Managing the effects of multiple stressors on aquatic ecosystems under water scarcity

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Introduction

Freshwater systems are under threat by a variety of stressors (e.g., organic and inorganic pollution, cover change, water abstraction, land use). The joint occurrence of many stressors (chemical, geomorphologic, biological) under water scarcity may produce novel and unfamiliar synergies and effects of unknown consequences. Therefore, it is crucial to understand deeply how water scarcity interacts with other stressors in freshwaters and to convey this information to managers, stakeholders and policymakers in order to minimise impacts, to adapt to oncoming changes, and to improve our management and policies.

Challenges

- Understand the mechanisms of multiple stressors and their potential synergistic linkages
- Analyse the effects of multiple stressors on biodiversity and ecosystem functioning
- Analyse the implications on socio-economic development
- Understand the role of water scarcity and the relationships between biota and stressors in this condition
- Develop a modelling framework to assess scenarios affecting availability, quality and demand of water
- Achieve a better understanding of how current management practices and policies could be improved by identifying their main drawbacks and alternatives

Approach

To answer the integrated questions posed within GLOBAQUA, a cross-scale approach was applied in six representative basins: Ebro (Spain), Sava (Slovenia, Croatia, Bosnia and Herzegovina, and Serbia), Evrotas (Greece), Souss Massa (Morocco), Anglian (UK) and Adige (Italy). These basins encompass a rich set of socio-ecological conditions and a wide geographic coverage (forested mountainous areas, highly populated regions relying on water transfers, agricultural areas and industrial clusters), and a wide geographic coverage, but are all affected by water scarcity either due to climatic or societal reasons. Each case study focuses on a specific set of stressors to illustrate different management scenarios. The basic research element was the kilometre-scale river reach, including the river channel, the alluvial plain and associated groundwater.
Conceptual framework

GLOBAQUA structure offers a strong interdisciplinary team, enhancing and improving the applied component of the proposal and facilitating the knowledge transfer between the research and stakeholder sectors. The project was organised through four main scientific modules:

- **Module 1, STRESSORS:** was defined to understand the mechanisms behind the multiple stressors acting in each case study.
- **Module 2, RECEPTORS:** analysed the effects of the stressors on biodiversity and ecosystem functioning.
- **Module 3, IMPLICATIONS:** studied the implications for ecosystem services and socio-economy.
- **Module 4, ENVIRONMENTAL MANAGEMENT:** dealt with relevant issues associated to the impact of multiple stressors on water quality, quantity, and ecosystems, as well as on the potential implementation of the major findings on European policy.

Consortium

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Multiple-stressor mechanisms in European freshwater systems

Introduction

European freshwater systems are threatened by organic and inorganic pollution, geomorphological alterations, climate and land use change, water abstraction, invasive species or pathogens; often, such threats act simultaneously to create multiple-stress situations. Water scarcity, a key stressor itself, adds adversely and exacerbates the interactions between other stressors. The STRESSORS Module is designed to understand the mechanisms and connections of multiple stressors in the GLOBAQUA case-study river basins.

Challenges

- Gather and compile data generated at European level and make them publicly available
- Build integrated climatic and socioeconomic scenarios to determine and connect the drivers of change and their impact on land and water management
- Exploit the connection between drivers and water quality parameters on the chemical and ecological status of water bodies and on their ecosystem functionality in multiple-stress conditions
- Identify sediment/pollutant related stressors and link these to land use, hydrology and climate to account for pressure-stressor relationships
- Characterize and investigate the occurrence of selected pollutants in water, sediments and biota of the case-study basins under different hydrological and multiple-stress conditions

Activities

1. Integrate reference data with climate and socioeconomic projections to simulate changes in land use and water management
2. Employ modelling to improve hydrological process understanding
3. Determine, compare and link trends in water quality parameters of 3 large Mediterranean basins to the drivers of change
4. Determine the main factors and relationships that drive sediment fluxes at the basin scale and assess particle related pollutant concentrations and fluxes based on event sampling campaigns
5. Create and load an internal Relational Data Base and Data Repository to provide historical data and select external data sources to be accessed from the Water-Hub
6. Audit, select, process and downscale climate projections to the case study scale
7. Develop proxies relating stressors to land use, climate, hydrology and other factors
8. Perform 2 general sampling campaigns and 2 event-driven field samplings (Sava, Evrotas and Adige) and a fish sampling campaign (Sava)
9. Investigate the effect of environmental factors on in-stream attenuation of micro-contaminants
10. Study biodegradation, photolysis, and adsorption/desorption processes of pollutants under different weather conditions

Approach

This module aims to understand the mechanisms and interactions of multiple stressors by: (i) collecting and distributing existing information and experimental data; (ii) providing climatic and socioeconomic drivers to set the boundary conditions for impact models; and (iii) analysing surface and groundwater hydrological patterns, sediment and pollutant transport, quality of physical habitat and fate of inorganic and organic pollutants.
Scientific results

An in-depth regional climate model (RCM) analysis reveals a substantial increase of water scarcity in most case-study basins. Trends in water quality can be attributed to varying drivers and result from climate, as well as population and tourism or agricultural change. Field campaigns, event based sampling and novel chemical analyses of water, sediment and biota offer new ways to evaluate the potential impact of pollutants on aquatic ecosystems under multiple stressor conditions.

Key outcomes

- Homogenized data and information systems are crucial for the success of interdisciplinary research
- Climate change and intensified land use increase water scarcity and exacerbate multi-stress situations
- The effect of climate change on hydrological fluxes changes spatially, thereby calling for fine grid simulations able to capture such variability
- Sediment flux is an important factor in multi-stress analysis as it may contribute to habitat-, hydrology- and pollutant-related stressor/pressure relationships
- Results of chemical analyses illustrate new possibilities to evaluate the potential impact of pollutants on the environment and biota under multiple stressor conditions

Recommendations

- Well-equipped and carefully managed monitoring networks are highly important to assess the complex relationship between stressors and water quality parameters
- High-resolution spatio-temporal data are essential as input for detailed hydrological modelling
- Sediment yield is an important factor in multi-stress analysis; efforts to derive data sets on a pan-European scale should be supported
- Analyzing suspended sediments or bulk water samples proofs reliable with respect to pollutant related stressor identification
- Climate and socioeconomic change must be integrated to soundly assess impacts on freshwater systems
- Programmes of measures must be adapted to dynamically changing climate and land use
- Especially due to flood event exposure, measures must be taken to prevent contamination of the riparian soil by agricultural and industrial activities
- Due to the extremely high Hg, MeHg and dioxins concentrations found in predator fish, their consumption in the lower Sava stretch is not recommended or should be restricted to minimum

References

Buendía C. et al. (2016) An appraisal of the sediment yield in western Mediterranean river basins. Science of the Total Environment 572: 538–553
Diamantini E. et al. (2017) Driver detection of water quality trends in three large European river basins. Science of the Total Environment 612-613: 49-62
Huber Garcia V. et al. (2018) Deriving spatially explicit water uses from land use change modelling results in four river basins across Europe. Science of the Total Environment (submitted)
Gampe D. et al. (2016) Using an ensemble of regional climate models to assess climate change impacts on water scarcity in European river basins. Science of the Total Environment 573:1503-1518
Giuilivo M. et al. (2017) Occurrence of halogenated and organophosphate flame retardants in sediment and fish samples from three European river basins. Science of the Total Environment 586-587: 782-791
Milačič R. et al. (2017) Potentially toxic elements in water and sediments of the Sava River under extreme flow events. Science of the Total Environment 605-606: 884-905
Schweitenkamp M. et al. (2017) A parsimonious approach to estimate PAH concentrations in river sediments of anthropogenically impacted watersheds. Science of the Total Environment 601–602: 636-645
Viglisch O. et al. (2018) Uncertainty of modelled flow regime for flow-ecological assessment in Southern Europe. Science of the Total Environment 616:10528-10547
Multiple stressors effects on biodiversity and river ecosystem functioning

Introduction

Conjoint occurrence of stressors under water scarcity produces novel and unfamiliar synergies. The RECEPTORS Module within GLOBAQUA aims to assess the effects of multiple stressors on the biodiversity of bacteria, algae, macrophytes, invertebrates and fish and on functioning of river ecosystems.

Challenges

- Clarify relationships between stressors and biodiversity, and ecosystem function
- Improve experimental design in data collection for better modelling outputs
- Predict changes in functional diversity for aquatic communities under stress
- Identify the best ecosystem functional descriptors to assess stressors effects
- Provide information for analyses of ecosystem services

Approach

The effects of different pressures on biodiversity and ecosystem functioning have been tested combining the analysis of historical available data, on-site surveys, as well as controlled field and manipulative laboratory experiments. Potential and real effects of multiple stressors are reported in each case-study basin. The ecosystem functions selected operate at different spatial and temporal scales, and are easily linked to key ecosystem services.

Activities

1. Two field samplings in the case-study basins to collect biological samples
2. Identification of the environmental pressures in the case studies and analyses of their effects on biodiversity
3. Risk assessment of non-native species dispersion, establishment, and associated impacts
4. Occurrence and dynamics of pathogens in relation to different pressures
5. Identification of species traits in the biological communities affected by single or multiple stressors
6. Ecotoxicity of water and sediments in the case-study basins
7. Definition of a toolbox to measure and assess ecosystem functions
8. Analysis of the effects of multiple stressors on the degradation of natural and human-produced organic substances
9. Assessment of the effects on nutrient retention and metabolism associated to water scarcity and other stressors
10. Field and laboratory experiments to assess the effects of stressor interactions on biodiversity and ecosystem functioning
Scientific results
Hydrological stress and urban and agricultural land uses determine changes in richness and abundance of biological groups in the case-study basins. Invertebrate species traits and their combination determine stressor tolerance of invertebrate communities and certain combination of traits are stressor-specific. Different experiments have tested the effects of water abstraction and water scarcity and pollution.

Key outcomes
- Results on biodiversity indicators and ecosystem processes and their response to multiple environmental stressors provide useful information to model and evaluate ecosystem services
- Knowledge on the dispersion of invasive alien species contributes to the implementation of the EU regulation on prevention and management of the introduction and spread of these species
- Modelling and experimental approaches help linking specific disturbances with their responses, making predictions and improving recommendations for managers
- Ecosystem functions respond to environmental stressors in contrasting ways, so there is no one-fits-all-situations-type indicator
- A new toolbox developed to measure key ecosystem processes for routine monitoring contributes to a more dynamic view in river research and management

Recommendations
- River ecosystems should be assessed by both their structure and functions
- Stressors and receptors (community, ecosystem processes) should be studied simultaneously to better explore and evaluate ecosystem responses in a multi-stressors context
- Functions potentially most affected by the existing environmental pressures and those most interesting for ecosystem services should be carefully identified
- Potentially non-linear effects are critical when forecasting the consequences of environmental change

References
Kalogianni E. et al. (2017) Combined effects of water stress and pollution on macroinvertebrate and fish assemblages in a Mediterranean intermittent river. Science of the Total Environment 603-604: 639-650
Karanazas I. et al. (2017), Assessing the ecological effects of water stress and pollution in a temporary river - implications for water management. Science of the Total Environment (in press)
Kuzmanovic M. et al. (2017) Environmental stressors as a driver of the trait composition of benthic macroinvertebrate assemblages in polluted Iberian rivers. Environmental Research, 156, 486-493
Mondy C. P. et al. (2016) Life-history strategies constrain invertebrate community tolerance to multiple stressors: A case study in the Ebro basin. Science of the Total Environment 572: 196-206
Panov V.E. et al. (2009) Assessing the Risks of Aquatic Species Invasions via European Inland Waterways: from Concepts to Environmental Indicators. Integrated Environmental Assessment and Management 5:110-126
Sabater S. et al. (2016) Shared effects of organic microcontaminants and environmental stressors on biofilms and invertebrates in impaired rivers. Environmental pollution 210: 303-314
Schima D. et al. (2017) Functional diversity: a review of methodology and current knowledge in freshwater macroinvertebrate research. 787: 27-44
van Schiller D. et al. (2017) River ecosystem processes: a synthesis of approaches, criteria of use and sensitivity to environmental stressors. Science of the Total Environment, 596-597: 465-480
Module 3: IMPLICATIONS

Participatory valuation of Ecosystem Services (ES) aligned with The Economics of Ecosystems and Biodiversity (TEEB) approach

Introduction

People rely on ecosystems to provide many beneficial services. The beneficiaries of ES and those who own and manage landscapes that produce them play a key role in ES analysis. They identify the services they receive from a water body and its catchment. Non-monetary valuation relies on perception and values of these stakeholders. The ES framework aims to support informed decision making by explicitly linking the goods and services produced by functioning ecosystems to human well-being.

The IMPLICATIONS Module aimed to valuate ESs in the case-study basins, by means of integrated modelling, development of methodologies for socioeconomic management, and economic valuation.

Challenges

- Natural capital valuation
- Ecosystems assessment
- Stakeholder participation
- Evidence-based decision making

Activities

1. Policy review and appraisal
2. Ecosystem Service identification and quantification
3. Scenario development (Sustainable and Myopic) and downscaling to case study level
4. Ecosystem Service prioritisation and assessment
5. Preliminary assessment of a monetary value to a change in the provision of ESs

Approach

The research adopted a mixed approach using both quantitative and qualitative methods.

ESs such as water provisioning, erosion control, waste treatment, water purification, and habitat for species were quantified in biophysical units using the InVEST model; while stakeholder workshops across all six case study regions were carried out in order to identify the most relevant for each particular river basin. Finally econometric methods were used to determine the value of these services under various scenarios.
Scientific results

While the most relevant ESs across all case studies resulted as water provisioning, soil erosion, habitat for species and recreational services, it was found via the downscaling process (based on literature and data acquired from stakeholders) that value attributed to the different ESs varied from one river basin to another. The policy appraisal revealed inconsistency between the key ES threats and pressures to be addressed via the Programmes of Measures proposed within the various River Basin Management Plans.

Key outcomes

- ESs are not currently appropriately considered within the WFD
- The link between key ESs, their threats and the pressures addressed by the relevant policy is undefined
- Regionally appropriate methods for valuing ESs are currently not implemented
- Stakeholder insight and contribution to the valuation process is vital

Recommendations

For Policy Makers:

- Greater emphasis needs to be placed on embedding ESs within all relevant natural resources management policy
- One-size-fits-all valuation methods will fail to capture the eccentricities at lower scales of analysis and assessment, as such downscaling must comprise an essential part of the process
- Stakeholder participation is key and the relevant beneficiaries need to be drawn into the policy making process in a more meaningful manner than mere consultation

For River Basin Managers:

- Greater capacity and awareness must be developed in the application of natural resource valuation methods for optimal resource management, e.g. through training workshops
- More open lines of communication and dialogue with beneficiaries within the river basin districts is required; not only to aid implementation of policy directives, but also to serve as a feedback loop to inform bottom-up policy intervention and improvements

References

Brauman K.A. et al (2014) Ecosystem Services and River Basin Management. In: Brils, J., Brack, W., Müller-Grabherr, D., Niegel, P., Vermaat, J.E. (Eds.) Risk-Informed Management of European River Basins Series: The Handbook of Environmental Chemistry, Vol. 29: Springer Berlin Heidelberg

Brouwer R. et al. (2013) A synthesis of approaches to assess and value ecosystem services in the EU in the context of TEEB. Report to the European Commission, 15 May 2013

Christie M. et al. (2012) An evaluation of monetary and non-monetary techniques for assessing the importance of biodiversity and ecosystem services to people in countries with developing economies. Ecological Economics 83: 67-79

Coninx I. and Luttik J. (2013) Contribution of natural heritage to regional economic prosperity: preliminary assessment and an introduction to the WEGAN tool. Wageningen : Alterra Wageningen UR, (Alterra-rapport 2423)

Morris J. and Camino M. (2011) UK National Ecosystem Assessment. Working Paper Economic Assessment of Freshwater, Wetland and Floodplain (FWF) Ecosystem Services. School of Applied Sciences, Cranfield University Bedford, UK

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Introduction

EU freshwater policy contains other elements, but the Water Framework Directive (WFD) is of over-arching importance. The Directive was adopted to replace traditional management practices, predicated upon the command and control paradigm that looked at pressures in isolation and reduced environmental systems to their constituent elements when setting specific water objectives. The Module ENVIRONMENTAL MANAGEMENT aims to deliver a better understanding of how current management practices and policies could be improved by identifying the main drawbacks and alternatives, and identifies opportunities and recommendations for improving policy making and implementation. It also aims to achieve an integrated representation of multiple stressors under water scarcity and their impacts on water ecosystems and society, moving from the case-study basins to the European scale.

Challenges

- Review the current EU water policy framework to make the connection between the occurrence and impact of multiple stressors under water scarcity and water policy implementation
- Review the WFD implementation and identify constrains for adaptive and sustainable water management
- Identify areas and policy needs where GLOBAQUA research could deliver benefits
- Deliver a solid assessment framework to systematically consider all relevant stressors and pressures in river basins, towards achieving the environmental objectives of the WFD
- Make the connection between different scientific disciplines, to feed the practice of river basin managers

Activities

1. Development of the conceptual assessment framework and online optimization tool
2. Development of a system of pan-European pressure indicators, including uncertainty and sensitivity assessment of the indicators
3. Application of the framework in 4 case-study basins and generalization to European scale
4. Assess how current EU water policy and management practices are dealing with complex multiple stressor situations and water scarcity
5. Evaluate the effectiveness of the current EU water policy implementation
6. Investigate the reasons that might have limited the effectiveness of the WFD
7. Elaboration of policy/regulatory oriented documents as recommendations for adaptive and sustainable water management policies based on the GLOBAQUA findings

Approach

An integrated assessment framework was established to identify the key pressures determining departures from the desired status of water bodies. Reduction targets will be identified for individual pressures after the incorporation of socioeconomic possibilities and willingness to commit, to facilitate the development of Programmes of Measures (PoMs). In addition, the reasons why the WFD was introduced were reviewed to establish the right benchmark for the policy analysis (Figure 4.1). Consecutively, the project assessed how effective the WFD implementation has been in addressing these, and the extent to which it has contributed to the limited delivery and the delays in water quality improvements. Outputs from the analysis were used to establish the policy needs where GLOBAQUA research could deliver benefits.

Figure 4.1 The evaluation of the Water framework Directive’s effectiveness in implementation
Scientific results

Findings from the policy analysis identified the deviation from the WFD’s intent and methodological approach as a fundamental problem with its implementation (Figure 4.2). Misunderstandings with the definition and the role of ecological status in the WFD process were identified as a major barrier to the harmonized transposition of the Integrated River Basin Management (IRBM) paradigm.

Key outcomes

- Concept paper on the integrated framework and an upcoming web-based tool
- System of pressure indicators at EU scale, tested in the case-study basins
- The types of uncertainty that need to be taken into account in water policy were established and recommendations were provided for different adaptive management regimes
- Systems thinking in the implementation of the WFD was identified as a pre-requisite to delivering water quality improvements

Recommendations

- Enabling a paradigm shift through the harmonised transposition of the IRBM paradigm is the way to account for multiple pressures interactions and to address complexities bounded in water management
- Shifting from element compliance to system understanding
- Improving transparency, interdisciplinarity and stakeholder engagement in the decision-making process is key to address complexities and manage uncertainties
- More attention should be given to collaborative knowledge sharing and production between all actors involved
- Promote the integration of ecosystem services in the policy implementation process
- Organise a decision support system with the right balance of accounting for socioeconomic preferences and willingness to commit, and quantitative models to address questions of fact, while avoiding technocratic approaches
- Consider the multi-dimensionality of measures and the multiple benefits they may bring in

Figure 4.2 The departure from the Water framework Directive’s systemic intention and methodological approach

References

Pistocchi, A. et al. (2017) An integrated assessment framework for the analysis of multiple pressures in aquatic ecosystems and the appraisal of management options. Science of the Total Environment 575: 1477–1488
Vlachopoulou, M. et al. (2014) The potential of using the Ecosystem Approach in the implementation of the EU Water Framework Directive. Science of the Total Environment 470–471:684–694
Voulvoulis, N. et al. (2017) The EU Water Framework Directive: From great expectations to problems with implementation. Science of the Total Environment 575:358–366
