as well as STECF (2016) for demands placed by the the marine fishing industry.
3. A third step consists of **understanding the link between the production of final goods and services and the demand and use of goods and services** provided by aquatic ecosystems. In many cases, this link can be evaluated by implemented apparent productivity indicators (such as yield per cubic meter in irrigated agriculture), or input output requirements (such as cubic meters per Kilowatt in hydropower or in cooling thermal power plants). These indicators can be represented along time to show the evolution of

productivity. This third step provides the basis to link the production of goods and services with the drivers, or the demand and use of ecosystems goods and services.[12]

4 A fourth important step consists of **describing and analysing the primary activities devoted to the co-production of the goods and services** provided by aquatic ecosystems, such as the full system provisioning water for irrigation, for household consumption or for manufacturing (including water impoundment, delivery, distribution and application), the dredging of river beds to improve navigation services, the capture of living species for the food industry, mining marine surfaces, etc. These activities can also be represented by their productivity, traditionally in terms of units of goods and services (water or fish) per unit of effort (energy for pumping or power used, etc.) depending on the technology in use (gravity irrigation, trawling, etc.) providing relevant information to assess margins to enhance productivity and reduce the pressures resulting from the satisfaction of current and prospective demands of nature provided goods and services (or simply from the drivers) (see Galioto et al., 2015 and Haqiqi et al., 2016 for irrigation and STECF, 2016 for marine fisheries). This analysis provides the basis to understand the resource efficiency as well as the regulations that allow or restrain the use of aquatic ecosystem services.

This activity-based approach allows focusing on individual ecosystems services (such as recreation or provision of water), where demands can be linked to the size and the characteristics of the sector. Thus, analyses of this kind are sector specific: for instance, the water demand for irrigation depends on the irrigated surface, the water requirements of the specific crops planted, the efficiency of the water transport, distribution and application systems in place, the prices of water, etc. (Galioto et al., 2015; Haqiqi et al., 2016 and Liu et al., 2016). Actually, the analysis of economic activities is the basis to understand the current and prospective demand for the goods and services provided by water-related ecosystems services that drive ecosystem change (see Kahil et al., 2015 and Garrote et al., 2015 for the demand for water services for irrigation in Europe and OECD, 2016 for a comprehensive analysis of all economic activities that benefit from marine ecosystems).

It is important to note that in evaluating *how* to describe the primary activities, we also need to consider how the measures selected can inform us about any associated pressures and effects on ecosystem state measures. For example, the size and productivity of a fishing fleet may tell us something about this economic activity, but we need to know the spatial distribution of the fleet and the characteristics of the boats (types of gear deployed, target species, size and power of vessels) involved to be able to evaluate the distribution and magnitude of associated pressures (e.g., abrasion on the seafloor) and overlap with different components (e.g., habitats or functional groups like fish or birds) of the ecosystem.

[12] Productivity and input output indicators are sector specific. Indicators in agriculture based upon Input/Output methodologies, see for instance Blanco et al. (2014) for irrigated agriculture, STECF (2014) for fish-processing industries and Lehr (2008) for employment in energy industries.

Linking economic activities with social processes

Besides activity analysis, deepening the understanding of drivers requires the analysis of social decisions that lead to the demands for goods and services provided by aquatic ecosystems. This implies consideration of decisions at different levels (individual and/or institutional decisions taken at local, regional and international levels). Decision-making processes are complex (see Knights et al., 2014) and involve multiple scales, from global through regional to local, and multiple agents closely connected to each other. For this reason, it is important to distinguish between social processes, such as climate change adaptation, population growth, technology development and innovation, and policy-making, which also determine the drivers of change. However, the way these social processes influence the drivers of change in ecosystems is mediated by many individual and collective decisions, from individuals and institutions, made at local and regional scales, that each need to be understood to explain how the demands on nature (and resulting activities and pressures) might vary.

All of these decisions have the ultimate purpose of meeting the demand for ecosystems services and abiotic outputs provided by aquatic ecosystems. Thus, understanding the drivers is the equivalent to understanding the underlying factors that determine the demand for any water-related service. For instance, if we like to measure the demand for fish at a place and a moment of time, we could get this information from the fish market. However, if we really want to understand the demand for fish, we should understand people's preferences, the regulations in place that define catch allowances (EU, 2012; Carpenter et al., 2016), the economic incentives that determine the financial returns to the fishing industry, the size of the fleet and the technologies in use (STECF, 2016). In addition, if EBM solutions should be developed, we need to understand the future of fishing. Accordingly, we need to explore how regulations, economic incentives and technologies will evolve through time and also what the expected trends of future fish demand and the capacity of ecosystems to match it are (e.g., OECD, 2016). Moreover, fishing is only the primary activity that conveys an important marine ecosystem service to other human activities, i.e. industries, such as the fish processing industry (STECF.a, 2014) that satisfy the final demand for wild fish in combination with, for instance, the outputs of the aquaculture industry (Bostock, 2016; OECD, 2016 and STECF.b, 2014).

Considering non-market ecosystem services

Activity-based analysis must be complemented with the analysis of other non-market or non-monetary services, such as flood security, health protection or cultural values linked to recreation, landscapes and biodiversity. Adding non-market ecosystem services to the picture allows a better understanding of the drivers of ecosystems' change for the following reasons:

- First, it helps to understand the opportunity costs of the matching past, current and prospective demands for provisioning ecosystems services to the different economic activities. For instance, the overall demand for water (a provisioning service to the market economy) may be in excess to long term renewable resources. This will have important consequences over many other non-market services, such as water security in the distant future (due to increasing water scarcity, see EEA, 2009), and in any moments of time (due to higher exposure to droughts, floods and other water related natural hazards, see Gosling et al. (2016)), and might lead to negative consequences to both nature (due to the loss of diversity and regulation ability, see Navarro-Ortega et al., 2015 and Tendall et al., 2014) and people (due to health risks, production and employment losses; Kapengst et al., 2011).

- Second, it provides the background to understand the critical trade-offs involved in business-as-usual scenarios (that helps to explain current and prospective social and economic outcomes) and policy scenarios (that call for a different way to sort out the difficult trade-offs involved in balancing the mix of services provided by ecosystems). These scenarios must be considered to build a sustainable future and to secure the provision of ecosystem services and abiotic outputs (see for instance Berger et al., 2015 to consider tradeoffs between water scarcity and climate change adaptation).
- Third, besides the identification of the benefits and the beneficiaries of the provision of ecosystems services for each economic activity, the inclusion of non-market ecosystems services brings the potential benefits and beneficiaries of preserving the ecosystems in particular through the successful implementation of EBM approaches to the spotlight (see for instance Hawkings et al., 2016; Brouwer et al., 2015 and Vaughan et al., 2015 for a review of the benefits and beneficiaries of water conservation).
- Fourth, bringing non-market values to the frontline allows for better understanding the emerging drivers of ecosystems' change. These new drivers can be understood as adaptive social and economic responses to the cumulative and detrimental changes in ecosystems (that is to say as adaptive responses to water scarcity, degraded water quality, increased exposure to water related risks, lower water security, etc.), or by more stringent regulations (that is to say by restrictive water or fishing quotas, higher water quality standards, etc.). These constraints are important to understand the development of emerging activities such as aquaculture (STECF, 2014), water reutilisation and desalination (e.g., Angelakis et al., 2014 and Wilcox, 2016) advances in technology, the discovery and adoption of innovations to take advantage of new business opportunities linked to resource efficiency and sustainability that are increasingly important to explain the demand for ecosystem services in contemporary economies (in areas as diverse as water efficiency, reuse, desalination, energy, food, textiles, mining, soil conservation, etc. (e.g., IPCC, 2015 and OECD, 2016).
- Fifth, the analysis of drivers of ecosystems' change may be adapted in order to provide a better understanding of emerging drivers, such as innovative responses to water and energy scarcity, for instance through the expansion of infrastructures to generate renewable energy based on freshwater and marine ecosystems (OECD, 2016), water efficient technologies to increase water security in agriculture (Elliot et al., 2014), and fishing (Rezaee, 2016). In fact, it is not just public decisions but also business decisions that are increasingly driven by the need to transform environmental problems (such as

climate change, water scarcity, etc.) into new actions linked to enhanced water security, adapting to climate change, reducing risk exposure, etc. (e.g., Kriegler et al., 2014).

- Finally, most of the drivers, in particular the emerging ones, result from synergies and trade-offs among economic activities. This way, for instance, looking for alternative sources of energy may become a driver of further demands of freshwater (Hussey et al., 2012), such as in the case of biofuels or the expansion of fracking technologies, and finding alternative water sources may be a driver of higher energy demand, as in the case of water desalination and reuse (Olsson, 2015). Similarly, new business opportunities may emerge with the opportunity to solve various problems simultaneously, as in the case of dry cooling systems in thermal power or energy self-sufficient boats. These problems can only be addressed if the interactions between economic activities are considered (e.g., Benson, 2012).

All social processes, economic activities and drivers of change in ecosystems must be properly understood at different temporal and spatial scales. For instance, the scale of drinking water demand, a critical driver for water intake and for freshwater conservation, depends, among other factors, on the population size, the number of households and family income. Temporal and spatial scales are key in the identification of the determining factors that are under the control of policy-makers and those that are not, but must be considered as exogenous contour conditions and as state variables. For instance, at a local level, factors such as innovation, population and income growth, national or EU regulations are state/exogenous factors rather than control/manageable variables. Thus, management must focus on control variables, such as the number of households using water from a particular source, the size and the structure of water prices, settlement regulations, development plans, local regulations, etc. (EEA, 2015).

The same can be said for irrigation water, where the overall demand depends on food demand, irrigation surface, the crops planted and the associated irrigation requirements, global markets, etc. Nevertheless, at a local scale, these decisions depend on water prices, crop subsidies, land regulations, water infrastructures, rainfall and runoff, etc. All these manageable factors are essential to understand why and how the same activity (drinking water provision, irrigated agriculture, etc.) can be sustained or not depending on local ecosystems availability and the efficiency with which these services are used.

Similarly, to a large extent, advances in technology are independent of short-term local water management. But local water management is essential to understand the rate of adoption and speed of diffusion of new technologies once they become available. All this depends on incentives, resource constraints and water regulations that can only be understood at a local scale. In AQUACROSS, we may distinguish between high level drivers (such as income, population and technology development trends at an aggregate level) and low level drivers that are critical to understand the demand for ecosystems service.

3.2.1 Newly emerging drivers

The social drivers of ecosystem change are increasingly shaped by the extension of the progressive and cumulative impacts of human activities over marine, coastal and freshwater ecosystems, as well as by the consequences of climate change and the need to adapt business and social responses to a new situation. Technological development and innovation processes are ever more driven by the need to adapt to a more constrained and more uncertain supply of environmental services and to take advantage of the new business opportunities that result from all the above-mentioned factors.

Marine-, coastal- and freshwater-based economic activities are increasingly constrained by further deterioration of aquatic ecosystems (OECD, 2016; IPBES, 2016). Different from traditional analysis of drivers of ecosystems change, AQUACROSS recognises how these cumulative effects have progressively transformed resource and environmental constraints into new emerging drivers of social and economic decisions that must be factored into the analysis in order to understand emerging activities and drivers of aquatic ecosystems' change. New approaches in activities such as agriculture (smart irrigation techniques, water reuse, desalinisation, soil conservation practises, etc.), urban development (smart cities, green infrastructures, sustainable urban drainage systems, etc.), energy (sea-based renewable energy, fracking, etc.) and transport (autonomous vessels) can hardly be understood without consideration of emerging trends in technology development and innovation driven by resource scarcity concerns.

Scarcity and insecurity of supply is an emerging driver of innovation. These are reasons to put into value all and new methods to enhance the efficiency with which virtually all services provided by aquatic ecosystems are used. These developments are visible in areas such as irrigation, cooling of thermal and nuclear plants, wastewater treatment. Innovations in biotechnology, advanced materials, autonomous systems, new fuels, and other areas are expected to result in important changes in fisheries and navigation. Nevertheless, business concerns and policy debates will continue over the extent to which these new technologies will result in more sustainable practices and less pressures over ecosystems or in further advances of the economic activities and the creation of market values with no positive impacts over aquatic ecosystems.

Furthermore, worries about the future implications of climate change for aquatic ecosystems are important for making visible the role of oceans and the hydrological cycle to regulate climate and also to understand the different uncertainties about the future availability of provisioning and regulating services brought by climate change. This will affect rain patterns and run off is likely to increase the number and the severity of weather extremes with considerable but unpredictable consequences in habitat changes in both marine and freshwater ecosystems, as well as in many economic activities ranging from food, energy, tourism and fishing to aquaculture, bioprospecting and many others.

These new drivers will come with new economic activities and new business opportunities. In some cases this will trigger new business models to halt ongoing degradation processes and new threats to marine and continental waters. These impacts can be analysed on a one by one basis. For instance, sustainable drainage systems are increasingly finding their way in cities with substantial benefits for runoff regulation, groundwater recharge, biodiversity, etc. with collective benefits in terms of energy savings, flood control and recreation and substantial financial savings in water storm management. In a similar sense, advances in biotechnology has served to reduce detrimental impacts of aquaculture, improve fish health, increase yields and reduce dependence on wild fishing, and new communications technology have opened the possibility to enforce fishing restrictions in distant seas. But this is not the only possible outcome. New technologies can also support the possibility to drive pressures and impacts to a new level. This may be the case if, for instance, mining the sea floor is facilitated by advances in robotics and satellite technologies, or if the use of big data and geo-localisation leads to putting additional pressures over decreased fish stocks and advances in cruise materials, logistics and fuel efficiency lead to the exponential growth of cruise tourism with all the associated detrimental impacts over coastal areas.

3.2.2 Summary

As described under the three main areas of approach in chapter 3.2, to fully capture the drivers of change acting on aquatic ecosystems, and to understand how and why they vary, it is necessary:

- To evaluate how economic activities drive demand for aquatic ecosystem services and abiotic outputs, and how this demand causes activity in other related economic activities;
- To explore how social processes limit and generate demand on the economic activities that utilise aquatic ecosystem services and abiotic outputs; and
- To include evaluation of non-market aquatic ecosystem services (e.g., many provisioning and cultural services that do not have clear market value)[13] and their use, without which it is impossible to reach a full understanding of how sustainability can be achieved and thus to deliver Ecosystem-based Management (see Deliverable 3.2 the AQUACROSS Assessment Framework).

Finally, we described how newly emerging drivers are pervasive in our current conditions, and that these must too be considered in the complex, adaptive socio-ecological systems we explore in AQUACROSS. It is acknowledged that evaluation of all aspects described is difficult and that not all case studies may be able to achieve full coverage, never mind quantification of everything described, but we urge case study teams to consider the approaches outlined above, and to explore what could be captured to fully understand the drivers of change acting on their case study systems. As a minimum we should acknowledge, at least conceptually, what is not captured and how this could affect uncertainty in the understanding of the socio-ecological systems explored.

[13] See Deliverable 5.1 for a full description of the types of ecosystem service supplied by aquatic ecosystems

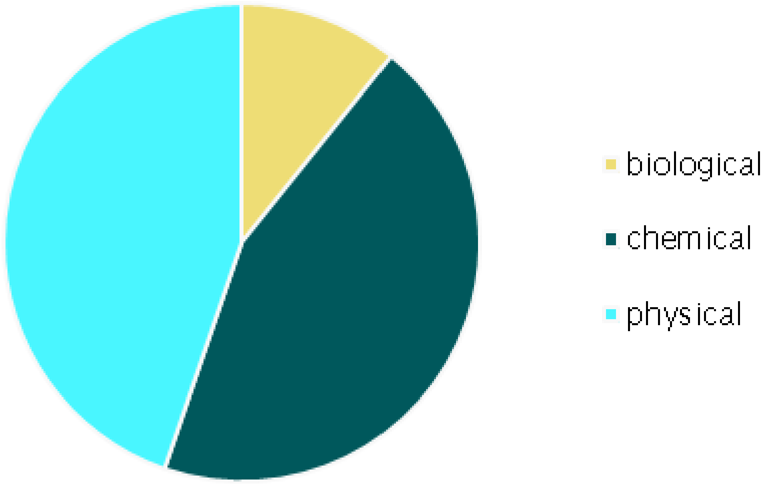
3.3 Pressures and the primary activities that introduce them

As indicated in the policy review under Chapter 3.1, the use of the term pressure is not always consistent, and this is also the case in the academic literature, where scientists utilise the same or similar expressions for their purposes in different contexts; for example, the term ‘stressor’ is often used interchangeably with pressure, to describe environmental factors that exceed the normal level of variation, and trigger a response in the system of interest, where these factors can include natural as well as human-induced origins (Hering et al., 2015; Piggott et al., 2015; Nõges et al., 2016).

Going forward in Aquacross, we have adopted the definition of pressure given under chapter 2.2 as “the mechanism through which an activity has an effect on any part of the ecosystem”, following Knights et al. (2011). In the context of AQUACROSS, a pressure is always related to an anthropogenically induced effect (from a human activity) 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 such that the change seen is beyond what would be expected due to natural variability. 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 (see Figure 6, Section 2.2). Importantly, most pressures do not create a clear-cut impact on the ecosystem but substantially change the probability of unfavourable conditions.

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. Translating the stressors investigated by Stendera et al. (2012) into biological, chemical and physical pressures gives a clear picture (Figure 8), of which pressures are dominating in freshwater ecosystems, for example. Out of 353 classified records 45% comprised chemical or physical pressures each, leaving 10% for biological pressures. The deterioration of water quality by nutrients is one of the major pressures in freshwater ecosystems (Schinegger et al., 2012; Nõges et al., 2016).

Figure 8 Share of pressure types in freshwater ecosystems based on Stendera et al (2012); N=353



3.3.1 Common typologies of pressures and primary activities

As a basis for further work in the AQUACROSS case studies, common typologies are developed that systematically align the nomenclatures and definitions of activities (Table 3 below) and pressures (Table 4 below) and are based on previous classifications including those from the WFD, MSFD, HD (see chapter 3.1) and the statistical classification of economic activities (NACE) (EC, 2006), also referring to previous typologies from White et al. (2013), Connor (2015) and Smith et al. (2016). None of these lists alone capture all of the relevant human activities and pressures for all aquatic ecosystems and the typologies here attempt to be more comprehensive. However, we provide examples and not a fully exhaustive list of primary activities even though there is the attempt to be comprehensive. Generally, the primary activities can fit within broad activity types, 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 (see Figure 6). For example, land claim could come under 'environmental management', where the activity is due to the need to recover land from rising sea level for purposes such as agriculture (the secondary activity that produces the final goods and services, Figure 6, and drives the primary activities of land claim). However, land claim could also come under 'residential and commercial development' where the activity is occurring due to, for example, the desire for commercialising a waterfront.

Table 3: Proposed Aquacross Activity types and (non-exhaustive) examples of more specific primary activities within those types, that co-produce nature based goods and services, which can directly cause pressures in the ecosystem.

Activity type	Example of Primary Activity
Agriculture & Forestry	Cultivation
	Forestry activities
	Livestock
Aquaculture	Finfish
	Macroalgae
	Shellfisheries
Fishing	Benthic trawls
	Fixed nets
	Other fishing
	Pelagic trawls
	Potting/creeling
Environmental Management	Beach replenishment
	Flood defence
	Land Claim
	Seawalls/Breakwaters/Groynes
	Navigational dredging
Manufacturing (land-based)	Specific to locality or region
Waste management	Disposal of waste or other material
	Sewage treatment
Residential & Commercial Development	Urban dwellings
	Marinas
	Dock/port facilities
	Land Claim
Services (e.g., transport, utilities, water supply, defence)	Telecommunications
	Transport
	Utilities
	Water abstraction and supply
	Navigational dredging
	Military
	Reservoirs
	Shipping & other commercial vessels
	Road and railroads
Mining, extraction of materials	Land Quarrying

Activity type	Example of Primary Activity
	Marine Aggregates
	Mining
	Salt works
Non-renewable energy	Oil & Gas
	Peat
Renewable Energy	Wind
	Geothermal
	Hydropower
	Solar
	Tidal
Tourism, recreation & non-commercial harvesting	Boating/Yachting, Water sports
	Diving/Dive sites
	Terrestrial sports
	Tourist resorts
	Bait digging
	Recreational fishing & angling

The broad activity types listed in Table 3 above will not necessarily cover all economic activities that drive the demand for ecosystem services from aquatic ecosystems (the secondary activities as described with Figure 6); the focus is on the primary activities that introduce pressures directly to these systems. These primary activities can be linked to pressure categories and their attributed pressures (Table 4**).** This should enable the creation of linkage pathways that highlight the relationships between the different elements of the demand side (see chapter 3.4).

In the case studies, there may be a clear picture of the important primary activities and pressures already known for that system. This should be the starting point of the assessment. The typologies of activities and pressures described above can then be used to review under Task 4.2 whether other sets of impact chains may exist that have not yet been considered, thus making the assessment more holistic. If there is no clear picture initially, the typologies can be used as a starting point in the case study. An ultimate aim of this work is to draw together final typologies of activities and pressures which are reflective of those relevant across aquatic ecosystems in Europe, based on the experiences in the case studies (for Deliverable 4.2).

Table 4: Proposed Aquacross Pressures categories relevant to aquatic realms identified from the alignment of threats and pressures from the HD, MSFD, WFD

Prressure Category	Pressures
Biological disturbance	Introduction of microbial pathogens
	Introduction of non-indigenous species
	Translocations of species (native or non-native)
	Selective extraction of species
	Introduction of genetically modified species
Chemical change, chemicals and other pollutants	pH changes
	Salinity change
	Introduction of non-synthetic compounds
	Introduction of radionuclides
	Introduction of synthetic compounds
	Emissions (to air)
	Litter
	Nitrogen and Phosphorus enrichment
Physical change	Water abstraction
	Water flow rate changes
	Death or injury by collision
	Emergence regime change
	Abrasion/Damage
	Barrier to species movement
	Change in wave exposure
	Changes in input of organic matter
	Changes in siltation
	Sealing
	Selective extraction non-living resources
	Smothering
	Alteration of channel
	Disturbance (visual, odour) of species due to presence of activity (e.g., on marine mammals)
	Artificialisation of habitat (e.g., artificial reefs)
	Change of habitat structure/morphology
Energy	Electromagnetic changes
	Thermal change
	Underwater Noise
	Input of light
Exogenous/Unmanaged (e.g., due to climate change)	Emergence regime change (climate change, large-scale)
	Change in wave exposure (climate change, large-scale)
	Thermal change (climate change, large-scale)
	Water flow rate changes (climate change, large-scale)
	pH changes (climate change, large-scale)
	Precipitation regime change (climate change, large-scale)
	Salinity change (climate change, large-scale)
	Geomorphological change (e.g., due to tectonic events)

Source: Connor (2015), White et al. (2013) and Smith et al. (2016)

3.3.2 Representing and quantifying pressure effects

Under chapter 3.2 the various approaches available to identify and represent drivers of change, including the activities captured therein are described. Here we go on to introduce briefly the considerations for capturing pressure distributions and effects, but this is also expanded on in much more detail under Chapters 4 and 5.

Across Europe, pressures caused by human activities affect aquatic ecosystems and their inhabiting communities. Today, a complex mixture of physical, chemical and biological pressures exist that impair the functioning of ecosystems and can affect the provision of ecosystem services (Schinegger et al., 2012). Pressure distributions and intensities can be described using metrics (sometimes composite indices) and indicators (see chapter 5).In the past, the impacts of single pressures such as organic pollution or trawling disturbance have been the focus of assessments and there are many extant studies documenting this in aquatic ecosystems. Some of the pressures listed under Table 4, are however, much less well studied and understood (e.g., noise pollution) and the difference in availability of data and understanding will need to be considered when addressing the overall case study systems under Task 4.2.

Different 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. Without the consideration of these synergistic or antagonistic interactions, the effects of pressures can be under- or overestimated (Piggott et al., 2015). However, understanding the cumulative effects of combined pressures is a relatively recent topic in aquatic ecology. Initially, these effects have been tested in experimental settings (e.g., Matthaei et al., 2010; Piggott et al., 2012), followed by field studies with limited extent (Roberts et al., 2013; Lange et al., 2014). Meanwhile, the effects are also tested on continental scales (Schinegger et al., 2016). However, despite a recognisable conceptual setting on how multiple pressures can interact (Piggott et al., 2015), there are a limited number of studies that actually provide quantitative evidence of multiple stressor effects on biota, especially over large spatial extents (Judd et al., 2015; Nõges et al., 2016). Furthermore, Nõges et al. (2016), who reviewed 219 papers on ecological evidence of multiple stressor impacts, underlined the lack of standardised investigation methods. Considering cumulative effects can help (e.g., higher explanatory power of stress-effect for fish in all aquatic environments) in the analyses but it also may reduce the explanatory power of models (e.g., for benthic flora).

3.3.3 Summary

Going forward in Aquacross, we have adopted the definition of pressure given under chapter 2.2 as “the mechanism through which an activity has an effect on any part of the ecosystem”, following Knights et al. (2011). 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 related to an anthropogenically induced effect (from a human activity) on the state of an ecosystem.

As a basis for further work in the AQUACROSS case studies, common typologies have been developed that systematically align the nomenclatures and definitions of activities (Table 3) and pressures (Table 4). We recommend that these typologies are used as a reference to help define drivers and pressures for case studies under Task 4.2 (although expansion is required to fully capture drivers, see chapter 3.2). An ultimate aim of this work is to draw together final typologies of activities and pressures which are reflective of those relevant across aquatic ecosystems in Europe, based on the experiences in the case studies (for Deliverable 4.2).

In this chapter 3.3, we briefly summarise the issues to consider in trying to evaluate pressures in the Aquacross assessments (the approaches for activities are covered in much more detail under chapter 3.2). Ultimately, we know that there is good information and understanding on some of the key pressures affecting aquatic ecosystems in Europe, but that for some of the more emerging pressures (e.g., noise pollution) we work with much greater uncertainty. Furthermore, we acknowledge that cumulative effects of the multiple pressures introduced into aquatic realms, are poorly understood, with investigative approaches used rarely standardised. As a starting point, case study teams should at least identify where cumulative pressure effects could be an important issue in their case studies going forward.

3.4 A framework approach to linking drivers and pressures, ecosystem states (and services) across aquatic realms

This sub-chapter will focus on the linkage framework that was recently developed for the marine realm within the EU FP7 project ODEMM (www.odemm.com). The framework basically consists of a series of interconnected matrices between typologies of activities, pressures ecosystem components, ecosystem services and policy objectives. In ODEMM the linkage framework was used to explore and evaluate the combinations of impact chains found in Erueopean regional seas also providing a framework for the selection of management options and development of management strategies. Under Task 4.2 of AQUACROSS this work will be built on and expanded to include matrices from case studies across all aquatic realms. Further details on linkage frameworks are provided on the ODEMM website http://odemm.com/content/linkage-framework).

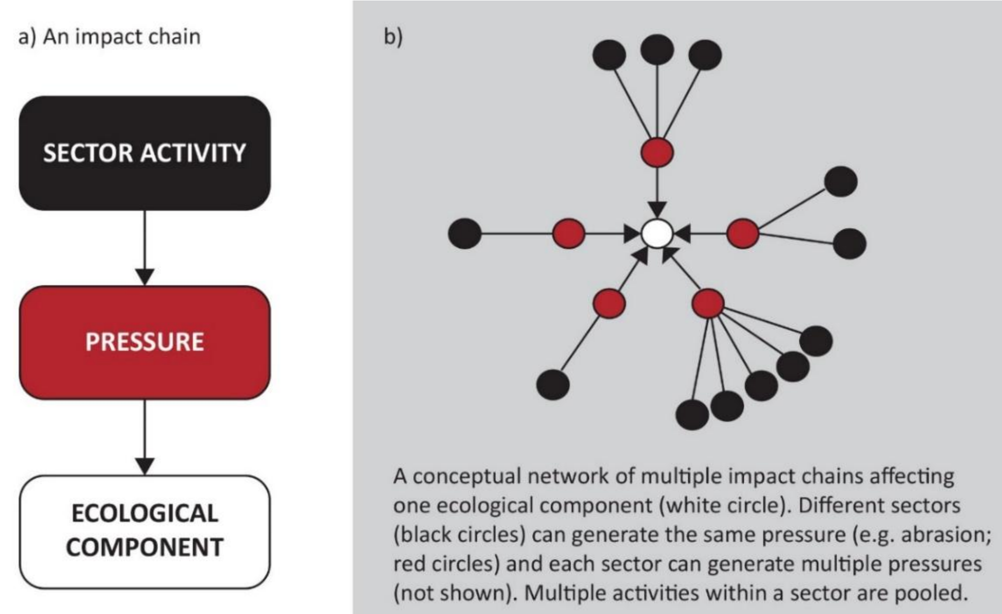
We will start with the linking up of the typologies described under chapter 3.3, into a matrix to show all possible interactions of activities and pressures relevant to a case study system (under Task 4.2). We will need to consider how, and to what extent, it is possible to cover links between primary activities, drivers, secondary activities and social processes (see Figure 6) in developing the linkage framework and matrices within each case study. Furthermore, links will be built between activity/pressures and the metrics of ecosystem state relevant to the case study ecosystems and ecosystem services supplied by those ecosystems (see Deliverable 5.1), formalising the links between WPs 4 and 5 through Milestones 4.1 and 5.2. Linkages will be identified and supported by expert knowledge as well as by evidence from literature. The linkage framework 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.

3.4.1 Uses of the linkage frameworks developed

The linkage framework within the overall AQUACROSS architecture provides an operational framework, which is a characterisation of the system and serves as a starting point for further analyses (described below in Chapters 4 and 5 of this document). In the creation of detailed linkage matrices within the case studies (as part of Deliverable 4.2), evidence should be provided for the linkages between drivers, activities, pressures and ecosystem components. There are already a number of extant databases documenting, for example, literature that supports the links between certain activities and pressures introduced. Additional literature can be identified by search terms (including terms of drivers and pressures and the aquatic realms) in scientific literature databases (Scopus, Web of Science). Based on a snowball principle the references of a fitting paper may provide further adequate references to be included (e.g., see Pullin and Stewart, 2006). Where literature is not available, expert judgement may be required (as is used in many well respected fields such as medicine and engineering).

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 (e.g., mining of non-ferrous metal ores or water abstractions). Moreover, one primary activity may be the source of multiple pressures and any single pressure may be caused by more than one activity (Figure 9 below), such as a many-to-many relationship in a relational database and an advance of one-to-one relationships as presented in DSPIR circles (Figures 2-4). For example, both aggregate extraction and navigational dredging cause abrasion, a physical change pressure that can affect a number of different ecological characteristics. The same pressure can also result in different impacts and multiple pressures can cause the same impact. For example, the physical pressure 'abrasion' can result in impacts that include mortality to benthic invertebrates and change in habitat properties (such as particle size distribution, stability etc.), as can the 'smothering' pressure.

Figure 9 Multiple impact chains



Legend: (a) A generic hierarchical impact chain linking sectors and activities to an ecological component via a specific pressure. An ecological component can be impacted by multiple sectors and multiple pressures, forming (b) a complex network of sector-pressure impact chains. A separate impact chain is generated for every combination of sector (black circles), pressure (red circles), and ecological component (central white circle) (from Knights et al. 2013 and Robinson et al. 2014).

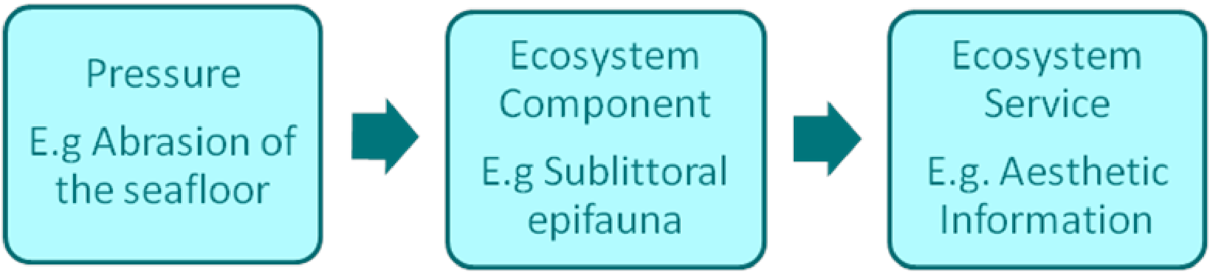
The linkage framework can be used as the basis for exploratory analysis of the system, including simple network analyses (see Chapter 4.2). By simply taking the linkage matrices, it is possible to examine the complexity and connectivity in the aquatic ecosystem. Knights et al. (2013) have explored this, using analyses taken from food-web ecology and network analysis theory. This helps to highlight aspects such as: which primary activities interact with most ecological components, which pressures are most pervasive in the system in terms of connectivity between activities and ecological components, and where are there similarities between sectors and/or pressures in terms of how they interact with the ecological components of the ecosystem.

The ODEMM pressure assessment methodology (Robinson et al., 2013; Robinson et al., 2014) could also be used to weight the interactions between primary activities, pressures and ecological components based on the exposure, severity and recovery lag associated with each interaction in order to focus management on the greatest threats to policy objectives. This recognises that not all activities undertaken are necessarily as harmful as each other. By centring the approach on pressures, it is possible to focus on the most damaging aspects of primary activities and thus to target management strategies with a higher level of precision. Threats based on the ODEMM pressure assessment can be summarised as risks (Knights et al., 2015) and then linked to management options to evaluate their effectiveness (Piet et al., 2015). This approach is described in Robinson et al. (2014, available at www.odemm.com).

3.4.2 Potential for extension of the linkage framework developed

As well as allowing the consideration of multiple links in the system, the linkage framework also facilitates the consideration of feedback loops. 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 (Linking to WP5; see Deliverable 5.1) (Figure 10). 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 (see also Figure 1).

Figure 10: Example of a single impact chain



Legend: From a pressure, which leads to a change in state in an ecosystem component, which impacts on the supply of an ecosystem service.

Existing drivers and pressures, and the links to ecosystem components and services, can be linked to management options through the work envisaged in WP8. Management responses may target drivers, human activities (sectors), pressures or the ecosystem components themselves (e.g., restoration). Thus, scenarios of management options project changes of ecosystem components, such as through changes in sectoral activities, the pressures introduced by these, and changes in the structures and functions of the ecosystem and therefore the ability to provide ecosystem services and abiotic outputs.

3.4.3 Summary

This sub-chapter focused on the linkage framework that was recently developed for the marine realm within the EU FP7 project ODEMM (www.odemm.com). The framework basically consists of a series of interconnected matrices between typologies of activities, pressures ecosystem components, ecosystem services and policy objectives.

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.

The linkage matrices can be used as a basis for qualitative and quantitative analyses that are carried out (see Chapters 4 and 5). We also described some existing approaches developed in ODEMM, which can be implemented where data is lacking.

4 Approaches to Investigate Drivers and Resulting Pressures

The major question of this chapter is: How to investigate the relationships of drivers, activities, pressures and ecosystem states? Therefore, different approaches for analysing the interactions in the demand-side relationship (Figure 6) will be reviewed. The presented approaches should go beyond just describing the trends in drivers, pressures and state characteristics, and should provide the possibility to analyse and explore linkages between the single elements within the D-P-S cascade.

Basically, the assessment of drivers must be purposely designed to contribute to two central objectives:

1 On descriptive grounds, the assessment of drivers of ecosystem change 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 (e.g., in terms of composition structure and dynamics), but also those drivers that push the system beyond its sustainability thresholds and that cause impacts on ecosystem services (linking here to WP5). Comprehensive lists and detailed classification of drivers and activities (Table 3 and 4, chapter 3.3) might help for this screening exercise. Accordingly, they are useful to focus on relevant drivers and activities as well as to avoid omitting potentially relevant interactions. This analysis is also key to take stock of information and to organise the information system

2 On analytical grounds, 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. Complex decision processes that include the autonomous outcome of markets but also the regulating capacity of the institutions in place mediate both demands and technologies. Fulfilling these analytical ambitions requires a proper understanding of social, economic and political processes (linkage to WP2).

The assessment of drivers can be organised in two parts. The first one concerns the comprehensive description and representation of the drivers and compiles available information for its assessment. This is key for screening drivers that might help to identify sustainability challenges, to set policy objectives, and to measure sustainability gaps. 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. It involves growth scenarios as well as a basic understanding of the institutional driving factors of technological choices as well as the assessment of these choices in order to find opportunities to overcome barriers for improvement. Both, the descriptive and analytical dimensions of the assessment of drivers, are key to build baseline and policy scenarios as well as to develop the heuristic approach and subsequently to inform the design and implementation of EBM responses (link to WP7 and WP8).

4.1 Social and economic analysis for the assessment of drivers

As explained above, 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 way we define 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. There are different approaches to address the demand analysis of water related services that range from the study of individual demands of single services depending on a limited set of determining factors (partial equilibrium analysis), to more comprehensive approaches considering all the areas of the economy and a complete set of determining factors (general equilibrium analysis).

Examples of partial equilibrium analysis can be found in many areas, such as the demand for water in residential areas (Rinaudo et al., 2012; Carragher et al., 2012), for manufacturing (Donkor et al., 2012; Flörke et al., 2013), tourism (Holden, 2016; Gosslin et al., 2012), for agriculture (Hendrix et al., 2012; Elliot et al., 2014), including climate change adaptation (Wada et al., 2013; Garrote et al., 2015), as well as the impact of distinct economic instruments (Lago et al., 2015).

More ambitious and comprehensive, general equilibrium analysis of the demand for water-related services and outputs under various policy scenarios is increasingly used (e.g., Solis et al., 2015; Calzadilla et al., 2016). Less information-demanding Input-Output analysis has also been developed in the last two decades, as a means to support water-related policy making processes (Antonelli et al., 2012; Cascarro et al., 2013; Steen-Olsen, 2012). An alternative to combining economic and social analysis consists of the so called agent-based models (e.g., Jenkings et al., 2016 for London flood risk; Murphy et al., 2016 for managing invasive species in EU coastal areas; Vegesana et al., 2015 for understanding farmers decisions are some recent examples).

The above mentioned examples are just some of the more representative methodological approaches offered by economics and social sciences to allow for a systematic approach to understand the determining factors of the drivers of change in ecosystems and to link the social system with the biophysical one within the demand side analysis of the AQUACROSS architecture.

4.2 Quantitative approaches to assess the links between drivers, pressures and ecosystem components

Management of aquatic ecosystems involves assessing the drivers and pressures in relation to the ecosystem state of a system and making educated decisions about the response of that state to changes. Although there is a strong scientific basis, predicting the outcome of specific management decisions is always associated with an unknown level of uncertainty, which stems e.g. small data sets, unknown noise in the data and unknown level of interaction between variables. Availability of quantitative predictive modelling techniques is almost unlimited and independent evaluations of models have often been unable to demonstrate the pre-eminence of any single one (Araujo and New, 2007). Effective resource management will require the targeted selection of analysis method that accounts for the specific situation in the respective system.

The availability of different quantitative approaches and modelling techniques is high. The various techniques can be summarised in different categories dependant on statistical background, data basis, fitting method or use for explanatory and predictive modelling. A short description of a variety of available methods with references for method details and examples for the application of drivers, pressures and states is given in Table 5.

Ordination and classification techniques (e.g., principal component analysis, cluster analysis, non-metric multidimensional scaling) are widely used to analyse correlations/co-occurrence of multiple human drivers and pressures, identify most pressured sites, summarise multiple stressors as stressor gradients or pressure indices and to investigate the impact of multiple human stressors on the ecological status across realms (e.g., Sanchez-Montoya et al., 2010; Vasconcelos et al., 2007; Seguardo et al., 2013; Drouineau et al., 2012). In this respect, they are commonly used to reduce dimensionality and multicollinearity of predictor variables for regression analysis or other sensitive methods (Munoz and Felicisimo, 2004). Famous examples are the RIVPACS (Wright et al., 1995) and BEAST (Reynoldson et al., 1995), where biological data are clustered in groups and group membership is predicted via environmental variables. Whereas ordination methods accounts for additive effects of multiple drivers and pressures, their relevance of interactions of those for ecological status cannot be analysed.

Correlation and regression based analysis has the advantage of simplicity and produces model equations (in case of regression) with parameters that can be directly related to scientific hypotheses or used for predictions. Therefore, it has been the main choice in traditional modelling studies. Regression based models can show good performance in comparative studies (e.g., Elith and Graham, 2009; Ennis et al., 1998), but for complex systems they are often outperformed by more complex modelling techniques (e.g., Death et al., 2015; Jeong et al., 2016). Correlation analysis is widely used to test for significant relationships between single pressures and pressure indices to indices for the ecological status to test for the sensitivity of these indices to different pressures across realms (e.g., Seguardo et al., 2013; Romero et al., 2007). However, analysing for the additive impact or interactions between multiple pressures is not possible. More complex systems can be analyses with different types of regression analysis. It is widely used to find main factors or variables (pressures) that affect ecosystem state in an additive way (e.g., García-Sánchez et al., 2012; Bacci et al., 2013). Additionally, regression analysis (e.g., piecewise regression) can be used to analyse for ecological thresholds of ecosystem state along gradients of pressure intensity (McClanahan et al., 2011). For a further approach, Villeneuve et al. (2015) used PLS regression (an extension of classical linear regression developed to mitigate the instability of the regression coefficients due to the collinearity of the predictors) to identify importance of various strongly correlated stressors on ecological status of rivers. Spatial variations in correlation between water pollution and land use were analysed by Tu (2011) and Hung et al. (2015). Specifically for complex systems especially for interactions of multiple drivers and pressures, mainly machine learning techniques are selected as the appropriate tool.

Structural equation modelling (SEM) is an important tool for explanatory modelling in ecological systems. Conceptual models can be specified and assessed against empirical data. It can be seen as a modern version of path analysis that allows investigation of complex causal relationships between variables and can be used to distinguish between direct and indirect predictors (e.g., Guisan et al., 2006; Surridge et al., 2014). SEM might thus be used as a tool for the selection of independent variables for predictive modelling (Guisan et al., 2006). Surridge et al. (2014) developed a procedure where SEM combined with a machine learn technique as an effective way to bring together predictive and explanatory modelling.

Machine learning techniques (e.g., artificial neural networks, classification trees, random forests, bayesian believe networks) are a family of statistical techniques with origins in the field of artificial intelligence, are recognised as being flexible enough to handle complex problems with multiple interacting elements and typically outcompete traditional approaches (e.g., generalised linear models), making them ideal for modelling ecological systems (Olden et al., 2008). These techniques are emerging as tools for habitat modelling as well as research and management to describe and predict causal linkages and complex interactions between multiple environmental drivers and pressures and ecological state (e.g., Death et al., 2015; Jeong et al., 2016).

Within this group there is also a lot of interest in "ensemble learning" techniques (e.g., random forests, conditional inference forest, generalised boosting method) — methods that generate many classifiers and aggregate their results. Therefore this techniques are also emerging for explanatory modelling (Peters et al., 2010; Teichert et al., 2016; Monteil et al., 2005) and are frequently used for habitat modelling as well as research and management to describe and predict causal linkages and complex interactions between multiple environmental drivers and pressures and ecological state (e.g., Death et al., 2015; Jeong et al., 2016).

For example random forest (RF) and boosted regression tree models are used to analyse for the importance of different stressors and interactions among different stressors for the ecological status taking synergistic and antagonistic effects into account (e.g., Teichert et al., 2016; Feld et al., 2016). Villeneuve et al. (2015) used conditional inference trees (CIT) to predict the status of water bodies based on pressure data. Besides the qualitative application described in chapter 3.4, Bayesian Belief Models can also be used in a quantitative way based on data. Death et al. (2015) tested such a quantitative approach against other statistical and machine learn techniques for the assessment of the link between drivers, pressures and ecosystem state and could show a specifically good performance in comparison to the other methods.

Bayesian Belief Networks (BBN) are also successfully applied to analyse complex interactions of environmental conditions and species diversity and abundance within a trophic network (Mori and Saitoh, 2014). Boets et al. 2015 used BBN to analyse the vulnerability of habitats to be invaded by IAS (invasive alien species) and could show that tool can efficiently be used to support the management of IAS as these models are visually appealing, transparent and facilitate integration of monitoring data and expert knowledge. Emerging analytical techniques, such as Random Forests or TITAN analysis, are also seen as powerful methods for detecting ecological thresholds along multiple environmental gradients (Baker and King, 2010) and are already used to find community thresholds along single stressor variables (e.g., King and Baker, 2010; King et al., 2011). Artificial Neural Networks (ANN) were found to be an useful tools to define and prioritise the most effective variable for integrated water resources management and water quality modelling (e.g., Iliadis and Maris, 2007; Jalala et al., 2011; Zhang and Stanley, 1997).

Also, **process-based models** are widely used to link drivers to pressures. A process-based simulation model is the mathematical representation (formulated as mathematical functions) of one or several processes, including physical or biochemical based processes, based on a function of generic principles or empirical knowledge (expert knowledge) and might be fitted based on empirical data. Those modelling approaches are very specific for each respective application and sector and can be applied as dynamic approaches that account for time-dependant changes or static (or steady-state) where the system is calculated in equilibrium (the model is time-invariate). Examples are pressure quantification models, like hydrological models or catchment models for nutrient (e.g., Venohr et al., 2011), and water quality simulations (e.g., Saloranta and Andersen, 2007), economic analysis (e.g., Rekolainen et al., 2003) or species distribution models (Dormann et al., 2012).

Table 5: Description of available quantitative methods (alphabetical order) with references for method details and examples for D-P-S application.

Model code	Description	Reference method details	Example driver/pressure analysis
ANN	Artificial neural network (ANN) is a machine-learning method that replicates the functioning of the human brain. This highly flexible method builds accurate models for prediction when the functional form of the underlying equations is unknown [Venables and Ripley, 2002]. ANNs were fitted by setting the maximum number of iterations to 200 (Biomod 2 default). To prevent the ANNs to over fit, four-fold cross-validation was implemented to stop the training of the networks.	Carling (1992), Gutierez-Estrada et al. (2009), Hill and Lewicki (2007)	Iliadis and Maris (2007), Jalala et al. (2011), Zhang and Stanley (1997)
ANOVA	Analysis of variance assesses the average contribution of categorical predictors and interactions between those to the overall mean of a response.	Hill and Lewicki (2007), Roberts and Russo (1999), Zar (1984)	Virbickas and Kesminas (2007)
ALR, SGLM	Auto-logistic regression and spatial generalizsed linear models are extensions of GLM describing or correcting for spatial autocorrelation.	Caragea and Kaiser (2009) Hughes and Haran (2013), Gotway (1997)	Lin et al. (2010)
BBN	Bayesian belief networks (BBNs) are probabilistic graphical networks, rule-based machine learn modelling technique, based on bayesian statistics using probability theory. They consists of two components: direct acyclic graph (DAG) and conditional probability tables (CPT). Variables in the network are represented by nodes, dependencies are represented by Links (arrows). Interactions between predictors are automatically incorporated, models are capable of modeling highly complex non-linear systems including interactions and hirarchical structure.	Mccann, Marcot and Ellis (2006), Uusitalo (2007), Pourret, Naim and Marcot (2008)	Death et al. (2015), Boets et al. (2015)
BT/BAT	Bagging trees (BT) creates multiple bootstrapped (i.e., sampled with replication) classification and regression trees and then averages the results. Therefore similar data sets are created by resampling with replacement and trees are grown without pruning. These are then averaged reducing the variance component of the output error. It is based on the recognition that the output error of a single tree is due to the specific choice of training data set (Prsad et al. 2006).	Breiman (1996), Death (2007), Prasad et al. (2006)	

Model code	Description	Reference method details	Example driver/pressure analysis
CART/CT/RTA	Classification tree analysis (CTA) and Regression tree analysis (RTA) generates a binary tree through binary recursive partitioning i.e. the nodes are split based on true/false answers for classification trees and based on maximising homogeneity of the two resulting groups for regression trees concerning the values of predictors [Venables and Ripley, 2002]. An overgrown tree is produced that is later pruned back via cross-validation to avoid over-fitting [Breiman et al., 1984; Therneau and Atkinson, 1997].	Death and Fabricious (2000), Harrell (2001), Prasad et al. (2006)	
CIT/cTREE/CTF	Conditional inference trees (CIT) or the ensemble approach of the method, conditional tree forest (CIF) are an extension of CART where predictive variables are selected based on a permutation test at each node (Villeneuve et al. 2015). Procedure was developed to obtain unbiased variable selection (Strobl et al. 2007)	Hothorn et al. (2006)	Villeneuve et al. (2015)
CLA	Cluster analysis divides data into groups (cluster) based on the structure of the data. The greater the similarity within groups and difference between groups the more distinct is the clustering result. Several procedures exist including hierarchical, K-means and density-based clustering. The approach is widely used for the summarisation and compression of data.	Everitt et al. (2011), Hill and Lewicki (2007), Romesburg (2004)	
COR	Correlation analysis is a statistical tool widely used to quantify the relationship between two numerical variables. Parametric (Pearson) and non-parametric (e.g., Spearman) approaches are available.		Seguardo et al. (2013), Romero et al. (2007)
DA/LDA/FDA/MDA	Discriminant analysis is a well-known, classic statistical procedure going back to Fisher (1936), which finds a linear combination of the input variables that maximises the ratio between the separation of class means and the within-class variance of a categorical independent variable (Venables and Ripley, 2002). Flexible discriminant analysis (FDA) is a non-parametric equivalent of the linear discriminant analysis (LDA) [Hastie et al., 1994]. FDA is a multi-group nonlinear classification technique that replaces the linear regression by any nonparametric method [Hastie et al., 1995]. Mixture discriminant analysis (MDA) (Hastie and Tibshirani, 1996) is an extension of linear discriminant analysis (LDA) (. MDA assumes that the distribution of the class of each environmental variable follows a Gaussian distribution thus enhancing the LDA, allowing the classifier to handle different prototype classes such as a mixture of Gaussians.	Fisher (1936), Venables and Ripley (2002)	
GAM	Generalised additive models (GAM) are a flexible generalisation of linear regression. Unspecified smooth functions relate the predictor variables to the expected value of a response.	Hastie and Tibshirani (1990), Hastie et al. (2009), Hill and Lewicki (2007)	

Model code	Description	Reference method details	Example driver/pressure analysis
GBM/BOT/BRT	Generalised boosting method (GBM) is a sequential ensemble modeling method that combines a large number of iteratively fitted classification and regression trees to a single model with improved prediction accuracy [Elith et al., 2008]. GBMs automatically incorporate interactions between predictors and are capable of modeling highly complex non-linear systems.	Death (2007), Moisen et al. (2006), Sutton (2005)	Wait (2014)
GLM	Generalised linear models (GLM) are a flexible generalisation of linear regression. Predictor variables are linearly related to the expected value of a response through a link function. Analysis of variance and regression analysis can be combined using both numerical and categorical variables.	Harrell (2001), Hill and Lewicki (2007), McCullagh and Nelder (1989)	García-Sánchez et al. (2012), Donohue et al. (2006)
GWR	Geographically weighted regression (GWR) is an extension of MLR used when model parameters are not constant over the spatial extent of study. Parameters in a global regression model can be estimated locally at every point by giving higher weights to graphically proximal data points (Fotheringham et al. 2002).	Austin (2007), Foody (2004), Fotheringham et al. (1998)	Tu (2011), Huang et al. (2015)
LR	Linear regression models the relationship between one or more numerical predictor variables and a response variable by fitting a linear equation to observed data.	Harrell (2001), Hill and Lewicki (2007), Zar (1984)	Bacci et al. (2013)
MARS	Multivariate adaptive regression splines (MARS) merge standard linear regression, mathematical spline construction and binary recursive partitioning in order to produce a local model in which relationships between response and explanatory variables are either linear or non-linear [Friedman, 1991]. First the model is overfitted in a second step the knots that contribute least to the overall fit are removed using a specific pruning technique based on RSS (residual sum-of-squares).	Friedman (1991), Hill and Lewicki (2007), Prasad et al. (2006)	
MDS/NMDS/PCoA	Multidimensional scaling (NMDS) is a distance based ordination technique frequently used in ecological studies that attemtts to iterratively map n-dimensional (n, number of variable pairs) distribution of samples into smaller dimensions. A stress value is estimated indicating how well n-dimensional distance between samples is preserved in the analysis. It is a robust flexible procedure that can be used to analyse correlations/co-occurrence of multiple human drivers and pressures, identify most pressured sites, summarise multiple stressors as stressor gradients or pressure indices. This type of models include non-metric multidimensional scaling (NMDS) and Principal Coordinate Analysis (PCoA).		Laurance et al. (2002)

Model code	Description	Reference method details	Example driver/pressure analysis
NLR	In non-linear regression (NLR) predictor variables are non-linearly related to the response variable through a known function.	Hill and Lewicki (2007), Huet et al. (1996), Smyth (2002)	Borja et al. (2009), Donohue et al. (2006)
PCA	Principal component analysis (PCA) is a statistical procedure that uses orthogonal transformation to calculate linearly uncorrelated variables (principal components) from correlate variables. It can be used to analyse correlations/co-occurrence of multiple human drivers and pressures, identify most pressured sites, summarise multiple stressors as stressor gradients or pressure indices.		Seguardo et al. (2014), Sanchez-Montoya et al. (2010)
PLS	PLS regression is an extension of classical linear regression. It was developed to mitigate the instability of the regression coefficients due to the colinearity of the predictors and can be used to obtain reliable results even in the case of strong correlation between the predictors.	Wold et al. (2001)	Villeneuve et al. (2015)
QR	Quantile regression is an adaptation of a linear regression where the median or other quantiles of the response variable are modeled instead of the mean.	Austin (2007), Koenker and Basset (1978), Koenker and Hallock (2001)	Fornaroli et al. (2015)
RBFM	Automatically induced fuzzy rule-based models use a set of algorithms for the combination of fuzzy discretisation and fuzzy operators, rule induction and rule filtering (Vinterbo et al. 2005). The model was especially designed for the production of an easily interpretable small number of short rules and are based on a set of "if-then" rules and fuzzy logic (Wieland, 2008).	Vinterbo et al. (2005), Wieland (2008)	
RF	The random forest (RF) is a parallel ensemble method that generates a large ensemble of classification and regression trees forming a “forest”. Each tree is subsequently built by randomly selecting a training dataset from the observations (i.e., bootstrap sample with replacement). In addition, four explanatory variables in each tree were randomly selected for calculating the best split on these predictors in the training set [Breiman, 2001]. This procedure is iterated over all trees in the ensemble and the RF algorithm detects the classification appearing most frequently in the model selection process (i.e., the random forest prediction). Similar to BATs except a random set of predictor variables are used to build each tree.	Breiman (1996), Death (2007), Prasad et al. (2006)	Teichert et al. (2016), Feld et al. (2016)
SEM	A structural equation model (SEM) can be seen as a modern version of path analysis that allows investigation of causal relationships between variables and can be used to distinguish between direct and indirect predictors and reciprocal effects (e.g., Guisan et al. 2006, Surridge et al. 2014) and thus complex	Austin (2007), Grace (2008), Palmores et al. (1998)	Surridge et al. (2014), Santos-Martin et al. (2013), Samiya et al. (2016)

Model code	Description	Reference method details	Example driver/pressure analysis
	interaction among variables. Pre defined theoretical models can be specified and assessed against empirical data.		
SVM	Support vector machine (SVM) are kernel-based learning classifiers based upn statistical learning theory. It has been developed from a linear classifier using a maximum margin hyperplane to separate two classes. In a non-linear case training data are mapped into a higher dimensional feature space and are computed separating hyperplanes that achieve maximum separation between the classes (Schölkopf and Smola, 2002, Kampichler et al. 2010) using an internal cross-validation procedure. It can be trained using small number of samples and can represent nonlinear effects and interactions between variables (Knudby et al. 2010). It is widely used for remote sensing and a promising tool for modeling ot systems with low data availability (Crisci et al. 2010)	Hastie et al. (2009), Hill and Lewicki (2007), Moguerza and Munoz (2006)	
TITAN	Threshold Indicator Taxa ANalysis is a tool for the analysis of ecological thresholds. It detects changes in the distribution of single taxa along an environmental gradient over space or time, and assess synchrony among taxa change points as evidence for community thresholds. It has also potential for detecting ecological thresholds along multiple environmental gradients.	Baker and King (2010)	King and Baker, (2010), King et al. (2011)
TN	TreeNet (TN) or multiple additive regression trees is a ensemble modeling method that combines a large number of iteratively fitted classification and regression trees to a single model with improved prediction accuracy based on stochastic gradient boosting [Friedmann, 1999]. TN automatically incorporate interactions between predictors and can explore the impact of outlier removal.	Friedman (2002), Friedman and Meulman (2003)	

Recommendation

The linkage matrices developed for each case study (Chapter 3.4) can be used as a starting point and to frame quantitative analyses such as BBN, RF, and ANN described above.

4.3 Meta-analysis of strategies for quantitative model fitting

Whereas the model creation in qualitative modelling is based on expert judgement or evidence from literature, fitting quantitative statistical models or machine learning models, i.e. make a quantitative decision which model fits the data best, requires a quantitative measure of goodness of fit or predictive accuracy. The most common ones in predictive modelling are the Akaike information criterion (AIC) for categorical data and root mean squared error (RMSE) for continuous data and in explanatory modelling R2-type values and statistical significance. The Bayesian Information Criterion (BIC; Schwarz, 1978) is discussed within both frameworks (Shmueli, 2010). There are several procedures in which these measures are implemented including the aim to select the most important independent variables, reduce overfitting and find the most parsimonious model. The most common strategies are summarised here.

Ensemble learning

Recently there has been a lot of interest in "ensemble learning". Three ensemble techniques are frequently used for modelling especially, bagging, boosting and stacking. Bagging (Bootstrap aggregation, e.g., Shapire et al., 1998) is a way to decrease the variance in predictive models by generating additional data for training out of the original dataset using e.g. combinations with repetitions or random subsets to produce multisets of the same size as the original data. These are then used as training set for model creation. The outputs of the models are combined by averaging or voting to create a single model. This procedure is suitable for models with high variance and low bias (complex models) and is effective when using unstable nonlinear models. Widely used examples are bagging trees (BT), conditional tree forest (CIF) and random forest (RF) (See Table 5).

Boosting (Breiman, 1996) is a two-step approach that aims to increase predictive force of the final model. First subsets of the original data are generated and models are produced on each dataset. The subset creation is not random and depends upon the performance of the previous models. Each step tries to add a model that does well where previous models lack. Procedure is suitable for models with low variance and high bias. Additive regression is a classic example of boosting. The algorithm starts with an empty ensemble and incorporates new members sequentially. A widely used example from machine learning models is generalised boosting method (GBM); See Table 5).

Stacking or ensemble modelling applies several model techniques to the same dataset, single models are then combined into one weighted by the performance of the single models. This strategy is for example implemented in the R package BIOMOD.

Pruning is a common strategy to reduce the risk of overfitting (poor generalisation, poor performance on independent dataset) of a model, by reducing the size (e.g., sections of a tree of a classification or regression tree (CART) or knots of a multivariate adaptive regression spline model (MARS); see Table 5) and complexity of the model and thus increasing predictive performance and accuracy. A common strategy is to create an overfitted model and then reducing the size of the model without reducing performance using e.g. cross-validation. This procedure is similar to backward selection used in classical statistics like linear regression.

4.4 Model validation

Model validation is a critical point to evaluate the robustness of the applied techniques. However, strategies for model validation are various. Whereas in explanatory modelling validation includes statistical methods like factor analysis or goodness-of-fit tests, like normality tests, and model diagnostics such as residual analysis, in the framework of predictive modelling training and testing and cross-validation are most commonly used (Shmueli, 2010). In many cases random test data are selected to validate a model. The overall set of data is split randomly and one set is used for model generation and the second one for testing. To test the generality of a model independent test data are required. The model is fitted on one data set and then tested on an independent test data set. This procedure aims to test the transferability to other systems and generality of the respective models. Cross-validation (e.g., k-fold, random, bootstrap, Leave-one-out; Stone, 1974) generally splits the overall set of data into subsets several times and performs trainings each time leaving out one of the subsets from training and using the omitted test set for training. It is a way to predict the fit of a model to a hypothetical validation set when an explicit validation set is not available.

In applications involving scarce data strategies further validation strategies are available including sensitivity analysis, expert knowledge (e.g., validation by stakeholder) or comparison against other models representing the same problem (Aguilera et al., 2011). Sensitivity analysis (Jensen and Nielsen, 2007) determines which variables and states of the variables are more influential with respect to the target variable. It shows when small changes in the state of the independent variables returns great changes in the state of the dependant variable.

4.5 Comparison of quantitative models

Comparative studies show that predictions by alternative quantitative models can vary substantially and came to no consistent conclusion (Araujo and New, 2006). Various studies that compare multiple quantitative methods within the framework of classical statistics, machine learning techniques and ensemble modelling are mainly available from predictive species distribution modelling (SDM), and few of them also in the framework of D-P-S assessment. Where methods comparison is available done under comparable conditions is the ensemble software package BIOMOD (R developer software). Further comparative studies are done independently using different software. As a logical next step results of those comparative studies can be used to analyse the performance of the different modelling strategies in dependence of the structure of used data.

4.5.1 Methods

Data records on the predictive accuracy of various models (including AUC, RMSE, Cohen's Kappa, TSS, specificity, sensivity or CCI) were collected from studies comparing at least three modelling techniques with the same dataset to get a comparable sample. To explore the performance of different methods in dependency of the conditions of the respective study information on number of records and number of independent variables were included. Information on method of validation, realm and taxonomic unit was additionally collected. Studies were selected randomly by searching for pairs of modelling techniques with the aim to collect a representative sample of available studies. (Multivariate) methods with a strong focus on the analysis of biodiversity and community composition (e.g., correspondence analysis, generalised dissimilarity model) were not included in the review as these are in focus of WP 5.

Generally, accuracy values reflect errors in site selection, sampling procedure, measurements, laboratory analysis, calculations as well as random errors beside the model related error. To distinguish between uncertainty within the dataset itself and uncertainty related to the respective predictive model, data were normalised with respect to overall predictive performance across all methods by ranking those with respect to percentile values within one study/dataset. Each model was ranked with respect to its accuracy level (measured with AUC and RMSE) in relation to the other models based on percentile values in one study. 1: lower than the 20% percentile, 2: in-between 20 and 40% percentile, 3: in-between 40 and 60% percentile, 4: in-between 60 and 80% percentile and 5: higher than the 80% percentile. Based on this ranking relative performance of single methods and groups of methods can be compared across all studies. Additionally, an absolute value of relative performance was calculated by subtracting the mean over all methods per study/dataset from the respective single values per method. A correlation analysis was conducted to analyse the relationship between relative value of model performance (based on AUC) and number of samples and independent variables included in the different studies.

Table 6: Correlation analysis between relative performance of nine models

	N samples	N explanatory variables	Number of datasets
ANN	ns	0.19*	137
CART	0.21**	-0.33**	153
DA	ns	ns	116
GAM	ns	ns	152
GBM	ns	ns	146
GLM	ns	ns	155
MARS	ns	ns	135
RF	ns	0.42**	142
SVM[1]	ns	0.39*	27

NN, CART, DA, GAM, GBM, GLM, MARS, RF - and number of included independent variables per dataset and model. (based on relative performance ranks)

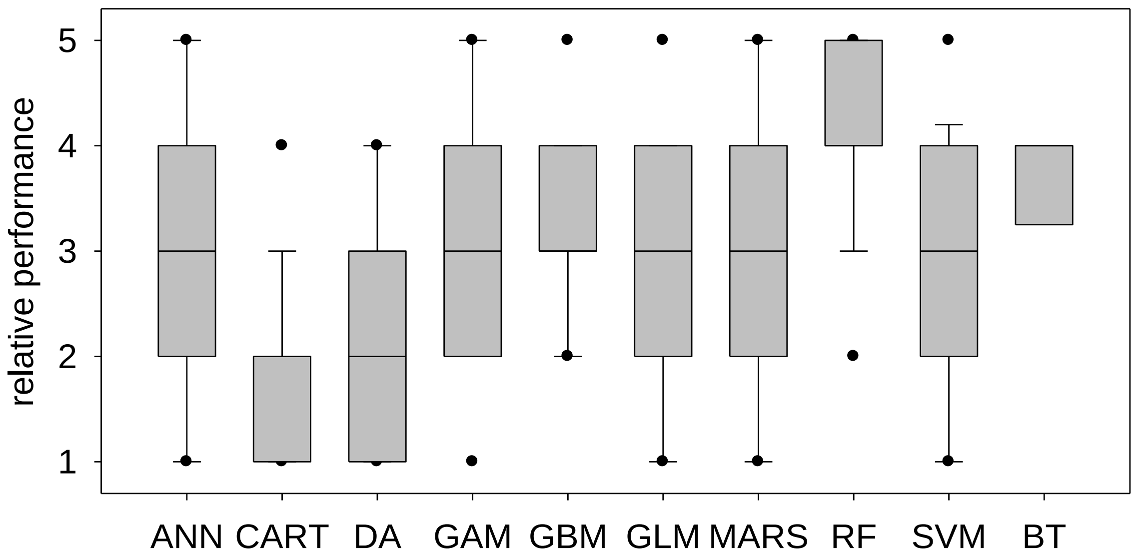
4.5.2 Results

Altogether, 1383 single records were collected from 185 different datasets within 38 comparative studies comprising the modelling techniques SVM, RF, TN, RBFM, MARS, GLM, GAM, GBM, DA, CART, BT, BBN and ANN. For ten techniques a quantitative summary of relative model performance could be calculated (Figure 11).

Comparative studies are in relatively good concordance in the rank of different model types (Figure 11). The machine learn ensemble method RF significantly (Tamhane Post-Hoc test $p<0.001$) outperforms all other methods, it is followed by the ensemble methods GBM and BT together with the machine learn techniques ANN and SVM and the group of simple and adapted regression based methods (GLM, MARS and GAM) which also show a good average performance. CART and DAs are in many cases significantly outperformed by other methods.

A significant positive correlation (Table 6) between relative model performance and number of included independent variables could be found for RF, SVM and ANN. These methods can better handle large number of predictor variables and outperforms other methods due to their variable selection procedure. In contrast CART decreases in its predictive performance when large number of predictors are included and gets more reliable with high number of samples. Other methods perform equally independent from sample size and number of predictors.

Figure 11: Relative performance of ten statistical model types



Legend: In total 185 different datasets within 38 comparative studies were used. Each model was ranked with respect to its accuracy level (measured by AUC and RMSE) in relation to the other models based on percentile values in one study. Relative performance ranks: 1: lower than the 20% percentile, 2: in-between 20 and 40% percentile, 3: in-between 40 and 60% percentile, 4: in-between 60 and 80% percentile and 5: higher than the 80% percentile.

4.5.3 Discussion

Machine-learning ensemble techniques, especially random forests produces models with excellent performance can produce significant better models with high numbers of predictor variables since they are specific for their highly reliable variable selection procedure and are therefore also used to analyse for the importance of different stressors and interactions among different stressors (e.g., Teichert et al., 2016; Feld et al., 2016). In this framework, CIF are a promising emerging tool for variable selection (Villeneuve et al., 2015), since the procedure was developed to obtain unbiased variable selection (Strobl et al., 2007). So far it is not widely tested. Additionally, support vector machines (SVM) are an emerging tool for ecological application. It outperforms ensemble methods generally in very high dimensions. This was found by Drake et al. (2006) and Crisci et al. (2010), who observed that useful information can be obtained from SVM models by the addition of more environmental variables even if they are highly correlated, obtaining more consistent models without previous data reduction (Table 7).

Common regression analysis rapidly becomes unreliable when dimensionality (number of predictors and their possible interactions) becomes high (Hastie and Tibshirani, 1990) and these techniques do not generally account for complex interactions between predictors (Oliver et al., 2012). Additionally, Marmion et al. (2008) could show that regression based techniques such as GLM, GAM and DA are higly sensitive to autocorrelation. Predictive accuracy of these techniques was highly influenced by geographical attributes, whereas machine learning techniques such as RF, ANN, GBM, MARS and CTA were not or only moderately affected. When using regression based techniques, extensions like autologistic models can help to overcome the problem of autocorrelation (Wintle and Bardos 2006; Lin et al., 2010).

However, machine learn techniques like RFs tend to over-fit to data which is good for interpolating missing values, but poor for extrapolating. Wenger and Olden (2012) showed that RF can produce models with excellent in-sample performance but poor transferability. The same was found by Heikinnen et al. (2012). For artificial neural networks, Wenger and Olden (2012) found a trade-off between in sample accuracy and transferability in dependency of model complexity. Traditional linear models (Wenger and Olden 2012) had greater transferability and GAM as well as GBM (Heikinnen et al., 2012) had both greater transferability and predictive accuracy (Wenger and Olden 2012). They recommend the use of a transferability assessment whenever there is interest in making inferences beyond the data set used for model fitting (Table 7).

Additionally, the high reliability of machine learn and ensemble models comes along with a low ecological interpretability since such combined models and many machine learn techniques have no simple way of graphical representation and are in most cases highly complex. Many of the complex machine learn (ANN, SVM) and ensemble approaches (RF, GBM, BT, CIF) can be considered a “black box” approach that may be difficult to communicate in an open planning process (Guisan et al., 2005). Also discriminant analysis, beside its below average performance, has the disadvantage that the contributions of single dependant variables are hidden because of the multidimensional nature (Schmutz et al., 2007). Some machine learning techniques like RF include procedures for calculation of variable importance and there are independent procedures available to analyse the relative contribution of predictor variables as one tool for communication. However, a graphical representation of the complex interactions and hierarchical structure cannot be depicted. Thus for management often simpler methods like GLM or GAM, or if complex interaction and hierarchical structure should be included CART, are selected (Guisan et al., 2005). A promising tool are BBNs, which are specific for their useful visual depiction and high potential to produce models of high accuracy and to include complex interactions and hierarchical structure. Quantitative BBN are an emerging tool but are so far not intensively tested against other methods (Death et al., 2015).

Table 7: Summary of different model characteristics and results from quantitative model comparison

Model	Regression/ machine learn	Ensemble	Complex interaction and hierarchical structure	Graphical representation/ communication/ "black box"	High dimensionality/variable selection	Performance
DA	r	no	no	low	0	–
GAM	r	no	no	high	0	+
GLM	r	no	no	high	0	+
MARS	r/m	no	no	high	0	+
ANN	m	no	yes	low	+	+
CART	m	no	yes	high	–	–
SVM	m	no	yes	low	+	+
BBN	m	no	yes	high		
TN	m	no	yes	low	0	
GBM	m	yes	yes	low	0	+
RF	m	yes	yes	low	+	++
BT	m	yes	yes	low		+

4.5.3.1 Quantitative, qualitative or both

In a review of over 100 BN applications in environmental sciences, Aguilera et al. (2011) found that 15 percent of the models were based on data, one third on expert judgement and in most cases both strategies were included. Over a third (38%) of the studies did not perform any form of model evaluation. Among the studies using validation, expert knowledge and sensitivity analysis were the most common strategies. Anyway model evaluation is seen as critical for developing rigorous expert models, regardless of data availability (Chen and Pollino, 2012; Hamilton et al., 2015).

There are several levels between fully data driven and completely expert based models. In statistical methods like GLM and GAM the model structure has to be defined a priori by expert judgement whereas in many machine learn methods (e.g, RF, GBM, CART, MARS) models are developed as a direct function of the relationship between predictor and independent variables in a specific dataset in a fully quantitative manner (Miller and Franklin, 2002; Elith et al., 2008). In BBNs it is even possible that the decision about the independent variable (target variable) is calculated within the application of the model. Another example for models involving both expert knowledge and empirical data is the quantification of expert judgement within a quantitative model. In BBN or fuzzy rule based models expert knowledge can be quantitatively summarised and graphically depicted and used for decision in management. Additionally, methods like fuzzy cognitive mapping (Lorenz et al., 2015) can be used to quantitatively analyse data derived from expert knowledge or literature research. BBN can also directly include expert judgement and quantitative data analysis in one model. A particular expert based part of the graph can be fixed, while the rest is learned from data (Aguilera et al., 2011). Also process-based models fit in this gradient, where models are developed entirely based on expert knowledge "forward" or can be defined based on knowledge and physical laws and then calibrated based on analytical results or simulation in a semi-quantitative way (Dormann et al., 2012).

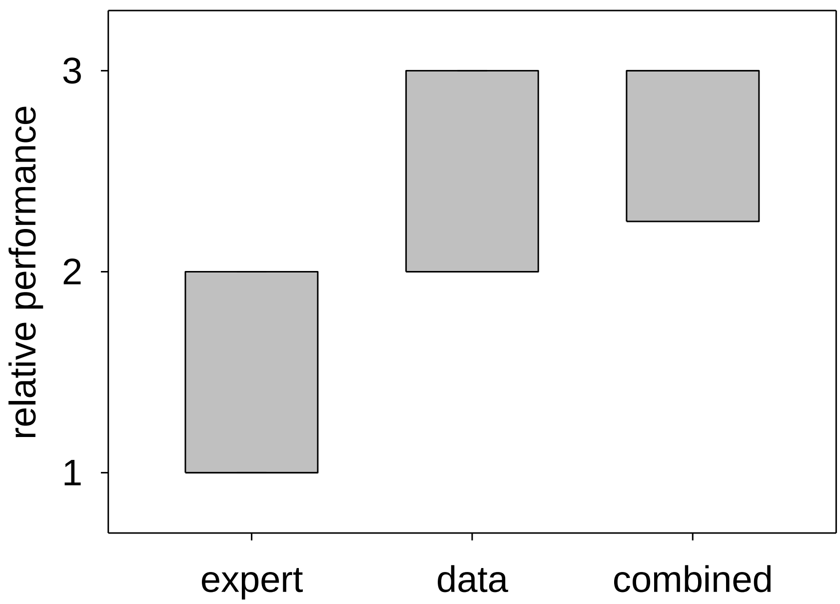
Different authors tested the performance of expert models, quantitative data driven models and such combined approaches (based on data and expert knowledge) with respect to their relative predictive performance (Mouton et al., 2009; Boets et al., 2015; Gontier et al., 2010; Hamilton et al., 2015) using mainly BBN and fuzzy rule based modelling including altogether 30 models.

In Figure 12, the relative performance of the three model types is summarised. Each model was ranked with respect to its accuracy level (measured with AUC and Kohens Kappa) in relation to the other models based on percentile values in one study. 1: lower than the 35% percentile, 2: in-between 35 and 65% percentile and 3: higher than the 65% percentile.

Across the four included studies, the relative performance of the three modelling strategy gives a homogenous picture and shows a clear trend. Data based models outperform expert based models in many cases, and data driven models are in most cases outperformed by combined approaches including expert judgement and data. Expert models have a high variability in their performance; in few cases they also outperform quantitative approaches. Authors conclude that expert models can only be successfully applied when there is detailed information on the ecology, habitat preferences and response to environmental parameters available for the selected biodiversity components. The quality of solely data driven models rely on the quality of the available data. Only data driven models can give new insight into the studied system. Therefore, data-driven model development may complement expert knowledge approaches (Mouton et al., 2009). Even though data driven models do not necessarily require expert knowledge, there is strong evidence that combined models development helps to improve the models performance (Gontier et al., 2010) and produces more robust models (Hamilton et al., 2015) with higher ecological importance and interpretability (Boets et al., 2015).

Similarly causality in modelling is discussed for correlation and process-based models by Dormann et al. (2012). In process-based models causality in processes is defined a-priory based on expert knowledge or physical or biochemical laws, assuming that the model structure and process formulation is correct, whereas in correlative methods mainly post hoc interpretation is causal beside the fact that also the explanatory variables are employed (mostly by expert judgement) in such a way that they are expected to represent causal mechanisms. In that sense causality is not necessarily assured and a critical issue in both approaches. They conclude that a combined workflow using both model types may be fruitful.

Figure 12: Relative performance of the three model types data-driven, expert-based and combined.



Legend: The evaluation included five studies (Death et al., 2015; Mouton et al., 2009; Boets et al., 2015, Gontier et al., 2010; Hamilton et al., 2015) comparing the accuracy of data-driven, expert-based and combined models.

4.6 Summary

As described in chapter 3.4, the development of a linkage matrix is recommended for each case study within AQUACROSS and can be used as a starting point to link drivers, pressures and states in the case studies. The matrix can then be used to frame detailed qualitative and quantitative analyses to investigate the relationships of drivers, activities, pressures and ecosystem states described in chapters 4.1 and 4.2.

The meta-analysis of alternative quantitative and qualitative methods conducted in chapter 4.5 showed that model performance can vary substantially, dependent on the structure of available data and information, and model selection should be case specific. 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 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 the techniques have no simple way of graphical representation and are in most cases highly complex compared to regression and more simpler machine learning techniques. If the results should be used as a communication tool for management, more simple methods with a good graphical representation and straight-forward interpretability should be preferred, whereas for complex situations including interactions and hierarchical structure of drivers and pressures complex methods may be more advantageous (see chapter 4.5.3)..
- 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 models will be more advantageous (see chapter 4.5.3).
- 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 is directly dependant 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., BBN) often produce the most reliable, robust and interpretable models (see chapter 4.5.3.1).

Further recommendations are essential for the implementations in the case studies:

- Model evaluation is essential for the development of reliable explanatory or predictive models independent of whether those are data or expert based (see chapter 4.4 for description of available methods).

Parallel or combined application of different modelling techniques (including qualitative and quantitative methods) to the same analytical problem increases robustness and impact of results (see chapter 4.3 and 4.5.3.1). Furthermore, it is then important to identify and implement adequate indicators to gain meaningful insights in relation to drivers, pressures and states. These indicators will be discussed in chapter 5 of this deliverable.

5 Pressure-sensitive Indicators

The major question of this chapter is: Which are the most commonly used, sensitive and cost-effective indicators for the D-P-S part of the AQUACROSS AF. Therefore, we identify widely used indicators as well as review characteristics and definitions of indicators across realms and policies.

- In chapter 5.1 we review the characteristics and definitions of indicators as well as the requirements for a “good” indicator. A clear and common concept of indicators, metrics and indices is presented that was defined together with WP5.
- In chapter 5.2, we identify commonly used and cost-effective indicators across realms and policies.
- In chapter 5.3, we integrate the identified indicators 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. Finally, we present a common list of indicators supplemented with examples for metrics and indices across realms and policies.

The chapter aims to provide a common concept of indicators across realms and policies and therefore to bring case study work in line within the D-P-S part of the AQUACROSS AF. What it does not do is to aim at presenting a complete or prescriptive list of indicators for the case studies, since the selection of the indicators should be done dependant on the context and specific purpose of the respective system.

5.1 Characteristics of indicators

The term ‘indicator’ is widespread in use. Generally, indicators provide aggregated information on specific target criteria (Wiggering and Müller, 2004), and try to depict qualities, quantities, states or interactions that are not directly accessible (Kandziora et al., 2013). Ecological indicators are considered necessary to evaluate effect-oriented nature and environmental policy (Turnhout et al., 2007). However, the term indicator is still profoundly ambiguous with different meanings in different contexts (Heink and Kowarik, 2010). Indicators gained and still gain importance in environmental assessments, especially to evaluate the necessity respectively efficacy of management objectives and measures. 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 (Turnhout et al., 2007). Hence, indicators are communication tools to supply information between science, policy, decision makers, stakeholders as well as the broader public (EEA, 1999).

Accordingly, indicators should have the ability to isolate key aspects from an otherwise overwhelming amount of information and help the target audience to see the larger patterns of what is happening and help to determine appropriate action (Niemeijer, 2002). The purpose of indication strongly determines the type of indicator needed to address a problem and the spatial scale of application (Feld et al., 2009). Effective environmental management requires that the condition of complex environmental systems are captured in one or more simple figures or indicators, which are understandable for policy- and decision makers right through to the general public (Niemeijer, 2002). According to Heink and Kowarik (2010), an indicator is defined as: 'An indicator in ecology and environmental planning is a component or a measure of environmentally relevant phenomena used to depict or evaluate environmental conditions or changes or to set environmental goals. Environmentally relevant phenomena are pressures, states, and responses as defined by the OECD (2003)'.

Box 1: Definition of Indicators, Index, Metric and Measure in the context of AQUACROSS[14]

It is important to clarify how the concept of *indicator*, and the related terms *index*, *metric* and *measure* are understood and used within AQUACROSS. The terms are defined and consistently used across throughout the AQUACROSS assessment framework and D4.1 and D5.1

The term *measure* refers to a value measured against standardised units. A measure of something does not necessarily indicate something useful.

The term *metric* refers to a quantitative, a calculated or composite measure based upon two or more measures. Metrics help to put a variable in relation to one or more other dimensions.

The term *index* refers to a metric 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 management, regulatory or policy context.

The term *indicator* is refers to a variable that provides aggregated information on certain phenomena, acting as a communication tool that facilitates a simplification of a complex process. It relates to the component or process responsive to changes in the social-ecological system, but does not possess a measurable dimension, and therefore it is not an operational tool in itself.

An example of the use of the terminology above mentioned could be:

Fish (such intolerant species or assemblage structure) are good *indicators* of ecosystem state, for which specific *metrics* (e.g., proportion of rheophilic species (%), number of species (N)), which can describe their characteristics and are sensitive to pressures, need to be identified and incorporated into *indices* (e.g., Index of Biotic Integrity) that allow evaluating their status and tracking progress in space and time.

However, there are scientific as well as applied demands on indicators (Kandziora et al., 2013). Scientific correctness comprises a clear representation of the indicandum by the indicator, a proven cause-effect relation, an optimal sensitivity of the representation,

[14] The definitions of indicators, index, metric and measure have been aligned between WP4 and WP5. Accordingly, these terms are also consistently used in D5.1.

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 basing upon (Wiggering and Müller, 2004 in Kandziora et al., 2013). Finally, cost-effectiveness is also a crucial factor.

5.1.1 Uncertainty associated with indicators

The use of indicators, respectively the calculation of related metrics and indices is associated with uncertainties. Accordingly, to meaningfully apply metrics and indices and to provide robust information by their means, consciousness about the associated uncertainties is helpful. Uncertainties can stem from various sources, such as spatial and temporal variability or analysis methods. Environmental assessments that incorporate indicators are often related to reporting requirements stemming from legislation (e.g., EU directives) and Member States own legal requirements. However, the legislative texts of those directives also address the uncertainty aspect, as for example stated in the WFD the monitoring should consider "*parameters which are indicative of the status*" and "*estimates of the level of confidence and precision of the results provided by the monitoring programmes shall be given*". Hence, confidence and precision are two central elements to describe the uncertainty of an indicator. Precision is strongly related to statistical parameters, such as the mean and the confidence interval around it. Confidence represents an estimate of the probability that a classification is correct (Lindegarth et al., 2011).

Uncertainty in metrics and indices mainly stems from three sources: (1) sampling and analysis methods, (2) spatial variability, and (3) temporal variability. The design and dimensionality of the monitoring/sampling systems is an important factor to determine the precision and confidence of metrics and indices derived from the sampling data. Furthermore, temporal and spatial variation have to be considered. Over different spatial and temporal extents, fluctuations and gradients can occur that bring uncertainty into the calculation of metrics and indices.

5.2 Identification of currently used and cost-effective indicators

This sub-chapter aimed to review and summarise the knowledge on existing types of pressure-sensitive indicators, considering indicators that are actually used in different aquatic realms and focussing on the relationship of pressures and states. Furthermore, an overview will be provided on existing indicators that are currently used in relation to existing EU policies and can give support to evaluate drivers, pressures and states respectively.

Accordingly, the presented indicators will be described to which part of the socio-ecological system they are related to (economic vs. environmental) and at which element of D-P-S they are characterising.

The EEA described already in 1999, that changes in environmental state cause Impacts on the ecosystem functioning relevant for the provisioning of ecosystem services, such as the provision of adequate conditions for health, resources availability and biodiversity. On large scales, the level of pressure effects can be easily related to coarse socio-economic indicators such as population or affluence (Rosa et al., 2004) due the fact that decoupling of socio-economic performance from deterioration of nature is still insufficient (Vackar et al., 2012). Accordingly, several institutions collected and proposed indicators to monitor the effects of human-induced changes on the environment.

5.2.1 Indicators related to biodiversity

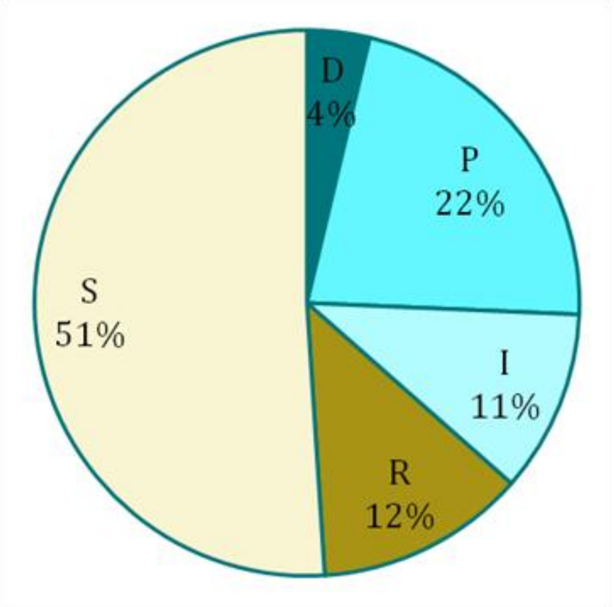
The characterisation of biodiversity status and trends is inevitable to stop the loss of biodiversity. Even though the commitments taken by the EU have been reflected in the Convention on Biological Diversity in 2010, there is a much longer history in European indicators to characterise biodiversity respectively drivers and pressures that affect it. In the following sections, indicators from the EEA inventory of biodiversity-related indicators and the SEBI 2010 are introduced.

In 2003, the EEA published an exhaustive list of biodiversity-related indicators in Europe (EEA, 2003). Even though this list has been created some while ago, it still more or less contains all relevant issues that can be measured. The review of biodiversity-related indicators showed that there is an enormous variety of indicators that have been developed to assess aspects of biodiversity at the national, international or global scale. Furthermore, many indicators have been proposed or developed, but only a limited number of them are actually in use on a regular basis.

Table 8: Overview of the biodiversity-related indicators per sector

Sectors/themes	Number of indicators	Relative portion (%)
Nature protection	387	58
Forestry	78	12
Energy	1	0
Recreation	4	1
Climate change	12	2
Urban development	4	1
Rural development	0	0
Water	43	7
Infrastructure	11	2
Trade	2	0
Fisheries	22	3
Agriculture	91	14

Figure 13: Relative portion of the biodiversity-related indicators in the DPSIR categories



See Annex 2 for the full list of the indicators (N=654)

The EEA core set of indicators comprises 37 indicators that were selected based on nine key criteria in respect to relevance to policy priorities, objectives and targets, the availability of high-quality spatial and temporal data, and the application of well-founded methods for indicator calculation (EEA, 2005). Three indicators aim at biodiversity considering issues on threatened and protected species, designated areas and species diversity, and seven further indicators are dealing with water mostly related to water quality issues. Three indicators aim at fisheries including status of marine fish stocks, aquaculture production and fleet capacity (table 9).

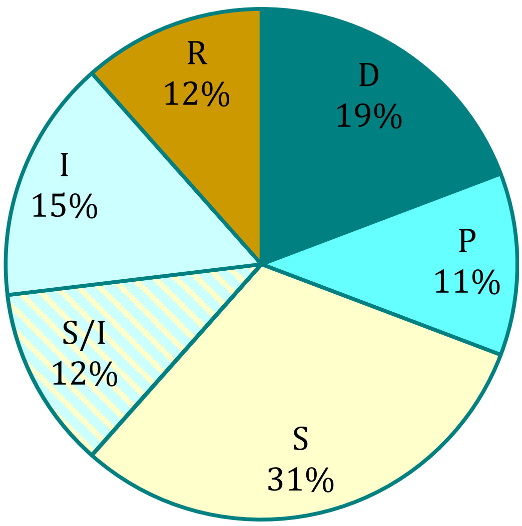
Table 9: Position in the DSPIR cycle of the 37 EEA core set indicators

	Driver	Pressure	State	Impact	Response
Air quality and ozone depletion		4		2	
Biodiversity			1	1	1
Climate change		2	2		
Terrestrial			1		1
Waste		1.5			0.5
Water		1	5		1
Agriculture					1
Energy	3				2
Fishery	1	1	1		
Transport	2				1
Total	6	10.5	10.5	3	7

In 2003, a report was published describing the present state and development of policy relevant indicators for eutrophication, hazardous substances, oil and ecological quality in the marine and coastal environment in Europe related to the input of substances affecting these issues (EEA, 2003c). The indicators included in the report are part of the EEA core set of water indicators.

Beside the core set of indicators that aims at the environment, the 'Streamlining European Biodiversity Indicators 2010' (SEBI2010) initiative was launched in 2005 to develop a European set of biodiversity indicators based on the conceptual framework of the Convention on Biological Diversity (CBD) (EEA, 2007). This initiative was renewed in 2012 by 'Streamlining European biodiversity indicators 2020' (EEA, 2012). The 26 SEBI 2010 indicators (Annex 3) were selected on the basis of 13 criteria including policy and biodiversity relevance, cause-effect relationship, representativeness of DPSIR as well as aggregation and flexibility. A closer look on the different indicators underlines the differences in the nature of the indicators according to the DPSIR cycle (Figure 14). Even though, the majority of indicators can be assigned to the state or impact category (58%), a reasonable portion is related to drivers (30%), pressures and responses (each 11%).

Figure 14: Relative portion of the SEBI 2010 indicators in the DPSIR categories.



Legend: See Annex 3 for the full list of the indicators (N=26)

5.2.2 Indicators related to the Water Framework Directive

In 2003, the EEA already published the report 'Europe's water: An indicator-based assessment' (EEA, 2003a). This report basically describes the framework and indicators to assess the quality of Europe's water resources. Besides the ecological quality, assessments of nutrients and organic pollution, hazardous substances and water quantity were highlighted.

In respect of 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 WFD postulates the good ecological status for all surface waters by 2015 (with two 6-year extensions to update the management plans). The second river basin management plans (RBMPs), published in 2015, showed previous achievements and highlighted the future objectives in relation to the WFD.

Table 10: Overview of WFD state indicators

(Type: B=biotic, NB=non-biotic)

	Impact	State	Type
Biological	macrophytes	composition abundance	B
	phytoplankton	composition abundance biomass	B
	planktonic blooms	frequency intensity	B
	benthic invertebrates	composition abundance	B
	fish	composition abundance age structure	B
	eutrophication	chlorophyll concentration	B
Hydromorphological	hydrological regime	quantity and dynamics of water flow connection to groundwater bodies residence time	NB
	tidal regime	freshwater flow direction of dominant currents wave exposure	NB
	river continuity	passable length, existance of barriers	NB
	morphology	depth and width variation quantity, structure and substrate of the bed structure of the riparian zone, lake shore or intertidal zone	NB
Chemical and physico-chemical	transparency	concentration of total suspended solids turbidity Secchi disc transparency (m)	NB
	thermal conditions	temperature (oC)	NB
	oxygenation conditions	concentration	NB
	conductivity	conductance converted to concentration of total dissolved solids	NB
	salinity	concentration	NB
	nutrient status	concentration of nitrogen and phosphorus, loads in view of sea protection	NB
	acidification status	pH alkalinity acid neutralising capacity (ANC)	NB
	priority substances	concentration	NB
	other pollutants	concentration	NB

The good ecological status is conceptually associated with the ecological integrity of the water body. The indicator 'ecological status (or potential)' can be used to illustrate the state of the ecosystems across water categories (i.e., rivers, lakes, transitional and coastal waters) in Europe (Solheim et al., 2012). The assessment of the ecological status is based on biological quality elements (BQEs) and is determined by the worst scoring BQE (one out – all out principle), with adjustments using the supporting quality elements according to certain rules (Solheim et al., 2012). BQEs comprise fish, benthic invertebrates, phytoplankton as well as macrophytes and phytobenthos, i.e. these biological elements are used as indicator of the ecosystem state. Hence, several bio-assessment methods have been designed across Europe since the implementation of the WFD. Birk et al. (2012) reviewed 297 bio-assessment methods that are applied to evaluate the ecological status of surface water bodies in respect of the WFD including rivers, coastal waters, lakes and transitional waters. Benthic invertebrates were the most prevalent biological quality element used in freshwater bioassessment followed by macrophytes and phytoplankton. Fish and phytobenthos are comparatively rarely used as biological quality element for assessment (Table 11). The majority of methods focussed on the detection of eutrophication and organic pollution. There is strong empirical evidence that different BQEs respond differently to individual pressures (Marzin et al., 2012).

Table 11: Percentage of metric types used in freshwater bio-assessment

		Rivers	Lakes	Transitional-waters	Coastal-Waters
Taxonomy-based	Richness	12.1	7.2	11.4	13.1
	Abundance	16.4	46.2	42.4	47.3
	Diversity	4.5	5.5	4.7	5.7
	Assemblage composition	0.5	1	3	0.4
Autecology-based	Sensitivity	37.3	25.7	10.2	20.8
	Ecological traits	25.7	11	21.6	5.3
	Individual condition	0.5	0	4.7	7.3
	Alien	3	3.4	0.8	0
Non-biotic			0	1.3	0

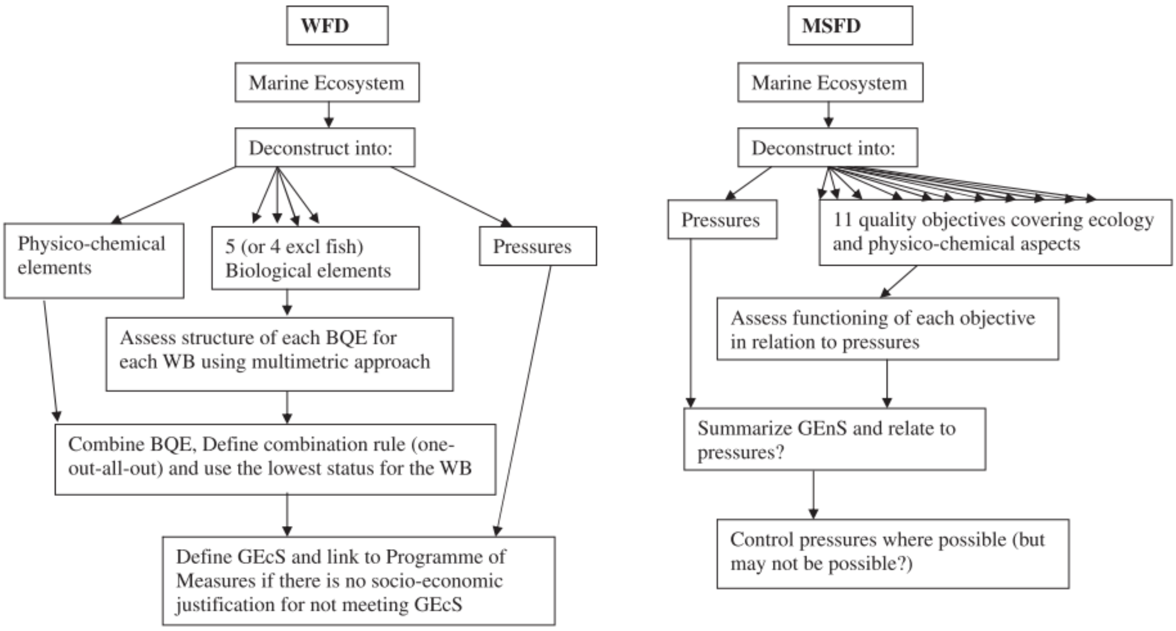
Source: based on Birk et al., 2012

5.2.3 Indicators related to the Marine Strategy Framework Directive

The MSFD indicators as identified by the EC (2011) are presented per GES descriptor (Annex 4) and within an integrated table, linking state characteristics to pressures (Annex 5). For descriptors D1 (biological diversity), D4 (food webs) and D6 (seafloor integrity) there are no pressure indicators identified by the EC (2011). However, Berg et al. (2016) relate pressure/state indicator(s) to D6. There seems to be some overlap between the interpretation of pressure and state indicators (Figure 14). It has been noted that some experts regard their indicators as useful for reflecting some pressure level while others use them as sole state indicators and refrain to establish a direct causal effect (Berg et al., 2015).

In respect of environmental policies, pressures are evaluated in respect of their impact and resulting state. The good ecological status (WFD) and the good environmental status (MSFD) are strongly related to biological quality elements that indicate the integrity of the ecological system. However, the concept how the ecosystem state is evaluated differs between WFD and MSFD as the WFD deconstructs the ecosystem assessment into single elements in contrast to the MSFD (Figure 15).

Figure 15: Comparison of status assessment between WFD and MSFD



Source: Borja et al. (2010)

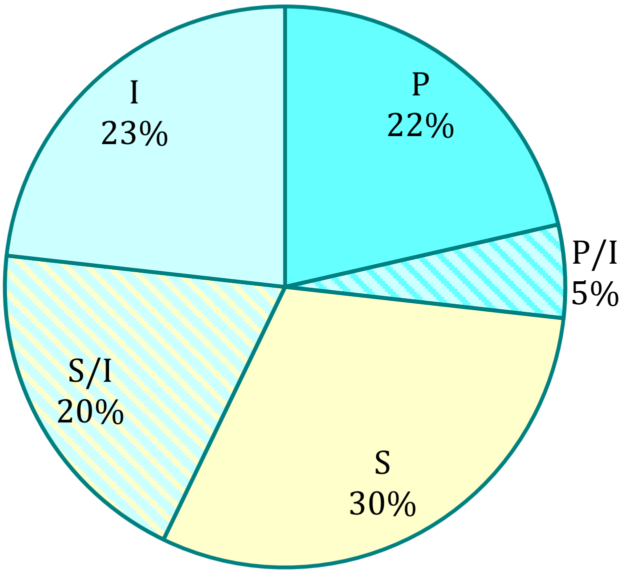
In the WFD, the aquatic ecosystems were separated into different quality elements, and the status of each is assessed, assuming that the condition of the worst element used in the assessment adequately determines the status of the whole system, thus not considering the effects of multiple human pressures. In contrast, in the MSFD the marine ecosystems are divided into a set of process-based descriptors (Table 12) that are recombined within a holistic framework and therefore explicitly addressing the detection of impacts from multiple human pressures (Mancinelli and Vizzini, 2015). 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 (Allan et al., 2013).

Table 12: Overview of the MSFD descriptors

Descriptor	ID	Number of indicators
Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions.	D1	14
Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems.	D2	3
Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock.	D3	8
All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity.	D4	3
Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters.	D5	8
Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected.	D6	6
Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems.	D7	3
Concentrations of contaminants are at levels not giving rise to pollution effects.	D8	3
Contaminants in fish and other seafood for human consumption do not exceed levels established by EU legislation or other relevant standards.	D9	2
Properties and quantities of marine litter do not cause harm to the coastal and marine environment.	D10	4
Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.	D11	2

These descriptors are used in MSFD assessment. Several indicators are associated to the descriptors (based on EC, 2011b; for more details see Annex 2)

Figure 16: Relative portion of the MSFD indicators in the DPSIR categories



See Annex 4 for the full list of the indicators (N=56)

5.2.4 Further examples of indicators in use for the marine environment

Tillin and Tyler-Walters (2015) defined pressure indicators within the following pressure categories: hydrological changes, physical damage, physical loss, physical pressure, pollution and other chemical changes, and biological pressure (see Annex 6), which were applied within the sensitivity assessment developed by Tillin et al. (2010). Initial pressure benchmarks were developed for the identified pressures drawing on a range of sources (Tillin and Tyler-Walters, 2015):

- existing benchmarks from other sensitivity assessments (MarLIN website);
- environmental quality standards (for example, water quality standards established under the EC Water Framework Directive (2000/60/EC);
- guideline values for concentrations of contaminants in sediment and biota (e.g., OSPAR environmental Assessment Criteria (EAC's), Canadian Interim Sediment Quality Guidelines (ISQGs);
- initial thresholds developed for indicators of Good Environmental Status under the EC Marine Strategy Framework Directive (2008/56/EC) (Cardoso et al., 2010);
- climate change projections (UKCP09);
- expert knowledge of the nature and scale of hydrological changes associated with marine infrastructure developments in UK waters.

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) is a legislative instrument that regulates the international cooperation for the protection of the North-East Atlantic. OSPAR identified a number of common and candidate indicators with the aim that those indicators are implemented into the monitoring and assessment. Those common and candidate indicators are further recommended to be used 'OSPAR-wide' (Annex 7) or in specific regions (Region I - Region V) (Annex 8). In autumn 2016 the most recent version of those indicators was published. Martin et al. (2014) present results of the MARMONI project, within the framework of which a number of new, cost-effective and innovative indicators for the assessment of marine biodiversity in the Baltic Sea was developed as a proposal for inclusion in national monitoring programmes. Among the defined indicators, there are several pressure indicators (Annex 9).

5.3 Integrative indicators

The AQUACROSS AF evolves from the traditionally DPSIR cycle by explicitly considering ecosystem functions and services, human well-being, and both social as well as ecological processes (Gomez et al., 2016). 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. A 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.

5.3.1 Integrative indicators for primary activities, pressures and ecosystem components

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 impractically 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. Accordingly, this chapter summarises indicators, metrics and indices that can be useful for the case studies.

The purpose of this chapter is to integrate the identified existing indicators (chapter 5.3) into the overall structure of the AQUACROSS AF (deliverable 3.2), to make it operational and to assure that the selection of indicators is in line with the other parts of the assessment framework, so that a successful flow of information is achieved. Therefore identified indicators are

1. integrated in the common typology developed within the **linkage framework** and
2. integrated in the AQUACROSS concept of **indicators, indices and metrics**

Basically, the linkage framework facilitates the identification of the existing and relevant relationships between drivers, primary activities, pressures and ecosystem components (respectively states). Thus, it facilitates the fundamental identification of indicators needed to describe critical parts within the demand-side analyses. The typologies, developed systematically (see chapter 3, Tables 3 and 4), organise the nomenclatures and definitions of activities and pressures from existing policies, which are most relevant for the different aquatic ecosystems across the realms, and allow to link back the findings of the AQUACROSS case studies to improve and align the policies. In D2.2, existing policy data and spatial information sources in relation to policies are summarised.[15] This information can support the identification of general valid data sets to derive metrics and indices on drivers and pressures. For each component of the D-P-S relationship, possible sources and examples of indicators are included in the set of integrative indicators (Table 14 and Table 15).

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 principal differentiation between **biotic indicators** and according metrics and indices (referring to organisms: indicator species, species richness, etc.; characterising the status and/or trends of biotic communities and biodiversity) and **abiotic indicators** and according metrics and indices (referring to the non-organismic environment: physical, chemical related to the level of environmental stress or disturbance impacting the ecosystem) can be further refined into:

- Indicators of simple structure including, e.g. taxon abundances and biomasses, species richness, diversity, evenness, stratification structure, water level, temperature, matter concentrations in the water, fish size and age structure.
- Indicators of functional structure. For surface waters they include structural metrics with functional attributes (e.g., biological features ('traits') related to tolerance, trophic position, reproduction, habitat and migration). Indicators of this group are sometimes termed 'functional metrics' (e.g., Hering et al., 2004; Pont et al., 2006).
- Functional or process indicators (sensu Palmer and Febria, 2012), i.e. metrics for fluxes or rates and equilibria of processes such as nutrient uptake, photosynthesis, growth rate, respiration rate etc.

[15] O'Higgins, T; Barbosa, A; Iglesias-Campos, A; Arvévalo-Torres, J; Barbière, J; De Wever, A; Lillebø, A; Nogueira, A; Schmidt-Kloiber, A; Schinegger, R (2016) D2.2 - Review and analysis of policy data, information requirements and lessons learnt in the context of aquatic ecosystems; http://aquacross.eu/content/deliverable-22-review-and-analysis-policy-data-information-requirements-and-lessons-learnt

These indicators mainly reflect ecosystem state. Therefore, they are capable of integrating the effects of primary activities and/or pressures on the ecosystem.

The proposed set of indicators is not intended to be prescriptive or complete and each case study should select indicators more adequate for the context and purpose of the study, and may identify other ones that are more relevant in the context of the case study. However, for the selection of indicators within the case studies it is most important to be in line with the other stages of the assessment framework, i.e. via the linkage framework, and to enable a consistent view on the relevant drivers, activities, pressures and effects on the ecosystem components. Lessons learnt from this application of indicators to the case studies will inform the final adaptation of the AQUACROSS AF through work completed under Task 4.3.

Table 13: Proposed set of integrative indicators describing activities

Broad category of primary activity	Detailed primary activity	Indicator	Metric/**index** examples	Source
Agriculture and Forestry	Cultivation	Agricultural area and intensity	Arable land per capita	1
			Agricultural area by crops (cereal, oil crops, forage, woodlands)	1
			Agricultural area (intensively farmed, semi-intensively farmed and uncultivated)	1
			Share of irrigated agricultural land	1
			Percentage environmentally managed land of total agricultural land	2
			Percentage area with intensive cropping of total agricultural land	2
			Change in traditional land-use practice	3
			Agriculture intensity: area used for intensive arable agriculture	3
			Matrix of changes in land cover classified by type and size	4
			Change in land use 1950-99 (30 land-use types)	3
			Rate of vegetation clearing by activity (agriculture, urban development, deforestation	1
			Use of agricultural pesticides	1
			Change in area of agricultural land area (conversion to or from agriculture)	1
			Intensification and extensification of agricultural land use	1
			Percentage of agricultural land under exploitation	1
			Use of fertilisers	1
			Trends: intensification/extensification, specialisation	4
			Agriculture: nitrogen balance	5
			Average annual fertiliser use	6
			Pesticide use	6
			Sown area	8
			% habitat managed for production	1

Broad category of primary activity	Detailed primary activity	Indicator	Metric/**index** examples	Source
			Area of water limited crop production	7
			Actual irrigation water requirements	7
			Percentage of watershed that is irrigated area	6
	Forestry activities	Area and intensity of forestry management	Export of timber and timber products	8
			Annual volume and area of timber harvested — indigenous and plantation	1
			Per capita wood consumption	1
			Matrix of changes in land cover classified by type and size	4
			Change in land use 1950-99 (30 land-use types)	3
			Rate of vegetation clearing by activity (agriculture, urban development, deforestation	1
			Average annual % change of forests 1990-95	6
			Average annual % change of natural forests 1990-95	6
			Average annual % change of plantations 1990-95	6
			Total area of drained forest land & total length of forest ditches	2
			Percentage of forest managed for wood production	1
			Percentage of forest used by people for subsistence	1
			Wood harvesting intensity	1
			Total forest felling	8
	Livestock	Benefits from demesticated species	Benefits from extracted resources from domesticated species by sector	9
			Change in area and use of grasslands	7
Aquaculture	Aquaculture total and per component	Aquaculture production per component	Aquaculture production per country, environment and component (tonnes of live weight)	7
Fishing	Commercial fisheries per component	Capacity of commercial fisheries per component	Number of boats and capacity of the national fishing fleet in the countries	1
			Number of large scale bottom trawling vessels per 1 000 km of coastal area	1
Waste management	Seawage treatment	Proportion of population with sewage treatment	Coastal population without purification treatment of sewage	1
Services (e.g.,transport, water supply)	Transport (terrestrial)	Density of infrastructure network and traffic intensity	Road density	8
			Traffic intensity on the roads of European importance	8
			Total length of the roads, railroads and powerlines per area	2
			Density of infrastructure network	2
			Areas more than 5 km from the nearest road, railway or powerline	2
			Density of road network	1
			Proximity of transport infrastructure to designated nature areas	7
			Land take by transport infrastructure	7
	Water use	Use of ground water	Annual groundwater withdrawals as percentage of annual recharge	6

Broad category of primary activity	Detailed primary activity	Indicator	Metric/**index** examples	Source
	Urban development	Poplulation density and built-up area	Coastline land cover	1
			Percentage of coastal zone with populations exceeding 100 inhabitants/km2	1
			Population density in/adjacent to key habitats	1
			Percentage of watershed that is built-up area	6
			Population density in/adjacent to protected areas	1
			Rate of housing development	1
			Water resource vulnerability index	1
			Percentage increase in structural hard surface in the coastal zone	4
	Shipping, total and per sector	Shipping intensity per sector	Energy consuption by shipping per sector	7
Non-renewable energy	Energy per sector and total	Energy per sector and total	Primary energy consumption by fuel per country decreas from 2005 to 2012	7
Renewable Energy	Energy per sector and total	Use of renewable energy per sector	Use of renewable electricity per country and sector in percentage of total energy	7
			Total of renewable energy in gross inland energy consumption	7
			Share of renewable energy in gross final energy consumption	7
Tourism Recreation	Tourism intensity per sector and total	Benefits from tourism services, Tourism intensity per category	Household expenditure for tourism and recreation	7
			Tourism travel by transport mode	7
			The number of nights spent by tourists in the coastal zone each year	4
			Total boats, canoes operated on island or per village	1

Sources: 1: UNEP 1999, 2001; 2: Bosch & Söderbäck 1997; 3: Eurostat 2001; 4: EC 2001; 5: SEBI 2010; 6: UNDP et al. 2000; 7: EEA website; 8: BEF2000; 9: Prescott-Allen et al. 2000.

Table 14: Proposed set of integrative indicators describing pressures.

Pressure Category	Pressures	Indicator	Metric/Index examples	Source
Biological disturbance	Introduction of microbial pathogens	Introduction and distributions of aquatic pests and disease	The introduction of relevant microbial pathogens or metazoan disease vectors to an area where they are currently not present (e.g., Martelia refringens and Bonamia, Avian influenza virus, viral Haemorrhagic Septicaemia virus).	2
	Introduction of non-indigenous species	Invasion, trends in presence, location, distribution, temporal occurence or numbers of invasive species	% habitat colonised by invasive species	1
			% protected area colonised by invasive species	1
			Number of introduced species and genomes	1
			Percentage of habitat colonised by invasive species	1
			Percentage of protected area colonised by invasive species	1
			Number of exotic and local species outbred and location of affected areas	1
			Ratio between exotic species and native species	1
			Number of inland fish species introduced	1
			Number of exotic flora and fauna species, e.g. fish, aquatic weeds	1
			BioContamination Index (SBC)	10
			The introduction of one of more invasive nonindigenous species (IINIS)	2
	Translocation of species	Genetic modification & translocation of indigenous species	Translocation of indigenous species and/or introduction of genetically modified or genetically different populations of indigenous species that may result in changes in genetic structure of local populations, hybridization, or change in community structure.	2
	Selective extraction of species	Removal of target species: european commercial and non-commercial stocks	Species used by local residents (number or percentage)	1
			Marine fish catch metric tons 1995-	6

Pressure Category	Pressures	Indicator	Metric/Index examples	Source
			97	
			Marine fish catch percentage change since 1985-87	6
			Freshwater fish catch metric tons 1995-97	6
			Freshwater fish catch percentage change since 1985-87	6
			Percentage of stocks outside safe biological limits	11
			Catch per unit effort	11
			Mollusc and crustacean catch metric tons 1995-97	6
			Mollusc and crustacean catch percentage change since 1985-87	6
			Benthic species and habitats: removal of species targeted by fishery, shellfishery or harvesting at a commercial or recreational scale	2
			Number of individuals traded by species group	6
			Change in proportion of fish catches by species per specific season	1
			Quantity of specimens or species of economic/scientific interest removed from the environment	1
			Annual catches of species at risk, expressed in tonnes live weight equivalent of the landings	4
			Game-hunting rate — diversity and abundance	1
			Ratio between catch and biomass index ('catch/biomass ratio')	3
			Number of wild species used as food sources by communities	1
		Removal of non-target species, By-catch (unwanted)	Fishing mortality of non-targeted species	13
			Removal of features or incidental non-targeted catch (by-catch) through targeted fishery, shellfishery or harvesting at a commercial or recreational scale.	2
Chemical change, pollution	Salinity change	Salinity status, Physical loss (to land or Freshwater habitat)	Permanent loss of existing saline habitat	2
	Hazardous substances	Introduction of substances (solid, liquid or gas), Contamination in	Introduction of substances, compliance with all AA EQS, conformance with PELs, EACs/ER-Ls	2

Pressure Category	Pressures	Indicator	Metric/Index examples	Source
		critical points, Potential risk of hazardous substance pollution		
			Amount of poison chemicals and dynamite used for reef fishing	1
			The amount of mercury, cadmium, copper, lead and zinc emitted directly or by riverine inputs to coastal zones and the marine environment	4
			The total accidental, licensed and illegal disposal of mineral oil into the coastal and marine environment	4
			Radionuclide contamination: An increase in 10µGy/h above background levels	2
			Occurrence, origin (where possible), extent of significant acute pollution events (e.g., slicks from oil and oil products) and their impact on biota physically affected by this pollution	3
			Water risk Index (WRI)	9
	Emission of nutrient and organic substances	Deposition and emission of nutrients and organic substances per pathway	Type of collection and treatment system of urban wastewater loads per population equivalent	9
			Number of agglomerations per PE	9
			Amount of urban waste water load expressed as population equivalentes	9
			Discharge of BOD (tons per year) via urban waste water	9
			Discharge of COD (tons per year) via urban waste water	9
			Release of COD (tons per year) per industrial sector	9
			Discharge of TN (tons per year) via urban waste water	9
			Discharge of TP (tons per year) via urban waste water	9
			Release of TN (tons per year) from industry and agricultural point sources	9
			Release of TP (tons per year) from industry and agricultural point sources	9
			Diffuse water emissions of TN per pathway (tons per year)	9
			Diffuse water emissions of TP per pathway (tons per year)	9

Pressure Category	Pressures	Indicator	Metric/Index examples	Source
			Amount of nutrients (tonnes N and P per year) discharged into coastal zones directly or by rivers	4
			Effluent water quality from finfish farms	5
	Litter	Litter- Quantity, composition and distribution of litter deposited along costalines, in the water column and on the sea-floor	Trends in the amount of litter washed ashore and/or deposited on coastlines, including analysis of its composition, spatial distribution and, where possible, source	3
			Trends in the amount of litter in the water column (including floating at the surface) and deposited on the sea-floor, including analysis of its composition, spatial distribution and, where possible, source	3
			Trends in the amount, distribution and, where possible, composition of micro-particles (in particular micro-plastics)	3
			Introduction of manmade objects able to cause physical harm (surface, water column, sea floor and/or strandline)	2
Physical change	Selective extraction non-living resources	Water abstraction and consumption	River water bodies significantly affected by impoundments, water abstraction or hydropeaking	9
			Water consumption index by the sectors (agricultural, energy, industry, tourism and services), the index being the quotient between the consumptive demand (detraction — return) and the potential resource	1
	Water flow rate changes, Water abstraction	Water flow changes, hydrological alteration - local, including sediment transport considerations	A change in peak mean spring bed flow velocity of between 0.1m/s to 0.2m/s for more than 1 year	2
			Extent of area affected by permanent hydrographical alterations	3
			River water bodies significantly affected by impoundments, water abstraction or hydropeaking	9
			Collection of future infrastructure projects (hydrological alteration)	9
	Visual disturbance	Visual disturbance, introduction of light	Change in incident light via anthropogenic means.	2

Pressure Category	Pressures	Indicator	Metric/Index examples	Source
			Daily duration of transient visual cues exceeds 10% of the period of site occupancy by the feature	2
	Disturbance of substrate	Physical anthropogenic disturbance of substrate; Abrasion	Extent of the seabed significantly affected by human activities for the different substrate types	3
			Damage to surface features (e.g., species and physical structures within the habitat)	2
			Extraction of substratum to 30 cm (where substratum includes sediments and soft rocks but excludes hard bedrock)	2
			seafloor exploitation index Damage to sub-surface features (e.g., species and physical structures within the habitat)	12 2
	Barrier to species movement	Barrier to species movement: Interruption of longitudinal river continuity, river fragmentation	Permanent or temporary barrier to species movement ≥50% of water body width or a 10% change in tidal excursion	2
			Antrophogenic interruption of rivers, rithral >0.7m hight, potamal >0.3m height or lower if considered as relevant	9
	Changes in siltation, Smothering	Smothering, siltation and sedimentation rate changes(depth of vertical sediment overburden)	Light' deposition of up to 5 cm of fine material added to the habitat in a single, discrete event 'Heavy' deposition of up to 30 cm of fine material added to the habitat in a single discrete event	2
			A change in sedimentation rate of one rank on the WFD (Water Framework Directive) scale e.g. from clear to intermediate for one year	2
	Conversion and destruction of habitat	Habitat loss and fragmentation due to human activities	Peat cutting activities	8
			Habitat loss by km2 through human activities, and through natural causes.	1
			Extent of wetland drainage and filling	1
			Rate of destruction of water habitats per annum	1
			The loss of wetland area in the coastal zone, expressed as the percentage lost with reference to an	4

Pressure Category	Pressures	Indicator	Metric/Index examples	Source
			appropriate baseline year	
			Rate of destruction of water habitats by types of activities	1
	Death or injury by collision	Death or injury by collision	0.1% of tidal volume on average tide, passing through artificial structure	2
	Emergence regime change	Emergence regime changes - local, including tidal level change considerations	A change in the time covered or not covered by the sea for a period of ≥ 1 year. OR An increase in relative sea level or decrease in high water level for ≥ 1 year.	2
Energy	Electromagnetic changes	Electromagnetic changes	Local electric field of 1V m-1. Local magnetic field of 10µT	2
	Underwater Noise	Quantity and changes in (underwater) noise	Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1µPa^2.s) or as peak sound pressure level (in dB re 1µPa$_{peak}$) at one metre, measured over the frequency band 10 Hz to 10 kHz	3
			Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS: average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate	3
			Above water noise: None Underwater noise: MSFD indicator levels (SEL or peak SPL) exceeded for 20% of days in calendar year	2
	Thermal change	Thermal change of water bodies	Extent of area affected by permanent hydrographical alterations	3
			A 5°C change in temp for one month period, or 2°C for one year	2
Exogenous/ Unmanaged e.g. Climate change	Emergence regime change (climate change, large-scale)	Trends in sea level	Trends in sea levels between 1992 and 2013	7
			Trend in relative sea level between 1970 and 2012 per gauge station	7
	Thermal change (climate change, large-scale)	Trends in air and water temperatures	Trends in annual temperature between 1960 and 2015 per climate station	7
			Observed trends in warm days between 1960-2015 per year	7

Pressure Category	Pressures	Indicator	Metric/Index examples	Source
			Trend in water temperature of main rivers and lakes across Europe from 1900-2010	7
			Mean annual sea surface temperature trend 1987-2011	7
	Water flow rate changes (climate change, large-scale)	Trends in flood and drough events	People affected by flood and wet mass movement (2000-2011)	7
			Theoretic increase in frequency of flooding events in coastal region	7
			Trend in length of dry and wet periods and heave precipitation events	7
			Water scarcity and drough events during the last decade	7
			Occurence of river flood events between 1998 and 2009	7
	pH changes (climate change, large-scale)	change in acidification	Change in acidification of ocean water from 1984-2010	7
	Precipitation regime change (climate change, large-scale)	Change in precipitation and water balance	Rate of change of meteorological water balance (from 1975-2010)	7
			Trends in annual precipitation from 1960-2013	7
			Change of water availability (from 1975-2010)	7

Sources: 1: UNEP 1999, 2001; 2: Tillin and Tyler-Walters, 2015; 3: MSFD; 4: EC, 2001; 5: SEBI, 2010; 6: UNDP et al., 2000; 7: EEA website; 8: BEF, 2000; 9: ICPDR, 2015; 10: Arbačiauskas et al., 2008; 11: Zenetos, 2001; 12: Martin et al., 2014; 13: Piet et al., 2009.

Table 15: Proposed set on integrative indicators describing state/ecosystem components.

State	Component/indicator	Metric/index examples	Source
Biological state	macrophytes	composition, abundance	WFD: Birk et al. 2012; Van Hoey et al. 2010; MSFD: Ferreira et al. 2011; Rice et al. 2012; Van Hoey et al. 2010; Rombouts et al. 2013; Probst et al. 2013; Galgani et al. 2014; Simboura et al. 2012; Caroppo et al. 2013; Shepard et al. 2011; Greenstreet et al. 2012
	phytoplankton	composition, abundance, biomass, food web	
	planktonic blooms	frequency intensity	
	benthic invertebrates	composition, abundance, population characteristics, food web	
	fish	composition, abundance, age structure, population characteristics, food web	
	eutrophication	chlorophyll concentration, BOD	
	waterbirds	composition, abundance, population characteristics, food web	
	mammals and reptiles	composition, abundance, population characteristics, food web	
	habitats	coverage, composition	
Chemical state	pH, acidification status	pH alkalinity	Bosch & Söderbäck, 1997
		acid neutralising capacity (ANC)	Bosch & Söderbäck, 1997
	Salinity status	Salinity (concentration) of lakes/sea/groundwater/river	Tillin & Tyler-Walters, 2015
	Conductivity	concentration of total suspended solids	Tillin & Tyler-Walters, 2015
	Hazardous substances	Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals). Includes those priority substances listed in Annex II of Directive 2008/105/EC.: Compliance with all AA EQS, conformance with PELs, EACs/ER-Ls	MSFD
		Transition elements & organo-metal (e.g., TBT) contamination. Includes those priority substances listed in Annex II of Directive 2008/105/EC. Compliance with all AA EQS, conformance with PELs, EACs/ER-Ls	Tillin & Tyler-Walters, 2015

State	Component/indicator	Metric/index examples	Source
		Hydrocarbon & PAH contamination. Includes those priority substances listed in Annex II of Directive 2008/105/EC: Compliance with all AA EQS, conformance with PELs, EACs/ER-Ls	Tillin & Tyler-Walters, 2015
	Status of nutrients and organic substances	Organic enrichment: A deposit of 100gC/m2/yr	Tillin & Tyler-Walters, 2015,UNEP, 2001, Bosch & Söderbäck, 1997, SEBI, 2010
	Water quality	Biochemical oxygen demand (BOD) of water bodies (eutrophication)	UNEP, 2001
		Nutrient ratios (silica, nitrogen and phosphorus) in the water column	MSFD
		Nutrient status: compliance with WFD criteria for good status	Tillin & Tyler-Walters, 2015
Physical state	Disturbance of substrate	Change in sediment type by 1 Folk class (based on UK SeaMap simplified classification). Change from sedimentary or soft rock substrata to hard rock or artificial substrata or vice-versa.	Tillin & Tyler-Walters, 2015, Martin et al. 2014
	Thermal conditions	temperature (°C)	
	Change in wave exposure	A change in near shore significant wave height >3% but <5% for more than 1 year	Tillin & Tyler-Walters, 2015
	Alteration of morphology	Percentage channelled watercourses of total length	Bosch & Söderbäck, 1997
		Areas of wetland/floodplains which are reconnected or with reconnection potential	DRBMP, 2015
		Hydromorphological status	WFD
	Bottom sediment	Relative proporotion of bed substrate	Beisel et al., 2000
	Hydrological regime	Mean, minimum, maximum flow	Poff et al. 2010, Bunn & Arthington 2002

6 Conclusion

In WP4, the focus lies on the demand-side aspects of the AQUACROSS Architecture (Figure 1, Gomez et al., 2016). From this starting point, it is our aim that through work completed in the case studies under Task 4.2, it will be possible to identify drivers and pressures across the aquatic realms that are most relevant for ecosystem state in the case studies, and therefore for impacts on aquatic biodiversity and its capacity to support ecosystem services (Task 5.2). As the description under chapter 2.2 should illustrate, 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 (the primary activities of Figure 6); the economic activities that require input from the nature-provided services and deliver final goods and services to society should also be considered (and have often been more of the focus in economic/social science approaches). These activities lead to the demand of ecosystem services from the environment and without accounting for them, it is impossible to understand what can cause changes in drivers acting on the ecosystem. Furthermore, the social processes (exogenic and endogenic) that lead to variability in demand must also be considered to fully evaluate the demand side.

6.1.1 Guidance to identify drivers of change

As described under the three main areas of approach in chapter 3.2, to fully capture the drivers of change acting on aquatic ecosystems, and to understand how and why they vary, it is necessary:

1. to evaluate how economic activities drive demand for aquatic ecosystem services and abiotic outputs, and how this demand causes activity in other related economic activities;
2. to explore how social processes limit and generate demand on the economic activities that utilise aquatic ecosystem services and abiotic outputs, and
3. to include evaluation of non-market aquatic ecosystem services (e.g., many provisioning and cultural services that do not have clear market value[16]) and their use, without which it is impossible to reach a full understanding of how sustainability can be achieved and thus to deliver Ecosystem-based Management (see Deliverable 3.2 the AQUACROSS AF).

Finally, we described how newly emerging drivers are pervasive in our current conditions, and that these must too be considered in the complex, adaptive socio-ecological systems we explore in AQUACROSS. It is acknowledged that evaluation of all aspects described is difficult

[16] See Deliverable 5.1 for a full description of the types of ecosystem service supplied by aquatic ecosystems

and that not all case studies may be able to achieve full coverage, never mind quantification of everything described, but we urge case study teams to consider the approaches outlined above, and to explore what could be captured to fully understand the drivers of change acting on their case study systems. As a minimum we should acknowledge, at least conceptually, what is not captured and how this could affect uncertainty in the understanding of the socio-ecological systems explored.

6.1.2 Guidance to identify pressures

Going forward in Aquacross, we have adopted the definition of pressure given under chapter 2.2 as "the mechanism through which an activity has an effect on any part of the ecosystem", following Knights et al. (2011). 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 related to an anthropogenically induced effect (from a human activity) on the state of an ecosystem.

As a basis for further work in the AQUACROSS case studies, common typologies have been developed that systematically align the nomenclatures and definitions of activities (Table 3) and pressures (Table 4). We recommend that these typologies are used as a reference to help define drivers and pressures for case studies under Task 4.2 (although expansion is required to fully capture drivers, see chapter 3.2). As a minimum, we recommend that each case study utilises the broad activity types and pressure categories to help standardisation of approach across the project. An ultimate aim of this work is to draw together final typologies of activities and pressures which are reflective of those relevant across aquatic ecosystems in Europe, based on the experiences in the case studies (for Deliverable 4.2).

In chapter 3.3.2 we briefly summarise the issues to consider in trying to evaluate pressures in the Aquacross assessments (the approaches for activities are covered in much more detail under chapter 3.2). Ultimately, we know that there is good information and understanding on some of the key pressures affecting aquatic ecosystems in Europe, but that for some of the more emerging pressures (e.g., noise pollution) we work with much greater uncertainty. Furthermore, we acknowledge that cumulative effects of the multiple pressures introduced into aquatic realms, are poorly understood, with investigative approaches used rarely standardised. As a starting point, case study teams should at least identify where cumulative pressure effects could be an important issue in their case studies going forward.

6.1.3 Guidance on linkage framework

Chapter 3.4 focused on the linkage framework that was recently developed for the marine realm within the EU FP7 project ODEMM (www.odemm.com). The framework basically consists of a series of interconnected matrices between typologies of activities, pressures ecosystem components, ecosystem services and policy objectives.

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.

The linkage matrices can be used as a basis for qualitative and quantitative analyses that are carried out (see Chapters 4 and 5). We also described some existing approaches developed in ODEMM, which can be implemented where data is lacking.

6.1.4 Guidance on modeling approaches

The meta-analysis of alternative quantitative and qualitative methods conducted in chapter 4.6 showed that model performance can vary substantially dependent on the structure of available data and information, and model selection should be case specific. 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 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 the techniques have no simple way of graphical representation and are in most cases highly complex compared to regression and more simpler machine learning techniques. If the results should be used as a communication tool for management, more simple methods with a good graphical representation and straight-forward interpretability should be preferred, whereas for complex situations including interactions and hierarchical structure of drivers and pressures complex methods may be more advantageous (see chapter 4.6.3).
- 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 models will be more advantageous (see chapter 4.6.3).
- 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 is directly dependant 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., BBN) often produce the most reliable, robust and interpretable models (see chapter 4.6.3.1).

Further recommendations are essential for the implementations in the case studies:

- Model evaluation is essential for the development of reliable explanatory or predictive models independent of whether those are data or expert based (see chapter 4.5 for description of available methods).
- Parallel or combined application of different modelling techniques (including qualitative and quantitative methods) to the same analytical problem increases robustness and importance of results (see chapter 4.4 and 4.6.3.1).
- Furthermore, where possible, it is then important to identify and implement adequate indicators to gain meaningful insights in relation to drivers, pressures and states. Indicators are discussed in chapter 5 of this deliverable and the main points/recommendations are summarised below.

6.1.5 Guidance on indicators

Indicators and associated metrics and indices can play a vital role, on the one hand to describe and quantify drivers and pressures, on the other hand to identify relationships between drivers, pressures and ecosystem components.

Characteristics and definitions of "good" indicators across realms and policies have been reviewed (chapter 5.1). We identified the most commonly used, sensitive and cost-effective indicators for the D-P-S part of the AQUACROSS AF across policies and realms, including indicators developed under the WFD, MSFD or the inventory of biodiversity-related indicators from the EEA. The identified indicators were 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 developed together with WP 5 (chapter 5.1, Box 1) and presented as a list of common indicators with examples for indices and metrics across realms for human activities (Table 14), pressures (Table 15) and ecosystem state (Table 16).

The proposed set of indicators is intended to serve as a first basis for indicator selection and harmonisation across all case studies in AQUACROSS under Task 4.2; it is not intended to be prescriptive or complete and each case study should select indicators more adequate for the context and purpose of the study respectively. For the selection of indicators within the case studies it is most important to be in line with the other stages of the assessment framework, i.e. via the linkage framework, and to enable a consistent view on the relevant drivers, activities, pressures and effects on the ecosystem components. Lessons learnt from this application of indicators to the case studies will inform the final adaptation of the AQUACROSS assessment framework under Task 4.3.

6.1.6 Final thoughts

In this Deliverable, we have described many of the conceptual and methodolological issues required to explore drivers of change and their pressures acting in aquatic realms. Under Task 4.2, we will need to clarify exactly how case study teams wish to proceed with this information in mind. For example, in some case studies, detailed analyses based on well supported indicators may be possible, but in others, network based approaches that are not supported by indicators, and perhaps require some expert judgement input, may be more applicable. Overall, the typologies and linkage framework described under chapter 3 should help to guide discussions on how the work proceeds across case studies, but in all cases it may not be sensible, or feasible, to fully extend such an approach. Furthermore, we recognise the need to further develop the interaction between the socio-economic and more natural science based approaches described herein, which we see as a key aspect of Task 4.2 going forward.

7 References

Aguilera, P. A., Fernández, A., Fernández, R., Rumí, R., & Salmerón, A. (2011) Bayesian networks in environmental modelling. Environmental Modelling & Software, 26(12), 1376-1388.

Allan J.D., Mcintyre P.B., Smith S.D.P., Halpern B.S., & Boyer G.L. (2013) Joint analysis of stressors and ecosystems services to enhance restoration effectiveness. PNAS, 110, 372-377.

Angelakis, A. N., & Gikas, P. (2014). Water reuse: overview of current practices and trends in the world with emphasis in EU states. Water Util. J., 6, 67-78.

Antonelli, M., Roson, R., & Sartori, M. (2012). Systemic input-output computation of green and blue virtual water 'flows' with an illustration for the Mediterranean region. Water Resources Management, 26(14), 4133-4146.

Araújo, M. B., & New, M. (2007) Ensemble forecasting of species distributions. Trends in ecology & evolution, 22(1), 42-47.

Bacci, T., Rende, S. F., Penna, M., Trabucco, B., Montefalcone, M., Cicero, A. M., & Giovanardi, F. (2013) A methodological approach to understand functional relationships between ecological indices and human-induced pressures: The case of the Posidonia oceanica meadows. Journal of environmental management, 129, 540-547.

Baker, M. E., & King, R. S. (2010) A new method for detecting and interpreting biodiversity and ecological community thresholds. Methods in Ecology and Evolution, 1(1), 25-37.

Balmford, A. et al. (2005) The convention on biological diversity's 2010 Target. Science 307: 212?213.

Bauer, E., & Kohavi, R. (1998) An empirical comparison of voting classification algorithms: Bagging, boosting, and variants. Machine learning, 36(1), 2.

Beaumont, L. J., Gallagher, R. V., Downey, P. O., Thuiller, W., Leishman, M. R., & Hughes, L. (2009) Modelling the impact of Hieracium spp. on protected areas in Australia under future climates. Ecography, 32(5), 757-764.

Bedia, J., Busqué, J., & Gutiérrez, J. M. (2011) Predicting plant species distribution across an alpine rangeland in northern Spain. A comparison of probabilistic methods. Applied Vegetation Science, 14(3), 415-432.

Benson, D., Gain, A., & Rouillard, J. (2015). Water governance in a comparative perspective: From IWRM to a'nexus' approach?. Water Alternatives, 8(1).

Berg T., K. Fürhaupter, H. Teixeira, L. Uusitalo and N. Zampoukas (2015): The Marine Strategy Framework Directive and the ecosystem-based approach – pitfalls and solutions, Marine Pollution Bulletin, Volume 96, Issues 1–2, 15 July 2015, Pages 18-28, http://dx.doi.org/10.1016/j.marpolbul.2015.04.050.

Berger, M., Pfister, S., Bach, V., & Finkbeiner, M. (2015). Saving the planet's climate or water resources? The trade-off between carbon and water footprints of European biofuels. Sustainability, 7(6), 6665-6683.

Birk S., Bonne W., Borja A., Brucet S., Courrat A., Pokane S., Solimini A., van de Bund W., Zampoukas N., & Hering D. (2012) Three hundred ways to assess Europe's surface waters: An almost complete overview of biological methods to implement the Water Framework Directive. Ecological Indicators, 18, 31-41.

Boets, P., Landuyt, D., Everaert, G., Broekx, S., & Goethals, P. L. (2015) Evaluation and comparison of data-driven and knowledge-supported Bayesian Belief Networks to assess the habitat suitability for alien macroinvertebrates. Environmental Modelling & Software, 74, 92-103.

Borja, A., Elliott M., Carstensen J., Heiskanen A.S., & van de Bund W. (2010) Marine management – Towards an integrated implementation of the European marine strategy framework and the water framework directives. Marine Pollution Bulletin, 60, 2175-2186.

Borja, A., Elliott, M., Andersen, J.H., Berg, T., Carstensen, J., Halpern, B.S., Heiskanen, A-S., Korpinen, S., Lowndes, J.S., Stewart, M G., Rodriguez-Ezpeleta, N. (2016) Overview of Integrative Assessment of Marine Systems: The Ecosystem Approach in Practice. Frontiers in Marine Science, 3, 1-20.

Borja Á., Galparsoro I., Solaun O., Muxika I., Tello E.M., Uriarte A., & Valencia V. (2006) The European Water Framework Directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status. Estuarine, Coastal and Shelf Science, 66, 84-96.

Bostock, J., Lane, A., Hough, C., & Yamamoto, K. (2016). An assessment of the economic contribution of EU aquaculture production and the influence of policies for its sustainable development. Aquaculture International, 24(3), 699-733.

Breiman, L. (1996) Bagging predictors. Machine learning, 24(2), 123-140.

Breiman, L. (2001) Random forests. Machine learning, 45(1), 5-32.

Brouwer, R., Martin-Ortega, J., Dekker, T., Sardonini, L., Andreu, J., Kontogianni, A., ... & Rolfe, J. (2015). Improving value transfer through socio-economic adjustments in a multicountry choice experiment of water conservation alternatives. Australian Journal of Agricultural and Resource Economics, 59(3), 458-478.

Butchart S.H.M., Walpole M., Collen B., van Strien A., Scharlemann J.P.W., Almond R.E.A., Baillie J.E.M., Bomhard B., Brown C., Bruno J., Carpenter K.E., Carr G.M., Chanson J., Chenery A.M., Csirke J., Davidson N.C., Dentener F., Foster M., Galli A., Galloway J.N., Genovesi P., Gregory R.D., Hockings M., Kapos V., Lamarque J.-F., Leverington F., Loh J., McGeoch M.A., McRae L., Minasyan A., Morcillo M.H., Oldfield T.E.E., Pauly D., Quader S., Revenga C., Sauer J.R., Skolnik B., Spear D., Stanwell-Smith D., Stuart S.N., Symes A., Tierney M., Tyrrell T.D., Vie J.-C., & Watson R. (2010) Global Biodiversity: Indicators of Recent Declines. Science, 328, 1164-1168.

Calzadilla, A., Rehdanz, K., Roson, R., Sartori, M., & Tol, R. S. (Eds.). (2016). Review of CGE Models of Water Issues. In WORLD SCIENTIFIC REFERENCE ON NATURAL RESOURCES AND ENVIRONMENTAL POLICY IN THE ERA OF GLOBAL CHANGE: Volume 3: Computable General Equilibrium Models (pp. 101-123).

Caragea, P. C., & Kaiser, M. S. (2009) Autologistic models with interpretable parameters. Journal of agricultural, biological, and environmental statistics, 14(3), 281-300.

Carling, A. (1992) Introducing Neural Networks. Wilmslow: Sigma Press.

Carpenter, g.: Kleinjans, R.; Villasante, S. O'Leary, B. (2016) Landing the blame: The influence of EU Member States on quota setting. Marine Policy. Vol. 64: 9-15

Cazcarro, I., Duarte, R., & Sánchez Chóliz, J. (2013). Multiregional input-output model for the evaluation of Spanish water flows. Environmental science & technology, 47(21), 12275-12283.

Chapin F.S., Zavaleta E.S., Eviner V.T., Naylor R.L., Vitousek P.M., Reynolds H.L., Hooper D.U., Lavorel S., Sala O.E., Hobbie S.E., Mack M.C., & Díaz S. (2000) Consequences of changing biodiversity. Nature, 405, 234-42.

Chefaoui, R. M., Assis, J., Duarte, C. M., & Serrão, E. A. (2016) Large-Scale Prediction of Seagrass Distribution Integrating Landscape Metrics and Environmental Factors: The Case of Cymodocea nodosa (Mediterranean-Atlantic) Estuaries and Coasts, 39(1), 123-137.

Chen, S. H., & Pollino, C. A. (2012) Good practice in Bayesian network modelling. Environmental Modelling & Software, 37, 134-145.

Cianfrani, C., Le Lay, G., Maiorano, L., Satizábal, H. F., Loy, A., & Guisan, A. (2011) Adapting global conservation strategies to climate change at the European scale: the otter as a flagship species. Biological Conservation, 144(8), 2068-2080.

CICES (2016). http://cices.eu/ (accessed, November 2016).

Connor, D. (2015) A generic framework of activities, pressures and impacts relevant to the marine environment. DG Environment. Revised 12 June 2015.

Cooley, J. R., Marshall, D. C., Simon, C., Neckermann, M. L., & Bunker, G. (2013) At the limits: habitat suitability modelling of northern 17-year periodical cicada extinctions (Hemiptera: Magicicada spp.) Global Ecology and Biogeography, 22(4), 410-421.

Crego, R. D., Didier, K. A., & Nielsen, C. K. (2014) Modeling meadow distribution for conservation action in arid and semi-arid Patagonia, Argentina. Journal of Arid Environments, 102, 68-75.

Crego, R. D., Nielsen, C. K., & Didier, K. A. (2014) Climate change and conservation implications for wet meadows in dry Patagonia. Environmental Conservation, 41(02), 122-131.

Crisci, C., Ghattas, B., & Perera, G. (2012) A review of supervised machine learning algorithms and their applications to ecological data. Ecological Modelling, 240, 113-122.

Cutler, D. R., Edwards, T. C., Beard, K. H., Cutler, A., Hess, K. T., Gibson, J., & Lawler, J. J. (2007) Random forests for classification in ecology. Ecology, 88(11), 2783-2792.

Daskalov G.M., Grishin A.N., Rodionov S., & Mihneva V. (2007) Trophic cascades triggered by overfishing reveal possible mechanisms of ecosystem regime shifts. Proceedings of the National Academy of Sciences of the United States of America, 104, 10518-23.

Death, G. & Fabricious, E. K. (2000) Classification and regression trees: a powerful yet simple technique for ecological data analysis. Ecology 81, 3178-3192.

Death, G. (2007) Boosted trees for ecological modeling and prediction. Ecology, 88(1), 243-251.

Death, R. G., Death, F., Stubbington, R., Joy, M. K., & Belt, M. (2015) How good are Bayesian belief networks for environmental management? A test with data from an agricultural river catchment. Freshwater Biology, 60(11), 2297-2309.

Domíguez-Vega, H., Monroy-Vilchis, O., Balderas-Valdivia, C. J., Gienger, C. M., & Ariano-Sánchez, D. (2012) Predicting the potential distribution of the beaded lizard and identification of priority areas for conservation. Journal for Nature Conservation, 20(4), 247-253.

Donohue I., Jackson A L., Pusch M., & Irvine K. (2009) Nutrient enrichment homogenizes lake benthic assemblages\rat local and regional scales. Ecology, 90, 3470-3477.

Dormann, C. F., Schymanski, S. J., Cabral, J., Chuine, I., Graham, C., Hartig, F., ... & Singer, A. (2012) Correlation and process in species distribution models: bridging a dichotomy. Journal of Biogeography, 39(12), 2119-2131.

Drake, J. M., Randin, C., & Guisan, A. (2006) Modelling ecological niches with support vector machines. Journal of Applied Ecology, 43(3), 424-432.

Drouineau, H., Lobry, J., Delpech, C., Bouchoucha, M., Mahevas, S., Courrat, A., ... & Lepage, M. (2012) A Bayesian framework to objectively combine metrics when developing stressor specific multimetric indicator. Ecological Indicators, 13(1), 314-321.

Dudgeon D., Arthington A., Gessner M., Kawabata Z.-I., Knowler D., Lévêque C., Naiman R., Prieur-Richard A.-H., Soto D., Stiassny M., & Sullivan C. (2006) Freshwater biodiversity: importance, threats, status and conservation challenges. Biological reviews of the Cambridge Philosophical Society, 81, 163-82.

Duque-Lazo, J., Van Gils, H. A. M. J., Groen, T. A., & Navarro-Cerrillo, R. M. (2016) Transferability of species distribution models: The case of Phytophthora cinnamomi in Southwest Spain and Southwest Australia. Ecological Modelling, 320, 62-70.

EC (1992) Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, L 206/7.

EC (2000) Establishing a framework for Community action in the field of water policy. Directive 2000/60/EC of the European Parliament and of the Council'. Official Journal of the European Communities, L327, 1-72.

EC (2001): Environmental pressure indicators for the EU. http://ec.europa.eu/eurostat/documents/3217494/5630393/KS-36-01-677-EN.PDF/e203abb8-81e1-490d-9416-6ab79f983b05?version=1.0

EC (2006) Regulation (EC) No 1893/2006 of the European Parliament and of the Council of 20 December 2006 establishing the statistical classification of economic activirties NACE Revision 2 and amending Council Regulation (EEC) No 3037/90 as well as certain EC Regulations on specific statistical domains. Official Journla of the European Union, L393/1.

EC (2008) 'Establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) Directive 2008/56/EC of the European Parliament and of the Council.', Official Journal of the European Union, vol. L164, pp. 19-40.

EC (2011a) Our life insurance, our natural capital: an EU biodiversity strategy to 2020, Brussels, 17p

EC (2011b): Relationship between the initial assessment of marine waters and the criteria for good environmental status. Commission staff working paper. European Commission, Brussels, 14.10.2011. SEC(2011) 1255 final. http://ec.europa.eu/environment/marine/pdf/SEC_2011_1255_F_DTS.pdf

EEA (1999) Environmental indicators: Typology and overview, Technical report No 25, Copenhagen, 19p

EEA (2003a) Europe's water: An indicator-based assessment Summary, 24p

EEA (2003b) An inventory of biodiversity indicators in Europe,

EEA (2003c) Testing of indicators for the marine and coastal environment in Europe - Part 3: Present state and development of indicators for eutrophication, hazardous substances, oil and ecological quality. Technical report 86, 65p.

EEA (2005) EEA core set of indicators - Guide, EEA Tech. Rep. 01/2005, Luxembourg.

EEA (2007) Halting the loss of biodiversity by 2010: proposal for a first set of indicators to monitor progress in Europe. EEA Tech. Rep. 11/2007, Luxembourg.

EEA (2009) Water Resources Across Europe: confronting water scarcity and drought. EEA Report 2/2009.

EEA (2012) Streamlining European biodiversity indicators 2020:Building a future on lessons learnt , from the SEBI 2010 process, EEA Tech. Rep. 11/2012, Luxembourg.

Elith, J., & Graham, C. H. (2009) Do they? How do they? WHY do they differ? On finding reasons for differing performances of species distribution models. Ecography, 32(1), 66-77.

Elith, J., Graham, C.H., Anderson, R.P., Dudik, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J.M., Peterson, A.T., Phillips, S.J., ichardson, K., Scachetti-Pereira, R., Schapire, R., Soberón, J., Williams, S., Wisz, M.S. & Zimmermann, N.E. (2006) Novel methods improve prediction of species' distributions from occurrence data. Ecography, 29, 129-151.

Elliott, J., Deryng, D., Müller, C., Frieler, K., Konzmann, M., Gerten, D., ... & Eisner, S. (2014). Constraints and potentials of future irrigation water availability on agricultural production under climate change. Proceedings of the National Academy of Sciences, 111(9), 3239-3244.

Engler, R., Randin, C. F., Thuiller, W., Dullinger, S., Zimmermann, N. E., Araújo, M. B., ... & Choler, P. (2011) 21st century climate change threatens mountain flora unequally across Europe. Global Change Biology, 17(7), 2330-2341.

Ennis, M., Hinton, G., Naylor, D., Revow, M., Tibshirani, R. (1998) A comparison of statistical learning methods on the GUSTO database. Stat. Med. 17, 2501-2508.

European Commission (2001), A framework for indicators for the economic and social dimensions of sustainable agriculture and rural development, working document, European Commission, Directorate-General for Agriculture, Brussels (http://europa.eu.int/comm/agriculture/publi/reports/sustain/index_en.pdf).

European Union (2012). Excess Fishing Cappacities in the Reform of Common European Fisheries Policy. DIRECTORATE-GENERAL FOR INTERNAL POLICIES POLICY DEPARTMENT B: STRUCTURAL AND COHESION POLICIES. IP/B/PECH/IC/2012_09

Eurostat (2001), Towards environmental pressure indicators for the EU (TEPI), Eurostat project web site (http://www.e-m-a-i-l.nu/tepi/).

Everitt, B., Landau, S., Leese, M. & Stahl, D. (2011) Cluster Analysis. Chichester: Wiley.

FAO (2010) Biodiversity for Food and Agriculture – Contributing to food security and sustainability in a changing world, Rome, ISBN 978-92-5-106748-2

Feld C.K., Da Silva P.M., Sousa J.P., De Bello F., Bugter R., Grandin U., Hering D., Lavorel S., Mountford O., Pardo I., Pärtel M., Römbke J., Sandin L., Bruce Jones K., & Harrison P. (2009) Indicators of biodiversity and ecosystem services: A synthesis across ecosystems and spatial scales. Oikos, 118, 1862-1871.

Feld, C. K., Segurado, P., & Gutiérrez-Cánovas, C. (2016) Analysing the impact of multiple stressors in aquatic biomonitoring data: a 'cookbook'with applications in R. Science of the Total Environment.

Fletcher, D. H., Gillingham, P. K., Britton, J. R., Blanchet, S., & Gozlan, R. E. (2016) Predicting global invasion risks: a management tool to prevent future introductions. Scientific reports, 6.

Flörke, M., Kynast, E., Bärlund, I., Eisner, S., Wimmer, F., & Alcamo, J. (2013). Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study. Global Environmental Change, 23(1), 144-156.

Folmer, E. O., van Beusekom, J. E., Dolch, T., Gräwe, U., Katwijk, M. M., Kolbe, K., & Philippart, C. J. (2016) Consensus forecasting of intertidal seagrass habitat in the Wadden Sea. Journal of Applied Ecology.

Forester, B. R., DeChaine, E. G., & Bunn, A. G. (2013) Integrating ensemble species distribution modelling and statistical phylogeography to inform projections of climate change impacts on species distributions. Diversity and Distributions, 19(12), 1480-1495.

Fornaroli, R., Cabrini, R., Sartori, L., Marazzi, F., Vracevic, D., Mezzanotte, V., ... & Canobbio, S. (2015) Predicting the constraint effect of environmental characteristics on macroinvertebrate density and diversity using quantile regression mixed model. Hydrobiologia, 742(1), 153-167.

Fotheringham, A. S., Brunsdon, C., & Charlton, M. (2003) Geographically weighted regression: the analysis of spatially varying relationships. John Wiley & Sons.

França, S., & Cabral, H. N. (2015) Predicting fish species richness in estuaries: Which modelling technique to use?. Environmental Modelling & Software, 66, 17-26.

Friberg N. (2010) Pressure-response relationships in stream ecology: Introduction and synthesis. Freshwater Biology, 55, 1367-1381.

Friedman, J. H. (1991) Multivariate adaptive regression splines. The annals of statistics, 1-67.

Friedman, J.H., (2002) Stochastic gradient boosting. Computational Statistics & Data Analysis 38, 367-378.

Fronzek, S., Carter, T. R., & Luoto, M. (2011) Evaluating sources of uncertainty in modelling the impact of probabilistic climate change on sub-arctic palsa mires. Natural Hazards and Earth System Sciences, 11(11), 2981-2995.

Fukuda, S., De Baets, B., Waegeman, W., Verwaeren, J., & Mouton, A. M. (2013) Habitat prediction and knowledge extraction for spawning European grayling (Thymallus thymallus L.) using a broad range of species distribution models. Environmental modelling & software, 47, 1-6.

Galioto, F., Cuming, D., Raggi, M., & Viaggi, D. (2015, June). Drivers and Barriers Over the Adoption of Precision Irrigation in Europe. In 2015 Fourth Congress, June 11-12, 2015, Ancona, Italy (No. 207846). Italian Association of Agricultural and Applied Economics (AIEAA).

García-Sánchez, M., Pérez-Ruzafa, I. M., Marcos, C., & Pérez-Ruzafa, A. (2012) Suitability of benthic macrophyte indices (EEI, E-MaQI and BENTHOS) for detecting anthropogenic pressures in a Mediterranean coastal lagoon (Mar Menor, Spain) Ecological Indicators, 19, 48-60.

Garrote, L., Iglesias, A., Granados, A., Mediero, L., & Martin-Carrasco, F. (2015). Quantitative assessment of climate change vulnerability of irrigation demands in Mediterranean Europe. Water Resources Management, 29(2), 325-338.

Gaudard, L., & Romerio, F. (2014). The future of hydropower in Europe: Interconnecting climate, markets and policies. Environmental Science & Policy, 37, 172-181.

Gómez et al. (2016) The AQUACROSS Innovative Concept. Deliverable 3.1, European Union's Horizon 2020 Framework Programme for Research and Innovation grant agreement No. 642317

Gontier, M., Mörtberg, U., & Balfors, B. (2010) Comparing GIS-based habitat models for applications in EIA and SEA. Environmental Impact Assessment Review, 30(1), 8-18.

Gosling, S. N., & Arnell, N. W. (2016). A global assessment of the impact of climate change on water scarcity. Climatic Change, 134(3), 371-385.

Gössling, S., Peeters, P., Hall, C. M., Ceron, J. P., Dubois, G., & Scott, D. (2012). Tourism and water use: Supply, demand, and security. An international review. Tourism management, 33(1), 1-15.

Gotway, C. A., & Stroup, W. W. (1997) A generalized linear model approach to spatial data analysis and prediction. Journal of Agricultural, Biological, and Environmental Statistics, 157-178.

Grace, J. B. (2008) Structural equation modelling for observational studies. The Journal of

Guisan, A., & Thuiller, W. (2005) Predicting species distribution: offering more than simple habitat models. Ecology letters, 8(9), 993-1009.

Guisan, A., Edwards, T. C., & Hastie, T. (2002) Generalized linear and generalized additive models in studies of species distributions: setting the scene. Ecological modelling, 157(2), 89-100.

Guisan, A., Lehmann, A., Ferrier, S., Austin, M., OVERTON, J., Aspinall, R., & Hastie, T. (2006) Making better biogeographical predictions of species' distributions. Journal of Applied Ecology, 43(3), 386-392.

Haqiqi, I., & Hertel, T. W. (2016). Decomposing Irrigation Water Use in Equilibrium Models Top-Down vs Bottom-Up.

Hällfors, M. H., Aikio, S., Fronzek, S., Hellmann, J. J., Ryttäri, T., & Heikkinen, R. K. (2016) Assessing the need and potential of assisted migration using species distribution models. Biological Conservation, 196, 60-68.

Hamilton, S. H., Pollino, C. A., & Jakeman, A. J. (2015) Habitat suitability modelling of rare species using Bayesian networks: Model evaluation under limited data. Ecological Modelling, 299, 64-78.

Hannah, L., Ikegami, M., Hole, D. G., Seo, C., Butchart, S. H., Peterson, A. T., & Roehrdanz, P. R. (2013) Global climate change adaptation priorities for biodiversity and food security. PloS one, 8(8), e72590.

Hastie, T. J., & Tibshirani, R. J. (1990) Generalized additive models (Vol. 43) CRC Press.

Hastie, T., & Tibshirani, R. (1996) Discriminant analysis by Gaussian mixtures. Journal of the Royal Statistical Society. Series B (Methodological), 155-176.

Hastie, T., Buja, A., & Tibshirani, R. (1995) Penalized discriminant analysis. The Annals of Statistics, 73-102.

Hastie, T., Tibshirani, R., & Buja, A. (1994) Flexible discriminant analysis by optimal scoring. Journal of the American statistical association, 89(428), 1255-1270.

Hawkins, C. A., & Berthold, T. A. (2016). A literature review: developing an information feedback interface to encourage water conservation behavior among utility customers. Texas Water Journal, 7(1), 40-55.

Heikkinen, R. K., Marmion, M., & Luoto, M. (2012) Does the interpolation accuracy of species distribution models come at the expense of transferability?. Ecography, 35(3), 276-288.

Heink U. & Kowarik I. (2010) What are indicators? On the definition of indicators in ecology and environmental planning. Ecological Indicators, 10, 584-593.

Hendricks, N. P., & Peterson, J. M. (2012). Fixed effects estimation of the intensive and extensive margins of irrigation water demand. Journal of Agricultural and Resource Economics, 1-19.

Hering D., Carvalho L., Argillier C., Beklioglu M., Borja A., Cardoso A.C., Duel H., Ferreira T., Globevnik L., Hanganu J., Hellsten S., Jeppesen E., Kodeš V., Solheim A.L., Nõges T., Ormerod S., Panagopoulos Y., Schmutz S., Venohr M., & Birk S. (2015) Managing aquatic ecosystems and water resources under multiple stress - An introduction to the MARS project. Science of the Total Environment, 503-504, 10-21.

Hering D., Meier C., Rawer-Jost C., Feld C.K., Biss R., Zenker A., Sundermann A., Lohse S., & Böhmer J. (2004) Assessing streams in Germany with benthic invertebrates: Selection of candidate metrics. Limnologica, 34, 398-415.

Hill, T. & Lewicki, P. (2007) Statistics: Methods and Applications. Tulsa, OK: Statsoft.

Holden, A. (2016). Environment and tourism. Routledge.

Hothorn, T., Hornik, K., & Zeileis, A. (2006) Unbiased recursive partitioning: A conditional inference framework. Journal of Computational and Graphical statistics, 15(3), 651-674.

Huang, J., Huang, Y., Pontius, R. G., & Zhang, Z. (2015) Geographically weighted regression to measure spatial variations in correlations between water pollution versus land use in a coastal watershed. Ocean & Coastal Management, 103, 14-24.

Hughes, J., & Haran, M. (2013) Dimension reduction and alleviation of confounding for spatial generalized linear mixed models. Journal of the Royal Statistical Society: Series B (Statistical Methodology), 75(1), 139-159.

Hussey, K., & Pittock, J. (2012). The energy-water nexus: Managing the links between energy and water for a sustainable future. Ecology and Society, 17(1), 31.

Iliadis, L. S., & Maris, F. (2007) An Artificial Neural Network model for mountainous water-resources management: The case of Cyprus mountainous watersheds. Environmental Modelling & Software, 22(7), 1066-1072.

Intergovernmental Panel on Climate Change. (2015). Climate change 2014: mitigation of climate change (Vol. 3). Cambridge University Press.

Jalala, S., Hani, A., & Shahrour, I. (2011) Characterizing the socio-economic driving forces of groundwater abstraction with artificial neural networks and multivariate techniques. Water resources management, 25(9), 2147-2175.

Jenkins, K., Surminski, S., Hall, J., & Crick, F. (2016). Surface water flood risk and management strategies for London: An Agent-Based Model approach. In E3S Web of Conferences (Vol. 7, p. 22003). EDP Sciences.

Jensen, F.V., Nielsen, T.D. (2007) Bayesian Networks and Decision Graphs. Springer.

Jeong JH, Resop JP, Mueller ND, Fleisher DH, Yun K, Butler EE, et al. (2016) Random Forests for Global and Regional Crop Yield Predictions. PLoS ONE 11(6): e0156571. i:10.1371/journal. pone.0156571

Judd, A.D., Backhaus, T. & Goodsir, F. (2015) An effective set of principles for practical implementation of marine cumulative effects assessment. Environmental Science and Policy, 54, 254-262.

Kahil, M. T., Connor, J. D., & Albiac, J. (2015). Efficient water management policies for irrigation adaptation to climate change in Southern Europe. Ecological Economics, 120, 226-233.

Kandziora M., Burkhard B., & Müller F. (2013) Interactions of ecosystem properties, ecosystem integrity and ecosystem service indicators: A theoretical matrix exercise. Ecological Indicators, 28, 54-78.

Knights A.M., Koss R.S., & Robinson L.A. (2013) Identifying common pressure pathways from a complex network of human activities to support ecosystem-based management. Ecological Applications, 23, 755-765.

Kampichler, C., Wieland, R., Calmé, S., Weissenberger, H., & Arriaga-Weiss, S. (2010) Classification in conservation biology: a comparison of five machine-learning methods. Ecological Informatics, 5(6), 441-450.

Kandel, K., Huettmann, F., Suwal, M. K., Regmi, G. R., Nijman, V., Nekaris, K. A. I., ... & Subedi, T. R. (2015) Rapid multi-nation distribution assessment of a charismatic conservation species using open access ensemble model GIS predictions: Red panda (Ailurus fulgens) in the Hindu-Kush Himalaya region. Biological Conservation, 181, 150-161.

Kandziora M., Burkhard B., & Müller F. (2013) Interactions of ecosystem properties, ecosystem integrity and ecosystem service indicators: A theoretical matrix exercise. Ecological Indicators, 28, 54-78.

Kaphengst, T, Bassi, S, Davis, M, Gardner, S, Herbert, S, Lago, M, Naumann, S, Pieterse, M and Rayment, M (2011) Taking into account opportunity costs when assessing costs of biodiversity and ecosystem action. A report for DG Environment. http://ecologic.eu/sites/files/project/2014/documents/taking-into-account-opportunity-costs-when-assessing-costs-of-biodiversity-and-ecosystem-action-2011-kaphengst.pdf

Keenan, T., Maria Serra, J., Lloret, F., Ninyerola, M., & Sabate, S. (2011) Predicting the future of forests in the Mediterranean under climate change, with niche-and process-based models: CO2 matters!. Global change biology, 17(1), 565-579.

King, R. S., & Baker, M. E. (2010) Considerations for analyzing ecological community thresholds in response to anthropogenic environmental gradients. Journal of the North American Benthological Society, 29(3), 998-1008.

King, R. S., Baker, M. E., Kazyak, P. F., & Weller, D. E. (2011) How novel is too novel? Stream community thresholds at exceptionally low levels of catchment urbanization. Ecological applications, 21(5), 1659-1678.

Knights, A.M., Culhane, F., Hussain, S.S., Papadopoulou, K.N., Piet, G.J., Raakær, J., Rogers, S.I., and Robinson L.A. (2014). A step-wise process of decision-making under uncertainty when implementing environmental policy. Environmental Science & Policy 39, 56-64.

Knudby, A., Brenning, A., & LeDrew, E. (2010) New approaches to modelling fish-habitat relationships. Ecological Modelling, 221(3), 503-511.

Koenker, R. & Hallock, K. F. (2001) Quantile regression. Journal of Economic Perspectives 15, 143-156.

Komac, B., Esteban, P., Trapero, L., & Caritg, R. (2016) Modelization of the Current and Future Habitat Suitability of Rhododendron ferrugineum Using Potential Snow Accumulation. PloS one, 11(1), e0147324.

Kriegler, E., Weyant, J. P., Blanford, G. J., Krey, V., Clarke, L., Edmonds, J., ... & Rose, S. K. (2014). The role of technology for achieving climate policy objectives: overview of the EMF 27 study on global technology and climate policy strategies. Climatic Change, 123(3-4), 353-367.

Lago, M., Mysiak, J., Gomez, CM, Delacamara, G., and Maziotis. A., (Eds.) Use of Economic Instruments in Water Management - Insights from International Experience. Book published by Springer International Publishing AG, Cham (October 2015).

Lange K., Townsend C.R., Gabrielsson R., Chanut P.C.M., & Matthaei C.D. (2014) Responses of stream fish populations to farming intensity and water abstraction in an agricultural catchment. Freshwater Biology, 59, 286-299.

Lehr, U., Nitsch, J., Kratzat, M., Lutz, C., & Edler, D. (2008). Renewable energy and employment in Germany. Energy policy, 36(1), 108-117.

Li, X., Tian, H., Wang, Y., Li, R., Song, Z., Zhang, F., ... & Li, D. (2013) Vulnerability of 208 endemic or endangered species in China to the effects of climate change. Regional Environmental Change, 13(4), 843-852.

Lin, Y. P., Chu, H. J., Wu, C. F., & Verburg, P. H. (2011) Predictive ability of logistic regression, auto-logistic regression and neural network models in empirical land-use change modeling-a case study. International Journal of Geographical Information Science, 25(1), 65-87.

Lindegarth, M., Carstensen J., Johnson, R.K. Uncertainty of biological indicators for the WFD in Swedish water bodies: current procedures and a proposed framework for the future. Deliverable 2.2-1, WATERS Report no. 2013:1. Havsmiljöinstitutet, Sweden.

Liu, J., Hertel, T., Lammers, R., Prusevich, A., Baldos, U., Grogan, D., & Frolking, S. (2016). Achieving Sustainable Irrigation Water Withdrawals: Global Impacts on Food Production and Land Use (No. 235503). Agricultural and Applied Economics Association.

Lorenz, S., Martinez-Fernández, V., Alonso, C., Mosselman, E., García de Jalón, D., González del Tánago, M., ... & Wolter, C. (2016) Fuzzy cognitive mapping for predicting hydromorphological responses to multiple pressures in rivers. Journal of Applied Ecology, 53(2), 559-566.

Mancinelli G. & Vizzini S. (2015) Assessing anthropogenic pressures on coastal marine ecosystems using stable CNS isotopes: State of the art, knowledge gaps, and community-scale perspectives. Estuarine, Coastal and Shelf Science, 156, 195-204.

Marmion, M., Luoto, M., Heikkinen, R. K., & Thuiller, W. (2009) The performance of state-of-the-art modelling techniques depends on geographical distribution of species. Ecological Modelling, 220(24), 3512-3520.

Marmion, M., Parviainen, M., Luoto, M., Heikkinen, R. K., & Thuiller, W. (2009) Evaluation of consensus methods in predictive species distribution modelling. Diversity and distributions, 15(1), 59-69.

Martin G., H. Fammler, K. Veidemane, N. Wijkmark, A. Auniņš, H. Hällfors and A. Lappalainen (Eds) (2014): List of indicators for assessing the state of marine biodiversity in the Baltic Sea developed by the life MARMONI project, September 2014.

http://marmoni.balticseaportal.net/wp/wp-content/uploads/2011/03/A2_REPORT_INDICATORS.pdf

Marzin A., Archaimbault V., Belliard J., Chauvin C., Delmas F., & Pont D. (2012) Ecological assessment of running waters: Do macrophytes, macroinvertebrates, diatoms and fish show similar responses to human pressures? Ecological Indicators, 23, 56-65.

Matthaei C.D., Piggott J.J., & Townsend C.R. (2010) Multiple stressors in agricultural streams: interactions among sediment addition, nutrient enrichment and water abstraction. Journal of Applied Ecology, 47, 639-649.

McCann, R. K., Marcot, B. G., & Ellis, R. (2006) Bayesian belief networks: applications in ecology and natural resource management. Canadian Journal of Forest Research, 36(12), 3053-3062.

McClanahan TR, Graham NAJ, MacNeil MA, Muthiga NA, Cinner JE, Bruggemann JH, Wilson SK. (2011) Critical thresholds and tangible targets for ecosystem-based management of coral reef fisheries. Proceedings of the National Academy of Sciences of the United States of America 108:17230-17233.

McCullagh, P., & Nelder, J. A. (1989) Generalized linear models (Vol. 37) CRC press.

Mehra, L. K., Cowger, C., Gross, K., & Ojiambo, P. S. (2016) Predicting pre-planting risk of Stagonospora nodorum blotch in winter wheat using machine learning models. Frontiers in plant science, 7.

Miller, J., & Franklin, J. (2002) Modeling the distribution of four vegetation alliances using generalized linear models and classification trees with spatial dependence. Ecological Modelling, 157(2), 227-247.

Moguerza, J. M. & Munoz, A. (2006) Support vector machines with applications. Statistical Science 21, 322-336.

Mori, T., & Saitoh, T. (2014) Flood disturbance and predator-prey effects on regional gradients in species diversity. Ecology, 95(1), 132-141.

Mostafavi, H., Pletterbauer, F., Coad, B. W., Mahini, A. S., Schinegger, R., Unfer, G., ... & Schmutz, S. (2014) Predicting presence and absence of trout (Salmo trutta) in Iran. Limnologica-Ecology and Management of Inland Waters, 46, 1-8.

Mouton, A. M., De Baets, B., & Goethals, P. L. (2009) Knowledge-based versus data-driven fuzzy habitat suitability models for river management. Environmental Modelling & Software, 24(8), 982-993.

Muñoz, J., & Felicísimo, Á. M. (2004) Comparison of statistical methods commonly used in predictive modelling. Journal of Vegetation Science, 15(2), 285-292.

Murphy, J. T., Johnson, M. P., & Viard, F. (2016). An Agent-Based Modelling Approach to Biological Invasion by Macroalgae in European Coastal Environments. In Proceedings of ECCS 2014 (pp. 105-115). Springer International Publishing.

Naimi, B., Hamm, N. A., Groen, T. A., Skidmore, A. K., & Toxopeus, A. G. (2014) Where is positional uncertainty a problem for species distribution modelling?. Ecography, 37(2), 191-203.

Nassl M. & Löffler J. (2015) Ecosystem services in coupled social – ecological systems : Closing the cycle of service provision and societal feedback. Ambio, 44, 737-749.

Navarro-Ortega, A., Acuña, V., Bellin, A., Burek, P., Cassiani, G., Choukr-Allah, R., ... & Grathwohl, P. (2015). Managing the effects of multiple stressors on aquatic ecosystems under water scarcity. The GLOBAQUA project. Science of the Total Environment, 503, 3-9.

Nelson, G.C. (2005) Drivers of Change in Ecosystems and their Services. Chapter 4 in: Millennium Ecosystem Assessment MEA. Ecosystems and Human Well-being: A Framework for Assessment. Island Press

Niemeijer D. (2002) Developing indicators for environmental policy: Data-driven and theory-driven approaches examined by example. Environmental Science and Policy, 5, 91-103.

Nõges P., Argillier C., Borja Á., Garmendia J.M., Hanganu J., Kodeš V., Pletterbauer F., Sagouis A., & Birk S. (2016) Quantified biotic and abiotic responses to multiple stress in freshwater, marine and ground waters. Science of The Total Environment, 540, 43-52.

OECD (2003) Core Environmental Indicators. Development Measurement and Use. Organisation for Economic Co-Operation Development, Paris, 37 pp.

OECD (2016), The Ocean Economy in 2030, Organisation for Economic Co-Operation Development, Paris. http://dx.doi.org/10.1787/9789264251724-en

Oesterwind D., A. Rau and A Zaiko (2016): Drivers and pressures – Untangling the terms commonly used in marine science and policy. Journal of environmental management. Vol: 181 pp: 8-15. 10.1016/j.jenvman.2016.05.058

Olden, J. D., Lawler, J. J., & Poff, N. L. (2008) Machine learning methods without tears: a primer for ecologists. The Quarterly review of biology, 83(2), 171-193.

Oliver, T. H., Gillings, S., Girardello, M., Rapacciuolo, G., Brereton, T. M., Siriwardena, G. M., ... & Fuller, R. J. (2012) Population density but not stability can be predicted from species distribution models. Journal of Applied Ecology, 49(3), 581-590.

Olsson, G. (2015). Water and energy: threats and opportunities. Iwa Publishing.

Palmer M.A. & Febria C.M. (2012) The heartbeat of case management. Science.

Parviainen, M., Marmion, M., Luoto, M., Thuiller, W., & Heikkinen, R. K. (2009) Using summed individual species models and state-of-the-art modelling techniques to identify threatened plant species hotspots. Biological Conservation, 142(11), 2501-2509.

Patrício J, Teixeira H, Borja A, Elliott M, Berg T, Papadopoulou N, Smith C, Luisetti T, Uusitalo L, Wilson C, Mazik K, Niquil N, Cochrane S, Andersen JH, Boyes S, Burdon D, Carugati L, Danovaro R, Hoepffner N. (2014). DEVOTES recommendations for the implementation of the Marine Strategy Framework Directive. Deliverable 1.5, 71 pp. DEVOTES project. JRC92131

Pearson, R.G. et al. (2006) Model-based uncertainty in species' range prediction. J. Biogeogr. 33, 1704-1711.

Pérez_Blanco, C.D. and Thaler, T. (2014) An Input-Output assessment of Water Productivity in the Castile and León Region (Spain). Water 2014, 6, 929-944; doi:10.3390/w6040929

Petschel-Held, G.; Lasco, R.; Bohensky, E.; Domingos, T,; Guhl, A.; Lundberg, J. Zurek, M. (2005) Drivers of Ecosystem Change. Chapter 7 in. Millennium Ecosystem Assessment MEA. Ecosystems and Human Well-being: A Framework for Assessment. Island Press

Piggott J.J., Lange K., Townsend C.R., & Matthaei C.D. (2012) Multiple stressors in agricultural streams: a mesocosm study of interactions among raised water temperature, sediment addition and nutrient enrichment. PloS one, 7, e49873.

Piggott J.J., Townsend C.R., & Matthaei C.D. (2015) Reconceptualizing synergism and antagonism among multiple stressors. Ecology and Evolution.

Pikesley, S. K., Maxwell, S. M., Pendoley, K., Costa, D. P., Coyne, M. S., Formia, A., ... & Ngouessono, S. (2013) On the front line: integrated habitat mapping for olive ridley sea turtles in the southeast Atlantic. Diversity and Distributions, 19(12), 1518-1530.

Pont D., Hugueny B., Beier U., Goffaux D., Melcher a., Noble R., Rogers C., Roset N., & Schmutz S. (2006) Assessing river biotic condition at a continental scale: a European approach using functional metrics and fish assemblages. Journal of Applied Ecology, 43, 70-80.

Portela, J., Cristobo, J., Ríos, P., Acosta, J., Parra, S., Del Río, J. L., ... & Vilela, R. (2015) A first approach to asses the impact of bottom trawling over vulnerable marine ecosistems on the high seas of the Southwest Atlantic. Biodiversity in ecosystems-linking structure and function. InTech, 28.

Povak, N. A., Hessburg, P. F., McDonnell, T. C., Reynolds, K. M., Sullivan, T. J., Salter, R. B., & Cosby, B. J. (2014) Machine learning and linear regression models to predict catchment-level base cation weathering rates across the southern Appalachian Mountain region, USA. Water Resources Research, 50(4), 2798-2814.

Prasad, A. M., Iverson, L. R., & Liaw, A. (2006) Newer classification and regression tree techniques: bagging and random forests for ecological prediction. Ecosystems, 9(2), 181-199.

Pullin A.S. & Stewart G.B. (2006) Guidelines for systematic review in conservation and environmental management. Conservation Biology, 20, 1647-1656.

Rekolainen, S., Kämäri, J., Hiltunen, M., & Saloranta, T. M. (2003) A conceptual framework for identifying the need and role of models in the implementation of the Water Framework Directive. International Journal of River Basin Management, 1(4), 347-352.

Reynoldson, T. B., Bailey, R.C., Day, K. E., and Norris, R.H. (1995) Biological guidelines for freshwater sediment based on BEnthic Assessment of SedimenT (the BEAST) using multivariate approch for predicting biological state. Australian Journal of Ecology 20: 198-219.

Rezaee, S., Seiler, C., Pelot, R., & Ghasemi, A. (2016). Will commercial fishing be a safe occupation in future? A framework to quantify future fishing risks due to climate change scenarios. Weather and Climate Extremes, 13, 73-85.

Rinaudo, J. D., Neverre, N., & Montginoul, M. (2012). Simulating the impact of pricing policies on residential water demand: a Southern France case study. Water Resources Management, 26(7), 2057-2068.

Robinson, L.A., Culhane, F.E., Baulcomb, C., Bloomfield, H., Boehnke-Henrichs, A., Breen, P., Goodsir, F., Hussain, S.S., Knights, A.M., Piet, G.J., Raakjaer, J., van Tatenhove, J. and Frid, C.L.J. (2014). Towards delivering ecosystem-based marine management: The ODEMM Approach. Deliverable 17, EC FP7 Project (244273) 'Options for Delivering Ecosystem-based Marine Management'. University of Liverpool. ISBN: 978-0-906370-89-6 : 96 pp.

Roberts, D. R., & Hamann, A. (2012) Method selection for species distribution modelling: are temporally or spatially independent evaluations necessary?. Ecography, 35(9), 792-802.

Roberts, D. R., Nielsen, S. E., & Stenhouse, G. B. (2014) Idiosyncratic responses of grizzly bear habitat to climate change based on projected food resource changes. Ecological Applications, 24(5), 1144-1154.

Roberts J.J., Fausch K.D., Peterson D.P., & Hooten M.B. (2013) Fragmentation and thermal risks from climate change interact to affect persistence of native trout in the Colorado River basin. Global Change Biology, 19, 1383-1398.

Romero, J., Martínez-Crego, B., Alcoverro, T., & Pérez, M. (2007) A multivariate index based on the seagrass Posidonia oceanica (POMI) to assess ecological status of coastal waters under the water framework directive (WFD) Marine Pollution Bulletin, 55(1), 196-204.

Rosa E. A., York R., & Dietz T. (2004) Tracking the anthropogenic drivers of ecological impacts. Ambio, 33, 509-512.

Rouillard, J., Lago, M., Abhold, K., Roeschel, L., Kafyeke, T., Klimmek, H. and Mattheiß, V. (2016) "Synergies and Differences between Biodiversity, Nature, Water and Marine Environment EU Policies: Deliverable 2.1 Executive Summary." Report as part of the Horizon 2020 project AQUACROSS (Knowledge, Assessment, and Management for AQUAtic Biodiversity and Ecosystem Services aCROSS EU policies).

Salmoral, G., & Garrido, A. (2015). The Common Agricultural Policy as a driver of water quality changes: the case of the Guadalquivir River Basin (southern Spain). Bio-based and Applied Economics, 4(2), 103-123.

Saloranta, T. M., & Andersen, T. (2007) MyLake—A multi-year lake simulation model code suitable for uncertainty and sensitivity analysis simulations. Ecological Modelling, 207(1), 45-60.

Sánchez-Montoya, M. M., Vidal-Abarca, M. R., & Suárez, M. L. (2010) Comparing the sensitivity of diverse macroinvertebrate metrics to a multiple stressor gradient in Mediterranean streams and its influence on the assessment of ecological status. Ecological Indicators, 10(4), 896-904.

Scales, K. L., Miller, P. I., Ingram, S. N., Hazen, E. L., Bograd, S. J., & Phillips, R. A. (2016) Identifying predictable foraging habitats for a wide-ranging marine predator using ensemble ecological niche models. Diversity and Distributions, 22(2), 212-224.

Scarnati, L., Attorre, F., Farcomeni, A., Francesconi, F., & Sanctis, M. D. (2009) Modelling the spatial distribution of tree species with fragmented populations from abundance data. Community Ecology, 10(2), 215-224.

Schaldach, R., Koch, J., der Beek, T. A., Kynast, E., & Flörke, M. (2012). Current and future irrigation water requirements in pan-Europe: An integrated analysis of socio-economic and climate scenarios. Global and Planetary Change, 94, 33-45.

Schinegger R., Palt M., Segurado P., & Schmutz S. (2016) Untangling the effects of multiple human stressors and their impacts on fish assemblages in European running waters. Science of The Total Environment, 573, 1079-1088.

Schinegger R., Trautwein C., Melcher A., & Schmutz S. (2012) Multiple human pressures and their spatial patterns in European running waters. Water and Environment Journal, 26, 261-273.

Schölkopf, B., & Smola, A. J. (2002) Learning with kernels: support vector machines, regularization, optimization, and beyond. MIT press.

Schwarz, G. (1978) Estimating the dimension of a model. The annals of statistics, 6(2), 461-464.

Scientific, Technical and Economic Committee for Fisheries (STECF) - The 2016 Annual Economic Report on the EU Fishing Fleet (STECF 16-11); Publications Office of the European Union, Luxembourg; EUR 27758 EN; doi:10.2788/805055

Scientific, Technical and Economic Committee for Fisheries (STECF) - The economic performance of the EU aquaculture sector (STECF 14-18). 2014. Publications Office of the European Union, Luxembourg, EUR 27033 EN, JRC 93169, 451 pp.

Scientific, Technical and Economic Committee for Fisheries (STECF) - The Economic Performance Report on the EU Fish Processing (STECF-14-21).2014. Publications Office of the European Union, Luxembourg, EUR 27029 EN, JRC 93340, 355 pp.

Segurado, P., Caiola, N., Pont, D., Oliveira, J. M., Delaigue, O., & Ferreira, M. T. (2014) Comparability of fish-based ecological quality assessments for geographically distinct Iberian regions. Science of the Total Environment, 476, 785-794.

Shmueli, G. (2010) To explain or to predict?. Statistical science, 289-310.

Smith C.J., Papadopoulou K.-N., Barnard S., Mazik K., Elliott M., Patrício J., Solaun O., Little S., Bhatia N., & Borja A. (2016) Managing the Marine Environment, Conceptual Models and Assessment Considerations for the European Marine Strategy Framework Directive. Frontiers in Marine Science, 3, 1-19.

Smyth. G. K. (2002) Nonlinear regression. In Encyclopedia of Environmetrics, Vol. 3 (El-Shaarawi, A. H. & Piegorsch, W. W. eds) pp. 1405-1411. Chichester: John Wiley & Sons, Ltd.

Solís, A. F., & Zhu, X. (2015). Water markets: insights from an applied general equilibrium model for extremadura, Spain. Water Resources Management, 29(12), 4335-4356.

Steen-Olsen, K., Weinzettel, J., Cranston, G., Ercin, A. E., & Hertwich, E. G. (2012). Carbon, land, and water footprint accounts for the European Union: consumption, production, and displacements through international trade. Environmental science & technology, 46(20), 10883-10891.

Stewart G. (2010) Meta-analysis in applied ecology. Biology letters, 6, 78-81. United Nations, 1992 Convention on biological diversity, 30p

Stone, M. (1974) Cross-validatory choice and assesment of statistical predictions (with discussion) J. Roy. Statist. Soc. Ser. B 39 111-147.

Strobl, C., Boulesteix, A. L., Zeileis, A., & Hothorn, T. (2007) Bias in random forest variable importance measures: illustrations, sources and a solution. BMC Bioinformatics.

Steffen W., Broadgate W., Deutsch L., Gaffney O., & Ludwig C. (2015) The trajectory of the Anthropocene: The Great Acceleration. The Anthropocene Review, 2, 81-98.

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

Schmutz, S., Melcher, A., Frangez, C., Haidvogl, G., Beier, U., Böhmer, J., ... & Ferreira, M. T. (2007) Spatially based methods to assess the ecological status of riverine fish assemblages in European ecoregions. Fisheries management and Ecology, 14(6), 441-452.

Surridge, B. W., Bizzi, S., & Castelletti, A. (2014) A framework for coupling explanation and prediction in hydroecological modelling. Environmental Modelling & Software, 61, 274-286.

Talavera, G., Espadaler, X., & Vila, R. (2015) Discovered just before extinction? The first endemic ant from the Balearic Islands (Lasius balearicus sp. nov.) is endangered by climate change. Journal of Biogeography, 42(3), 589-601.

Teichert, N., Borja, A., Chust, G., Uriarte, A., & Lepage, M. (2016) Restoring fish ecological quality in estuaries: implication of interactive and cumulative effects among anthropogenic stressors. Science of The Total Environment, 542, 383-393.

Tendall, D. M., Hellweg, S., Pfister, S., Huijbregts, M. A., & Gaillard, G. (2014). Impacts of River Water Consumption on Aquatic Biodiversity in Life Cycle Assessment: A Proposed Method, and a Case Study for Europe. Environmental science & technology, 48(6), 3236-3244.

Therneau, T. M., & Atkinson, E. J. (1997) An introduction to recursive partitioning using the RPART routines.

Thuiller, W. (2003) BIOMOD-optimizing predictions of species distributions and projecting potential future shifts under global change. Global change biology, 9(10), 1353-1362.

Tillin, H.M., Hull, S.C., Tyler-Walters, H. 2010. Development of a Sensitivity Matrix (pressures-MCZ/MPA features). Report to the Department of Environment, Food and Rural Affairs from ABPMer, Southampton and the Marine Life Information Network (MarLIN) Plymouth: Marine Biological Association of the UK. Defra Contract No. MB0102 Task 3A, Report No. 22. http://www.marlin.ac.uk/assets/pdf/MB0102_Task3-PublishedReport.pdf

Tillin, H.M. & Tyler-Walters, H., 2015. Finalised list of definitions of pressures and benchmarks for sensitivity assessment. May 2015. http://www.marlin.ac.uk/assets/pdf/Finalised-pressure-benchmarks-May2015.pdf

Tu, J. (2011) Spatially varying relationships between land use and water quality across an urbanization gradient explored by geographically weighted regression. Appl. Geogr. 31 (1), 376e392.

Turnhout E., Hisschemöller M., & Eijsackers H. (2007) Ecological indicators: Between the two fires of science and policy. Ecological Indicators, 7, 215-228.

UNEP (United Nations Environment Programme) (1999), Development of indicators of biological diversity, UNEP/CBD/SBSTTA/5/12, Subsidiary body on scientific, technical and technological advice (http://www.biodiv.org/doc/meetings/sbstta/sbstta-05/official/sbstta-05-12-en.doc).

UNEP (United Nations Environment Programme) (2001), Indicators and environmental impact assessment: Designing national-level monitoring and indicator programmes, UNEP/CBD/SBSTTA/7/12, Subsidiary body on scientific, technical and technological advice (http://www.biodiv.org/doc/meetings/sbstta/sbstta-07/official/sbstta-07-12-en.pdf).

Uusitalo L. (2007) Advantages and challenges of Bayesian networks in environmental modelling. Ecol. Model. 203(3-4): 312-318

Vackar D., Ten Brink B., Loh J., Baillie J.E.M., & Reyers B. (2012) Review of multispecies indices for monitoring human impacts on biodiversity. Ecological Indicators, 17, 58-67.

Vasconcelos, R. P., Reis-Santos, P., Fonseca, V., Maia, A., Ruano, M., França, S., ... & Cabral, H. (2007) Assessing anthropogenic pressures on estuarine fish nurseries along the Portuguese coast: a multi-metric index and conceptual approach. Science of the Total Environment, 374(2), 199-215.

Vaughan, W. J., & Russell, C. S. (2015). Freshwater recreational fishing: The national benefits of water pollution control. Routledge.

Vegesana, K. B., & McKenzie, F. D. (2015, April). An agent based model to simulate farmer decision process. In Proceedings of the Symposium on Agent-Directed Simulation (pp. 53-60). Society for Computer Simulation International.

Venables, W.N., Ripley, B.D. (1997) Modern applied statistics with S-PLUS, 2nd edition. Springer, New York, p. 548.

Venohr, M., Hirt, U., Hofmann, J., Opitz, D., Gericke, A., Wetzig, A., ... & Mahnkopf, J. (2011) Modelling of nutrient emissions in river systems-MONERIS-methods and background. International Review of Hydrobiology, 96(5), 435-483.

Villeneuve, B., Souchon, Y., Usseglio-Polatera, P., Ferréol, M., & Valette, L. (2015) Can we predict biological condition of stream ecosystems? A multi-stressors approach linking three biological indices to physico-chemistry, hydromorphology and land use. Ecological Indicators, 48, 88-98.

Vinterbo, S. A., Kim, E. Y., & Ohno-Machado, L. (2005) Small, fuzzy and interpretable gene expression based classifiers. Bioinformatics, 21(9), 1964-1970.

Virkkala, R., Marmion, M., Heikkinen, R. K., Thuiller, W., & Luoto, M. (2010) Predicting range shifts of northern bird species: influence of modelling technique and topography. Acta Oecologica, 36(3), 269-281.

Vitousek P.M., Mooney H. a, Lubchenco J., & Melillo J.M. (1997) Human Domination of Earth' s Ecosystems. Science, 277, 494-499.

Vörösmarty C.J., McIntyre P.B., Gessner M.O., Dudgeon D., Prusevich a., Green P., Glidden S., Bunn S.E., Sullivan C. a., Liermann C.R., & Davies P.M. (2010) Global threats to human water security and river biodiversity. Nature, 467, 555-561.

Wada, Y., Wisser, D., Eisner, S., Flörke, M., Gerten, D., Haddeland, I., ... & Tessler, Z. (2013). Multimodel projections and uncertainties of irrigation water demand under climate change. Geophysical Research Letters, 40(17), 4626-4632.

Wenger, S. J., & Olden, J. D. (2012) Assessing transferability of ecological models: an underappreciated aspect of statistical validation. Methods in Ecology and Evolution, 3(2), 260-267.

Were, K., Bui, D. T., Dick, Ø. B., & Singh, B. R. (2015) A comparative assessment of support vector regression, artificial neural networks, and random forests for predicting and mapping soil organic carbon stocks across an Afromontane landscape. Ecological Indicators, 52, 394-403.

White, L.J., Koss, R.S., Knights, A.M., Eriksson, A. and Robinson, L.A. 2013. ODEMM Linkage Framework Userguide (Version 2). ODEMM Guidance Document Series No.3. EC FP7 project (244273) 'Options for Delivering Ecosystem-based Marine Management'. University of Liverpool. ISBN: 978-0-906370-87-6: 14 pp.

Wieland, R. (2008) Fuzzy models. In: Jørgensen, S.E., Fath, B.D. (Eds.), Encyclopedia of Ecology, Vol. 2. Elsevier, Amsterdam, The Netherlands, pp. 1717-1726.

Wiggering, H., Müller, F. (Eds.) (2004) Umweltziele und Indikatoren. Springer, Berlin/Heidelberg/New Wildlife Management 71, 14-22.

Wilcox, J., Nasiri, F., Bell, S., & Rahaman, M. S. (2016). Urban water reuse: A triple bottom line assessment framework and review. Sustainable Cities and Society, 27, 448-456.Waite, I. R. (2014) Agricultural disturbance response models for invertebrate and algal metrics from streams at two spatial scales within the US. Hydrobiologia, 726(1), 285-303.

Wintle, B. A., & Bardos, D. C. (2006) Modeling species-habitat relationships with spatially autocorrelated observation data. Ecological Applications, 16(5), 1945-1958.

Wold, S., Sjöström, M., & Eriksson, L. (2001) PLS-regression: a basic tool of chemometrics. Chemometrics and intelligent laboratory systems, 58(2), 109-130.

Wright, J. F. (1995) Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. Australian Journal of Ecology 20: 181-197.

Zar, J. H. (1984) Biostatistical Analysis. 2nd edn. Englewood Cliffs, NJ: Prentice Hall.

Zenetos, A. (2001), Scoping study for fisheries indicators, unpublished report for the European Environment Agency, Copenhagen.

Zhang, Q., and Stanley, S.J. (1997) Forecasting raw-water quality variables for the North Saskatchewan River by neural network modelling. Water Res. 31(9): 2340-2350.

8 Annexes

Annex 1: Studies included in the meta-analysis on quantitative and qualitative model applications

Further information on the addressed realm and biological component in the study is given.

Reference	BIOMOD application	Realm	Component
Beaumont et al. 2009	yes	terrestrial	plant
Bedia et al. 2011	no	terrestrial	plant
Bisrat et al. 2012	no	freshwater	amphibia
Boets et al. 2015	no	freshwater	index
Chefaoui et al. 2016	yes	marine	plant
Cianfrani et al. 2011	yes	freshwater	mammal
Cooley et al. 2013	yes	terrestrial	invertebrate
Crego et al. 2013	yes	freshwater	plant
Crego et al. 2014	yes	terrestrial	plant
Crisci et al. 2010	no	terrestrial	infection rate
Cutler et al. 2007	no	terrestrial	plant
Death et al. 2015	no	freshwater	index
Elith et al. 2009	no	terrestrial	artificial
Fletcher et al. 2016	yes	freshwater	fish
Folmer et al. 2016	no	marine	plant
Forester et al. 2013	yes	terrestrial	plant
Franca &Cabral 2015	no	marine	fish
Fronzek et al. 2011	yes	terrestrial	plant
Furkada et al. 2013	no	freshwater	fish
Gontier et al. 2010	no	terrestrial	bird
Hällfors et al. 2016	yes	terrestrial	plant
Hamilton et al. 2015	no	freshwater	invertebrate
Kampichler et al. 2010	no	terrestrial	bird
Keenan et al. 2011	yes	terrestrial	plant
Kendal et al. 2015	yes	terrestrial	mammal
Knudby et al. 2010	no	marine	fish
Komac et al. 2016	yes	terrestrial	plant
Mehra et al. 2016	no	terrestrial	disease
Mostafavi et al. 2014	yes	freshwater	fish
Mouton et al. 2009	no	freshwater	invertebrate
Oliver et al, 2010	yes	terrestrial	bird
Parvianien et al. 2009	yes	terrestrial	plant
Pikesley et al. 2015	yes	marine	vertebrate

Portela et al. 2015	yes	marine	index
Povak et al. 2013	no	terrestrial	mineral weathering
Roberts et al. 2014	yes	terrestrial	plant
Scales et al. 2016	yes	marine	bird
Scarnati et al. 2010	no	terrestrial	plant
Talavera et al. 2015	yes	terrestrial	invertebrate
Virkkala et al. 2010	yes	terrestrial	bird
Wenger & Olden 2012	no	freshwater	fish
Were et al. 2015	no	terrestrial	soil organic carbon
Xinhai et al. 2013	yes	terrestrial	mammal

Annex 2: List of all biodiversity-related indicators (EEA, 2003b)

No	Category	DPSIR	Indicator name and definition	Use	Information source
1	Nature protection	S	Species richness (number of species, number of species per unit area, andnumber of species per habitat type)	Impleme nted	Reid *et al.*, 1993; UNEP, 2001
2	Nature protection	S	Species (populations) threatened with extinction (number or percentage)	Develope d	Reid *et al.*, 1993
3	Nature protection	S	Species (populations) threatened with extirpation (number or percentage)	Develope d	Reid *et al.*, 1993
4	Nature protection	S	Endemic species (number or percentage)	Develope d	Reid *et al.*, 1993
5	Nature protection	S	Endemic species threatened with extinction (number or percentage)	Impleme nted	Reid *et al.*, 1993; UNEP, 2001
6	Nature protection	S	Species risk index (number of endemic species per unit area in a community multiplied by the percentage of the natural community that has been lost)	Impleme nted	Reid *et al.*, 1993; UNEP, 2001
7	Nature protection	S	Species (populations) with stable or increasing populations (number or percentage)	Impleme nted	Reid *et al.*, 1993
8	Nature protection	S	Species (populations) with stable or decreasing populations (number or percentage)	Impleme nted	Reid *et al.*, 1993
9	Nature protection	S	Threatened species in protected areas (number or percentage)	Impleme nted	Reid *et al.*, 1993; UNEP, 2001
10	Nature protection	S	Endemic species in protected areas (number or percentage)	Impleme nted	Reid *et al.*, 1993; UNEP, 2001
11	Nature protection	R	Threatened species maintained in *ex situ* collections (number or percentage)	Develope d	Reid *et al.*, 1993
12	Nature protection	R	Threatened species with viable (reproducing) *ex situ* populations (number or percentage)	Impleme nted	Reid *et al.*, 1993; UNEP, 2001
13	Nature protection	P	Species used by local residents (number or percentage)	Impleme nted	Reid *et al.*, 1993; UNEP, 2001
14	Nature protection	S	Percentage (extent) of area (province/nation/ecoregion) dominated structurally by non-domesticated species	Develope d	Reid *et al.*, 1993
15	Nature protection	I	Rate of change from structural dominance of non-domesticated species to domesticated species	Develope d	Reid *et al.*, 1993
16	Nature protection	S	Percentage (extent) of area (province/nation/ecoregion) dominated by non-domesticated species occurring in patches greater than 1 000 km2	Develope d	Reid *et al.*, 1993

17	Nature protection	R	Percentage (extent) of area (province/nation/ecoregion/community type) in strictly protected status	Impleme nted	Reid *et al.*, 1993
18	Nature protection	R	Accessions of crops and livestock in *ex situ* storage (number or percentage)	Impleme nted	Reid *et al.*, 1993; UNEP, 2001
19	Nature protection	R	Accessions of crops regenerated in the past decade (percentage)	Impleme nted	Reid *et al.*, 1993; UNEP, 2001
20	Nature protection	I	Crops (livestock) grown in an ecoregion or a nation as a percentage of the number grown 30 years previously	Develope d	Reid *et al.*, 1993
21	Nature protection	I	Varieties of each crop (livestock) grown in an ecoregion or a nation as a percentage of the number grown 30 years previously	Develope d	Reid *et al.*, 1993
22	Nature protection	I	Coefficient of kinship or parentage of crops	Impleme nted	Reid *et al.*, 1993; UNEP, 2001
23	Nature protection	S	Original/potential land area of major land ecosystems and habitats	Testing	Prescott-Allen *et al.*, 2000
24	Nature protection	S	Current area of the major land ecosystems/habitats. Percentage unconverted/converted to cultivation/converted to infrastructure — 3 variants	Testing	Prescott-Allen *et al.*, 2000
25	Nature protection	I	Degree of fragmentation of the unconverted portion of each land ecosystem — 2 variants	Testing	Prescott-Allen *et al.*, 2000
26	Nature protection	S	Status and trend of ecological communities within each land ecosystem (communities at risk as a percentage of all communities in that ecosystem)	Testing	Prescott-Allen *et al.*, 2000
27	Nature protection	S	Original/potential area of major aquatic ecosystems and habitats	Testing	Prescott-Allen *et al.*, 2000
28	Nature protection	S	Current area of major aquatic ecosystems/habitats. Percentage unconverted/converted to infrastructure	Testing	Prescott-Allen *et al.*, 2000
29	Nature protection	I	Degree of fragmentation of unconverted portion of each aquatic ecosystem	Testing	Prescott-Allen *et al.*, 2000
30	Nature protection	S	Percentage of each aquatic ecosystem (unconverted portion) natural/modified	Testing	Prescott-Allen *et al.*, 2000
31	Nature protection	S	Status and trend of ecological communities within each aquatic ecosystem (communities at risk as a percentage of all communities in that ecosystem)	Testing	Prescott-Allen *et al.*, 2000
32	Nature protection	S	Percentage of species threatened with extinction/extirpation	Testing	Prescott-Allen *et al.*, 2000
33	Nature protection	S	Status and trend of specified indicator species (or species groups)	Testing	Prescott-Allen *et al.*, 2000
34	Nature protection	S	Percentage of population of particular wild species at risk of extinction	Testing	Prescott-Allen *et al.*, 2000
35	Nature protection	I	Percentage of varieties or breeds of a particular crop or livestock species threatened	Testing	Prescott-Allen *et al.*, 2000
36	Nature protection	I	Turnover rate of varieties and breeds	Testing	Prescott-Allen *et al.*, 2000
37	Nature protection	I	Number of varieties or breeds making up 90 % (or 80 %) of production of selected crops or livestock	Testing	Prescott-Allen *et al.*, 2000

38	Nature protection	I	Number of varieties or breeds accounting for at least 2 % (or at least 5 %) of production of selected crops or livestock	Testing	Prescott-Allen *et al.*, 2000
39	Nature protection	I	Coefficient of kinship or parentage of selected crops or livestock	Testing	Prescott-Allen *et al.*, 2000
40	Nature protection	P	Main human stresses on each land ecosystem or habitat. Percentage contribution of each stress to ecosystem/habitat concerned	Testing	Prescott-Allen *et al.*, 2000
41	Nature protection	P	Main human stresses on each aquatic ecosystem or habitat. Percentage contribution of each stress to ecosystem/habitat concerned	Testing	Prescott-Allen *et al.*, 2000
42	Nature protection	P	Main human stresses on each species assessed as threatened or declining. Percentage contribution of each stress to species concerned	Testing	Prescott-Allen *et al.*, 2000
43	Nature protection	P	Main human stresses on each population, variety or breed assessed as threatened or declining. Percentage contribution of each stress to ecosystem/habitat concerned	Testing	Prescott-Allen *et al.*, 2000
44	Nature protection	P	Total stress on biodiversity due to habitat destruction due to ecosystem conversion/habitat destruction due to modification of unconverted ecosystem/stock depletion/pollution and poisoning/translocation of species	Testing	Prescott-Allen *et al.*, 2000
45	Nature protection	P	Total stress on biodiversity due to each of the main economic sector or human activities	Testing	Prescott-Allen *et al.*, 2000
46	Nature protection	P	Harvesting pressure on land animals and plants	Testing	Prescott-Allen *et al.*, 2000
47	Nature protection	I	Likelihood of a specific biodiversity component being lost and the probable magnitude of that loss	Testing	Prescott-Allen *et al.*, 2000
48	Nature protection	D	Benefits from extracted resources from domesticated species and converted ecosystems, by sector	Testing	Prescott-Allen *et al.*, 2000
49	Nature protection	D	Benefits from extracted resources from wild species and unconverted ecosystems, by sector and by biodiversity component	Testing	Prescott-Allen *et al.*, 2000
50	Nature protection	D	Benefits from on-site resources by tourism services, total and by biodiversity component	Testing	Prescott-Allen *et al.*, 2000
51	Nature protection	D	Benefits from genetic resources, by sector and by biodiversity component	Testing	Prescott-Allen *et al.*, 2000
52	Nature protection	D	Benefits from species services, by sector and by biodiversity component	Testing	Prescott-Allen *et al.*, 2000
53	Nature protection	D	Benefit by a given sector or use per unit of stress on the ecosystem	Testing	Prescott-Allen *et al.*, 2000
54	Nature protection	D	Benefit from a given biodiversity component per unit of stress on that component	Testing	Prescott-Allen *et al.*, 2000
55	Nature protection	I	Number of specific uses considered being sustainable. Percentage of the total number of specific uses assessed	Testing	Prescott-Allen *et al.*, 2000

56	Nature protection	I	Number of ecosystems/communities/species/populations considered being sustainable. Percentage of total number assessed	Testing	Prescott-Allen *et al.*, 2000
57	Nature protection	D	Main social and economic factors behind the stresses	Testing	Prescott-Allen *et al.*, 2000
58	Nature protection	D	Percentage of specified benefit obtained or received by specified groups	Testing	Prescott-Allen *et al.*, 2000
59	Nature protection	D	Flow of benefits from a specified genetic resource	Testing	Prescott-Allen *et al.*, 2000
60	Nature protection	R	National strategy/plan/programme developed for conservation and sustainable use of biodiversity	Testing	Prescott-Allen *et al.*, 2000
61	Nature protection	R	Sectoral or cross-sectoral plans/programmes/policies providing for conservation and sustainable use of biodiversity	Testing	Prescott-Allen *et al.*, 2000
62	Nature protection	R	Additional procedures to implement the CBD and improve the state of biodiversity	Testing	Prescott-Allen *et al.*, 2000
63	Nature protection	R	Provisions made to implement these procedures	Testing	Prescott-Allen *et al.*, 2000
64	Nature protection	R	System of protected areas established	Testing	Prescott-Allen *et al.*, 2000
65	Nature protection	S	Number of threatened species maintained in protected areas. Percentage of total number of threatened species	Testing	Prescott-Allen *et al.*, 2000
66	Nature protection	R	Area of degraded ecosystem undergoing rehabilitation or restoration/has been rehabilitated or restored. Percentage of total area of degraded ecosystem	Testing	Prescott-Allen *et al.*, 2000
67	Nature protection	R	Number of threatened species subject to recovery plan/recovering/no longer threatened. Percentage of total number of threatened species in group concerned	Testing	Prescott-Allen *et al.*, 2000
68	Nature protection	S	Status and trend of introduced species	Testing	Prescott-Allen *et al.*, 2000
69	Nature protection	R	Additional actions for in situ conservation	Testing	Prescott-Allen *et al.*, 2000
70	Nature protection	R	Number of threatened species maintained in *ex situ* collections. Percentage of total number of threatened species. Number reintroduced into their natural habitats.	Testing	Prescott-Allen *et al.*, 2000
71	Nature protection	R	Number of varieties or breeds of selected crops or livestock species maintained in gene banks. Percentage of total number of varieties or breeds of these species	Testing	Prescott-Allen *et al.*, 2000
72	Nature protection	R	Additional actions for ex situ conservation	Testing	Prescott-Allen *et al.*, 2000
73	Nature protection	R	Actions taken for sustainable use of components of biodiversity	Testing	Prescott-Allen *et al.*, 2000
74	Nature protection	S	Natural capital index: NCI = ecosystem quantity * ecosystem quality	Testing	ten Brink 2000
75	Nature protection	S	Ecosystem quantity: self-regenerating habitat	Proposed	UNEP, 1999

76	Nature protection	S	Ecosystem quantity: man-made habitat	Proposed	UNEP, 1999
77	Nature protection	S	Ecosystem quality: native vegetation fragmentation	Proposed	UNEP, 1999
78	Nature protection	S	Ecosystem quality: wetland drainage and filling	Proposed	UNEP, 1999
79	Nature protection	S	Ecosystem quality: conversion of coastal areas	Proposed	UNEP, 1999
80	Nature protection	S	Ecosystem quality: erosion	Proposed	UNEP, 1999
81	Nature protection	S	Ecosystem quality: irrigation	Proposed	UNEP, 1999
82	Nature protection	S	Ecosystem quality: species richness	Proposed	UNEP, 1999
83	Nature protection	S	Ecosystem quality: change in abundance and/or distribution of a selected core set of species	Proposed	UNEP, 1999
84	Nature protection	S	Ecosystem quality: % of total species or certain taxonomic group threatened	Proposed	UNEP, 1999
85	Nature protection	S	Ecosystem quality: % endemic species threatened	Proposed	UNEP, 1999
86	Nature protection	S	Ecosystem quality: threatened species in protected areas	Proposed	UNEP, 1999
87	Nature protection	S	Ecosystem quality: replacement of indigenous crops	Proposed	UNEP, 1999
88	Nature protection	S	Ecosystem quality: replacement of land races with few imported ones	Proposed	UNEP, 1999
89	Nature protection	P	Changes in proportion of commercial species	Proposed	UNEP, 1999
90	Nature protection	P	Soil quality	Implemented	UNEP, 1999; UNEP, 2001
91	Nature protection	P	% habitat colonised by invasive species	Proposed	UNEP, 1999
92	Nature protection	P	% protected area colonised by invasive species	Proposed	UNEP, 1999
93	Nature protection	R	% habitat protected as IUCN classes I-III	Proposed	UNEP, 1999
94	Nature protection	R	% habitat protected as IUCN classes IV-V	Proposed	UNEP, 1999
95	Nature protection	P	% habitat managed for production	Proposed	UNEP, 1999
96	Nature protection	P	Number of fires/areas burnt per year	Proposed	UNEP, 1999
97	Nature protection	S	% special habitat remaining	Proposed	UNEP, 1999
98	Nature protection	R	% special habitat protected	Proposed	UNEP, 1999
99	Nature protection	I	Protected area, loss, damage and defragmentation	Development	Eurostat, 2001
100	Nature protection	I	Wetland loss	Development	Eurostat, 2001
101	Nature protection	P	Change in traditional land-use practice	Development	Eurostat, 2001
102	Nature protection	S	Percentage area of biotopes important for biodiversity of total area	Proposed/implemented	Bosch & Söderbäck, 1997
103	Nature protection	S	Size of selected (threatened) ecosystem	Proposed/implemented	Bosch & Söderbäck, 1997
104	Nature protection	S	Changes in the area of natural and ancient semi-natural forest types	Proposed/implemented	Bosch & Söderbäck, 1997
105	Nature protection	I	Forest physical fragmentation (index)	Proposed/implemented	Bosch & Söderbäck, 1997
106	Nature protection	S	Tree species mix	Proposed/implemented	Bosch & Söderbäck, 1997

107	Nature protection	S	Proportion of annual area of natural regeneration in relation to total area regenerated	Proposed /implemented	Bosch & Söderbäck, 1997
108	Nature protection	S	Number of threatened species	Proposed /implemented	Bosch & Söderbäck, 1997
109	Nature protection	S	Number of endemic species of higher plants and vertebrates (excl. fish), respectively, at national level	Proposed /implemented	Bosch & Söderbäck, 1997
110	Nature protection	S	Percentage threatened species of total number of (forest dependent) species	Proposed /implemented	Bosch & Söderbäck, 1997
111	Nature protection	S	Number and percentage of threatened animal species by category	Proposed /implemented	Bosch & Söderbäck, 1997
112	Nature protection	S	Red lists	Proposed /implemented	Bosch & Söderbäck, 1997
113	Nature protection	S	Change in the number of species over time	Proposed /implemented	Bosch & Söderbäck, 1997
114	Nature protection	S	Fluctuations of populations	Proposed /implemented	Bosch & Söderbäck, 1997
115	Nature protection	S	Population levels of key forest species across their range	Proposed /implemented	Bosch & Söderbäck, 1997
116	Nature protection	S	Fluctuation in forest bird populations	Proposed /implemented	Bosch & Söderbäck, 1997
117	Nature protection	S	Point counts of migrating birds	Proposed /implemented	Bosch & Söderbäck, 1997
118	Nature protection	S	Nesting success of forest birds, predation pressure	Proposed /implemented	Bosch & Söderbäck, 1997
119	Nature protection	S	Selected birds, number and trends	Proposed /implemented	Bosch & Söderbäck, 1997
120	Nature protection	S	State and trends of some species groups: reptiles and amphibians	Proposed /implemented	Bosch & Söderbäck, 1997
121	Nature protection	S	State and trends of some species groups: mammals	Proposed /implemented	Bosch & Söderbäck, 1997
122	Nature protection	S	Changes in mammal populations	Proposed /implemented	Bosch & Söderbäck, 1997
123	Nature protection	S	Population status of forest mammals at risk	Proposed /implemented	Bosch & Söderbäck, 1997
124	Nature protection	S	Forest lichen and vascular plant indicator species	Proposed /implemented	Bosch & Söderbäck, 1997

125	Nature protection	S	Lichens and mosses	Proposed /implemented	Bosch & Söderbäck, 1997
126	Nature protection	S	Number of dragonfly and butterfly species changing in distribution	Proposed /implemented	Bosch & Söderbäck, 1997
127	Nature protection	S	Presence of moths and beetles	Proposed /implemented	Bosch & Söderbäck, 1997
128	Nature protection	S	Presence of amphibians	Proposed /implemented	Bosch & Söderbäck, 1997
129	Nature protection	P	Release of GMOs	Proposed /implemented	Bosch & Söderbäck, 1997
130	Nature protection	S	Index for biodiversity and nature and cultural heritage values in the arable landscape	Proposed /implemented	Bosch & Söderbäck, 1997
131	Nature protection	P	Land management, indexed	Proposed /implemented	Bosch & Söderbäck, 1997
132	Nature protection	P	pH and deposition of N	Proposed /implemented	Bosch & Söderbäck, 1997
133	Nature protection	S	Population levels of key species across their range	Proposed /implemented	Bosch & Söderbäck, 1997
134	Nature protection	S	Fluctuation in bird populations	Proposed /implemented	Bosch & Söderbäck, 1997
135	Nature protection	S	Mean number of plant species per plot in semi-improved grassland	Proposed /implemented	Bosch & Söderbäck, 1997
136	Nature protection	S	Mean number of plant species per plot in hedgerows	Proposed /implemented	Bosch & Söderbäck, 1997
137	Nature protection	S	Mean number of plant species per plot on streamsides	Proposed /implemented	Bosch & Söderbäck, 1997
138	Nature protection	S	Classification and distribution of valuable pasture lands	Proposed /implemented	Bosch & Söderbäck, 1997
139	Nature protection	S	Percentage of threatened species of total number	Proposed /implemented	Bosch & Söderbäck, 1997
140	Nature protection	P	Number of permits for GMO distribution	Proposed /implemented	Bosch & Söderbäck, 1997
141	Nature protection	S	Percentag of wetland area of total area	Proposed /implemented	Bosch & Söderbäck, 1997
142	Nature protection	S	Percentage of wet forest land	Proposed /implemented	Bosch & Söderbäck, 1997

143	Nature protection	S	Total area of wetlands	Proposed /implemented	Bosch & Söderbäck, 1997
144	Nature protection	S	Depth distribution of brown algal belts (Fucus vesiculosus)	Proposed /implemented	Bosch & Söderbäck, 1997
145	Nature protection	S	Freshwater invertebrates	Proposed /implemented	Bosch & Söderbäck, 1997
146	Nature protection	S	Biological quality index	Proposed /implemented	Bosch & Söderbäck, 1997
147	Nature protection	P	Peat cutting and other mining activities	Implemented	BEF, 2000
148	Nature protection	S	Threatened species on a national scale	Implemented	BEF, 2000
149	Nature protection	S	Threatened species on an international scale	Implemented	BEF, 2000
150	Nature protection	R	Protected areas according to IUCN category 1A and 1B	Implemented	BEF, 2000
151	Nature protection	R	Protected areas according to national law	Implemented	BEF, 2000
152	Nature protection	R	Fines for killing certain ‘charismatic’ species	Implemented	BEF, 2000
153	Nature protection	P	Pressures on grasslands	Implemented	EEA, 2001c
154	Nature protection	I	Change in area and use of grasslands	Implemented	EEA, 2001c
155	Nature protection	S	Species in dry grasslands	Implemented	EEA, 2001c
156	Nature protection	R	Protection of grasslands	Implemented	EEA, 2001c
157	Nature protection	R	Designation of SPAs	Implemented	EEA, 2001c
158	Nature protection	R	Number and extent of protected areas	Implemented	UNDP *et al.*, 2000
159	Nature protection	S	Species number per species group	Implemented	UNDP *et al.*, 2000
160	Nature protection	S	Number of endemic species per species group	Implemented	UNDP *et al.*, 2000
161	Nature protection	R	CITES entered into force	Implemented	UNDP *et al.*, 2000
162	Nature protection	R	% CITES reporting requirements met as of 1997	Implemented	UNDP *et al.*, 2000
163	Nature protection	P	Number of individuals traded by species group	Implemented	UNDP *et al.*, 2000
164	Nature protection	S	Number of seagrass species	Implemented	UNDP *et al.*, 2000
165	Nature protection	S	Number of Scleractinia coral genera	Implemented	UNDP *et al.*, 2000
166	Nature protection	S	Presence and abundance of threatened plant and bird species	Proposed /implemented	Fammler *et al.*, 1998; Roots &

					Talkop, 1997
167	Nature protection	S	Presence and abundance of bats, terrestrial beetles and bugs, breeding birds, lichens, threatened vascular plant species, mosses, community forming vascular plants	Proposed /implemented	From & Söderman, 1997
168	Nature protection	S	Presence of vagile (non-sessile) species (amphibians, mammals, crabs) on roads, numbers of accidental kills, forming of meta-populations, population characteristics (colonisation, local extinction rates, survivorship and mortality) of threatened species, genetic variability, inbreeding in populations	Proposed /implemented	Noss, 1990
169	Nature protection	S	Presence and abundance of threatened and specialised species	Proposed /implemented	Fammler *et al.*, 1998
170	Nature protection	S	Presence and abundance of threatened vascular plant species	Proposed /implemented	Fammler *et al.*, 1998; Roots & Talkop, 1997
171	Nature protection	I	Presence and abundance of specialised, threatened plant species	Proposed /implemented	Roots & Talkop, 1997
172	Nature protection	I	Changes in fish populations, benthic protozoans	Proposed /implemented	Tamás-Dvihally, 1987,; Nosek & Bereczky, 1993
173	Nature protection	S	Number of taxa and abundance of phytoplankton, bacterioplankton, number and abundance of macrophytes, zooplankton groups, fish species, coli index	Proposed /implemented	Roots & Talkop, 1997; Framstad, 1999; Sykes & Lane, 1996; Bíró, 1997; Somlyódi & van Straten, 1986
174	Nature protection	S	Number and abundance of molluscs, crustacean species	Proposed /implemented	Sykes & Lane, 1996
175	Nature protection	I	Number and abundance of fish species	Proposed /implemented	Bíró, 1997; Tamás-Dvihaly, 1987
176	Nature protection	I	Analysis of food webs, number and abundance of molluscs, and fish species, state of fish stocks	Proposed /implemented	Framstad, 1999
177	Nature protection	S	Presence of threatened vascular plant, moss and bird species	Proposed /implemented	Fammler *et al.*, 1998; From & Söderman, 1997

178	Nature protection	S	Presence and abundance of breeding and migrating birds, terrestrial molluscs, moths, orchid species, terrestrial and epiphytic fungi, butterflies, frogs, community forming and threatened plant species and grazing animals, other invertebrates	Proposed /implemented	From & Söderman, 1997; Sykes & Lane, 1996
179	Nature protection	S	Presence and abundance of terrestrial and epiphytic fungi, breeding birds, soil micro-organisms, mosses, orchids, species composition and abundance of vascular plants	Proposed /implemented	From & Söderman, 1997; Roots & Talkop, 1997; Noss 1990
180	Nature protection	S	Presence and abundance of threatened vascular plant, moss, mollusca species, soil micro-organisms	Proposed /implemented	From & Söderman, 1997; Roots & Talkop, 1997
181	Nature protection	I	Species composition and abundance of vascular plants, mosses, birds, soil micro organisms and epilithic lichens	Proposed /implemented	From & Söderman, 1997; Sykes & Lane, 1996
182	Nature protection	I	Abundance of terrestrial beetles and bugs, species composition and abundance of vascular plants	Proposed /implemented	de Groot *et al.*, 1995
183	Nature protection	I	Species composition and abundance of plants, proportion of threatened, endemic, rare species, primary production	Proposed /implemented	Sykes & Lane, 1996; Roots & Talkop, 1997; Kovács-Láng et al., 2000a; GTOS, 1997
184	Nature protection	I	Distribution of plant species among nature conservation values	Proposed /implemented	Simon, 1988
185	Nature protection	S	Presence and abundance of pollinators	Proposed /implemented	Roots & Talkop, 1997
186	Nature protection	I	Changes in invertebrate populations	Proposed /implemented	Sykes & Lane, 1996; Horváth et al., 1997
187	Nature protection	I	Plant species composition and abundance, proportion of rare and endangered species	Proposed /implemented	Roots & Talkop, 1997; Sykes & Lane, 1996; Hill & Carey, 1997
188	Nature protection	I	Net primary production (NPP) and leaf area index (LAI)	Proposed /implemented	GTOS, 1997
189	Nature protection	I	Abundance of insect populations	Proposed /implemented	Kozár, 1997

190	Nature protection	S	Plant species composition and abundance, number and abundance of bird species, terrestrial beetles and bugs, terrestrial and epiphytic fungi, terrestrial molluscs, mosses, orchids, small rodents, butterflies	Proposed /implemented	From & Söderman, 1997; Roots & Talkop, 1997; Sykes & Lane, 1996
191	Nature protection	I	Crown defoliation, leaf discoloration, epiphytic algae and lichens, terrestrial and epiphytic fungi, mosses, terrestrial molluscs	Proposed /implemented	De Vries *et al.*, 1998; From & Söderman, 1997; Roots & Talkop, 1997; Framstad, 1999; de Zwart, 1999; Eichhorn et al., 1998
192	Nature protection	I	Plant species composition and abundance, appearance of invasive species	Proposed /implemented	de Groot *et al.*, 1995
193	Nature protection	S	Plant species composition and abundance in the herb layer, presence and abundance of bats, sub-cortical beetles and bugs, breeding birds, terrestrial molluscs, nocturnal moths, butterflies, small rodents	Proposed /implemented	From & Söderman, 1997; Sykes & Lane, 1996
194	Nature protection	I	Structural characteristics (presence of vertical layers) plant species composition and abundance, ways of post-fire succession, presence and abundance of birds, mammals, and soil biota	Proposed /implemented	SEPA, 1998; Noss, 1990; Ferretti, 1997
195	Nature protection	S	Soil biota	Proposed /implemented	Ferretti, 1997
196	Nature protection	S	Presence and abundance of community forming and threatened plant species, birds, wild animals	Proposed /implemented	Horváth *et al.*, 1997; Kovács-Láng et al., 2000a
197	Nature protection	S	Plant species composition and abundance, presence and abundance of threatened species	Proposed /implemented	Zólyomi & Précsényi, 1964
198	Nature protection	I	Plant species composition and abundance, distribution of plant species among nature conservation values	Proposed /implemented	Simon, 1988
199	Nature protection	I	Plant species composition and abundance	Proposed /implemented	Kovács-Láng *et al.*, 2000b; De Vries *et al.*, 1998; Eichhorn *et al.*, 1998

200	Nature protection	I	Activity of soil micro-organisms, abundance of earth worm populations, colony-forming micro-organisms	Proposed /implemented	Roots & Talkop, 1997
201	Nature protection	S	Living planet index (LPI)	In use	Loh, 2000
202	Nature protection	S	Threatened species as a percentage of total native species	Testing	UNCSD, 1996
203	Nature protection	R	Protected area as a percentage of total area	Testing	UNCSD, 1996
204	Nature protection	S	Ecosystem area	Proposed	WCMC, 1996
205	Nature protection	S	Ecosystem quality	Proposed	WCMC, 1996
206	Nature protection	S	Threatened/extinct species	Proposed	WCMC, 1996
207	Nature protection	P	Biodiversity use	Proposed	WCMC, 1996
208	Nature protection	S	Number of wild species	Proposed	WCMC, 1996
209	Nature protection	S	Number of domesticates	Proposed	WCMC, 1996
210	Nature protection	S	Habitat index	Implemented on	Hannah, 1994a,b global scale
211	Nature protection	S	Keystone species	Proposed	Paine, 1969
212	Nature protection	S	World Bank/GEF natural capital indicator	Implemented	Rodenburg *et al.*, 1995
213	Nature protection	S	WRI ecosystems at risk indicator	Implemented on global scale	Bryant *et al.*, 1995; Bryant, 1997
214	Nature protection	S	Total number of known species (mammals, birds, amphibians, reptiles, fish, invertebrates, vascular plants, non-vascular plants)	Implemented	Eurostat
215	Nature protection	S	Number of endangered species (mammals, birds, amphibians, reptiles, fish, invertebrates, vascular plants, non-vascular plants)	Implemented	Eurostat
216	Nature protection	S	Number of critically endangered species (mammals, birds, amphibians, reptiles, fish, invertebrates, vascular plants, non-vascular plants)	Implemented	Eurostat
217	Nature protection	S	Number of vulnerable species (mammals, birds, amphibians, reptiles, fish, invertebrates, vascular plants, non-vascular plants)	Implemented	Eurostat
218	Nature protection	S	Number of declining species (mammals, birds, amphibians, reptiles, fish, invertebrates, vascular plants, non-vascular plants)	Implemented	Eurostat
219	Nature protection	S	Land use 1950-99 (30 land-use types)	Implemented	Eurostat
220	Nature protection	P	Change in land use 1950-99 (30 land-use types)	Implemented	Eurostat
221	Nature protection	P	Land degradation: soil erosion (12 land-use types)	Implemented	Eurostat

222	Nature protection	R	Percentage of protected area to total area	Impleme nted	UNEP, 2001
223	Nature protection	R	Total area of protected areas (using IUCN definition of protected areas)	Impleme nted	UNEP, 2001
224	Nature protection	R	Size and distribution of protected areas	Impleme nted	UNEP, 2001
225	Nature protection	R	Percent area in strictly protected status	Impleme nted	UNEP, 2001
226	Nature protection	P/S	Frozen ground activity	Impleme nted	UNEP, 2001
227	Nature protection	P/S	Karst activity	Impleme nted	UNEP, 2001
228	Nature protection	P/S	Slope failure (landslides)	Impleme nted	UNEP, 2001
229	Nature protection	S	Relative wilderness index	Impleme nted	UNEP, 2001
230	Nature protection	S	Changes in limiting factors for key species e.g. nest holes for parrots, fruit bat roosting trees	Impleme nted	UNEP, 2001
231	Nature protection	S	Volcanic unrest	Impleme nted	UNEP, 2001
232	Nature protection	S	Difference in total area of a particular habitat type	Impleme nted	UNEP, 2001
233	Nature protection	S	Changes in largest block of a particular habitat type	Impleme nted	UNEP, 2001
234	Nature protection	S	Changes in average size of a particular habitat type	Impleme nted	UNEP, 2001
235	Nature protection	S	Change in mean nearest distance between blocks of a particular habitat type	Impleme nted	UNEP, 2001
236	Nature protection	S	Change in average width of break in an identified habitat corridor	Impleme nted	UNEP, 2001
237	Nature protection	S	Change in habitat boundaries	Impleme nted	UNEP, 2001
238	Nature protection	S	Percentage of area dominated by non-domesticated species	Impleme nted	UNEP, 2001
239	Nature protection	S	Degree of connectivity of food web	Impleme nted	UNEP, 2001
240	Nature protection	R	Existence of institutional capacity, policy and regulatory framework for the planning, management and conservation of biological diversity	Impleme nted	UNEP, 2001
241	Nature protection	S	Change in number and/or distribution of keystone or indicator species	Impleme nted	UNEP, 2001
242	Nature protection	P	Number of introduced species and genomes	Impleme nted	UNEP, 2001
243	Nature protection	P	Change in presence, location, area, numbers of invasive plant or animal species	Impleme nted	UNEP, 2001

244	Nature protection	P	Quantity of specimens or species of economic/scientific interest removed from the environment	Impleme nted	UNEP, 2001
245	Nature protection	S	Percentage of area dominated by non-domesticated species occurring in patches greater than 1 000 km2.	Impleme nted	UNEP, 2001
246	Nature protection	S	Population growth and fluctuation trends of special interest species	Impleme nted	UNEP, 2001
247	Nature protection	S	Sex ratio, age distribution and other aspects of population structure for sensitive species, keystone species, and other special interest species	Impleme nted	UNEP, 2001
248	Nature protection	S	Presence of taxa on environmental integrity	Impleme nted	UNEP, 2001
249	Nature protection	S	Recorded species present by group	Impleme nted	UNEP, 2001
250	Nature protection	S	Indigenous species present by group	Impleme nted	UNEP, 2001
251	Nature protection	S	Non-indigenous species present by group	Impleme nted	UNEP, 2001
252	Nature protection	S	Number of endemic/threatened/ endangered/vulnerable species by group	Impleme nted	UNEP, 2001
253	Nature protection	S	Temporal change in number of species (increase/decrease)	Impleme nted	UNEP, 2001
254	Nature protection	S	Change in composition of species overtime	Impleme nted	UNEP, 2001
255	Nature protection	S	Species group: total number versus threatened species	Impleme nted	UNEP, 2001
256	Nature protection	S	Species with small populations vs. larger population size	Impleme nted	UNEP, 2001
257	Nature protection	S	Spatial differences in the number of rare vs. common species	Impleme nted	UNEP, 2001
258	Nature protection	S	Spatial differences in the restricted vs. wide-range species	Impleme nted	UNEP, 2001
259	Nature protection	S	Representativeness of intra-specific variability of endangered and economically important species	Impleme nted	UNEP, 2001
260	Nature protection	S	Diversity of native fauna	Impleme nted	UNEP, 2001
261	Nature protection	S	Species threatened with extirpation	Impleme nted	UNEP, 2001
262	Nature protection	S	Species threatened with extinction (number or percentage)	Impleme nted	UNEP, 2001
263	Nature protection	S	Species with stable or increasing populations	Impleme nted	UNEP, 2001
264	Nature protection	S	Species with decreasing populations	Impleme nted	UNEP, 2001
265	Nature protection	R	Threatened species in *ex situ* collections	Impleme nted	UNEP, 2001

266	Nature protection	S	Percentage of threatened species	Impleme nted	UNEP, 2001
267	Nature protection	P	Number of visitors to protected areas	Impleme nted	UNEP, 2001
268	Nature protection	S	Number of endangered mammal, bird, fish, and reptile species	Impleme nted	UNEP, 2001
269	Nature protection	S	Number of threatened species of mammal, bird, fish and reptile species	Impleme nted	UNEP, 2001
270	Nature protection	R	Government programmes, awareness campaigns	Impleme nted	UNEP, 2001
271	Nature protection	R	Government conservation legislation and policies	Impleme nted	UNEP, 2001
272	Nature protection	R	International conventions acceded to	Impleme nted	UNEP, 2001
273	Nature protection	R	NGOs programmes and action plans	Impleme nted	UNEP, 2001
274	Nature protection	P	Game-hunting rate — diversity and abundance	Impleme nted	UNEP, 2001
275	Nature protection	R	Percentage of protected area of different ecosystem types	Impleme nted	UNEP, 2001
276	Nature protection	S	Species of communal interest of all indigenous species (percentage)	Impleme nted	UNEP, 2001
277	Nature protection	S	Endangered species of all indigenous species (percentage)	Impleme nted	UNEP, 2001
278	Nature protection	P	Alien species of all indigenous species (percentage)	Impleme nted	UNEP, 2001
279	Nature protection	R	Endangered species with plans of action (all categories of endangerment and all types of plans of action)	Impleme nted	UNEP, 2001
280	Nature protection	S	Total number and area of communal interest habitats. Identification of priorities	Impleme nted	UNEP, 2001
281	Nature protection		ENP percentage with planning of approved arrangement, utilisation and management	Impleme nted	UNEP, 2001
282	Nature protection	P	Ratio between exotic species and native species in plantation area	Impleme nted	UNEP, 2001
283	Nature protection	S	Self-generating area per habitat type	Impleme nted	UNEP, 2001
284	Nature protection	S	Self-generating area as a percentage of total area	Impleme nted	UNEP, 2001
285	Nature protection	R	Percentage of protected area with clearly defined boundaries	Impleme nted	UNEP, 2001
286	Nature protection	S	Area and length and numbers of biological corridors	Impleme nted	UNEP, 2001
287	Nature protection	P	Annual volume and area of timber harvested — indigenous and plantation	Impleme nted	UNEP, 2001
288	Nature protection	S	Estimate of carbon stored	Impleme nted	UNEP, 2001

289	Nature protection	S	Absolute and relative abundance, density, basal area, cover, of various species	Impleme nted	UNEP, 2001
290	Nature protection	S	Threatened tree species as a percentage of the 20 most used for commercial purposes	Impleme nted	UNEP, 2001
291	Nature protection	S	Number of threatened, keystone, flagship species	Impleme nted	UNEP, 2001
292	Nature protection	S	Number of extinct, endangered, threatened, vulnerable and endemic forest dependent species by group (e.g., birds, mammals, vertebrates, invertebrates)	Impleme nted	UNEP, 2001
293	Nature protection	S	List of flora and fauna	Impleme nted	UNEP, 2001
294	Nature protection	R	Existence of procedures for identifying endangered, rare, and threatened species	Impleme nted	UNEP, 2001
295	Nature protection	R	Existing strategies for *in situ/ex situ* conservation of genetic variation within commercial, endangered, rare and threatened species of forest flora and fauna	Impleme nted	UNEP, 2001
296	Nature protection	S	Number of forest dependent species whose populations are declining	Impleme nted	UNEP, 2001
297	Nature protection	S	Population levels of representative species from diverse habitats monitored across their range	Impleme nted	UNEP, 2001
298	Nature protection	P	Number and extent of invasive species	Impleme nted	UNEP, 2001
299	Nature protection	S	Number of forest-dependent species that occupy a small portion of their former range	Impleme nted	UNEP, 2001
300	Nature protection	S	The status (threatened, rare, vulnerable, endangered, or extinct) of forest-dependent species at risk of not maintaining viable breeding populations, as determined by legislation or scientific assessment	Impleme nted	UNEP, 2001
301	Nature protection	S	The number of forest-dependent species	Impleme nted	UNEP, 2001
302	Nature protection	P	Rate of vegetation clearing by activity (agriculture, urban development, deforestation	Impleme nted	UNEP, 2001
303	Nature protection	P	Outbreak of veld fires by frequency	Impleme nted	UNEP, 2001
304	Nature protection	P	Percentage of habitat colonised by invasive species	Impleme nted	UNEP, 2001
305	Nature protection	P	Percentage of protected area colonised by invasive species	Impleme nted	UNEP, 2001

306	Nature protection	P	Habitat loss by km2 through human activities, and through natural causes.	Impleme nted	UNEP, 2001
307	Nature protection	S/P	Habitat loss through habitat fragmentation	Impleme nted	UNEP, 2001
308	Nature protection	S	Area and state of indigenous vegetation	Impleme nted	UNEP, 2001
309	Nature protection	P	Distribution of species considered as pests	Impleme nted	UNEP, 2001
310	Nature protection	P	Number of exotic and local species outbred and location of affected areas	Impleme nted	UNEP, 2001
311	Nature protection	R	Area of protected areas by vegetation type as percentage of total area	Impleme nted	UNEP, 2001
312	Nature protection	R	Revegetated areas by species or genus in hectares per annum and reasons thereof	Impleme nted	UNEP, 2001
313	Nature protection	S	Changes in crown cover	Impleme nted	UNEP, 2001
314	Nature protection	P	Number of wild species used as food sources by communities	Impleme nted	UNEP, 2001
315	Nature protection	S	Woodlands (km2)	Impleme nted	UNEP, 2001
316	Nature protection	S	Riverine forest (km2)	Impleme nted	UNEP, 2001
317	Nature protection	S	Riverine percentage of total land	Impleme nted	UNEP, 2001
318	Nature protection	S	Mangrove forest (km2)	Impleme nted	UNEP, 2001
319	Nature protection	S	Mangrove percentage of total land	Impleme nted	UNEP, 2001
320	Nature protection	S	Agricultural biodiversity	Impleme nted	UNEP, 2001
321	Nature protection	D	Agricultural area by crops (cereal, oil crops, forage, woodlands)	Impleme nted	UNEP, 2001
322	Nature protection	D	Agricultural area (intensively farmed, semi-intensively farmed and uncultivated)	Impleme nted	UNEP, 2001
323	Nature protection	S	Number of vertebrate species using habitat on agricultural land by species	Impleme nted	UNEP, 2001
324	Nature protection	S	Differences in species diversity and abundance of arthropods and earthworms in organically and conventionally cultivated arable land	Impleme nted	UNEP, 2001
325	Nature protection	S/P	Rate of change from dominance of non-domesticated species to domesticated species	Impleme nted	UNEP, 2001
326	Nature protection	P/S	Species diversity used for food	Impleme nted	UNEP, 2001
327	Nature protection	S	Erosion/loss of genetic diversity patrimony	Impleme nted	UNEP, 2001
328	Nature protection	S/P	Crops/livestock grown as a percentage of number of 30 years before	Impleme nted	UNEP, 2001

329	Nature protection	S/P	Replacement of indigenous crops	Impleme nted	UNEP, 2001
330	Nature protection	S/P	Inbreeding/outbreeding rate	Impleme nted	UNEP, 2001
331	Nature protection	S/P	Rate of genetic interchange between populations (measured by rate of dispersal and subsequent reproduction of migrants)	Impleme nted	UNEP, 2001
332	Nature protection	D	Share of irrigated agricultural land	Impleme nted	UNEP, 2001
333	Nature protection	P	Replacement of land races with imported ones	Impleme nted	UNEP, 2001
334	Nature protection	S	Changes in vegetation type along water courses	Impleme nted	UNEP, 2001
335	Nature protection	?	Water resource vulnerability index	Impleme nted	UNEP, 2001
336	Nature protection	P	Ratio between maximum sustained yield and actual average abundance	Impleme nted	UNEP, 2001
337	Nature protection	S	Glacier fluctuations	Impleme nted	UNEP, 2001
338	Nature protection	S	Wetland area	Impleme nted	UNEP, 2001
339	Nature protection	P	Extent of wetland drainage and filling	Impleme nted	UNEP, 2001
340	Nature protection	S	Fish family diversity	Impleme nted	UNEP, 2001
341	Nature protection	S	Benthic macroinvertebrates: communities	Impleme nted	UNEP, 2001
342	Nature protection	S	Macrophytes: species composition and depth distribution	Impleme nted	UNEP, 2001
343	Nature protection	S	Threatened freshwater fish species as a percentage of total freshwater fish species	Impleme nted	UNEP, 2001
344	Nature protection	P	Number of inland fish species introduced	Impleme nted	UNEP, 2001
345	Nature protection	P	Number of exotic flora and fauna species, e.g. fish, aquatic weeds	Impleme nted	UNEP, 2001
346	Nature protection	S	Number of endemic flora and fauna	Impleme nted	UNEP, 2001
347	Nature protection	S	Changes in distribution and abundance of native flora and fauna	Impleme nted	UNEP, 2001
348	Nature protection	S	Number of extinct, endangered, threatened/endangered/vulnerable/ endemic inland water species by group, e.g. birds, aquatic mammals, invertebrates, amphibians, vascular plants, bottom fauna	Impleme nted	UNEP, 2001
349	Nature protection	S	Indicator species	Impleme nted	UNEP, 2001
350	Nature protection	P	Rate of destruction of water habitats per annum	Impleme nted	UNEP, 2001

351	Nature protection	S	Area and state of water per habitat, i.e. riverine areas and wetlands	Implemented	UNEP, 2001
352	Nature protection	P	Rate of destruction of water habitats by types of activities	Implemented	UNEP, 2001
353	Nature protection	S	Genetic monitoring of salmon and whitefish	Implemented	UNEP, 2001
354	Nature protection	S	Reservoir that has eutrophication	Implemented	UNEP, 2001
355	Nature protection	S	Availability of regulated water resources: reserves of reservoir water	Implemented	UNEP, 2001
356	Nature protection	R	Improvements in the distribution of water	Implemented	UNEP, 2001
357	Nature protection	S	Coastal and marine biodiversity	Implemented	UNEP, 2001
358	Nature protection	S/P	Annual rate of mangrove conversion	Implemented	UNEP, 2001
359	Nature protection	S	Coral chemistry and growth pattern	Implemented	UNEP, 2001
360	Nature protection	S/P	Surface displacement	Implemented	UNEP, 2001
361	Nature protection	P	Amount of poison chemicals and dynamite used for reef fishing	Implemented	UNEP, 2001
362	Nature protection	S	Algae index	Implemented	UNEP, 2001
363	Nature protection	S	Threatened fish species as a percentage of total fish species known	Implemented	UNEP, 2001
364	Nature protection	S/P	Change in proportion of fish catches by species per specific season	Implemented	UNEP, 2001
365	Nature protection	R	Protected coastal area	Implemented	UNEP, 2001
366	Nature protection	R	Length of artificial coral reef	Implemented	UNEP, 2001
367	Nature protection	P	Contamination in critical points	Implemented	UNEP, 2001
368	Nature protection	R	Implementation of integrated management programmes of coastal areas	Implemented	UNEP, 2001
369	Nature protection	R	Gleaning or fishing off reef per village	Implemented	UNEP, 2001
370	Nature protection	S	Trends in seabird population	Implemented	UNEP, 2001
371	Nature protection	S/P	Pollutants in polar bears	Implemented	UNEP, 2001
372	Nature protection	?	Biological limits	Implemented	UNEP, 2001
373	Nature protection	S	Monitoring of population trends in marine mammals	Implemented	UNEP, 2001
374	Nature protection	S	Trends in wild bird populations: globally threatened species	Implemented	Heath & Rayment, 2001

375	Nature protection	S	Trends in wild bird populations: significant populations of species of European conservation concern	Impleme nted	Heath & Rayment, 2001
376	Nature protection	S	Trends in wild bird populations: significant populations of species listed on Annex I to the EU birds directive	Impleme nted	Heath & Rayment, 2001
377	Nature protection	S	Trends in wild bird populations: other common and widespread species	Impleme nted	Heath & Rayment, 2001
378	Nature protection	S	Change in cover of land-use types	Impleme nted	Heath & Rayment, 2001
379	Nature protection	P	Change in impact of 25 classes of impact to IBAs	Impleme nted	Heath & Rayment, 2001
380	Nature protection	R	Change in overlap of IBAs with national and international protected areas	Impleme nted	Heath & Rayment, 2001
381	Nature protection	R	Change in presence of management plans for IBAs	Impleme nted	Heath & Rayment, 2001
382	Nature protection	S	Species in dry grasslands	Impleme nted	EEA website, 2002
383	Nature protection	R	Protection of grasslands	Impleme nted	EEA website, 2002
384	Nature protection	P	Pressures on grasslands	Impleme nted	EEA website, 2002
385	Nature protection	D	Change in area and use of grasslands	Impleme nted	EEA website, 2002
386	Nature protection	S	National biodiversity index (NBI)	Impleme nted	SCBD, 2001
387	Forestry	D	Export of timber and timber products	Impleme nted	BEF, 2000
388	Forestry	P	Total forest felling	Impleme nted	BEF, 2000
389	Forestry	S	Forest extent 1990	Impleme nted	UNDP *et al.*, 2000
390	Forestry	S	Forest extent 1995	Impleme nted	UNDP *et al.*, 2000
391	Forestry	P	Average annual % change of forests 1990-95	Impleme nted	UNDP *et al.*, 2000
392	Forestry	S	Extent natural forest 1990	Impleme nted	UNDP *et al.*, 2000
393	Forestry	S	Extent natural forest 1995	Impleme nted	UNDP *et al.*, 2000
394	Forestry	P	Average annual % change of natural forests 1990-95	Impleme nted	UNDP *et al.*, 2000
395	Forestry	S	Extent plantations 1990	Impleme nted	UNDP *et al.*, 2000
396	Forestry	S	Extent plantations 1995	Impleme nted	UNDP *et al.*, 2000
397	Forestry	P	Average annual % change of plantations 1990-95	Impleme nted	UNDP *et al.*, 2000

398	Forestry	R	Extent natural forests certified with FSC label	Implemented	UNDP *et al.*, 2000
399	Forestry	R	Extent plantations certified with FSC label	Implemented	UNDP *et al.*, 2000
400	Forestry	R	Extent mixed forests certified with FSC label	Implemented	UNDP *et al.*, 2000
401	Forestry	S	Number of tree species threatened 1990s	Implemented	UNDP *et al.*, 2000
402	Forestry	S	Forest stands older than 100 years and distribution of dominant tree species in these stands	Implemented	BEF, 2000
403	Forestry	S	Changes in the proportion of stands managed for the conservation and utilisation of forest genetic resources	Implemented	Bosch & Söderbäck, 1997; UNEP, 2001
404	Forestry	P	Total area of drained forest land & total length of forest ditches	Proposed /implemented	Bosch & Söderbäck, 1997
405	Forestry	S	Percentage mono-specific forests of total forest area	Proposed /implemented	Bosch & Söderbäck, 1997
406	Forestry	S	Changes in the proportion of mixed stands of 2-3 tree species	Proposed /implemented	Bosch & Söderbäck, 1997
407	Forestry	S	Percentage area young coniferous forests with more than 20 % deciduous trees	Proposed /implemented	Bosch & Söderbäck, 1997
408	Forestry	S	Proportion of deciduous trees in coniferous forests	Proposed /implemented	Bosch & Söderbäck, 1997
409	Forestry	S	Number of trees more than 30 cm in diameter/ha in young forests	Proposed /implemented	Bosch & Söderbäck, 1997
410	Forestry	S	Tree age class distribution (index)	Proposed /implemented	Bosch & Söderbäck, 1997
411	Forestry	S	Number of large trees per ha in young forests	Proposed /implemented	Bosch & Söderbäck, 1997
412	Forestry	S	Amount of dead wood in forests	Proposed /implemented	Bosch & Söderbäck, 1997
413	Forestry	S	Number of dead trees more than 10 cm in diameter/ha in cut forest areas	Proposed /implemented	Bosch & Söderbäck, 1997
414	Forestry	S	Total area of mixed stands	Proposed /implemented	Bosch & Söderbäck, 1997
415	Forestry	I	Forest damage	Development	Eurostat, 2001
416	Forestry	I	Rate of timber extraction from forests	Testing	Prescott-Allen *et al.*, 2000
417	Forestry	S	Total forest area	Implemented	UNEP, 2001

418	Forestry	S	Total forest area as a percentage of total land area	Implemented	UNEP, 2001
419	Forestry	S	Percentage of forest cover by forest type (primary, secondary or plantation)	Implemented	UNEP, 2001
420	Forestry	P	Fragmentation of forests	Implemented	UNEP, 2001
421	Forestry	P	Number and size of forest fires	Implemented	UNEP, 2001
422	Forestry	R	Reforested and afforested areas	Implemented	UNEP, 2001
423	Forestry	I	Area and extent of degraded lands reclaimed through forest operations	Implemented	UNEP, 2001
424	Forestry	I	Area and percentage of forest area affected by anthropogenic effects (logging, harvesting for subsistence).	Implemented	UNEP, 2001
425	Forestry	I	Area and percentage of forest area affected by natural disasters (insect attack, disease, fire and flooding)	Implemented	UNEP, 2001
426	Forestry	R	Area and percentage of forests managed for catchment protection	Implemented	UNEP, 2001
427	Forestry	S	Area of forest rebuilding stands	Implemented	UNEP, 2001
428	Forestry	R	Area of managed forest with special environmental values	Implemented	UNEP, 2001
429	Forestry	S	Area of seed forest stands	Implemented	UNEP, 2001
430	Forestry	S	Burnt forest area per year	Implemented	UNEP, 2001
431	Forestry	I	Change in land use, conversion of forest land to other land uses (deforestation rate)	Implemented	UNEP, 2001
432	Forestry	R	Contribution of forest sector to gross domestic product	Implemented	UNEP, 2001
433	Forestry	S	Extent of area by forest type and by age class or successional stage	Implemented	UNEP, 2001
434	Forestry	S	Extent of area by forest type in protected area categories as defined by IUCN or other classification systems	Implemented	UNEP, 2001
435	Forestry	S	Extent of area by forest type relative to total forest area	Implemented	UNEP, 2001
436	Forestry	S	Extent of mixed stands	Implemented	UNEP, 2001
437	Forestry	I	Forest area change by forest type (primary, secondary or plantation)	Implemented	UNEP, 2001
438	Forestry	R	Forest area with revitalisation or ecological sites	Implemented	UNEP, 2001
439	Forestry	D	Forest conversion affecting rare ecosystems by area	Implemented	UNEP, 2001
440	Forestry	R	Forest protection rate	Implemented	UNEP, 2001
441	Forestry	I	Fragmentation of forest types	Impleme	UNEP, 2001

				nted	
442	Forestry	R	Managed forest ratio	Implemented	UNEP, 2001
443	Forestry	D	Per capita wood consumption	Implemented	UNEP, 2001
444	Forestry	R	Percentage of protected productive forest area of total productive area	Implemented	UNEP, 2001
445	Forestry	R	Percentage of forest land managed for recreation and tourism to total forest area	Implemented	UNEP, 2001
446	Forestry	D	Percentage of forest managed for wood production	Implemented	UNEP, 2001
447	Forestry	S	Percentage of forest protected areas by forest type by age, class, and successional stage)	Implemented	UNEP, 2001
448	Forestry	D	Percentage of forest used by people for subsistence	Implemented	UNEP, 2001
449	Forestry	R	Percentage of protected area of total forest area	Implemented	UNEP, 2001
450	Forestry	S	Relationship between forest cover and frequency of flooding	Implemented	UNEP, 2001
451	Forestry	P	Seedlings planted annually, exotic vs. indigenous	Implemented	UNEP, 2001
452	Forestry	P	Wood harvesting intensity	Implemented	UNEP, 2001
453	Forestry	S	Changes in the area of natural and ancient semi-natural forest types	Proposed	MCPFE, 2001a
454	Forestry	R	Changes in the area of strictly protected forest reserves	Proposed	MCPFE, 2001a
455	Forestry	R	Changes in the area of forests protected by special management regime	Proposed	MCPFE, 2001a
456	Forestry	S	Changes in the number and percentage of threatened species in relation to the total number of forest species	Proposed	MCPFE, 2001a
457	Forestry	S	Total area and changes in the area of forests and OWL which is undisturbed by man, natural or ancient semi-natural manged forest and OWL	Proposed	MCPFE, 2001b
458	Forestry	R	Total number, proportion and changes of forest-related species for selected species of which number of species whose status is 'indeterminate', 'rare', vulnerable', 'endangered', extinct/endangered' or 'extinct'	Proposed	MCPFE, 2001b
459	Forestry	R	Total area and changes in area of tree stands managed for the conservation and utilisation of tree/forest genetic resources (*in situ* and *ex situ* gene conservation)	Proposed	MCPFE, 2001b

460	Forestry	S	Total area and changes in area of forest and OWL classified by number of main tree species occurring in stands and by main forest types	Proposed	MCPFE, 2001b
461	Forestry	S	Total area of forest and OWL and changes in area classified by indigenous and introduced tree species	Proposed	MCPFE, 2001b
462	Forestry	S	Total volume and changes in volume of deadwood by forest type and decomposition stage	Proposed	MCPFE, 2001b
463	Forestry	S	Total area and changes in area of regeneration, by regeneration type	Proposed	MCPFE, 2001b
464	Forestry	S	Total area and changes in area of forest and other wooded land by various layers by forest type	Proposed	MCPFE, 2001b
465	Energy	P	Oil spills	Implemented	EEA website, 2002
466	Recreation	P	Household expenditure for tourism and recreation	Implemented	EEA website, 2002
467	Recreation	R	Tourism eco-labelling	Implemented	EEA website, 2002
468	Recreation	P	Tourism intensity	Implemented	EEA website, 2002
469	Recreation	P	Tourism travel by transport mode	Implemented	EEA website, 2002
470	Climate Change	I	Dates of insect appearance and activity	Implemented	Cannell *et al.*, 1999; ETC/ACC, 2001
471	Climate Change	S	Insect abundance	Implemented	Cannell *et al.*, 1999; ETC/ACC, 2001
472	Climate Change	I	Arrival date of the swallow	Implemented	Cannell *et al.*, 1999
473	Climate Change	I	Egg-laying dates of birds	Implemented	Cannell *et al.*, 1999; ETC/ACC, 2001
474	Climate Change	I	Small bird population changes	Implemented	Cannell *et al.*, 1999
475	Climate Change	P	Climatic change	Proposed	UNEP, 1999
476	Climate Change	I	Droughts: change in annual rainfall compared to the long-term average rainfall	Implemented	UNEP, 2001
477	Climate Change	S	Phenology/changes in the growing season	Proposed	ETC/ACC, 2001
478	Climate Change	S	Arrival date of birds	Proposed	ETC/ACC, 2001
479	Climate Change	S	Mountains and sub-arctic environments	Proposed	ETC/ACC, 2001
480	Climate Change	I	Changes in the composition of ecosystems	Proposed	ETC/ACC, 2001

481	Climate Change	S	Extreme events (fires, storms, etc.)	Proposed	ETC/ACC, 2001
482	Urban Development	P	Rate of housing development	Proposed	UNEP, 1999
483	Urban Development	P	Dams	Proposed	UNEP, 1999
484	Urban Development	P	Population density in/adjacent to key habitats	Proposed	UNEP, 1999
485	Urban Development	P	Population density in/adjacent to protected areas	Proposed	UNEP, 1999
486	Water	P	Annual groundwater withdrawals as percentage of annual recharge	In use	UNDP *et al.*, 2000
487	Water	P	Degree of river fragmentation	In use	UNDP *et al.*, 2000
488	Water	S	Percentage of watershed that is cropland	In use	UNDP *et al.*, 2000
489	Water	S	Percentage of watershed that is forest	In use	UNDP *et al.*, 2000
490	Water	S	Percentage of watershed that is grassland	In use	UNDP *et al.*, 2000
491	Water	P	Percentage of watershed that is built-up area	In use	UNDP *et al.*, 2000
492	Water	P	Percentage of watershed that is irrigated area	In use	UNDP *et al.*, 2000
493	Water	S	Percentage of watershed that is arid area	In use	UNDP *et al.*, 2000
494	Water	S	Percentage of watershed that is wetland	In use	UNDP *et al.*, 2000
495	Water	R	Number of Ramsar sites	In use	UNDP *et al.*, 2000
496	Water	P	Percentage channelled watercourses of total length	Proposed/implemented	Bosch & Söderbäck, 1997
497	Water	P	Water quality	Proposed	UNEP, 1999
498	Water	I	Extent and degree of water pollution	Testing	Prescott-Allen *et al.*, 2000
499	Water	I	Rate of water extraction	Testing	Prescott-Allen *et al.*, 2000
500	Water	I	Transitional and coastal waters: proportion of different types of transitional waters and coastal waters below good ecological status	Available	EEA, 2001a
501	Water	P	Biochemical oxygen demand (BOD) of water bodies (eutrophication)	Implemented	UNEP, 2001
502	Water	S	Fish family diversity	Implemented	UNEP, 2001
503	Water	S	Benthic macro-invertebrates (communities)	Implemented	UNEP, 2001
504	Water	P	Change in proportion of fish catches by species per specific season	Implemented	UNEP, 2001

505	Water	S	Threatened fish species as a percentage of total fish species known	Implemented	UNEP, 2001
506	Water	S	Shoreline position	Implemented	UNEP, 2001
507	Water	I	Escherichia coli counts and nutrient levels as a percentage of baseline levels	Implemented	UNEP, 2001
508	Water	D	Coastal population without purification treatment of sewage	Implemented	UNEP, 2001
509	Water	D/P	Coastline land cover	Implemented	UNEP, 2001
510	Water	S	Denatured coast	Implemented	UNEP, 2001
511	Water	S	Depletion of water points	Implemented	UNEP, 2001
512	Water	P	Dumping of pollutants to the ocean water basins	Implemented	UNEP, 2001
513	Water	S	Ground water quality: nitrates, salinity, toxicants	Implemented	UNEP, 2001
514	Water	S	Groundwater level (water table level)	Implemented	UNEP, 2001
515	Water	S	Lake levels and salinity	Implemented	UNEP, 2001
516	Water	S/I	Organic contamination	Implemented	UNEP, 2001
517	Water	R	Other alternatives of water production: drinkable water through techniques of desalination and water collected from rain	Implemented	UNEP, 2001
518	Water	D/P	Percentage of coastal zone with populations exceeding 100 inhabitants/km2	Implemented	UNEP, 2001
519	Water	S	Quality of water in the ocean	Implemented	UNEP, 2001
520	Water	S	Rivers with good quality according to biotic indexes	Implemented	UNEP, 2001
521	Water	I	Salinisation of aquifers (coastal and inland) of human origin	Implemented	UNEP, 2001
522	Water	S	Stream flow	Implemented	UNEP, 2001
523	Water	S/I	Stream sediment storage and load	Implemented	UNEP, 2001
524	Water	S	Surface water quality: nitrogen, dissolved oxygen, pH, pesticides, heavy metals, temperature	Implemented	UNEP, 2001
525	Water	S	System aqua index	Proposed/implemented	Bosch & Söderbäck, 1997
526	Water	P	Total boats, canoes operated on island or per village	Implemented	UNEP, 2001

527	Water	P	Water consumption index by the sectors (agricultural, energy, industry, tourism and services), the index being the quotient between the consumptive demand (detraction — return) and the potential resource	Impleme nted	UNEP, 2001
528	Water	S	Index of biotic integrity (IBI)	Impleme nted	Karr, 1987
529	Infrastructure	P	Road density	Impleme nted	BEF, 2000
530	Infrastructure	P	Traffic intensity on the roads of European importance	Impleme nted	BEF, 2000
531	Infrastructure	P	Total length of the roads, railroads and powerlines per area	Proposed /implem ented	Bosch & Söderbäck, 1997
532	Infrastructure	P	Density of infrastructure network	Proposed /implem ented	Bosch & Söderbäck, 1997
533	Infrastructure	P	Areas more than 5 km from the nearest road, railway or powerline	Proposed /implem ented	Bosch & Söderbäck, 1997
534	Infrastructure	I	Fragmentation of forests and landscapes by roads/intersections	Develop ment	Eurostat, 2001
535	Infrastructure	P	Road and transportation networks	Proposed	UNEP, 1999
536	Infrastructure	P	Density of road network	Impleme nted	UNEP, 2001
537	Infrastructure	P	Proximity of transport infrastructure to designated nature areas	Impleme nted	EEA, 2000
538	Infrastructure	P	Land take by transport infrastructure	Impleme nted	EEA, 2000
539	Infrastructure	S	Fragmentation of ecosystems and habitats	Impleme nted	EEA website, 2002
540	Trade	P	Tropical wood imports	Impleme nted	OECD, 1999
541	Trade	P	Net imports of specimens of wildlife species listed in annexes of CITES	Impleme nted	Traffic, 1999
542	Fisheries	P	Marine fish catch metric tons 1995-97	Impleme nted	UNDP *et al.*, 2000
543	Fisheries	P	Marine fish catch percentage change since 1985-87	Impleme nted	UNDP *et al.*, 2000
544	Fisheries	P	Freshwater fish catch metric tons 1995-97	Impleme nted	UNDP *et al.*, 2000
545	Fisheries	P	Freshwater fish catch percentage change since 1985-87	Impleme nted	UNDP *et al.*, 2000
546	Fisheries	P	Mollusc and crustacean catch metric tons 1995-97	Impleme nted	UNDP *et al.*, 2000
547	Fisheries	P	Mollusc and crustacean catch percentage change since 1985-87	Impleme nted	UNDP *et al.*, 2000
548	Fisheries	P	Pressure on fisheries	Testing	Prescott-Allen *et al.*, 2000
549	Fisheries	P	Fishing mortality	Proposed	Zenetos, 2001

550	Fisheries	P	Percentage of stocks outside safe biological limits	Proposed	Zenetos, 2001
551	Fisheries	S	Biomass of commercial fish species	Proposed	Zenetos, 2001
552	Fisheries	P	Catch per unit effort	Proposed	Zenetos, 2001
553	Fisheries	I	Relative abundance of juveniles versus adults	Proposed	Zenetos, 2001
554	Fisheries	I	Physical damage to habitats and species	Proposed	Zenetos, 2001
555	Fisheries	I	Discards	Proposed	Zenetos, 2001
556	Fisheries	I	Bird population changes	Proposed	Zenetos, 2001
557	Fisheries	P	By-catch (unwanted) of mammals	Proposed	Zenetos, 2001
558	Fisheries	P	By-catches in fisheries	Impleme nted	UNEP, 2001
559	Fisheries	P	Changes in fish catches by species	Impleme nted	UNEP, 2001
560	Fisheries	P	national fishing grounds	Impleme nted	UNEP, 2001
561	Fisheries	D	Number of boats and capacity of the national fishing fleet in the countries	Impleme nted	UNEP, 2001
562	Fisheries	S	Number of commercial fish populations inside/outside safe size	Impleme nted	UNEP, 2001
563	Fisheries	D	Number of large scale bottom trawling vessels per 1 000 km of coastal area	Impleme nted	UNEP, 2001
564	Agriculture	S	Total number of crop varieties/livestock breeds that have been registered and certified for marketing	Impleme nted	OECD, 2001
565	Agriculture	S	Share of key crop varieties in total marketed production for individual crops	Impleme nted	OECD, 2001
566	Agriculture	S	Share of key livestock breeds in respective categories of livestock numbers	Impleme nted	OECD, 2001
567	Agriculture	S	Number of national crop varieties/livestock breeds that are endangered	Impleme nted	OECD, 2001
568	Agriculture	S	Trends in population distributions and numbers of wild species related to agriculture	Impleme nted	OECD, 2001
569	Agriculture	S	Share of each crop in the total agricultural area	Impleme nted	OECD, 2001
570	Agriculture	I	Share of organic agriculture in the total agricultural area	Impleme nted	OECD, 2001
571	Agriculture	S	Share of agricultural area covered by semi-natural agricultural habitats	Impleme nted	OECD, 2001
572	Agriculture	I	Net area of aquatic ecosystems converted to agricultural use	Impleme nted	OECD, 2001
573	Agriculture	I	Area of ‘natural’ forest converted to agricultural use	Impleme nted	OECD, 2001

574	Agriculture	I	Share of habitat use units for which habitat area increased, decreased or remained constant	Impleme nted	OECD, 2001
575	Agriculture	S	Boundaries between patches	Proposed /testing	Wascher, 2000
576	Agriculture	S	Number of boundary types	Proposed /testing	Wascher, 2000
577	Agriculture	S	Landscape heterogeneity	Proposed /testing	Wascher, 2000
578	Agriculture	S	Proportion of cropped to uncropped land	Proposed /testing	Wascher, 2000
579	Agriculture	S	Length of linear landscape features in the habitat	Proposed /testing	Wascher, 2000
580	Agriculture	S	Extent of habitats associated with agricultural land management	Proposed /testing	Wascher, 2000
581	Agriculture	S	Extent of natural habitats as part of agricultural land	Proposed /testing	Wascher, 2000
582	Agriculture	S	Linkages between valuable natural/semi-natural habitat types	Proposed /testing	Wascher, 2000
583	Agriculture	S	Habitat diversity	Proposed /testing	Wascher, 2000
584	Agriculture	S	Proportion of declining to stable and increasing species	Proposed /testing	Wascher, 2000
585	Agriculture	S	Species richness/average species richness per taxon group	Proposed /testing	Wascher, 2000
586	Agriculture	S	Presence of particular indicator species or groups	Proposed /testing	Wascher, 2000
587	Agriculture	S	Ratio of specialist to wide-spread species	Proposed /testing	Wascher, 2000
588	Agriculture	S	Percentage of extinct vertebrate species	Proposed /testing	Wascher, 2000
589	Agriculture	S	Percentage of threatened vertebrate species	Proposed /testing	Wascher, 2000
590	Agriculture	S	Proportion of red data species/species with an unfavourable conservation status	Proposed /testing	Wascher, 2000
591	Agriculture	S	Proportion of species listed as key species in biodiversity action plans	Proposed /testing	Wascher, 2000
592	Agriculture	S	Gene pool diversity within populations of farm-related plant and animal species in semi-natural agricultural land	Proposed /testing	Wascher, 2000
593	Agriculture	S	Hedgerow length in farms < 2ha /tot. UAA	Proposed /testing	Wascher, 2000
594	Agriculture	S	Hedgerow length in farms > 50 ha/tot. UAA	Proposed /testing	Wascher, 2000
595	Agriculture	S	Ratio of number of field-grown varieties over No of land races in gene banks	Proposed /testing	Wascher, 2000

596	Agriculture	S	UAA to crop varieties with genetic resistance to pathogen and pest species	Proposed /testing	Wascher, 2000
597	Agriculture	S	Number of field-grown varieties	Proposed /testing	Wascher, 2000
598	Agriculture	S	Number of crop varieties with genetic resistance to pathogens and pests	Proposed /testing	Wascher, 2000
599	Agriculture	S	Change of the sum of all recognised varieties of domesticated livestock and plants over time	Proposed /testing	Wascher, 2000
600	Agriculture	S	UAA with higher genetic diversity/tot. UAA	Proposed /testing	Wascher, 2000
601	Agriculture	S	UAA with lower genetic diversity/tot. UAA	Proposed /testing	Wascher, 2000
602	Agriculture	R	Number of crop varieties under regulation for plant genetic resources conservation	Proposed /testing	Wascher, 2000
603	Agriculture	R	Commercials that encourage traditional products	Proposed /testing	Wascher, 2000
604	Agriculture	R	Proportion of biodiversity action plan targets met	Proposed /testing	Wascher, 2000
605	Agriculture	P	Landcover destruction	Develop ment	European Commission, 2000b
606	Agriculture	P	Increase in agricultural genetic diversity	Develop ment	European Commission, 2000b
607	Agriculture	P	Preservation of semi-natural habitats	Develop ment	European Commission, 2000b
608	Agriculture	S	Preservation of high nature and culture value landscapes	Develop ment	European Commission, 2000b
609	Agriculture	S	Species richness (bird species)	Develop ment	European Commission, 2000b
610	Agriculture	S	Bird species on agricultural land	Develop ment	European Commission, 2000b
611	Agriculture	P	Average annual fertiliser use	Impleme nted	UNDP *et al.*, 2000
612	Agriculture	P	Pesticide use	Impleme nted	UNDP *et al.*, 2000
613	Agriculture	P	Sown area	Impleme nted	BEF, 2000
614	Agriculture	I	Fragmentation of arable land	Proposed /implem ented	Bosch & Söderbäck, 1997
615	Agriculture	S	Total length of hedgerows and walls	Proposed /implem ented	Bosch & Söderbäck, 1997

616	Agriculture	P	Percentage environmentally managed land of total agricultural land	Proposed /implemented	Bosch & Söderbäck, 1997
617	Agriculture	P	Percentage area with intensive cropping of total agricultural land	Proposed /implemented	Bosch & Söderbäck, 1997
618	Agriculture	S	Changes in area of heathland, fallowland and hedgerows	Proposed /implemented	Bosch & Söderbäck, 1997
619	Agriculture	P	Agriculture intensity: area used for intensive arable agriculture	Development	Eurostat, 2001
620	Agriculture	P	Harvest production totals	Proposed	UNEP, 1999
621	Agriculture	P	Harvest export totals	Proposed	UNEP, 1999
622	Agriculture	P	Harvest import totals	Proposed	UNEP, 1999
623	Agriculture	P	Harvest local processing capacity	Proposed	UNEP, 1999
624	Agriculture	P	Harvest catch/effort	Proposed	UNEP, 1999
625	Agriculture	I	Extent and degree of soil degradation	Testing	Prescott-Allen *et al.*, 2000
626	Agriculture	R	Area under agri-environmental management contracts	Implemented	EEA, 2001b
627	Agriculture	R	Area under organic farming	Implemented	EEA, 2001b
628	Agriculture	P	Use of agricultural pesticides	Implemented	UNEP, 2001
629	Agriculture	S	Agricultural area by crops (cereals, oil crops, forage, woodlands)	Implemented	UNEP, 2001
630	Agriculture	P	Change in area of agricultural land area (conversion to or from agriculture)	Implemented	UNEP, 2001
631	Agriculture	S	Agricultural area (intensively farmed, semi-intensively farmed and uncultivated)	Implemented	UNEP, 2001
632	Agriculture	P	Intensification and extensification of agricultural land use	Implemented	UNEP, 2001
633	Agriculture	S	Species diversity used for food	Implemented	UNEP, 2001
634	Agriculture	P/S	Arable land per capita	Implemented	UNEP, 2001
635	Agriculture	P/S	Number of species of crops and trees used by local residents	Implemented	UNEP, 2001
636	Agriculture	S	Number of species threatened by agriculture by group (e.g., birds, mammals, vascular plants, vertebrates, invertebrates)	Implemented	UNEP, 2001
637	Agriculture	P	Percentage of agricultural land under exploitation	Implemented	UNEP, 2001
638	Agriculture	P	Use of fertilisers	Implemented	UNEP, 2001
639	Agriculture	R	Organic farming	Implemented	EEA website, 2002
640	Agriculture	D	Agricultural intensity	Implemented	EEA website, 2002

641	Agriculture	R	Agri-environmental management contracts	Impleme nted	EEA website, 2002
642	Agriculture	S	Availability of wildlife habitat on farmland	Impleme nted	Neave *et al.*, 2000
643	Agriculture	R	Area of farmland covered by the agri-environmental programmes under Regulation 1257/99 classified by type of activity	Proposed	European Commission, 2001e
644	Agriculture	R	Area and percentage of farmland subject to restrictions (due to Natura 2000 or by voluntary agreements), classified by type of farmland	Proposed	European Commission, 2001e
645	Agriculture	R	Area under organic farming	Proposed	European Commission, 2001e
646	Agriculture	P	Trends: intensification/extensification, specialisation	Proposed	European Commission, 2001e
647	Agriculture	P	Trends: marginalisation	Proposed	European Commission, 2001e
648	Agriculture	P/I	Matrix of changes in land cover classified by type and size	Proposed	European Commission, 2001e
649	Agriculture	S	Total number and shares in production of main crop varieties/livestock breeds	Proposed	European Commission, 2001e
650	Agriculture	I	Number of national crop varieties/livestock breeds that are endangered	Proposed	European Commission, 2001e
651	Agriculture	S	Area of high nature value	Proposed	European Commission, 2001e
652	Agriculture	S	Species richness	Proposed	European Commission, 2001e
653	Agriculture	S	Density of linear elements and diversity of land cover at the level of the holding	Proposed	European Commission, 2001e
654	Agriculture	S/I	Indices of overall and of agricultural diversity and of their evolution through time	Proposed	European Commission, 2001e

Annex 3: The Streamlining European Biodiversity Indicators 2010 with focal areas of the Convention on Biological Diversity plus an assignment of the position in the DPSIR cycle

CBD focal area	Headline indicator	SEBI 2010 specific indicator	DPSIR
Status and trends of the components of biological diversity	Trends in the abundance and distribution of selected species	1. Abundance and distribution of selected species a. birds b. butterflies	S
	Change in status of threatened and/or protected species	2. Red List Index for European species	S
		3. Species of European interest	S
	Trends in extent of selected biomes, ecosystems and habitats	4. Ecosystem coverage	S
		5. Habitats of European interest	S
	Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socioeconomic importance	6. Livestock genetic diversity	S
	Coverage of protected areas	7. Nationally designated protected areas	R
		8. Sites designated under the EU Habitats and Birds Directives	R
Threats to biodiversity	Nitrogen deposition	9. Critical load exceedance for nitrogen	I
	Trends in invasive alien species (numbers and costs of invasive alien species)	10. Invasive alien species in Europe	P
	Impact of climate change on biodiversity	11. Impact of climatic change on bird populations	I
Ecosystem integrity and ecosystem goods and services	Marine Trophic Index	12. Marine Trophic Index of European seas	S/I
	Connectivity/fragmentation of ecosystems	13. Fragmentation of natural and semi-natural areas	I
		14. Fragmentation of river systems	I
	Water quality in aquatic ecosystems	15. Nutrients in transitional, coastal and marine waters	S/I
		16. Freshwater quality	S/I

Sustainable use	Area of forest, agricultural, fishery and aquaculture ecosystems under sustainable management	17. Forest: growing stock, increment and fellings	S
		18. Forest: deadwood	S
		19. Agriculture: nitrogen balance	D
		20. Agriculture: area under management practices potentially supporting biodiversity	R
		21. Fisheries: European commercial fish stocks	P
		22. Aquaculture: effluent water quality from finfish farms	P
	Ecological Footprint of European countries	23. Ecological Footprint of European countries	D
Status of access and benefits sharing	Percentage of European patent applications for inventions based on genetic resources	24. Patent applications based on genetic resources	D
Status of resource transfers	Funding to biodiversity	25. Financing biodiversity management	D
Public opinion (additional EU focal area)	Public awareness and participation	26. Public awareness	D

Annex 4: Marine Strategy Framework Directive indicators (S=state, I=impact, P=pressure) (EC, 2011b)

Descriptor	Criterion	Indicator	Type of indicator
D1 Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions.	1.1 Species distribution	1.1.1 Distributional range	S
		1.1.2 Distributional pattern within the latter, where appropriate	S
		1.1.3 Area covered by the species (for sessile/benthic species)	S
	1.2 Population size	1.2.1 Population abundance and/or biomass, as appropriate	S
	1.3 Population condition	1.3.1 Population demographic characteristics (e.g., body size or age class structure, sex ratio, fecundity rates, survival/mortality rates)	S
		1.3.2 Population genetic structure, where appropriate	S
	1.4 Habitat distribution	1.4.1 Habitat distributional range	S
		1.4.2 Habitat distributional pattern	S
	1.5 Habitat extent	1.5.1 Habitat area	S
		1.5.2 Habitat volume, where relevant	S
	1.6 Habitat condition	1.6.1 Condition of the typical species and communities	S
		1.6.2 Relative abundance and/or biomass, as appropriate	S
		1.6.3 Physical, hydrological and chemical conditions	S
	1.7 Ecosystem structure	1.7.1 Composition and relative proportions of ecosystem components (habitats and species)	S
D2 Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems.	2.1 Abundance and state characterisation of non-indigenous species, in particular invasive species	2.1.1 Trends in abundance, temporal occurrence and spatial distribution in the wild of non-indigenous species, particularly invasive non-indigenous species, notably in risk areas, in relation to the main vectors and pathways of spreading of such species	P
	2.2 Environmental impact of invasive non-indigenous species	2.2.1 Ratio between invasive non-indigenous species and native species in some well studied taxonomic groups (e.g., fish, macroalgae, molluscs) that may provide a measure of change in species composition (e.g., further to the displacement of native species)	I
		2.2.2 Impacts of non-indigenous invasive species at the level of species, habitats and ecosystems, where feasible	I
D3 Populations of all commercially exploited fish and shellfish are	3.1 Level of pressure of the fishing activity	3.1.1 Fishing mortality (F)	P
		3.1.2 Ratio between catch and biomass index ('catch/biomass ratio')	P

within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock.	3.2 Reproductive capacity of the stock	3.2.1 Spawning Stock Biomass (SSB)	S/I
		3.2.2 Biomass indices	S/I
	3.3 Population age and size distribution	3.3.1 Proportion of fish larger than the mean size of first sexual maturation	S/I
		3.3.2 Mean maximum length across all species found in research vessel surveys	S/I
		3.3.3 95% percentile of the fish length distribution observed in research vessel surveys	S/I
		3.3.4 Size at first sexual maturation, which may reflect the extent of undesirable genetic effects of exploitation	S/I
D4 All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity.	4.1 Productivity (production per unit biomass) of key species or trophic groups	4.1.1 Performance of key predator species using their production per unit biomass (productivity)	S
	4.2 Proportion of selected species at the top of food webs	4.2.1 Large fish (by weight)	S
	4.3 Abundance/distribution of key trophic groups/species	4.3.1 Abundance trends of functionally important selected groups/species	S
D5 Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters.	5.1 Nutrients level	5.1.1 Nutrients concentration in the water column	P
		5.1.2 Nutrient ratios (silica, nitrogen and phosphorus), where appropriate	P
	5.2 Direct effects of nutrient enrichment	5.2.1 Chlorophyll concentration in the water column	I
		5.2.2 Water transparency related to increase in suspended algae, where relevant	I
		5.2.3 Abundance of opportunistic macroalgae	I
		5.2.4 Species shift in floristic composition such as diatom to flagellate ratio, benthic to pelagic shifts, as well as bloom events of nuisance/toxic algal blooms (e.g., cyanobacteria) caused by human activities	I
	5.3 Indirect effects of nutrient enrichment	5.3.1 Abundance of perennial seaweeds and seagrasses (e.g., fucoids, eelgrass and Neptune grass) adversely impacted by decrease in water transparency	I
		5.3.2 Dissolved oxygen, i.e. changes due to increased organic matter decomposition and size of the area concerned	I
D6 Sea-floor integrity is at a level that ensures that the structure and	6.1 Physical damage, having regard to substrate characteristics	6.1.1 Type, abundance, biomass and areal extent of relevant biogenic substrate	S/I

functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected.		6.1.2 Extent of the seabed significantly affected by human activities for the different substrate types	I
	6.2 Condition of benthic community	6.2.1 Presence of particularly sensitive and/or tolerant species	S/I
		6.2.2 Multi-metric indexes assessing benthic community condition and functionality, such as species diversity and richness, proportion of opportunistic to sensitive species	S/I
		6.2.3 Proportion of biomass or numbers of individuals in the macrobenthos above some specified length/size	S/I
		6.2.4 Parameters describing the characteristics (shape, slope and intercept) of the size spectrum of the benthic community	S/I
D7 Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems.	7.1 Spatial characterisation of permanent alterations	7.1.1 Extent of area affected by permanent alterations	P
	7.2 Impact of permanent hydrographical changes	7.2.1 Spatial extent of habitats affected by the permanent alteration	I
		7.2.2 Change in habitats, in particular the functions provided (e.g., spawning, breeding and feeding areas and migration routes of fish, birds and mammals), due to altered hydrographical conditions	I
D8 Concentrations of contaminants are at levels not giving rise to pollution effects.	8.1 Concentration of contaminants	8.1.1 Concentration of the contaminants mentioned above, measured in the relevant matrix (such as biota, sediment and water) in a way that ensures comparability with assessments under Directive 2000/60/EC	P
	8.2 Effects of contaminants	8.2.1 Levels of pollution effects on the ecosystem components concerned, having regard to the selected biological processes and taxonomic groups where a cause/effect relationship has been established and needs to be monitored	I
		8.2.2 Occurrence, origin (where possible), extent of significant acute pollution events (e.g., slicks from oil and oil products) and their impact on biota physically affected by this pollution	P/I
D9 Contaminants in fish and other seafood for human consumption do not exceed levels established by EU legislation or other relevant standards.	9.1 Levels, number and frequency of contaminants	9.1.1 Actual levels of contaminants that have been detected and number of contaminants which have exceeded maximum regulatory levels	P/I
		9.1.2 Frequency of regulatory levels being exceeded	P/I

D10 Properties and quantities of marine litter do not cause harm to the coastal and marine environment.	10.1 Characteristics of litter in the marine and coastal environment	10.1.1 Trends in the amount of litter washed ashore and/or deposited on coastlines, including analysis of its composition, spatial distribution and, where possible, source	P
		10.1.2 Trends in the amount of litter in the water column (including floating at the surface) and deposited on the sea-floor, including analysis of its composition, spatial distribution and, where possible, source	P
		10.1.3 Trends in the amount, distribution and, where possible, composition of micro-particles (in particular micro-plastics)	P
	10.2 Impacts of marine litter on marine life	10.2.1 Trends in the amount and composition of litter ingested by marine animals (e.g., stomach analysis)	I
D11 Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.	11.1 Distribution in time and place of loud, low and mid frequency impulsive sounds	11.1.1 Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1µPa^2.s) or as peak sound pressure level (in dB re 1µPa$_{peak}$) at one metre, measured over the frequency band 10 Hz to 10 kHz	P
	11.2 Continuous low frequency sound	11.2.1 Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS: average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate	P

Annex 5 Integration table, linking state characteristics to pressures through impacts (EC, 2011b)

Annex III Table 1			COM Decision	Annex III Table 2	Biological disturbance			Physical loss	Physical damage	Interference with hydrological processes	Other physical disturbance	Other physical disturbance	Contamination by hazardous substances	Systematic and/or intentional release of substances	Nutrient and organic matter enrichment
				Pressure	- Extraction of species, including non-target catches	- Non-indigenous species and translocations	- Microbial pathogens	- Smothering - Sealing	- Siltation - Abrasion - Extraction	- Thermal regime - Salinity regime	- Underwater noise	- Marine litter	- Synthetic compounds - Non-synthetic substances - Radio-nuclides	e.g. produced water, carbon storage	- Fertilisers & other nitrogen- & phosphorus-rich substances - Organic matter
Characteristic		Component	State criteria & indicators	Pressure criteria & indicators	3.1 Level of pressure of the fishing activity 3.1.1; 3.1.2	2.1 Abundance & state characterisation of non-indigenous species, in particular invasive species: 2.1.1		6.1 Physical damage, having regard to substrate characteristics	6.1 Physical damage, having regard to substrate characteristics	7.1 Spatial characterisation of permanent alterations: 7.1.1	11.1 Distribution in time & place of loud, low & mid frequency impulsive sounds: 11.1.1 11.2 Continuous low frequency sound: 11.2.1	10.1 Characteristics of litter in the marine & coastal environment: 10.1.1; 10.1.2; 10.1.3	8.1 Concentration of contaminants: 8.1.1 8.2.2: Acute pollution events 9.1 Levels, number & frequency of contaminants: 9.1.1; 9.1.2	8.1 Concentration of contaminants: 8.1.1	5.1 Nutrients level: 5.1.1; 5.1.2
Physical and chemical features	Physical	- Topography and bathymetry						6.1.1 Type, abundance, biomass & areal extent 6.1.2 Extent of seabed significantly affected	6.1.1 Type, abundance, biomass & areal extent 6.1.2 Extent of seabed significantly affected						
		- Temperature regime, ice cover, current velocity, upwelling, wave exposure, mixing characteristics, turbidity, residence time								7.2 Impact of permanent hydrographical changes: 7.2.2					5.2 Direct effects of nutrient enrichment: 5.2.2
	Chemical	- Salinity													
		- Nutrients (DIN, TN, DIP, TP, TOC) and oxygen	See pressure criterion 5.1	See 5.1.1, 5.1.2											5.3 Indirect effects of nutrient enrichment: 5.3.2
		- pH, pCO₂ profiles or equivalent													
Biological features (other than habitat types and ecosystems)	At level of individual species	- Fish - Mammals - Reptiles - Seabirds - Other species of Community legislation & international agreements - Genetically distinct forms of native spp.	1.1 Species distribution	1.1.1; 1.1.2; 1.1.3		2.2 Environmental impact of invasive non-indigenous species: 2.2.1; 2.2.2				7.2 Impact of permanent hydrographical changes: 7.2.2		10.2 Impacts of litter on marine life: 10.2.1	8.2 Effects of contaminants: 8.2.1; 8.2.2 (impact on biota)		
			1.2 Population size	1.2.1											
			1.3 Population condition	1.3.1; 1.3.2											
		- Fish & shellfish (commercially exploited) - additional criteria/indicators	3.2 Reproductive capacity of the stock	3.2.1; 3.2.2	3.2 Reproductive capacity of the stock: 3.2.1, 3.2.2 3.3 Population age & size distribution: 3.3.1, 3.3.2, 3.3.3, 3.3.4								8.2 Effects of contaminants: 8.2.1; 8.2.2 (impact on biota) 9.1 Levels, number & frequency of contaminants: 9.1.1; 9.1.2		
			3.3 Population age and size distribution	3.3.1; 3.3.2; 3.3.3; 3.3.4											
		- Non-indigenous species	See pressure criterion 2.1												
	At level of functional groups	- Fish - Mammals - Reptiles - Seabirds	1.6 Habitat condition	1.6.1; 1.6.2; 1.6.3		2.2 Environmental impact of invasive non-indigenous species: 2.2.1; 2.2.2							8.2 Effects of contaminants: 8.2.1; 8.2.2 (impact on biota)		
Habitat types	At level of habitats	- Predominant seabed & water column habitat types, including their biological communities (phytoplankton, zooplankton, angiosperms, macro-algae, bottom fauna)	1.4 Habitat distribution	1.4.1; 1.4.2	6.2 Condition of benthic community 6.2.1, 6.2.2, 6.2.3, 6.2.4	2.2 Environmental impact of invasive non-indigenous species: 2.2.1; 2.2.2		6.1.1 Type, abundance, biomass and areal extent of biogenic substrata 6.1.2 Extent of seabed significantly affected	6.1.1 Type, abundance, biomass & areal extent of biogenic substrata 6.1.2 Extent of seabed significantly affected 6.2 Condition of benthic community 6.2.1, 6.2.2, 6.2.3, 6.2.4	7.2 Impact of permanent hydrographical changes: 7.2.1; 7.2.2		10.2 Impacts of litter on marine life	8.2 Effects of contaminants: 8.2.1; 8.2.2 (impact on biota)		5.2 Direct effects of nutrient enrichment: 5.2.1; 5.2.3; 5.2.4 5.3 Indirect effects of nutrient enrichment: 5.3.1
			1.5 Habitat extent	1.5.1; 1.5.2											
			1.6 Habitat condition	1.6.1; 1.6.2; 1.6.3											
		- Special habitat types, especially those under Community legislation & international conventions	6.2 Condition of benthic community	6.1.1; 6.2.1; 6.2.2; 6.2.3; 6.2.4											
		- Habitats in particular areas (e.g. intense/ specific pressures, specific protection)													
Eco-systems	At level of ecosystems		1.7 Ecosystem structure	1.7.1		2.2 Environmental impact of invasive non-indigenous species: 2.2.2		6.1.2 Extent of seabed significantly affected	6.1.2 Extent of seabed significantly affected	7.2 Impact of permanent hydrographical changes: 7.2.1; 7.2.2			8.2 Effects of contaminants: 8.2.1; 8.2.2 (impact on biota)		5.3 Indirect effects of nutrient enrichment: 5.3.2
			4.1 Productivity of key species or trophic groups	4.1.1											
			4.2 Proportion of species at the top of food webs	4.2.1											
			4.3 Abundance/ distribution of key trophic groups/spp.	4.3.1											
Other features		- Chemicals giving rise to concern, sediment contamination, hotspots, health issues & contamination of biota (esp. for human consumption)	See pressure criterion 8.1										8.2 Effects of contaminants: 8.2.1; 8.2.2 (impact on biota) 9.1 Levels, number & frequency of contaminants: 9.1.1; 9.1.2		
		- Features or characteristics typical or specific to region or subregion													

KEY: Characteristics: Annex III table 1 | Pressures and impacts: Annex III table 2 | State criteria & indicators | Pressure criteria and indicators | Impact criteria and indicators

Annex 6: United Kingdom pressure benchmarks (from Tillin and Tyler-Walters, 2015)

Pressure theme	ICG-C Pressure	Benchmark
Hydrological changes (inshore/local)	Emergence regime changes - local, including tidal level change considerations	A change in the time covered or not covered by the sea for a period of ≥ 1 year. OR An increase in relative sea level or decrease in high water level for ≥ 1 year.
Hydrological changes (inshore/local)	Temperature changes -local	A 5°C change in temp for one month period, or 2°C for one year
Hydrological changes (inshore/local)	Water flow (tidal current) changes - local, including sediment transport considerations	A change in peak mean spring bed flow velocity of between 0.1m/s to 0.2m/s for more than 1 year
Hydrological changes (inshore/local)	Wave exposure changes - local	A change in near shore significant wave height >3% but <5% for more than 1 year
Physical damage (Reversible Change)	Changes in suspended solids (water clarity)	A change in one rank on the WFD (Water Framework Directive) scale e.g. from clear to intermediate for one year
Physical damage (Reversible Change)	Habitat structure changes - removal of substratum (extraction)	Extraction of substratum to 30 cm (where substratum includes sediments and soft rocks but excludes hard bedrock)
Physical damage (Reversible Change)	Abrasion/disturbance at the surface of the substratum	Damage to surface features (e.g., species and physical structures within the habitat)
Physical damage (Reversible Change)	Penetration and/or disturbance of the substratum below the surface, including abrasion	Damage to sub-surface features (e.g., species and physical structures within the habitat)
Physical damage (Reversible Change)	Smothering and siltation rate changes(depth of vertical sediment overburden)	Light' deposition of up to 5 cm of fine material added to the habitat in a single, discrete event 'Heavy' deposition of up to 30 cm of fine material added to the habitat in a single discrete event
Physical loss (Permanent Change)	Physical change (to another substratum type)	Change in sediment type by 1 Folk class (based on UK SeaMap simplified classification). Change from sedimentary or soft rock substrata to hard rock or artificial substrata or vice-versa.
Physical loss (Permanent Change)	Physical loss (to land or Freshwater habitat)	Permanent loss of existing saline habitat
Physical pressure (other)	Barrier to species movement	Permanent or temporary barrier to species movement ≥50% of water body width or a 10% change in tidal excursion
Physical pressure (other)	Electromagnetic changes	Local electric field of 1V m-1. Local magnetic field of 10µT
Physical pressure (other)	Death or injury by collision	0.1% of tidal volume on average tide, passing through artificial structure

Physical pressure (other)	Introduction of light	Change in incident light via anthropogenic means.
Physical pressure (other)	Litter	Introduction of manmade objects able to cause physical harm (surface, water column, sea floor and/or strandline)
Physical pressure (other)	Noise changes	Above water noise: None Underwater noise: MSFD indicator levels (SEL or peak SPL) exceeded for 20% of days in calendar year
Physical pressure (other)	Visual disturbance	Daily duration of transient visual cues exceeds 10% of the period of site occupancy by the feature
Pollution and other chemical changes	Organic enrichment	A deposit of 100gC/m2/yr
Pollution and other chemical changes	Deoxygenation	Exposure to dissolved oxygen concentration of less than or equal to 2mg/l for 1 week (a change from WFD poor status to bad status).
Pollution and other chemical changes	Introduction of other substances (solid, liquid or gas)	Compliance with all AA EQS, conformance with PELs, EACs/ER-Ls
Pollution and other chemical changes	Nutrient enrichment	Compliance with WFD criteria for good status
Pollution and other chemical changes	Hydrocarbon & PAH contamination. Includes those priority substances listed in Annex II of Directive 2008/105/EC	Compliance with all AA EQS, conformance with PELs, EACs/ER-Ls
Pollution and other chemical changes	Radionuclide contamination	An increase in 10µGy/h above background levels
Pollution and other chemical changes	Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals). Includes those priority substances listed in Annex II of Directive 2008/105/EC.	Compliance with all AA EQS, conformance with PELs, EACs/ER-Ls
Pollution and other chemical changes	Transition elements & organo-metal (e.g., TBT) contamination. Includes those priority substances listed in Annex II of Directive 2008/105/EC.	Compliance with all AA EQS, conformance with PELs, EACs/ER-Ls
Biological pressures	Genetic modification & translocation of indigenous species	Translocation of indigenous species and/or introduction of genetically modified or genetically different populations of indigenous species that may result in changes in genetic structure of local populations, hybridization, or change in community structure.

Biological pressures	Introduction of microbial pathogens	The introduction of relevant microbial pathogens or metazoan disease vectors to an area where they are currently not present (e.g., *Martelia refringens* and *Bonamia*, Avian influenza virus, viral Haemorrhagic Septicaemia virus).
Biological pressures	Introduction or spread of invasive nonindigenous species (INIS)	The introduction of one of more invasive nonindigenous species (IINIS)
Biological pressures	Removal of non-target species	Removal of features or incidental non-targeted catch (by-catch) through targeted fishery, shellfishery or harvesting at a commercial or recreational scale.
Biological pressures	Removal of target species	Benthic species and habitats: removal of species targeted by fishery, shellfishery or harvesting at a commercial or recreational scale

Annex 7: Common indicators of OSPAR

'OSPAR-wide' common indicators	
D1/6 BentHab2	Multimetric indices
D5 nutr conc	Winter nutrient concentratiions
D5 chlorophyll	Chlorophyll concentrations
D5 oxygen	Oxygen
D8 metals (biota)	Metal (Hg, Cd, Pb) concentrations in biota
D8 metals (sedim)	Metal (Hg, Cd, Pb) concentrations in sediment
D8 PCBs (biota)	PCB concentrations in biota
D8 PCBs (sedim)	PCB concentrations in sediments
D8 PAHs (sedim)	PAHs concentrations in sediments
D8 PAHs (biota)	PAHs concentrations in biota other than fish
D8 Organotin (sedim)	Organotin concentrationsin sediments
D8 PBDE (biota)	PBDE concentrations in biota
D8 PBDE (sedim)	PBDE concentrations in sediments
D8 imposex	Imposex/intersex
D10 on beach	Beach litter
D10 on seabed	Litter on the seabed
D11 impulsive noise	Impulsive noise

Annex 8: Additional OSPAR common indicators for Regions

Region IV – Bay of Biscay and Iberian Coast	
D4 FoodWeb 4	Changes in average trophic level of marine predators (cf MTI)
D1 PelHab 1	Changes of plankton functional types (life form) index Ratio
D1 PelHab 3	Changes in biodiversity index (s)
D5 input water	Waterborne nutrient inputs
Region III – Celtic Seas	
D1 Birds 1	Species-specific trends in relative abundance of non-breeding and breeding marine bird species
D1 Fish Ceph 1	Population abundance/biomass of a suite of selected species
D1 Fish Ceph 2	OSPAR EcoQO for proportion of large fish (LFI)
D1 Fish Ceph 8	Distributional pattern within range of a suite of selected species
D1 PelHab 1	Changes of plankton functional types (life form) index Ratio
D4 FoodWeb 3	Size composition in fish communities (LFI)
Region II – Greater North Sea	
D1 Mammals 3	Abundance of grey and harbour seal at haul-out sites & within breeding colonies
D1 Mammals 41	Abundance at the relevant temporal scale of cetacean species regularly present (incorporating previous D1 M2 “Distributional range and pattern of cetaceans species regularly present”)
D1 Mammals 5	Harbour seal and Grey seal pup production
D1 Mammals 6	Numbers of individuals within species being bycaught in relation to population
D1 Birds 1	Species-specific trends in relative abundance of non-breeding and breeding marine bird species
D1/6 Birds3	Breeding success/failure of marine birds
D1 Fish Ceph 1	Population abundance/biomass of a suite of selected species
D1 Fish Ceph 2	OSPAR EcoQO for proportion of large fish (LFI)
D1 PelHab 2	Plankton biomass and/or abundance
D5 input water	Waterborne nutrient inputs
D5 input air	Atmospheric nutrient inputs
D5 Phaeocystis	Species shift/indicator species: Nuisance species Phaeocystis
D8 input metal	Inputs of Hg, Cd and Pb via water and air
D10 in Fulmar	Fulmar litter ingestion (impact and floating litter)

Annex 9: Pressure indicators of the MARMONI project (Martin et al. 2014)

1 The seafloor exploitation index: This indicator measures the extent (area) of seabed that is impacted by direct physical anthropogenic disturbances (Martin et al., 2014). These disturbances are divided by Martin et al (2014) according to Foden et al. (2011) into:

- Smothering: covering the seabed with a layer of material. This activity includes disposal of dredged material.
- Obstruction: permanent structures fixed on the seabed. This activity includes pipelines, cables, wrecks, wind turbines, oil and gas platforms and other constructions.
- Abrasion: scouring and ploughing of the seabed. Abrasion activities include benthic fishing using trawl gear, burying activity during cable laying.
- Extraction: exploitation by removal of seabed resources. This activity includes dredging and aggregate extraction.

The seafloor exploitation index quantifies the spatial extent of these disturbances in regard to different seabed substrate types.

- Proportion of oiled waterbirds: This indicator reflects impact and specific pressure of oil pollution to waterbirds in marine environment (Martin et al., 2014). The indicator shows the proportion of birds in the collected population sample (or alternatively an index reflecting relative abundance of oiled birds) having been affected by oiling. The indicator can have single species and multi-species versions. Single-species version of the indicator is calculated separately for each species. This allows identifying species being more affected by oiling as the impact can vary among the species. The following species need to be considered: *Gavia arctica, Gavia stellata, Somateria mollis-sima, Polysticta stelleri, Clangula hyemalis, Melanitta nigra, Melanitta fusca, Alca torda*. Multi-species version of the indicator is calculated as a single measure for all waterbirds (i.e., all species pooled). This allows assessing total impact on waterbird community. The indicator reflects impact and pressure of oil pollution to birds in marine environment. Thus it shows condition of particular species at species level (single-species version) as well as condition of habitat typical species at habitat level (multi-species version). The proportion based indicator is expressed as proportion (%) of oiled birds from all birds collected in the specific survey. If visual observations are used, the indicator value is expressed as an abundance index, i.e. abundance of oiled birds in a particular year relative to abundance of oiled birds at base year (time period) or it is standardised as a density – number of observed oiled individuals per route unit.

- **Abundance index of beached birds**: This indicator reflects mortality of birds due to different reasons (mainly pollution and by-catch). It is expressed as relative abundance of stranded birds. The indicator can have single species and multi-species versions. Single-species version of the indicator is calculated separately for each species identified. This allows identifying changes in species-specific mortality as this parameter can vary among the species. The following species need to be considered: *Gavia arctica, Gavia stellata, Podiceps cristatus, Somateria mollissima, Polysticta stelleri, Clangula hyemalis, Melanitta nigra, Melanitta fusca, Alca torda*. Multi-species version of the indicator is calculated as a single measure for all waterbirds (i.e., all species pooled). This allows assessing changes in mortality in the whole waterbird community. The indicator value is expressed as an abundance index, i.e. abundance of beached birds in a particular year relative to abundance of beached birds at base year (time period) or it is standardised as a density – number of counted beached birds (individuals) per route unit.
- **Abundance index of by-caught birds**: This single-species indicator reflects mortality of birds due to drowning in fish nets (gillnets and driftnets) and thus specifically shows impact/pressure of gillnet fishery to marine birds. Single-species version of the indicator is calculated separately for each species. Some species are more affected by bycatch and the impact varies among the species. The following species need to be considered: *Gavia arctica, Gavia stellata, Podiceps cristatus, Podiceps grisegena, Phalacrocorax carbo, Aythya fuligula, Aythya marila, Somateria mollissima, Polysticta stelleri, Clangula hyemalis, Melanitta nigra, Melanitta fusca, Bucephala clangula, Mergus albellus, Mergus merganser, Mergus serrator, Alca torda, Uria aalge, Cepphus grylle*. Indicator is expressed as number of birds drowned per 1000 m of net length per day (birds/NMD).
- **Indicator on condition of waterbirds**: A body condition index based on condition of the pectoral flight muscles and the presence and quantity of subcutaneous and intestinal fat depots. Body condition of seabirds is measured by sampling by-caught seabirds as these probably represent a good subset of the whole population in the respective area (unlike beached birds that might rather represent diseased individuals). The indicator primary responds to the following pressures and drivers: removal of prey, disturbance, disease, hazardous substances. The index supplies general information on overall physical condition or the likely cause of death, e.g. starvation. Three components are evaluated for every collected specimen:
    - condition of the pectoral flight muscles
    - presence and quantity of subcutaneous fat depots

- presence and quantity of intestinal fat depots

These are scored on a scale ranging from 0 to 3. Subsequently, these scores are summed up to a condition index. Thus total score for each bird can be in range 0 to 9 (0-1 as mortally emaciated, 2-3 as critically emaciated, 4-6 as moderate body condition and 7-9 as good body condition).

- Feeding pressure on waterbird food sources: This indicator reflects impact and specific pressure of feeding marine birds on their food resources/other organisms in their food-chain/structure and conditions of their habitat and its forming species. Counts are carried out on daily (weekly) basis to assess presence and abundance of birds for certain time periods.

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