Science of the Total Environment 503–504 (2015) 10–21

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Managing aquatic ecosystems and water resources under multiple stress — An introduction to the MARS project

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HIGHLIGHTS

- We describe the aims and approaches of the EU-funded project MARS and its conceptual framework.
- MARS is operating at the water body, the catchment, and the European scales.
- It includes experiments, catchment modelling and large-scale data analysis.
- It addresses the link between multiple stressors, ecological responses and functions.
- The project will support the implementation of European water policies.

ARTICLE INFO

Article history:
Received 14 May 2014
Received in revised form 20 June 2014
Accepted 24 June 2014
Available online 10 July 2014

Keywords:
River Basin Management
Europe
Ecological status
Ecosystem services

ABSTRACT

Water resources globally are affected by a complex mixture of stressors resulting from a range of drivers, including urban and agricultural land use, hydropower generation and climate change. Understanding how stressors interfere and impact upon ecological status and ecosystem services is essential for developing effective River Basin Management Plans and shaping future environmental policy. This paper details the nature of these problems for Europe's water resources and the need to find solutions at a range of spatial scales. In terms of the latter, we describe the aims and approaches of the EU-funded project MARS (Managing Aquatic ecosystems and water Resources under multiple Stress) and the conceptual and analytical framework that it is adopting to provide this knowledge, understanding and tools needed to address multiple stressors. MARS is operating at three scales: At the water body scale, the mechanistic understanding of stressor interactions and their impact upon water resources, ecological status and ecosystem services will be examined through multi-factorial experiments and the analysis of long time-series. At the river basin scale, modelling and empirical approaches will be adopted

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http://dx.doi.org/10.1016/j.scitotenv.2014.06.106

to characterise relationships between multiple stressors and ecological responses, functions, services and water resources. The effects of future land use and mitigation scenarios in 16 European river basins will be assessed. At the European scale, large-scale spatial analysis will be carried out to identify the relationships amongst stress intensity, ecological status and service provision, with a special focus on large transboundary rivers, lakes and fish. The project will support managers and policy makers in the practical implementation of the Water Framework Directive (WFD), of related legislation and of the Blueprint to Safeguard Europe's Water Resources by advising the 3rd River Basin Management Planning cycle, the revision of the WFD and by developing new tools for diagnosing and predicting multiple stressors.

1. Introduction

Europe's water resources and aquatic ecosystems are impacted by multiple stressors, which affect ecological and chemical status, water quantity and ecosystem functions and services. The relevance of multiple stressors differs regionally (EEA, 2012a): in Alpine and upland northern regions hydropower plants have fundamentally changed river and lake hydrology, morphology, sediment transport and connectivity, in lowland areas of Northern and Central Europe intensive agriculture and flood protection are important drivers of degradation, whilst Mediterranean catchments are impaired by riparian degradation and water scarcity and transitional and coastal waters are affected by eutrophication, pollution, morphological changes and different resource exploitation. In addition, climate change increases the risk of floods, erosion and pollution in wet regions and of droughts in water scarce regions (EEA, 2012b).

According to Europe's first River Basin Management Plans (RBMPs), 56% of European rivers, 44% of lakes, 25% of groundwater bodies and 70% of transitional waters failed to achieve the good status targets of the Water Framework Directive (WFD) (EEA, 2012a; ETC-ICM, 2012a). There are, however, strong regional differences: in Northern Europe and in some Eastern European and Mediterranean countries more than 40% of river water bodies are in high or good status, whilst in Central European countries, such as Belgium, the Netherlands and Germany, more than 80% failed to achieve the WFD quality targets. The reasons are manifold. Recent reports (EEA, 2012a; ETC-ICM, 2012a) list the most important pressures impacting individual water categories: only 19% of water bodies was not significantly impacted, whilst two pressures prevail: diffuse pollution (rivers: 45%, lakes: >30%) and hydromorphological degradation (rivers: >40%, lakes: >30%). Viewed in more detail, both diffuse pollution and hydromorphological degradation are composed of several individual components with complex interactions. Diffuse pollution mainly refers to increased nutrient loads and associated eutrophication effects, often in conjunction with fine sediment, pesticides and other toxic substances. Hydromorphological degradation is an even more vague term, including hydrological stress from low flows and water abstraction, flash floods, and morphological stress from barriers, straightening, bank fixation, removal of riparian vegetation and subsequent increase of water temperatures (ETC-ICM, 2012b).

From this evidence, it is apparent that the causes of degradation of Europe's waters are manifold and complex. Whilst single stressors such as strong organic pollution and acidification of freshwaters are declining and nowadays affecting just 14% and 10% of river water bodies, respectively (EEA, 2012a), Europe's water bodies and water resources are now affected by a complex mixture of stressors resulting from urban and agricultural land use, hydropower generation and climate change (e.g. Stelzenmüller et al., 2010; Schinegger et al., 2012).

Although the Programmes of Measures included in the RBMPs should reduce stressors and improve water body status, their potential to address increasingly complex, multiple stress situations is limited by current knowledge. A recent inventory of RBMPs for Germany revealed a strong focus on measures targeting single pressures such as point-source pollution and river continuity (Kail and Wolter, 2011). Under conditions of multiple stress, however, restoration actions may also initiate complex cause-effect chains of recovery, which are poorly understood (Feld et al., 2011).

Overall, the first RBMPs have several problems:

- Programmes of Measures are often decoupled from ecological assessment.
- Although the majority of European water bodies are affected by more than one stressor, little is known about their combined effects.
- For multiple-stress situations, simple dose–response relationships between stress intensity and biological effects based on empirical data are not sufficient for developing appropriate management measures. There is a need for improved process understanding of how multiple stressors affect degradation and restoration.
- Besides the existing tools to assess water body status, tools are needed to prioritise measures and to predict ecological status following restoration.
- The implementation of measures requires convincing arguments beyond the concept of ecological status, whose value is difficult for the public and policy makers to understand. Supplementary indicators targeting ecosystem functions, ecosystem services and human benefits are required.

These are obstacles for the successful implementation of the WFD within the following set timeline: production of a 2nd version of the RBMPs in 2015, a 3rd version in 2021, and achievement of the overall WFD targets by 2027. A new stressor, climate change, is to be taken into account in the 2nd version. The planned revision of the WFD in 2019 offers an opportunity to advance its conceptual basis which is now almost 20 years old, and to consider the recent knowledge in addressing the WFD requirements (Hering et al., 2010). Major challenges for water resource management have emerged since the ratification of the WFD in 2000: New stressor combinations, including not least climate change, new pollutants, emerging pathogens and exploitation of the sub-surface for alternative forms of energy; more intense land use due to increased food prices and demand for biofuel; and increasingly diverging targets for food production, energy generation, water resource protection and biodiversity protection.

The WFD is the core of Europe's water policy, but there are several other relevant directives with manifold (and sometimes contrasting) approaches and targets. These include the Urban Waste Water Treatment Directive (91/271/EEC), the Nitrates Directive (91/676/EEC), the Bathing Water Directive (2006/7/EC), the Marine Strategy Framework Directive (2008/56/EC), the Habitats Directive (92/43/EEC), the Flood Risk Management Directive (2007/60/EC), the Strategy on Water Scarcity and Drought and the White Paper on Adaptation to Climate Change. The implementation of these policies to protect Europe's water resources strongly interacts with other policy domains, such as the Renewable Energy Directive (2009/28/EC) and in particular with the Common Agricultural Policy. The Fitness Check of EU Freshwater Policy (http://ec.europa.eu/environment/water/blueprint/fitness_en.htm) outlines the strength of the current legislative framework, and also exposes conflicts with other EU policies and the weaknesses in its implementation. Problems identified include the incorporation of water quantity issues into RBMPs, including the definition of ecological flows (cf. environmental flows, Postel and Richter, 2003; Poff et al., 2010), land use impacts in particular from agriculture, climate change impacts, translation of the ecosystem services concept into practice, and insufficient dissemination and sharing of data. Implicit in all these issues is the need to address multiple stressors. The ecosystem services approach offers a powerful option to harness the efforts of all relevant partners (Ormerod, 2014).

The Blueprint to Safeguard Europe's Water Resources (http://ec.europa.eu/environment/water/blueprint/index_en.htm) describes 39 actions to strengthen the implementation of Europe's water policies. Key amongst them are land use and ecological status, chemical status and pollution of EU waters, water efficiency, vulnerability of EU waters, and the need for cross-cutting problem solving and global aspects. Overall, the Blueprint provides a realistic assessment of achievements and problems of European water management, and embeds Europe's water policy into a wider political context. As with the Fitness Check, it identifies complex stressors resulting from intense land-use and over-abstraction as key problems, and outlines solutions possible through other policy fields such as the Common Agricultural Policy. According to the Blueprint, the Common Implementation Strategy (CIS) of the WFD ensures its prominent role for European water policies.

The EU-funded project MARS (Managing Aquatic ecosystems and water Resources under multiple Stress, www.mars-project.eu) addresses these challenges and is closely linked to the policy framework outlined above. This paper describes context, approaches and objectives of MARS and aims in particular to outline the conceptual model on which MARS is based and to describe the project's approaches acting at three different scales.

2. Current state-of-the-art

Water resources management in Europe is based on four distinct activities: (1) River Basin Management Planning is the over-arching framework of the WFD, which is informed by (2) assessment schemes for indicating status, (3) risk assessment for characterising pressures and stressors, and (4) economic analysis for evaluating the costs and benefits of management actions. The latter relates to an Ecosystem Services Approach and may be considered under the Ecosystem Service Cascade Framework (Haines-Young and Potschin, 2010). Whilst these four activities are implicitly connected, their linkages have rarely been put into practise.

2.1. River Basin Management planning

The concept for risk assessment, status assessment, economic assessment and stakeholder engagement in water resource management is provided by RBMPs under the WFD. It incorporates risk assessment and characterisation, monitoring of robust indicators for status assessment and stakeholder engagement with the economic assessment of management options. Integrated water resource management is often best exemplified at a local water body scale, where competing demands of different users and stakeholders can be communicated and managed effectively (May and Spears, 2012). However, conflicts can still exist between users and services across a catchment; therefore, management of floods, environmental flows and restoration is often best coordinated at the river basin scale. The International Danube Commission (ICPDR) provides an excellent example of integrated water resource management within the most international and one of the largest European river basins, requiring coordinated action across states on groundwater and surface water abstractions, flood management, energy production, navigation and water quality. However, despite such well coordinated actions, multiple stressors continue to threaten ecosystem health, biodiversity conservation (e.g. sturgeon and Danube salmon) and associated benefits of flood protection, water purification and tourism.

Despite the obvious strengths of the RBMP concept, and though most RBMPs fulfil the requirements of the WFD from a formal point of view, in reality many plans are vague in defining measures. Multiple-stressors make it particularly difficult to diagnose causes of deterioration and decide upon the best management options. For example, climate change was not consistently considered in the first RBMPs, and many water bodies were not assessed fully or require further investigation to identify how causes of degradation interact.

2.2. Status assessment

The WFD has been very successful in indicator development for status assessment of surface waters (e.g. Birk et al., 2012) and to a lesser extent of groundwaters (e.g. Hinsby et al., 2008). Research has predominantly examined the effects of individual stressors on various structural biological indicators (Birk et al., 2012; Lyche-Solheim et al., 2013). WFD status assessments integrate these indicators through the one-out-all-out principle lacking a holistic vision of what individual indicators represent and how they could potentially be used for more integrated assessments of ecosystem health, functioning and resilience in response to multiple stressor interactions (Hering et al., 2010). Nonetheless, robust indicators of freshwater, transitional and coastal ecosystem processes, services and vulnerability are lacking, as is the establishment of effective indicators for groundwater. At the same time, the development of new indicator types for monitoring stressors, status and ecosystem health is an active area of innovation, including biomarkers of stress, genetic methods (high throughput bar-coding and gene expression in relation to stressors), ecosystem metabolism and remote sensing (e.g. Hunter et al., 2010). Review and testing of these new approaches are needed to determine whether they could substitute or complement the classical indicator types. To be widely applicable, they need to be reviewed and tested in the context of ecological status and ecosystem services.

2.3. Risk assessment

Current approaches are well established for single toxic chemicals (Crane et al., 2006), drought and flood management (Prudhomme et al., 2003), and for predicting the spread of invasive species in relation to climate change (Leung et al., 2002). Risk assessment tools have also been developed for application in RBMPs, to assess risks of failure to achieve good status (Duethmann et al., 2009), to decide on mitigation strategies, and evaluate risks faced by water service providers or potential harm from water management actions (e.g. dam building or river restoration). Compared to the wide variety of existing indicators for status assessment, the capabilities to predict ecosystem responses to stress, to restoration or more generally to alternative management measures are underdeveloped. In particular, greater knowledge is needed on exposures to multiple stressors, stressor interactions (synergistic, additive or antagonistic effects), and the sensitivity to stress combinations. Such interactions have only been described in detail for few stressor combinations, e.g. the impact of climate warming and eutrophication in shallow lakes on selected organism groups (Jeppesen et al., 2007) and the impact of water quality, hydrological disturbances and morphological degradations in rivers (Marzin et al., 2013; Schinegger et al., 2012). Understanding of the effects of multiple stressors on ecosystem functioning and services is still rudimentary (Friberg, 2010; Ormerod et al., 2010). This lack of mechanistic understanding is an obstacle for more integrated risk assessment and for effective mitigation and restoration.

2.4. Valuation of ecosystem services

There is an implicit need to include ecosystem services into RBMPs, particularly in the economic analysis of water use and in the design of the Programmes of Measures (Vlachopoulou et al., 2014). Ecosystem services were provided by surface water bodies (rivers, lakes and transitional waters) and to a lesser degree by groundwater bodies which include provisioning services (e.g. water supply, food from fish farms, energy from hydropower generation), regulating and maintenance services (e.g. flood and drought regulation, climate regulation through carbon sequestration, water purification biodiversity, dispersal of matter, organisms and energy, nutrient cycling) and cultural services (e.g. recreation such as angling and water sports, tourism, and inspiration for arts and religion).

The development of indicators specifically targeting ecosystem services could greatly benefit from the experience of using WFD indicators for ecological status (e.g. Carvalho et al., 2013), resulting in a more coherent, integrated and applicable suite of indicators in advance of the WFD revision in 2019. At a European scale, the current research aims to integrate the Ecosystem Services paradigm into broader environmental planning and policy arenas (TEEB, 2010, 2011). Recently funded EU FP7 projects (OpenNESS and OPERAS) will deliver practical testing of Ecosystem Service assessment and valuation for different ecosystems, although application to coastal and freshwaters is limited.

3. Objectives and architecture of the MARS project

MARS (2014–2018), supported by the 7th Framework Programme of the EU, has 24 partners, five of which are application institutes such as water boards and environment agencies. MARS will support water managers and policy makers at the water body, river basin and European scales in the implementation of the WFD. Our specific objectives at the three different scales are:

- At the water body scale, to enhance the mechanistic understanding of how stressors interact and impact upon water resources, status and ecosystem services, and identify threshold responses to optimise stress reductions. We will address stressor combinations and response variables characteristic for major European regions. A focus will be on the effect of extreme climate events such as heavy rainfall, heatwaves as well as water scarcity and the effects of environmental flows.
- At the river basin scale (including in some cases rivers and transitional waters), to characterise relationships between multiple stressors and ecological responses, functions, services and water resources, and assess the effects of future land use and mitigation scenarios. Work in 16 river basins in Europe, chosen to represent a wide range of catchment characteristics and multiple stress conditions, will focus on water scarcity and flow alterations (Southern Europe); hydrology, morphology and nutrient alterations (Central Europe); and hydrology and temperature alterations (Northern Europe).
- At the European scale, to identify the relationships amongst stress intensity, status and service provision, with a special focus on large transboundary rivers, lakes, estuaries and fish as sentinels of multiple stressor impacts on biodiversity and direct providers of ecosystem services.

Finally, we will combine the newly generated information at the different scales with existing knowledge in the form of information systems and diagnostic and predictive tools, applicable at the three spatial scales.

The MARS consortium includes all major European regions: Northern Europe (UK, NO, FI, DK) is represented by six partners, Central and Western Europe (FR, NL, DE, AT) by six partners, Eastern Europe (CZ, EE, RO, SI) by five partners and Southern Europe (GR, TK, ES, PT) by five partners; in addition, two international organisations (EC-JRC, ICPDR) are included. Nineteen of the 24 partners are scientific institutions or universities, whilst five partners are large river basin authorities or environmental agencies/ministries.

4. The MARS model

MARS will be based on a framework that explicitly links the assessment of risk, status and ecosystem services within the framework of RBMPs (Fig. 1).

- Risk assessment combines the magnitude of a stressor (or a combination of stressors) with the consequences of exposure to it. The consequences are based on the sensitivity of the targeted indicators, e.g. species, habitats and ecosystem processes and services.
- WFD status assessment fits centrally within the DPSIR-framework: Drivers (D, e.g. intense land use) cause pressures (P, equivalent to

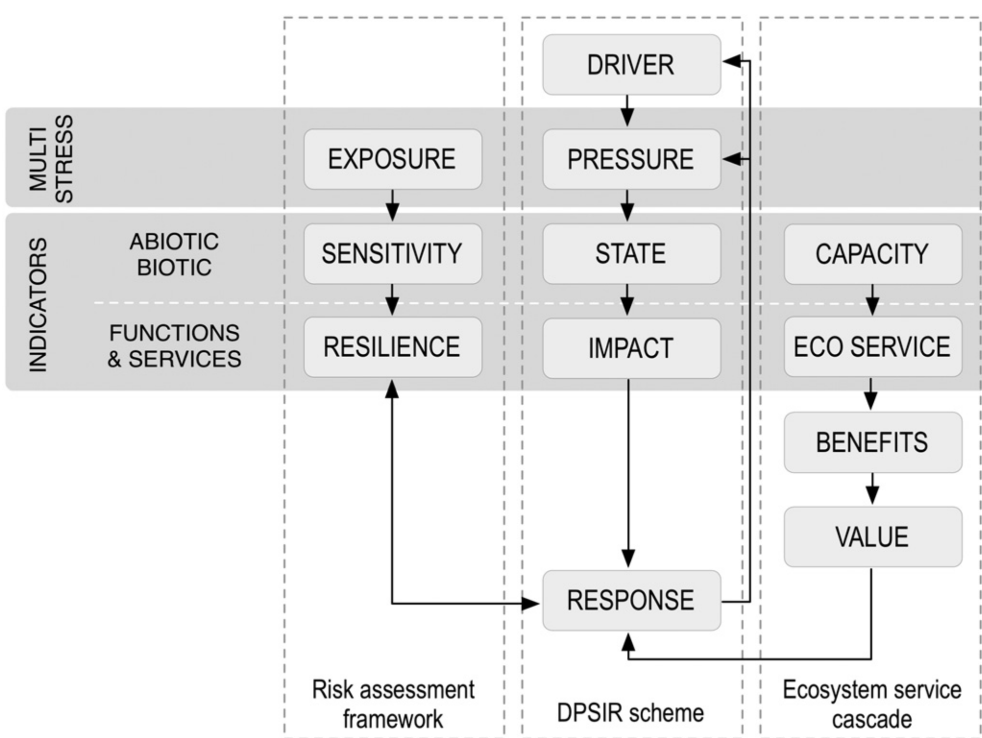

Fig. 1. The MARS conceptual model for an integrated assessment framework. DPSIR = Driver–Pressure–State–Impact–Response chain.

stressors; e.g. increased nutrient concentrations) and consequently affect water body state (S, e.g. chemical or ecological status or water quantity). This has impacts (I) on ecosystem functioning and consequently ecosystem services, which may require a management or policy response (R, e.g. restoration actions).
- Ecosystem services are generally considered through the "cascade model", which links the capacity of ecosystems (i.e. their structures, processes and functions) to flow of a specific service, which can be translated into benefits and values associated with human well-being (Haines-Young and Potschin, 2010). For example, river systems have the potential for denitrification and sedimentation, which determine nutrient and organic matter removal, or in other words water purification. The resulting benefit for human well-being is the provision of clean drinking water and safe recreation, which can be valued through different methods (Wallis et al., 2011).

There are obvious linkages between these three frameworks (Fig. 1), through indicators of a water body's sensitivity or resilience to stressors, its status and its capacity to provide services. Further, management decisions ("response") are not only based on the state-impact chain through the DPSIR model, but also must consider ecosystem service values, too. For the first time, we will use this linked model to support management decisions and scenario-testing explicitly through the ecosystem services paradigm by examining interactions between the structure and functioning of ecosystems, and benefits for human well-being (e.g. provision of drinking water, self purification, flood and drought regulation, and recreation).

The MARS conceptual model can be exemplified for a lake, which is important for water supply and recreation, but affected by intense agriculture in the catchment and climate change (drivers) (Fig. 2). Multiple stressor interactions between eutrophication and hydrological extremes (pressures) are indicated by enhanced total phosphorus concentrations and reduced flushing rates (abiotic status). Impaired ecological status (state) results, indicated by cyanobacterial blooms and poor fish communities (WFD indicators of lake status) and impacts on lake functioning (e.g. reduced grazing on toxic cyanobacteria). This relates to decreased capacity to provide clean drinking water and reduced value as a recreational site (ecosystem services), affecting societal benefits (reduced health and well-being of citizens) and economic value. Policy or management responses include changing land use along the rivers that feed into the lake, or ensuring sufficient flow through the lake. The impact magnitude depends on both, the ecosystem exposure to these stressors (e.g. the timing of nutrient loads in relation to algal growth) and the sensitivity of the ecosystem and its assemblage, e.g. the lake's capability to flush out and store nutrients and the sensitivity of particular fish species to eutrophication. The vulnerability of the services to these combined stressors can be mitigated by enhancing resilience, by building more reservoirs for water supply and recreation, or introducing water metering to reduce water use.

5. Approaches and work programme of MARS

MARS will be organised at three different scales to meet the demands of specific user groups (Fig. 3).

At the *water body scale*, the users targeted are water managers responsible for the assessment, restoration and management of individual water bodies, e.g. for the implementation of measures defined in RBMPs. MARS will develop new indicators, and compile existing indicators, to more fully represent the demands of the DPSIR scheme, of risk assessment and of the Ecosystem Service Cascade Framework. We will further produce a causal analysis scheme, enabling water managers to diagnose causes of water body deterioration in multiple stressor situations. We will enhance the mechanistic understanding of how interacting stressors and stress reductions affect status and ecosystem services. The focus will be on stressor combinations and response variables, which occur frequently in major European regions, but before now have been poorly investigated. Flume/mesocosm experiments will target the effects of stress combinations on selected indicators,

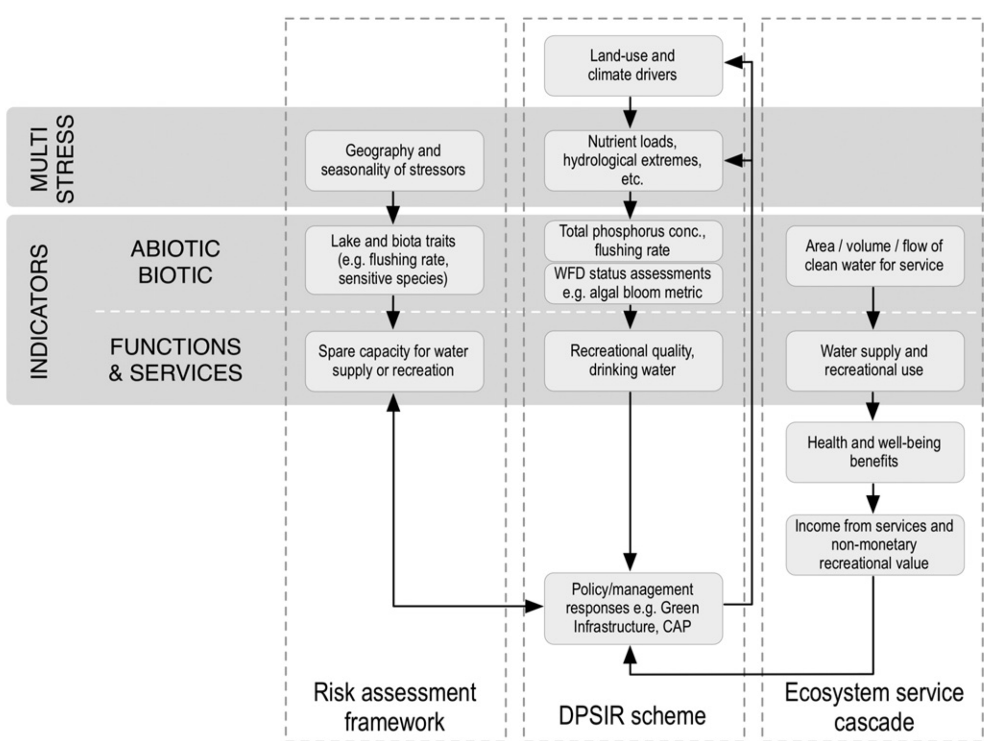

Fig. 2. The MARS conceptual model exemplified for a lake affected by intense agriculture and climate change. DPSIR = Driver–Pressure–State–Impact–Response chain; WFD = Water Framework Directive.

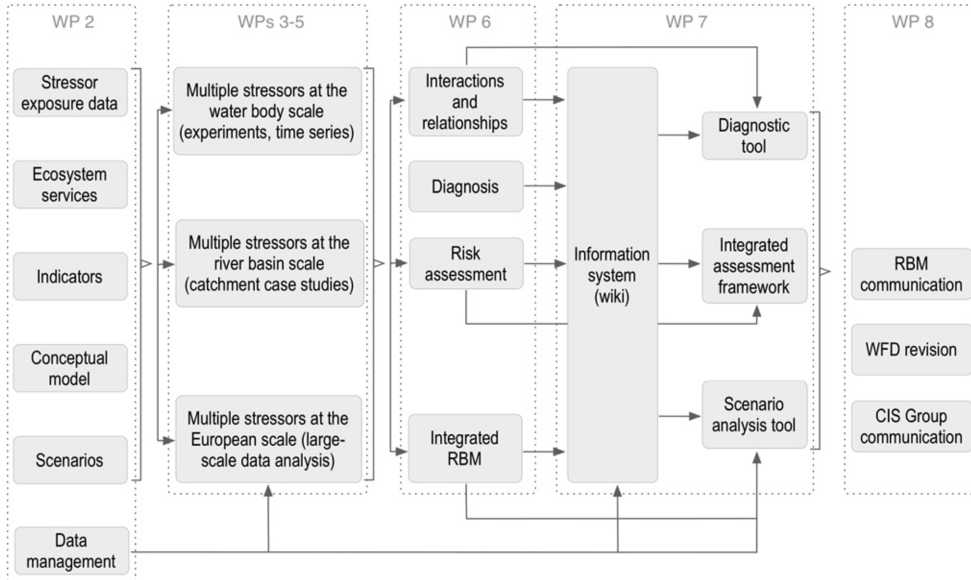

Fig. 3. Interconnection of MARS work packages and main tasks. WP = Workpackage; RBM = River Basin Management; WFD = Water Framework Directive; CIS = Common Implementation Strategy.

test new types of indicators (e.g. trait-based service indicators, and genetic diversity) and test variability of multiple stress (i.e. identifying critical time spans). For running waters, there will be four flume experiments respectively on lowland streams, mountain streams (Northern and Central Europe) and Mediterranean streams. For lakes, there will be three mesocosm studies of climate–nutrient interactions, with a focus on extreme climatic events, and functional trait responses that can be related to ecosystem services. The individual river experiments and the individual lake experiments will address a common set of stress combinations and indicators, whilst in some experiments new, more complex indicator types will be addressed (Table 1). As a common denominator, all lake experiments will target extreme events (extreme rain, extreme thermal events, extreme mixing) in combination with nutrient enrichment. All river experiments will address hydrological stress, in particular water scarcity/environmental flows, which will be combined with different water temperatures, habitat conditions and nutrient levels. All experiments will include a multifactorial design, combining different stress intensities either in different mesocosms (lakes) or in consecutive experimental runs (rivers). The experiments will be bolstered by the analysis of long time series at sites where monitoring has spanned periods when stressor combinations have changed substantially (both increased and reduced stress).

More specifically, there will be one lake mesocosm experiment (located in the UK) on the effects of extreme rainfall and warming, which are two key components of climate change that superimpose consequences of nutrient loads to lakes. Two temperature regimes (ambient, +4 °C) and two nutrient treatments (no addition, nitrate and phosphate addition) will be applied to 32 mesocosms equipped with computer-controlled heating devices. The two-factorial design will involve eight replicates. Once each season, extreme rainfall will be simulated in half of the mesocosms by physical mixing and irrigation to mimic enhanced runoff into lakes. A second lake mesocosm experiment (located in Denmark) will address extreme heatwaves using the world's longest running flow-through, fully-mixed mesocosm system (ambient, A2 scenario, A2 + 50% scenario — 4 replicates × 2 nutrient levels). We will raise temperature during summer by 5 °C for 1 month, follow responses over two years, and compare them with trends observed over 10 years of pre-treatment. Finally, there will be one experiment (located in Germany) combining the effects of extreme mixing and DOM loading. Deep mixing of lakes and pulsed DOM loading in response to extreme summer storms and rainfall are two of the most prominent impacts expected in the face of climate change. Twenty-four large mesocosms (9 m diameter, 20 m deep; http://www.lake-lab.de) in a stratified lake will be used to study these effects along a nutrient gradient. Extreme mixing and DOM treatments will be crossed with 6 nutrient levels (TP of 10–45 μg/l).

For rivers, one experiment (located in Norway) will address extreme flows in Nordic rivers, as the hydrological regimes of many Nordic rivers are controlled for hydropower. The negative impacts tend to be exacerbated by excess nutrients and climate change. We will use four streamside flumes (6 m length, 25 cm width, 5–25 cm water depth) to assess these interactive effects by manipulating flow regimes for 4–6 weeks in two flumes and using the two others as controls. A second experiment (located in Austria) addresses peak flows in Alpine rivers. Effects of peak flows resulting from hydropower operation and extreme rainfall are expected to vary with river channelization and climate warming. We will use the recently established "Hydromorphological and Temperature Experimental Channels" (HyTEC) to test for single and combined effects of river flow, riverbed morphology and temperature. HyTEC consists of two large channels (40 m length, 6 m width) fed with nutrient-poor lake water taken at different depths to vary water temperature. Peak flows of up to 600 l/s several times a day will be produced to mimic hydropeaking and extreme floods. Experiments will run for several hours or days in paired treatment and control channels. Replication (at least threefold) will be achieved by repeating experiments, with treatment and control channels randomly selected each time. A third experiment (located in Portugal) addresses water scarcity in Mediterranean rivers. Mediterranean rivers combine low mean discharge and prolonged summer droughts with flashiness during winter and spring. This regime is compounded by climate change, prompting complex ecological impacts (reduced connectivity, dry river beds that limit species dispersal, followed by strong disturbance during subsequent high-flow events). Chemical stressors interact with this variable environmental setting. An outdoor flume to address these stressor combinations is currently constructed. Finally, one experiment (located in Denmark) will address low flows in Nordic rivers. Extreme rainfall during winter and summer storms as a result of climate change will be accompanied by increased fine-sediment and nutrient loads to agricultural rivers, whereas

Table 1
Overview of experiments to be performed in MARS. BOD = Biological Oxygen Demand; DOC = Dissolved Organic Carbon; and PAR = Photosynthetic Active Radiation.

Location and partners	Type	Primary stressor	Secondary stressors	Explanatory physico-chemical responses	Explanatory biological responses
UK	Mesocosms	Extreme rain	Nutrients, temperature, hydrology	Oxygen, turbidity, nutrients, pH, temperature and PAR	Phytoplankton (major groups, chlorophyll a), zooplankton incl. protists, bacterioplankton via DNA extraction, macroinvertebrates, macrophytes and fish. Size structure of biota and metabolisms.
Denmark	Mesocosms	Thermal extremes	Nutrients, temperature	Oxygen, turbidity, nutrients, pH, temperature and PAR	Phytoplankton (major groups, chlorophyll a), zooplankton incl. protists, bacterioplankton via DNA extraction, macroinvertebrates, macrophytes and fish. Size structure of biota and metabolism.
Germany	Mesocosms (24)	Extreme mixing and DOC loading	Nutrients (10–45 µg TP/L)	Oxygen, Secchi depth, nutrients, pH, DOC, temperature and light profiles	Phytoplankton: Cyanobacteria chlorophyll, taxonomic composition, cyanobacteria biomass and toxins, phytoplankton size structure, functional groups, algal pigments, genetic diversity, edibility, zooplankton, bacteria sedimentation.
Norway	Flume	Extreme flows	Nutrients	Flow, flow velocity, water chemistry	Production and consumption, chlorophyll a, biomass accrual and grazing rates on colonisation tiles, trait composition, production and consumption rates, dual stable isotope signatures.
Portugal	Flume	Water scarcity	Organic load enrichment	Habitat morphology and hydraulics, water quality, BOD, water temperature	Fish movement and behaviour; invertebrate persistence, density and position in substrates; drift and mortality.
Denmark	Flume	Low flows	Fine sediment, nutrients	Flow, flow velocity, habitat characteristics, water chemistry	Community composition of phytobenthos, macrophytes and benthic invertebrates, food web structure.
Austria	Flume	Peak flows	Habitat morphology, temperature	Flow velocity, sheer stress, water depth, substrate, channel form, water temperature	Phytobenthos (productivity, composition, biomass, resource use, respiration), invertebrates (species composition, biomass, drift), fish (behaviour, drift, habitat use, stranding).

low flow in late summer will increase drought risk, sedimentation, benthic occlusion, nutrient concentrations and oxygen declines at night. We will use 12 outdoor flumes (12 m length, 30 cm width; 2–25 cm water depth m) receiving water from a local river. Flow will be reduced in six replicate flumes by 90% compared to the remaining six control flumes.

At the *river basin scale*, the users will be authorities responsible for RBMPs, and environment agencies with regional or national responsibility. We will address 16 river basins selected to cover the main European regions and their representative stressor combinations. Multiple stress effects on indicators will be modelled by linking the outcome of "abiotic" models (including groundwater and surface water hydrology) to the biota and to ecosystem processes and services, either empirically or using process-based models. Applying scenarios, we will differentiate the effects of the stress combinations and quantify the effects of management and mitigation options using a variety of models (Table 2). New model components linking multiple stressors to quantitative, qualitative and service-related indicators will be developed and validated. The results and experience will feed into a wiki information system produced by MARS, in particular information on indicators, models and decision support tools; we will further highlight best practise examples of catchment analysis and management, and will produce guidance on which models and tools are advisable under which circumstances. The 16 selected catchments reflect regional and local multistressor combinations affecting Europe's water resources and ecosystems, as well as their ecological sensitivities and responses (Table 2, Fig. 4). The three groups represent the following conditions:

- In Southern regions, the five river basins in Portugal, Spain, Greece, Turkey and Romania are affected by water scarcity from abstraction, groundwater over-exploitation and flow regulation. Agricultural intensification and, increasingly, climate change, affect the catchments. Severe flow alterations result in inadequate ecological flows coupled with reduced dilution of organic pollution, nutrients and pesticides. Effects are compounded by habitat loss and hydromorphological modification to support water transfers, whilst erosion and increased sediment delivery result from poor tillage, forest practices and soil desertification.
- In Central regions, the six catchments (four in lowland regions, two in mountain regions) are in the UK, the Netherlands, Denmark, Germany (2) and Austria, and are affected by hydrological stressors (floods, demand-related water scarcity and over-regulated flow), morphological alterations and water quality problems, mainly resulting from high population densities and intensive agriculture in the lowlands and water power generation in the mountain regions. Additional stress results from toxic pollution and pathogens, from invasive species and non-natural sediment regimes that compound interstitial de-oxygenation and habitat impairment.
- In Northern regions, five catchments are located in the UK, Norway (2), Finland and Estonia and are mainly affected by hydrological alterations and increasing temperature. Additional stress includes morphological modification, diffuse agricultural pollution, sediments, continued acidification, brownification and pollution by a range of toxic and organic pollutants.

Selection criteria for the catchments included the existence of calibrated nutrient and hydrological models, and a high density of biological sampling sites with ecological status indicators. We thus selected catchments where MARS can benefit from the existing work and previous major investment to focus on the effects of multiple stress.

All the basins have extensive physical, chemical and biological data, in several cases spanning 2–3 decades (Table 2). The total number of sampling sites includes 2500 for physical–chemical parameters, 1300 for fish, 4000 for macroinvertebrates, 2300 for macrophytes and 500 for microalgae. Research in each of the 16 major cases will follow a standard workflow whilst some will address region-specific issues, for example related to groundwater–surface water interactions and

Table 2
River basin case studies of MARS.
Stressors: E = Eutrophication/Organic pollution, H = Hydrology/Water scarcity, I = Invasives/Pathogens L = Temperature/Light, M = Morphology/Shipping, T = Toxics.
Multiple stressor groups: 1 = Hydrology/temperature, 2 = Hydrology, morphology, nutrients, 3 = Water scarcity, flow alterations.
Ecosystem Services: E = Ecological Flows, F = Fisheries, H = Hydropower, R = Recreation, S = Water supply, and W = Water purification.

	Sorraia (PT)	Nervion Ibaizabal (ES)	Pinios (GR)	Beysehir (TK)	Lower Danube (RO)	Thames (UK)	Regge and Dinkel (NL)	Odense (DK)	Elbe (DE)	Ruhr (DE)	Drava (AT)	Welsh basins (UK)	Vansjø-Hobøl (NO)	Otra (NO)	Kokemäenjoki (FI)	Võrtsjärv (EE)
Catchment characterisation																
Region (South, Central, North)	S	S	S	S	S	C	C	C	C	C	C	N	N	N	N	N
Stressors addressed	EHLMT	EMT	EHLMT	EHL	EHIM	EHILT	EHLM	EHMT	EHM	EHMT	HM	EHLMT	EIT	HILT	EHMT	EFHT
Multiple stressor groups	3	3	3	3	3	2	2	2	2	2	2	1	1	1	1	1
Ecosystem services addressed	EFSW	RS	HSW	FRS	FR	EFSW	S	RW	FW	SW	EFH	FRSW	HRS	FHR	HRWS	FRW
Available data																
Sample sites physico-chemistry	30	31	89	16	28	597	428	100	140	400	140	400	15	30	30	37
Sample sites fish	30	31	–	3	300	180	30	20	100	300	40	200	2	10	20	37
Sample sites invertebrates	30	31	80	–	18	250	1192	113	300	1600	40	400	5	10	20	37
Sample sites macrophytes	70	31	–	80	18	900	1003	40	45	50	12	50	5	10	20	27
Sample sites plankton/phytobenthos	30	31	–	2	18	20	117	27	90	50	12	100	8	8	20	37
Existence of long term data (>30 y)						●						●				●
Workflow planned																
Process-based "abiotic" models	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Lakes, Groundwater, Transitional Water	LGT	T	L	LG		LGT	G	LT	G				L		LG	L
Empirical linkage abiotic–biotic	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●
Process-based linkages	●		●				●	●	●	●					●	●
Ecosystem service evaluation	●	●	●	●	●	●		●		●		●	●	●	●	●
Climate, Restoration, Land use scenarios	CRL	RL	CL	CL	L	CRL	CRL	CRL	CRL	RL	RL	CRL	CRL	CRL	CRL	CRL

regionally important stress combinations. The following basins are addressed:

- Sorraia: The Sorraia basin (7611 km^2) drains into the Tagus estuary from irrigated croplands and cork-oak forest, and is characterised by widespread transfers, regulation and abstraction of surface and groundwaters. This, coupled with extended periods over 45 °C and annual precipitation of 642 mm, means that many rivers are intermittent, whilst climate change is expected to intensify floods and droughts. Models of fluxes of water, nutrients, sediments and organic pollutants will be used to assess the impact of these multiple stressors on water resources and quality and focus on identifying optimal management solutions to water conflicts, restoration, and the effects of climate warning.
- Nervion-Ibaizabal: Located in the Basque region, this mountainous catchment (1755 km^2) drains into a commercial and morphologically modified Atlantic estuary affected by declining urban, organic and metal discharges. The catchment has 140 sampling sites on rivers and 30 in transitional/coastal waters. Physical–chemical and biological data over the last 20 years will be used to investigate how various discharge and morphological change scenarios may affect ecological quality, recreation (bathing) and estuarine biodiversity and what are the preferred management strategies to improve water resource and ecological status.
- Pinios: The Pinios Basin (9500 km^2) is in Thessaly, Greece's most productive agricultural region, and is a WFD Pilot River Basin as well as a priority region for pilot projects aimed at halting desertification in Europe (DG-ENV Desertification 2010 and 2011). A hydrological model will link multiple water quality stressors to benthic macroinvertebrate data, and the consequences for management options related to the improvement of natural hydrological cycles, water supply and water purification will be appraised.
- Beyşehir: Lake Beyşehir and its catchment (4080 km^2) represent a typical Mediterranean middle-Eastern basin, dominated by irrigated cropland. Hydrological data span 50 years, augmented by physical–chemical, fish, macrophyte and phytoplankton data from the last two years. Lake levels oscillate already during wet-drought conditions, and these effects will be exacerbated by climate change, abstraction for irrigation, and excessive groundwater use. Eutrophication and its effects on biological communities occur all year round. MARS will examine the conflicting demands of water use for crops, people and ecosystems in this setting and will investigate how these multiple stressors can be effectively reconciled with good water resource and ecological status outcomes. Particular attention will be given to surface water–groundwater interaction and the optimal use of all water resources within the catchment.
- Lower Danube: The 800,000 km^2 Danube River Basin extends across 19 countries, of which 14 are contracting parties of the ICPDR. The Lower Danube is occupied mostly by Romania, including the Danube Delta which is important for tourism. Flood risk and water quality are already major problems, exacerbated by increasing urban land use, floodplain development, reduced river-bed capacity and deforestation. Hydromorphological pressures include 255 reservoirs, 80% embankment on the lower reaches, regulation (6600 km) and abstraction (138 significant abstractions). Flow and quality alterations will be modelled, and land use change scenarios tested in order to evaluate the implications for ecosystem services within the Basin.
- Thames: As the catchment draining the UK's capital city, the Thames (9948 km^2) is highly monitored for physico-chemistry, fish, macroinvertebrates, macrophytes and microalgae. Groundwater in the basin is extensively monitored for quality, and level. Stressors include agricultural nutrients, organic pollutants, endocrine disrupting compounds, nanoparticles and metals, invasive species and pathogens exacerbated by relatively low rainfall, extensive regulation, high and growing water demand and regular droughts. Linked abiotic and biotic models

Fig. 4. MARS case study river basins.

will be used to quantify response to multiple drivers using mechanistic and Bayesian approaches and so to characterise i.) the effects of climate change, land use changes and population growth on response surfaces describing nutrients stress, toxic compounds, temperature and pathogens, and ii.) the impact of a range of management scenarios on environmental services and outcomes under various multistressor conditions.

- Regge and Dinkel: This lowland catchment (1350 km^2) contains >1000 sites with biotic data and 500 with physical–chemical data, whilst groundwater monitoring is amongst Europe's most extensive. Agriculture has caused large hydromorphological alterations, base flow reductions and water quality deterioration. Droughts and groundwater abstraction lead to water scarcity affecting biological quality. Work will focus on surface–groundwater interactions, ecological flows, drainage and irrigation strategies, Natural Water Retention Measures and habitat assessment for selected biological groups.
- Odense: This lowland catchment (1100 km^2) includes rivers, lakes and transitional waters where the main stressors are eutrophication, pesticides from agriculture, droughts and groundwater abstraction leading to water scarcity. Ecological effects are exacerbated by extensive channelization, dredging and macrophyte removal. Mechanistic models will examine abiotic effects on phytoplankton, zooplankton, submerged vegetation and fish to understand consequences for key ecosystem services (water supply, nutrient retention, recreation and angling). Climate change and land use scenarios will be applied, and nutrient and sediment retention using new ten metre riparian buffers will be investigated as these will become mandatory from 2012 onwards.
- Elbe, Havel and Saale (148,268 km^2): The Havel and Saale catchments are parts of the extensively monitored lowland Elbe basin. Major stressors include eutrophication, hydromorphological alterations by damming, land use regulation structures (e.g. groynes), loss of bank vegetation and intensive shipping. Model applications will focus on services for flood risk reduction, fisheries, recreation and water purification (N and P-retention).
- Ruhr (4485 km^2): The Ruhr catchment is dominated by forestry and agriculture in the upper parts, and urbanisation in the lower parts. Biological data are extensive, hydromorphological data are available for each 100 m stretch and fine sediment inputs have been modelled for all sections. Models for nutrients and discharge will address ecosystem services including self-purification and biodiversity protection using empirical dose–response relationships to examine future scenarios of land use and restoration.
- Drava: This Alpine basin (2600 km^2) has good water quality, but hydropower and associated morphological alteration are key stressors affecting fisheries and recreation. Based on extensive data, empirical models will link hydromorphology to fish, invertebrates and phytobenthos. Faced with new hydropower plants, scenarios will address the conflicting ecosystem service effects on fisheries, recreation and hydropower.
- Welsh basins: The extensive Welsh river basins (4000 km^2) range hierarchically from continuously monitored experimental catchments to hundreds of other sub-catchments throughout Wales with extensive biological and physico-chemical data from 1981

to present that in combination allow factorial investigations of stressor combinations in time and space. Linking with large ongoing programmes (Duress project), scenarios and modelling will explicitly address links between land-use, climate and ecosystem service resilience (fish production, water quality regulation, decomposition and cultural values).

- Vansjø-Hobøl: This small lowland, lake-dominated catchment (690 km^2) is mostly agricultural and affected by diffuse pollution. Lakes are affected by regulation and eutrophication that cause cyanobacteria and nuisance algae. Empirical studies will link macrophytes, macroinvertebrates and fish to nutrients and temperature, whilst lake process models will address consequences for chlorophyll a.
- Otra: This mountain to fjord catchment (3740 km^2) provides hydroelectric power, salmon habitat, recreation, and protected habitat for important biota. Stressors include hydropower, acidification, metals, invasive species and nuisance macrophytes. Extensive and long-term data on hydrology, hydrochemistry and biology from the 1960s to the present allow empirical and mechanistic relationships between stressors and status of fish and benthic invertebrates.
- Kokemäenjoki: The Kokemäenjoki basin (27,040 km^2) includes highland and lowland rivers and lakes that become transitional waters. Data are available for all biological groups on rivers and lakes, where stressors combine eutrophication and pathogens from agriculture, hydromorphological change from hydropower and flood defence, climate change and brownification. Dynamic and hybrid modelling will assess stressor effects from forestry and agriculture on macrophytes, phytoplankton, concentrating particularly on 'brownification'.
- Võrtsjärv: Data on Lake Võrtsjärv and its lowland catchment (3104 km^2), in particular on lake fish, invertebrates and macrophytes, reach back to the 1950s. Lake models are operational and include surface–groundwater interfaces. Stressors on Lake Võrtsjärv include level fluctuations affecting ecosystem structure and CO_2 emissions, whilst catchment agriculture results in eutrophication. Climate change is further affecting hydrology, water level, temperature, ice regime, brownification and carbon balance. Large commercial fisheries are both ecosystem service and important pressures. Modelling within MARS will focus on climate change effects on water temperature and ice regime, brownification and carbon balance alterations.

At the *European scale*, the users targeted are European and national agencies and authorities responsible for international river basins. We will address interactions amongst stressors, and between stressors and indicators, which will be analysed and predicted across broadly defined regions and for Europe as a whole. Work will be based on existing databases such as WISER, BioFresh and EFI + and existing modelling tools (e.g. MONERIS, GlobWB, GREEN, InVEST), but new explanatory variables (e.g. water abstraction, modelling of pesticide/nutrient entry) and response variables (e.g. functions and services) will be added. We will address broadly defined quality and quantity dimensions of freshwater and transitional ecosystems with an overview analysis, emphasising selected indicators (e.g. fish as main providers of ecosystem services) and water types of general relevance to international water policy and management (e.g. large rivers) in more specific tasks:

- We aim to provide a Europe-wide overview of stress intensity, status and service provision at a coarser resolution than in the catchment case studies, but at a more comprehensive coverage. We will take advantage of new Europe-wide data sources such as those compiled by the European Environment Agency and BioFresh (www.freshwaterbiodiversity.eu).
- Large rivers are targeted in a specific task as they are challenging for water resource management but have been poorly represented in the previous EU-funded projects. Coherent data sources are now available to enable the analysis of interactions between multiple stressors, biota and processes/services, in particular the large river intercalibration dataset and the results of the Joint Danube Survey.
- Lakes are targeted in a specific task as another ecosystem group of large importance for which extensive, high quality data have recently been compiled by the EU-funded project WISER and in the framework of the intercalibration exercise. Lakes and reservoirs provide essential ecosystem services such as recreation and water supply. The statistical approaches being adopted for analysing lakes (e.g. quantile regression) are particularly relevant to addressing landscape-scale management and policy issues, for example the proportion of lakes in a region that will achieve good status under particular European policy scenarios. This is distinct from the questions related to individual water body management considered at the water body and catchment scales.
- A specific task on fish in rivers, lakes and estuaries reflects the importance of European fish as indicators of ecosystems health and of fisheries and recreational angling in aquatic ecosystem services. Comprehensive and high quality data sets for rivers (resulting from EFI +; www.efi-plus.boku.ac.at), lakes (WISER; www.wiser.eu), estuaries (WISER), and freshwaters in general (BioFresh; www.freshwaterbiodiversity.eu) offer new opportunities to compare the response of fish and associated services to multiple stressors across ecosystems and in particular to identify thresholds that impede connectivity for economically important migratory species.

Tools produced will include a GIS-based web Atlas of Europe-wide stressors, quality and services and a scenario development tool to appraise the outcomes of different models acting at the European scale. All maps will be developed within the WISE concept (Water Information System for Europe, http://water.europa.eu).

Reponses on different scales will be made comparable by using common "benchmark indicators" and scenarios. Based on the experiments at the water body scale, the catchment models and the Europe-wide analysis we will synthesise multiple stressor–response relationships across scales, comparing the strength and trajectories of relationships to identify indicators of water quantity, water quality, ecological status and ecosystem services using meta-analysis, response surfaces and Bayesian methods. We will examine whether the combined effects are synergistic, additive or antagonistic. Using both the strength and the shape of the responses we will identify sentinel indicators and thresholds of rapid response. The synthesised responses of functional indicators of biota, habitats or water-body types will also be used to identify which attributes at the water-body or landscape scale either increase or decrease exposure or sensitivity to multi-stressor conditions. The synthesis will bring together information on exposure and sensitivity to stressors with collated data on the importance and value of associated services to develop a risk classification of the European waters: rivers, lakes, transitional waters and groundwaters. Through the results of a structured questionnaire sent to river basin managers and through end-user workshops, we will synthesise current practice in River Basin Management and evaluate how effectively the elements of the MARS conceptual model are operationalised and integrated in existing RBMPs. This synthesis will help to identify where integration could be improved and gaps in knowledge or tools.

Tools produced within EU-funded projects face substantial challenges: Particularly at the regional scale, users rely on tools in national languages; a long and intense implementation phase is required to train and to convince the users; there is a compromise between tools being too specific (thus requiring complex adaptations for each catchment) and being too general (reproducing information already available). For these reasons, few tools produced by scientists have been adopted extensively by users. Positive examples are large-scale models such as MONERIS, catchment models such as INCA, some biological assessment systems such as EFI + (fish) and invertebrate-based assessment systems resulting from the projects AQEM and STAR. Decision support systems, however, have rarely been put into practise, as stressor combinations, stress intensities and demands for water management tools differ amongst and within the European states. As pointed out in the Blueprint to Safeguard Europe's Water Resources, there is no "one-size-fits-all" solution for integrated water management. Water managers need a tool box, where current knowledge is synthesised, best-practice is highlighted and practical tools are available for improved water management at water body, river basin, and European scales and to which databases from various sources can easily be linked. Against this background, and based on data and results from both MARS and related projects, MARS will use a strategy for tool development with the following components:

- As much as possible, we will build on existing tools or prototypes, which are already applied by a wide range of users. To these, we will add new components developed in MARS. Besides advantages for implementation, interoperability and re-use of software products offer significant cost reductions.
- The envisaged products will be jointly refined in dialogue with users, i.e. river-basin districts, environment agencies and European organisations, several of which are included as "applied partners" amongst the participants. This dialogue has already started in the proposal preparation phase and shaped some of the focus of the project.
- Overall, MARS will generate two product lines across the three geographical scales: (1) an information system and (2) diagnosis, analysis and predictive tools. The information system will be based on a wiki, transforming complex scientific results from MARS and other projects into simple facts, but at the same time allowing access to the original, more detailed information. The analysis and predictive tools will mainly link already existing systems and place them into the multiple stressor framework, whereas the diagnostic tools will draw extensively on the results of this project.

More specifically, MARS will produce the following tools:

- Web-based Information System: The starting point will be the wiki system developed in the REFORM project (http://www.reformrivers.eu). A wiki is a website which allows its users to add, modify, or delete content via a web browser. This system will be reconstructed, improved and extended by geographic elements (google earth or similar) to address multiple stressors and different water categories. A set of benchmark indicators addressing water quantity, water quality, ecological status, ecosystem functioning and ecosystem services will be presented. In addition, the tool will give aggregated information on multistressor conditions and their consequences on the status of water bodies in the European river basins. Cornerstone of the Information System will be a database on dose–response relationships resulting from the experiments, the catchment case studies and the Europe-wide analysis. Finally, it will contain information on tools for River Basin Management, exemplified at the river basin case studies; this section will present catchment characteristics, assessment of the multistressor conditions, predicted effectiveness of the measures studied, socio-economic benefits and the tools suited for assessment and prediction.
- Diagnostic tool for water bodies: We will develop a tool to diagnose changes in water quantity, chemical and ecological status of water bodies based on observed data. The starting point will be the CADDIS tool developed and maintained by the US-EPA, and the Eco-Evidence database and analysis tool developed by the eWater cooperative Research Centre in Australia, as well as related activities of the international Eco-evidence group (Norris et al., 2012). The tool will statistically analyse recent observed data, to derive trends and possible future changes on stressors and their effects on indicators. The tool will provide a guide for determining the causes of detrimental changes and undesirable biological conditions observed in aquatic systems. The CADDIS/Eco Evidence tool will be adapted to the European conditions. The tool will visualise a stepwise approach to detect detrimental changes using (benchmark) indicators and to identify possible causes at the water body scale.
- Combining abiotic and biotic models for River Basin Management planning: European water managers are currently using a wide range of tools in River Basin Management. In this task we will provide guidance on the use of modelling tools, in particular the coupling of "abiotic" and "biotic" models. Selected models will be improved, by incorporating additional stressor types or by including dose–response relationships between multiple stress and indicators. Several river basin case studies will be used to validate the improved models (Regge and Dinkel, Elbe, Otra/ Vansjø-Hobøl, Kokemäenjoki, Odense, Sorraia; see Table 2). The individual models will be connected to the MARS conceptual framework (Fig. 1) to structure the discussion between modellers and decision makers.
- Scenario analysis tool at the European scale: We will develop a quantitative approach to improve comparability of River Basin Management plans between regions and countries. Central element will be a Europe-wide data base that will include monthly input data on a scale of 250 km^2 (land use, nutrient emissions, water balances, etc.), groundwater and surface water flow and quality, and information on hydromorphology, habitat structure and biota. We will use GlobWB (water quantity) and MONERIS (water quality) to model multistressor conditions. Both modelling tools have been applied and tested on a European level, but not yet in a combined way. The tools will be linked according to the principles of open Model Interface and combined with a Bayesian network model incorporating stressor–response functions at the European level. The resulting tool will be applied to scenarios. This will result in a comprehensive framework describing the linkages between the climate, the water availability, the nutrient fluxes and the management options to quantify and evaluate changing multi-stressors and the related aquatic responses.

For *policy support and dissemination*, we will interact with user groups to precisely define product needs, to disseminate results and to advise implementation and revision of the WFD and the Blueprint to Safeguard Europe's Water Resources. Regional end users (i.e. river basin authorities) will be involved through the river basin case studies and through the developed multiple stressor tools. On a European scale we will interact with the relevant CIS groups (ECOSTAT, Floods, Water scarcity and Droughts, Groundwater, Climate Change and Water, Agriculture and Water, Science-Policy Group) and with MAES (Mapping and assessment of Ecosystem Services) by contributing to the guiding documents produced by them. Finally, it will channel the scientific input for the revision of the Water Framework Directive, which is due in 2019, e.g. how to integrate status, risk assessment and ecosystem services.

6. Conclusions

With the adoption of the first RBMPs, the almost completed intercalibration exercise and the publication of the Blueprint to Safeguard Europe's Water Resources, water management in Europe are now entering a new phase. Whilst a first assessment of Europe's water bodies using intercalibrated methods has been performed and Programs of Measures have been derived, the emerging challenges include implementing the measures, regarding multiple pressures in River Basin Management, taking account of ecosystem services and better linking the WFD to other policies in the water, energy and agricultural sectors. These challenges are similar for all European countries, but solutions differ regionally, as different stressor combinations are of relevance. Against this background, there are good reasons to address these challenges in a large international project. Sixty percent of the EU's territory lies in transboundary river basins. Many RBMPs therefore have a strong international component. Even within single RBMPs, tools for quality assessment, for deriving measures and for predicting their success need to be applicable in various countries. Though stressors differ, the principal challenges for water management are quite similar in the European countries. There is a great potential to learn from each other, and projects like MARS will provide a platform to facilitate this learning process. MARS aims at covering the most relevant stress combinations affecting water resources in Europe. As these differ strongly between regions, partners from many countries are required, addressing driver/stressor combinations such as hydropower generation (Northern and Alpine regions), intense agriculture and urban land use (Central Europe), and water abstraction and climate change (Southern Europe). Learning from experience, new tools (e.g. models, assessment methods) for River Basin Management should be developed in a way that enables applicability across Europe. In case of indicators for ecological status, more than 300 methods were developed throughout Europe, requiring a complex, time consuming and very expensive intercalibration process (Birk et al., 2012). To some degree this was unavoidable, as aquatic biota strongly differs between European ecoregions. There is still a need to improve many of the existing methods or modify the class boundaries to account for impacts of additional stressors. There may also be a need to reduce the number of methods to improve comparability of status assessments across Europe. Moreover, methods for assessing ecosystem services have to be included, which should be based on common principles across Europe. In this way, MARS could provide more harmonised or standardised methodologies. This is of particular importance for preparing the revision of the WFD in 2019.

Acknowledgements

This work is part of the MARS project (Managing Aquatic ecosystems and water Resources under multiple Stress) funded under the 7th EU Framework Programme, Theme 6 (Environment including Climate Change), Contract No.: 603378 (http://www.mars-project.eu).

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