



Managing the effects of multiple stressors on aquatic ecosystems under water scarcity. The GLOBAQUA project



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HIGHLIGHTS

- Information on the effects of water scarcity on river ecosystems is necessary.
- Multiple stressors should be considered.
- The GLOBAQUA project is designed to satisfy these demands.
- The general structure of the EU FP-7 project GLOBAQUA is outlined.

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ABSTRACT

Water scarcity is a serious environmental problem in many European regions, and will likely increase in the near future as a consequence of increased abstraction and climate change. Water scarcity exacerbates the effects of

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multiple stressors, and thus results in decreased water quality. It impacts river ecosystems, threatens the services they provide, and it will force managers and policy-makers to change their current practices. The EU-FP7 project GLOBAQUA aims at identifying the prevalence, interaction and linkages between stressors, and to assess their effects on the chemical and ecological status of freshwater ecosystems in order to improve water management practice and policies. GLOBAQUA assembles a multidisciplinary team of 21 European plus 2 non-European scientific institutions, as well as water authorities and river basin managers. The project includes experts in hydrology, chemistry, biology, geomorphology, modelling, socio-economics, governance science, knowledge brokerage, and policy advocacy. GLOBAQUA studies six river basins (Ebro, Adige, Sava, Evrotas, Anglian and Souss Massa) affected by water scarcity, and aims to answer the following questions: how does water scarcity interact with other existing stressors in the study river basins? How will these interactions change according to the different scenarios of future global change? Which will be the foreseeable consequences for river ecosystems? How will these in turn affect the services the ecosystems provide? How should management and policies be adapted to minimise the ecological, economic and societal consequences? These questions will be approached by combining data-mining, field- and laboratory-based research, and modelling. Here, we outline the general structure of the project and the activities to be conducted within the fourteen work-packages of GLOBAQUA.

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1. Introduction

Water is one of the most essential natural resources, and water-related services are major components of human wellbeing and key factors for socio-economic development (UNEP, 2007). Nowadays, freshwater ecosystems are under threat from the effects of multiple stressors, including organic and inorganic pollution, geomorphological alterations, land use changes, water abstraction, invasive species and pathogens (Vörösmarty et al., 2010). Although the interaction between stressors can result in complex effects on organisms (Coors and De Meester, 2008), and ultimately on ecosystems (Ormerod et al., 2010), little is known beyond the described effects of single stressors on the chemical and ecological status of water bodies and on their ecosystem functionality. This lack of knowledge limits our capacity to understand ecosystem responses to multiple stressors (Friberg, 2010).

Water scarcity is a key stressor in many river ecosystems as it tends to exacerbate the detrimental effects of other stressors, for instance by increasing the concentration and the ecological effects of pollutants (Petrovic et al., 2011). Water scarcity is particularly important in semi-arid regions such as the Mediterranean area (Ludwig et al., 2011; European Environmental Agency, 2012), but also in other regions where water demand approaches, or even exceeds, water availability. This includes large areas of Europe, as can be gleaned from the Water Exploitation Index (WEI), defined as the ratio of all annual abstractions over inter-annual resources (Barcelo and Sabater, 2010; European Environmental Agency, 2012). Although the main uses of water differ markedly on a regional basis (mainly agriculture in semi-arid regions, hydropower in wet mountain regions, industrial and urban uses in densely populated areas (Haddeland et al., 2013)), water demand is rising across most of the world (Steffen et al., 2011). At present there are over 45,000 large dams and over 800,000 smaller dams (Nilsson et al., 2005), in addition to extensive waterways and systems for groundwater abstraction (Acreman et al., 2000). In many regions water consumption is much higher than water availability (Boithias et al., 2014), a situation that can only be maintained by means of water transfers from other basins. Scenarios of future climate change predict increased water scarcity in large areas, including the Mediterranean basin (IPCC, 2014), as well as an increase in the magnitude of extreme floods and droughts (Dankers and Feyen, 2008). Regulation, diversion and abstraction of water are expected to increase in the near future in response to climate change and human population growth (Poff et al., 2003; Palmer et al., 2008; Finer and Jenkins, 2012). Therefore, the ecological and societal impacts of water scarcity can be even larger in the near future.

Water scarcity has become one of the most important drivers of change in freshwater ecosystems across the world. It is estimated that by 2025 about 1.8 billion people will be living under absolute water scarcity, and that two-thirds of the world's population could be under

serious conditions of water stress – the threshold for meeting the water requirements for agriculture, industry, domestic purposes, energy and the environment (UNEP, 2007). The joint occurrence of a myriad of stressors (chemical, geomorphological, biological) under water scarcity may produce novel and unfamiliar synergies and, most likely, very pronounced effects of unknown consequence. Further, water authorities rely on incomplete information to implement long-term strategies to mitigate the deleterious effects of these complex interactions. Water scarcity compromises the implementation of water policies and impairs the capacity of taking sound management decisions (Poesen and Hooke, 1997; Baron et al., 2002; Acuña et al., 2014). Furthermore, current management practices and policies often neglect the influence of multiple stressors on ecosystem services, and fail to appreciate the importance of future water scarcity. The limited information on the biophysical and economic values of ecosystems and the alterations they undergo as a consequence of global change limits the capacity of decision-makers to improve current policies. Human economy and social equilibrium also depend on the wise management of declining availability of fresh water resources. Therefore, it is urgent to gain scientific information on the potential effects of water scarcity on river ecosystems under multiple stressors, to understand how these will in turn affect ecosystem services, and to transfer all this knowledge into sound policies that can minimise the impacts of ongoing global change. The GLOBAQUA project is designed to satisfy these demands.

The objectives of this paper are to present an overall picture of the GLOBAQUA project, its structure, and to present an overview of the six river basins studied.

2. The GLOBAQUA project

GLOBAQUA is a project funded by the Seventh EU Framework Programme under the full title *Managing the effects of multiple stressors on aquatic ecosystems under water scarcity*. It is active since February 2014 and will continue until January 2019. It assembles a multidisciplinary team of hydrologists, chemists, biologists, geomorphologists, economists and sociologists, including experts in modelling, in socio-economics and governance science, and in knowledge brokerage and policy advocacy. GLOBAQUA comprises 21 partner organisations from 9 EU countries as well as one Associated Country (Serbia) and 2 non-EU partners (Morocco and Canada). Scientific, financial and administrative management of the project is carried out by the Institute of Environmental Assessment and Water Research of the Spanish Council of Scientific Research (IDAEA-CSIC). The team involves researchers, but also practitioners and end-users such as policy-makers and river basin managers.

The main aim of GLOBAQUA is to study the effects of water scarcity in a multiple stressor framework to achieve a better understanding of

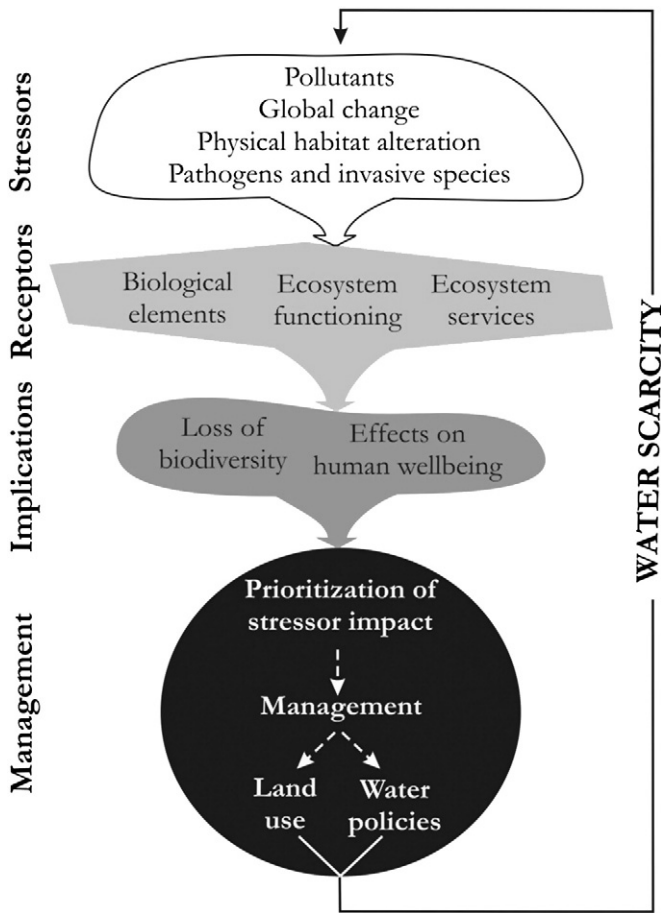


Fig. 1. Conceptual links being considered within GLOBAQUA.

how current management practices and policies could be improved by identifying their main drawbacks and alternatives (Fig. 1). More specifically, the project goals are:

- To understand the effects of water scarcity on the impacts of multiple stressors in selected case studies. Six contrasting river basins where water scarcity is a present or potential issue are being studied, and their main stressors are being identified. Field and laboratory experiments as well as modelling exercises will be performed to understand the effects of water scarcity on the environmental consequences of the identified stressors.
- To predict how these interactions will be altered according to different scenarios of future global change. The drivers of land use change and water management are being determined for each basin, and models will be used to assess integrated scenarios, taking into account projected changes of climate and socioeconomic measures at the river basin scale. Detecting the current hydrological trends and forecasting the future status of water resources require determining the nature of changes in surface and subsurface hydrological fluxes, coupling hydrological and biogeochemical models.
- To analyse the consequences of oncoming changes on biodiversity and ecosystem functioning. The effects of multiple stressors on biodiversity and ecosystem functioning are difficult to predict because of synergies, feedback and cross-amplification among stressors. Observational and experimental data will be combined to analyse the effects of nutrients, contaminants, degraded physical habitat and water scarcity on river biodiversity and ecosystem functioning. Models will be used to forecast further declines in biodiversity and associated changes in ecosystem functioning.
- To analyse the effects of water scarcity on ecosystem services in the

study basins. The implications of socio-economic development will be analysed to provide an economic and social valuation of ecosystem services, taking into account the user perspective. Thresholds will be identified beyond which water scarcity and multiple stressors would threaten ecosystem services and make it impossible to satisfy water demands.

- To explore how to adapt management and policies to minimise the ecological, economical and societal consequences of ongoing global change. Scientific results from the above objectives will be integrated with the demands of policymakers and national/EU environmental agencies to fill the communication gap in the Science–Policy Interface, by providing a user perspective.

3. Case studies

GLOBAQUA assesses the effects of water scarcity on aquatic ecosystems and their services by focusing on six contrasting river basins, and by following a cross-scale approach. The basic research element is the kilometre-scale river reach, including the river channel, the alluvial plain and the associated groundwater. Two basins from the Mediterranean European region (Ebro – Spain and Evrotas – Greece), as well as one north African basin (Souss Massa – Morocco), where water scarcity is the main current problem, have been selected to obtain a Mediterranean perspective. In order to achieve a wider European dimension, one continental (Sava, transboundary – Slovenia, Croatia, Bosnia and Herzegovina and Serbia), one Alpine (Adige – Italy) and one UK river basin (Anglian River basin district), where scarcity is a growing issue because of multiple uses and unequal yearly distribution of precipitation, have been included among the case studies. The selected basins encompass a rich set of socio-ecological conditions (forested mountainous areas, highly populated regions relying on water transfers, agricultural areas and industrial clusters), and a wide geographic coverage (Fig. 2), but are all affected by water scarcity due to either climatic or societal factors. Each basin focuses on a specific set of stressors to illustrate different management scenarios. In four of them (Adige, Sava, Ebro and Evrotas) extensive field work will be done, while in two of them (Anglian River basin district and Souss Massa) the existing data will be used to evaluate different management scenarios.

The Ebro is the largest Mediterranean Spanish river, 928 km in length and with a drainage basin of 85,550 km² (Sabater et al., 2009). Hydrology is markedly seasonal, with high flow peaks and long periods of low flow, and is severely affected by water scarcity. The Ebro is also extremely regulated by dams and channels, and includes important agricultural areas, as well as several industrial cities that host 45% of the population of the basin. Abstraction of ground and surface water, together with agricultural and industrial activities, and the impact of waste-water treatment plants (WWTPs), has deteriorated soil and water quality of some areas. Pollution due to persistent organic pollutants, pesticides, brominated flame retardants and, more recently, pharmaceuticals and illicit drugs, has been studied in the entire basin, and is very relevant in some areas of the river (Barceló and Petrovic, 2011). The abundant information gathered by the river basin authorities makes it an excellent basin for controlled experiments.

The Adige is the second longest river in Italy, with a length of 410 km and a drainage area of 12,000 km². Although the river is not within a dry region, it is periodically affected by water scarcity. Climate is characterized by dry winters, snowmelt in the spring and humid summers and falls. Because of the mountainous terrain and humid climate, the river basin is well suited to hydroelectric production, and to date 30 major reservoirs are in operation within the catchment, with a total storage capacity of 571 Mm³, resulting in severely altered hydrology. The main stressors in the basin are glacier melting, hydropower and pollution, especially associated to touristic activities. Earlier snow melting, due to climate change, is already reducing water resources during the

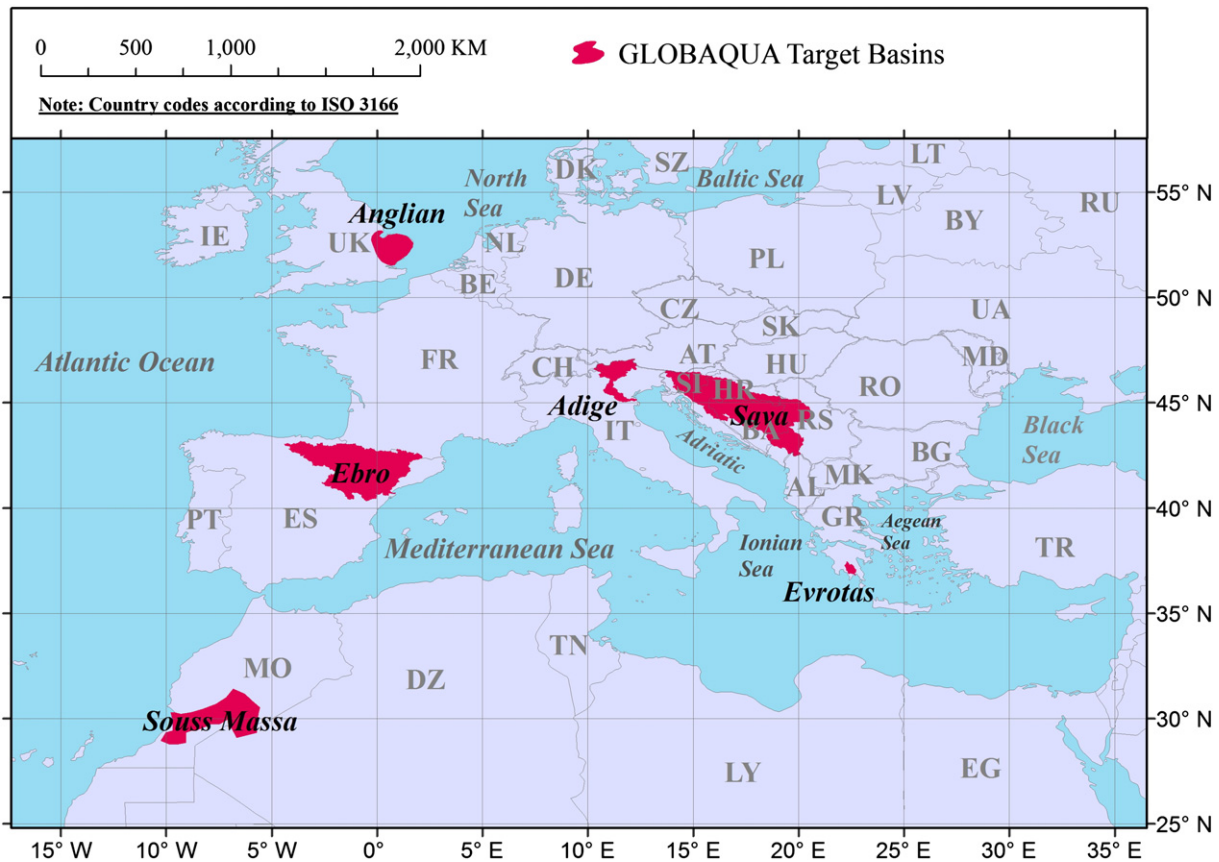


Fig. 2. Basins studied in GLOBAQUA.

irrigation period (June–August), while increased temperatures in summer months are expected to cause an increase in water demand and to accelerate glacier melting (Huss et al., 2010; Carturan et al., 2013). Diffuse pollution by agriculture in the central and lower course of the Adige River represents a relevant environmental pressure factor. Furthermore, hydropeaking can have severe consequences on the transport of contaminant loads. Additional potential stressors may include the release of pollutants accumulated in the glaciers, and the release of emerging pollutants from WWTPs.

The Sava River, the largest tributary of the Danube, is 945 km long and drains a catchment of 97,713 km². It is a transboundary river, and its management is therefore collaborative between the countries in the basin (Slovenia, Croatia, Bosnia and Herzegovina and Serbia). Although the pressures are similar to the Ebro, the hydrology is less variable. The population in the basin is about 8.2 million (46% of the total population of the four countries that share the basin) and is dependent on the Sava for drinking water. The upper reaches of the Sava basin are affected by hydromorphological pressures, the middle reaches by agricultural activities and eutrophication, and the lower reaches by industrial and urban pollution. The data available on the environmental status of the Sava River is currently limited to certain river sections or to particular variables (Torsten et al., 2008; Milacic et al., 2010).

The Evrotas River is one of the major rivers of the Peloponnese (Greece), with a length of 82 km and a drainage basin of 2418 km². Although not regulated, it is affected by overexploitation of water resources for irrigation, agro-industrial wastes (mainly oil mills), agrochemical pollution and geomorphological modifications. Overexploitation of groundwater aquifers and abstraction from surface waters result in the artificial desiccation of parts of the main stream and a number of tributaries (Skoulikidis et al., 2011). The time of desiccation and the hydroperiod of the remaining pools are critical for management and conservation purposes. Only one WWTP exists in the basin (city

of Sparta), while villages are served by traditional permeable and impermeable cesspools. The amount of data available in the basin is very small.

The Souss Massa basin covers an area of 1486 km² in western Morocco, within a very arid region, where rainfall has decreased 20% during the last 30 years (ABHSM, 2008). The quality of water resources is affected by pollution from different sources (domestic, industrial, agricultural), thus resulting in a severe scarcity of water resources. The negative balance between water supply and demand, of 250 million m³ per year, is covered by groundwater mining, causing a lowering of the water table by 3 to 5 m per year and seawater intrusion in coastal areas (Arrifi, 2013). Most of the available natural water (95%) is used for agricultural purposes.

Finally, the Anglian River basin district (UK) is mostly low lying, spotted with fens (artificially drained coastal and estuarine wetlands) comprising a large proportion of the area (3188 km²). This results in over one fifth of the basin being susceptible to coastal and surface flooding. The area has intense horticulture and pig and poultry farming. Building is the largest economic sector in the basin, followed by manufacturing. The area is classified as seriously water stressed, with 20–45% of the effective rainfall currently abstracted for human consumption. The negative effects of water abstraction are exacerbated by a rapidly growing population. There is considerable background knowledge of this basin (Environment Agency, 2009; Collins et al., 2012) that will be used to undertake a comprehensive study of future scenarios.

4. Overview of methods

The case-study work within GLOBAQUA starts with the collection of existing data, so that the relation between stressors and ecological status can be assessed. The most suitable river reaches are being identified based on the information available on water scarcity, main stressors and

specific ecosystem services. Three different strategies are combined within GLOBAQUA: descriptive field campaigns, controlled field experiments, and manipulative experiments in the laboratory and in artificial streams. General information from the case-study basins will be gathered by means of simultaneous field sampling on pollutants, biodiversity and ecosystem functioning. In a subsequent step, field experiments will be performed on selected river segments to test the effect of combined stressors (e.g., WWTP inputs with sediment deposition; occurrence of specific pollutants and invasive species) on biodiversity and ecosystem functioning. They will be complemented with manipulative laboratory experiments, which will also address specific questions such as the interaction between water temperature and concentration of pharmaceutical concentrations. Combining field and lab experiments will allow understanding of the mechanisms behind the interactions between stressors as well as their effects on the different receptors.

Validated methods for chemical analysis of a broad spectrum of metals, priority and emerging pollutants in water, sediment and biota (algae, mussels, small aquatic organisms and fish) are already available. In addition, immunoassays and non-target screening will be used for the rapid characterization of contaminants. Quantitative sampling will be carried out on algae, macrophytes, invertebrates and fish, paying special attention to invasive species, and the weight of the different stressors on the community structure will be assessed by multivariate statistical tools. Field and laboratory bioassays (Damásio et al., 2011) and biomarker analysis will be performed to detect lethal and sub-lethal responses to chemicals. Ecosystem functioning will be evaluated by means of integrative processes such as retention of nutrients, removal of pollutants, whole-ecosystem metabolism, and decomposition of organic matter, which differ in the temporal and spatial scales at which they respond (Aristi et al., 2012).

Finally, the modelling approaches used in GLOBAQUA will include mechanistic models based on the River Water Quality Model (RWQM) (Reichert et al., 2001); InVEST (Tallis and Polasky, 2011), a spatially explicit tool consisting of a suite of models that use land use and land cover patterns to estimate levels and economic values of ecosystem services; and a suite of other modelling approaches to gain a better

understanding of the hydrological processes at the catchment scale (mHM, GeoTransf, CATHY, WaSim, SWAT). Also, existing spatially distributed water quality and water quantity hydrological models (LISFLOOD, LISQUAL) will be used to upscale results from the study areas to an EU-wide scale. Special effort will be made to combine the different models, climatic, hydrologic, hydromorphologic and so on, crossing the barriers among disciplines. An integrated methodology for identifying the environmentally and socioeconomically sustainable management of water resource ecosystem services will be performed in each case study. This methodology is consistent with the WFD and the three-step methodology proposed in the WATECO document for the implementation of the socio-economic aspects of the WFD. It is based on the concept of Total Economic Value of Ecosystem Services (Koundouri, 2009).

5. Detailed structure of GLOBAQUA

GLOBAQUA is organised in fourteen work-packages (WPs), grouped in five main modules (Fig. 3). All WPs will be implemented in all six case-study river basins, although fieldwork will not be performed in all of them to the same extent.

- Module 1, STRESSORS (WPs 1 to 5): it analyses the effects of water scarcity on the impacts of multiple stressors occurring in each study river basin, and forecasts the consequences of future scenarios for global change. It especially considers surface and groundwater hydrology, sediment transport, physical habitat, water quality, and the fate of inorganic and organic pollutants, and considers the consequences of different climatic, socio-economic and land-use scenarios.
- Module 2, RECEPTORS (WPs 6 and 7): it analyses the consequences of water scarcity and multiple stressors on biodiversity and ecosystem functioning. Research is based on field studies and manipulative laboratory experiments, combining artificial streams, reach-scale measurements, and basin-scale surveys to understand the effects of stressors at different scales, as well as modelling to forecast future scenarios.

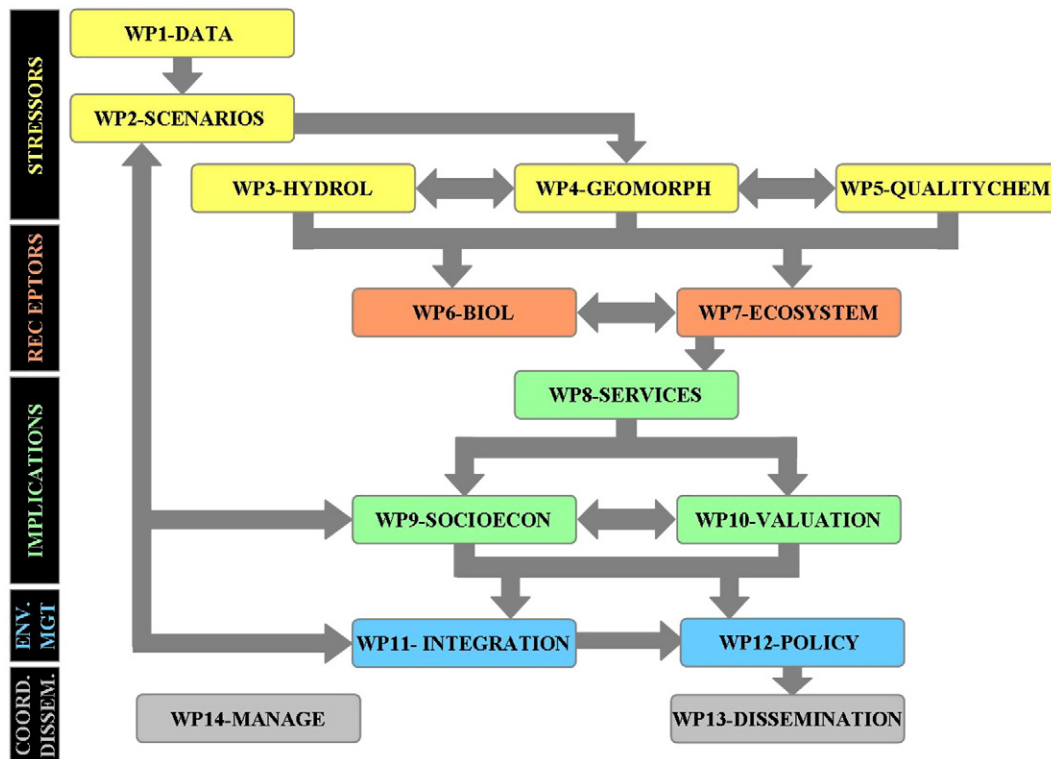


Fig. 3. Module and work-package structure of GLOBAQUA.

- Module 3, IMPLICATIONS (WPs 8 to 10): it analyses the socio-economic implications of the effects of impacts on water quality and availability, as well as on biodiversity and ecosystem functioning, by translating the information gathered by modules 2 and 3 into ecosystem services, and investigating the effects on the socio-economic development.
- Module 4, ENVIRONMENTAL MANAGEMENT (WPs 11 and 12): it integrates the results of the other modules to define a manageable perspective of water scarcity for the studied river basins. It is, thus, an interface between scientific results of the project and their policy implications.
- Module 5, PROJECT COORDINATION AND DISSEMINATION (WPs 13 and 14): it is devoted to the communication of the results to target groups (researchers, policy makers, water managers, land planners, etc.), and to stimulating the use of results through relations with stakeholders and end-users. It also seeks to coordinate project activities.

WP1-DATA manages data either internally generated by the project or acquired from external sources, and conveys them to a Hub platform to share the data among project members, and eventually among potential users, either scientists or managers.

WP2-SCENARIOS draws data stored by WP1-DATA to produce spatially explicit, integrated scenarios of environmental change for each case study, including climatic, socio-economic and land use factors. The primary climate model data set will be an ensemble of 1960–2100 transient runs performed with the RCA4 model at 50 km and 12.5 km. Comparisons will focus on the 2050 time horizon (2041–2070) versus the reference climatology (1981–2010). It encompasses numerous GCMs (~10) and RCMs (~6), as well as 3 of the CMIP5 Reference Concentration Pathways (RCPs 2.6., 4.5 and 8.5). The RCA4 data set will be complemented with data from other RCMs in EURO-CORDEX (Kjellström et al., 2013). The climate model data will further be bias-corrected to sufficiently reproduce the reference climatology. Finally, the climate data is spatially scaled to account for fine scale heterogeneities in complex terrain, using a model interface that superimposes stationary, topography-induced patterns of the hydrological model scale ($\leq 1 \times 1 \text{ km}^2$) on the RCM fields. The outputs of these exercises will be used by the modules STRESSORS and RECEPTORS. They will also be used to define the boundary conditions for the impact on ecosystem functioning and for interactions with the modules IMPLICATIONS and ENVIRONMENTAL MANAGEMENT.

WP3-HYDROL uses existing modelling approaches to link surface and subsurface hydrological fluxes and the impact of water scarcity on the ecological status of streams, including hyporheic, riparian and floodplain zones. Flow and transport processes are upscaled from point to basin and regional scales, accounting for the sources of uncertainty of the model outputs. Historical data series are analysed to disentangle the effect of multiple human impacts on water resources along time and across space. This WP uses global change scenarios built in WP2-SCENARIOS and data gathered in WP1-DATA, and provides information to WP4-GEOMORPH, WP6-BIOL, WP7-ECOSYSTEM and WP8-SERVICES.

WP4-GEOMORPH analyses the effects of changing hydrology, land use, and climate on sediment transport, channel morphology, physical habitat, and pollutant fluxes in rivers. It analyses the sediments as vectors for contaminant transport (Rügner et al., 2013; Schwientek et al., 2013) and retention, and the geomorphological change as driver of other impacts on fluvial communities. Thus, it has strong links with WP3-HYDROL (processes at the surface/subsurface boundaries), and with WP5-QUALITYCHEM (contaminant transport associated to sediments) and WP6-BIOL (impact of geomorphologic changes on habitats and communities).

WP5-QUALITYCHEM studies chemical contaminants, both inorganic and organic, and their relationship to the ecosystem status, providing data to the WPs of the module RECEPTORS. It analyses the occurrence, fate and behaviour of priority and emerging pollutants in rivers

(heavy metals, halogenated and organophosphate compounds, pharmaceuticals and hormones, personal care products, pesticides, perfluorinated compounds and nanomaterials), and identifies the effects of water scarcity across study basins. This WP combines general sampling surveys, field and laboratory experiments to test the effects of multiple pressures on the fate and behaviour of microcontaminants.

WP6-BIOL quantifies the effects of water scarcity and other stressors on river biodiversity, including bacteria, primary producers (algae, macrophytes), invertebrates, and fish, and how this affects biological traits and functional diversity (Statzner and Bêche, 2010). It pays special attention to the impairment of key habitats as it can reduce species resistance capacity and promote the spreading of invasive species (Rahel, 2007). On-site analyses are combined with field and mesocosm experiments, studying the changes induced by pathogens, micropollutants and invasive species on biodiversity in each study basin.

WP7-ECOSYSTEM assesses ecosystem functions at different spatial and temporal scales, by measuring processes such as nutrient retention, removal of pollutants, or whole-ecosystem metabolism (Palmer and Febria, 2012). Additionally, whole-river metabolism is reconstructed from historical data on oxygen concentration to determine the effects of climatic variation and new human stressors of known occurrence on river ecosystem functioning. The historical perspective of human occupancy and land use change is assessed through analyses of historic adjustment of river channels.

WP8-SERVICES uses the information on ecosystem functioning to establish cause-effect relationships between stressors and ecosystem services. Thus, it provides objective tools for decision systems to evaluate the effects of planned management interventions and to help planners manage the river basin as a whole, taking decisions to counteract the effects of multiple stressors on ecosystem attributes such as ecological or chemical status. The transversal component of WP8-SERVICES within GLOBAQUA requires a close relationship to WP6-BIOL, WP7-ECOSYSTEM, WP9-SOCIOECON, WP10-VALUATION and WP11-INTEGRATION.

WP9-SOCIOECON analyses the effects of water scarcity and multiple stressors on the socio-economic development of the case-study regions, in a case-study driven approach. This relies on the flow of information from and to WP8-SERVICES and WP10-VALUATION, and follows three-steps: socioeconomic characterization, estimation of the percentage of cost-recovery of water uses, and development of the package of socio-economic measures to achieve good water status (Koundouri, 2009). The outputs of WP9-SOCIOECON correspond directly to the WFD's Articles 5 and 9 and Annex III.

WP10-VALUATION aims to assess the economic effects derived from the interaction of multiple stressors on aquatic ecosystems under water scarcity. This WP analyses how biophysical changes in ecosystems are affecting human well-being, taking into account the users' perspective and valuation of ecosystem services. Participative workshops are organised to validate this perspective, and the outputs will integrate findings for the WP12-POLICY and the dissemination activities of WP13-DISSEMINATION.

WP11-INTEGRATION uses the information generated by the other WPs to integrate the main consequences of water scarcity for biodiversity and the human society. Therefore, it integrates across disciplines, from biophysical to the socio-economic fields, addressing the complex of abiotic and biotic interacting as ecosystem functions, and across scales, from river reach to basin and regional scale, towards a pan-European view

WP12-POLICY connects the impact of scarcity with water policy, following a systems approach that acknowledges the critical role of socio-economic policy instruments and investment for WFD implementation, and building on the findings of all WPs. Therefore, this WP defines the current EU context, identifies opportunities to assist policy making, and will produce recommendations for improvement.

WP13-DISSEMINATION ensures the communication of results to specific target groups (researchers, policy makers, water managers,

land planners, etc.), through relations with stakeholders and end-users and through training programmes for different end-users.

WP14-MANAGEMENT assists the coordinator to achieve the planned results and their maximum impact, as well as the transfer of results to stakeholders. For this, a special External Advisory Board is established, which will peer review the results, control the quality of deliverables, and suggest how to improve the outputs of the project to the needs of stakeholders.

6. Final remarks

Water scarcity already exerts strong environmental pressures in many European regions, and is a serious cause of concern in many more, according to scenarios of future environmental change. Therefore, it is crucial to gain sound scientific information on the ways water scarcity interacts with other stressors in freshwater ecosystems, in order to understand its environmental and socio-economical consequences, 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. These are the main tasks of GLOBAQUA, a project that brings together a large group of researchers, stakeholders, and policy makers across a wide range of disciplines. The added value of this collaboration lies in the possibility of addressing the problems arising from the scarcity and multiple stressors, as well as their effects on the ecosystem services and the overall effects of global changes. Hopefully, the close collaboration between scientist and stakeholders in GLOBAQUA, will allow implementing the approaches proposed in pilot sub-basins within the study areas, and to better fulfil water needs of both human and nature.

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References

- ABHSM. Situation hydrologique du bassin hydraulique de Souss Massa. Agadir, Morocco: Agence du Bassin Hydraulique de Souss Massa; 2008.
- Acreman MC, Adams B, Birchall P, Connorton B. Does groundwater abstraction cause degradation of rivers and wetlands? *J Chart Ins Environmental Management Manag* 2000;14:200–6.
- Acuña V, Detry T, Marshall J, Barceló D, Dahm CN, Ginebreda A, et al. Why should we care about temporary waterways? *Science* 2014;343:1080–1.
- Aristi I, Díez JR, Larrañaga A, Navarro-Ortega A, Barceló D, Elosegui A. Assessing the effects of multiple stressors on the functioning of Mediterranean rivers using poplar wood breakdown. *Sci Total Environ* 2012;440:272–9.
- Arrifi E. *Projet d'irrigation a partir de dessalement de l'eau de mer dans la plaine de choutka – maroc*. Rabat, Maroc: Direction de l'irrigation de l'amenagement de l'espace agricole; 2013.
- Barceló D, Petrovic M, editors. *The Ebro River basin. The handbook of environmental chemistry*. Berlin, Germany: Springer Verlag; 2011.
- Barceló D, Sabater S. Water quality and assessment under scarcity: prospects and challenges in Mediterranean watersheds. *J Hydrol* 2010;383:1–4.
- Baron JS, Poff NL, Angermeier PL, Dahm CN, Gleick PH, Hairston NG, et al. Meeting ecological and societal needs for freshwater. *Ecol Appl* 2002;12:1247–60.
- Boithias L, Acuña V, Vergoñós L, Ziv G, Marcé R, Sabater S. Assessment of the water supply:demand ratios in a Mediterranean basin under different global change scenarios and mitigation alternatives. *Sci Total Environ* 2014;470–471:567–77.
- Carturan L, Baroni C, Becker M, Bellin A, Cainelli O, Carton A, et al. Decay of a long-term monitored glacier: Careser glacier (Ortles-Cevedale, European Alps). *Cryosphere* 2013;7:1819–38.
- Collins A, Ohandja D-G, Hoare D, Voulvoulis N. Implementing the water framework directive: a transition from established monitoring networks in England and Wales. *Environ Sci Pol* 2012;17:49–61.
- Coors A, De Meester L. Synergistic, antagonistic and additive effects of multiple stressors: predation threat, parasitism and pesticide exposure in *Daphnia magna*. *J Appl Ecol* 2008;45:1820–8.
- Damáso J, Fernández-Sanjuan M, Sánchez-Avila J, Lacorte S, Prat N, Rieradevall M, et al. Multi-biochemical responses of benthic macroinvertebrate species as a complementary tool to diagnose the cause of community impairment in polluted rivers. *Water Res* 2011;45:3599–613.
- Dankers R, Feyen L. Climate change impact on flood hazard in Europe: an assessment based on high-resolution climate simulations. *J Geophys Res Atmos* 2008;113:D19105.
- Environment Agency. *Water for life and livelihoods: river basin management plan*. Anglian River Basin District; 2009.
- European Environmental Agency. *Climate change, impacts and vulnerability in Europe – an indicator-based report*. EEA report no 12/2012. European Environmental Agency; 2012.
- Finer M, Jenkins CN. Proliferation of hydroelectric dams in the andean amazon and implications for andes–amazon connectivity. *PLoS One* 2012;7.
- Friberg N. Pressure–response relationships in stream ecology: introduction and synthesis. *Freshw Biol* 2010;55:1367–81.
- Haddeland I, Heinke J, Biemans H, Eisner S, Flörke M, Hanasaki N, et al. Global water resources affected by human interventions and climate change. *Proc Natl Acad Sci* 2013;111(9):3251–6.
- Huss M, Hock R, Bauder A, Funk M. 100-year mass changes in the Swiss Alps linked to the Atlantic multidecadal oscillation. *Geophys Res Lett* 2010;37:L10501.
- IPCC. *Fifth assessment report: climate change 2014: impacts. Adaptation and vulnerability*. Cambridge, UK: Cambridge University Press; 2014.
- Kjellström E, P T, M R, JH C, F B, OB C, et al. Emerging regional climate change signals for Europe under varying large-scale circulation conditions. *Climate Res* 2013;56:103–19.
- Koundouri P. The use of economic valuation in environmental policy: providing research support for the implementation of EU water policy under aquastress; 2009.
- Ludwig R, Roson R, Zografos C, Kallis G. Towards an inter-disciplinary research agenda on climate change, water and security in southern Europe and neighboring countries. *Environ Sci Pol* 2011;14:794–803.
- Milacic R, Scancar J, Murko S, Kocman D, Horvat M. A complex investigation of the extent of pollution in sediments of the Sava River. Part 1: selected elements. *Environ Monit Assess* 2010;163:263–75.
- Nilsson C, Reidy CA, Dynesius M, Revenga C. Fragmentation and flow regulation of the world's large river systems. *Science* 2005;308:405–8.
- Ormerod SJ, Dobson M, Hildrew AG, Townsend CR. Multiple stressors in freshwater ecosystems. *Freshw Biol* 2010;55:1–4.
- Palmer MA, Febria CM. *Ecology: the heartbeat of ecosystems*. Science 2012;336:1393–4.
- Palmer MA, Reidy Liermann CA, Nilsson C, Flörke M, Alcamo J, Lake PS, et al. Climate change and the world's river basins: anticipating management options. *Front Ecol Environ* 2008;6:81–9.
- Petrovic M, Ginebreda A, Acuna V, Batalla RJ, Elosegi A, Guasch H, et al. Combined scenarios of chemical and ecological quality under water scarcity in Mediterranean rivers. *TrAC Trends Anal Chem* 2011;30:1269–78.
- Poesen JWA, Hooke JM. Erosion, flooding and channel management in Mediterranean environments of southern Europe. *Prog Phys Geogr* 1997;21:157–99.
- Poff NL, Wellnitz T, Monroe JB. Redundancy among three herbivorous insects across an experimental current velocity gradient. *Oecologia* 2003;134:262–9.
- Rahel FJ. Biogeographic barriers, connectivity and homogenization of freshwater faunas: it's a small world after all. *Freshw Biol* 2007;52:696–710.
- Reichert P, Dorchardt D, Henze M, Rauch W, Shanahan P, Somlyódy L. River water quality model no. 1. Scientific and technical report no. 12. London, UK: IWA publishing; 2001.
- Rügner H, Schwientek M, Beckingham B, Kuch B, Grathwohl P. Turbidity as a proxy for total suspended solids (TSS) and particle facilitated pollutant transport in catchments. *Environ Earth Sci* 2013;69:373–80.
- Sabater S, Feio MJ, Graça MAS, Muñoz I, Romaní AM. The Iberian rivers. In: Tockner K, Uehlinger U, Robinson CT, editors. *Rivers of Europe*. London: Academic Press; 2009. p. 113–49. [Chapter 4].
- Schwientek M, Rügner H, Beckingham B, Kuch B, Grathwohl P. Integrated monitoring of particle associated transport of PAHs in contrasting catchments. *Environ Pollut* 2013;172:155–62.
- Skoulikidis NT, Vardakas L, Karaouzas I, Economou AN, Dimitriou E, Zogaris S. Assessing water stress in Mediterranean lotic systems: insights from an artificially intermittent river in Greece. *Aquat Sci* 2011;73:581–97.
- Statzner B, Bêche LA. Can biological invertebrate traits resolve effects of multiple stressors on running water ecosystems? *Freshw Biol* 2010;55:80–119.
- Steffen W, Persson Å, Deutsch L, Zalasiewicz J, Williams M, Richardson K, et al. *The Anthropocene: from global change to planetary stewardship*. *Ambio* 2011;40:739–61.
- Tallis H, Polasky S. Assessing multiple ecosystem services: an integrated tool for the real world. *Natural capital*. In: Kareiva P, Tallis H, Ricketts T, Daily G, Polasky S, editors. *Theory and practice of mapping ecosystem services*. New York: Oxford University Press; 2011.
- Torsten K, Milačič R, Smital T, Thomas K, Vraneš S, Tollefsen K-E. Chronic toxicity of the Sava River (SE Europe) sediments and river water to the algae *Pseudokirchneriella subcapitata*. *Water Res* 2008;42:2146–56.
- UNEP. *Global environmental outlook 4. Environment for development*, United Nations Environment Programme; 2007.
- Vörösmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, et al. Global threats to human water security and river biodiversity (2010, vol. 467, pp. 555–561). *Nature* 2010;468:334–334.