Assessing water ecosystem services for water resource management

Grizzetti, Bruna; Lanzanova, Denis; Liquete, Camino; Reynaud, Arnaud; Cardoso, A.C.

How to cite

GRIZZETTI, Bruna et al. Assessing water ecosystem services for water resource management. In: Environmental Science & Policy, 2016, vol. 61, p. 194–203. doi: 10.1016/j.envsci.2016.04.008

This publication URL: https://archive-ouverte.unige.ch/unige:97002
Publication DOI: 10.1016/j.envsci.2016.04.008

Environmental Science & Policy 61 (2016) 194–203

Contents lists available at ScienceDirect

Environmental Science & Policy

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

Assessing water ecosystem services for water resource management

B. Grizzetti*, D. Lanzanova, C. Liquete, A. Reynaud, A.C. Cardoso

European Commission Joint Research Centre (JRC), I-21027 (VA), Italy

ARTICLE INFO

Article history:
Received 22 December 2015
Received in revised form 1 April 2016
Accepted 10 April 2016
Available online xxx

Keywords:
Water ecosystem services
Ecosystem services indicators
Ecosystem services valuation
Water Framework Directive

ABSTRACT

Ecosystem service concepts can offer a valuable approach for linking human and nature, and arguments for the conservation and restoration of natural ecosystems. Despite an increasing interest in the topic, the application of these concepts for water resource management has been hampered by the lack of practical definitions and methodologies. In this study we review and analyse the current literature and propose an approach for assessing and valuing ecosystem services in the context of water management. In particular, to study the link between multiple pressures, ecological status and delivery of ecosystem services in aquatic ecosystems under different scenarios of measures or future changes. This is of interest for the development of River Basin Management Plans under the EU Water Framework Directive. We provide a list of proxies/indicators of natural capacity, actual flow and social benefit for the biophysical assessment of the ecosystem services. We advocate the use of indicators of sustainability, combining information on capacity and flow of services. We also suggest methods for economic valuation of aquatic ecosystem for each service and spatial scale of application. We argue that biophysical assessment and economic valuation should be conducted jointly to account for the different values of ecosystem services (ecologic, social and economic) and to strengthen the recognition of human dependency on nature. The proposed approach can be used for assessing the benefits of conservation and restoration of aquatic ecosystems in the implementation of the EU water policy.

1. Introduction

Ecosystem services are defined as the benefits that people obtain from ecosystems (MEA, 2005a), and the direct and indirect contributions of ecosystems to human well-being (TEEB, 2010). The concept of ecosystem services is relevant for connecting people to nature. It makes visible the key role of ecosystem functioning and biodiversity to support multiple benefits to humans. Understanding the linkages between the natural and socio-economic systems can lead to improved and more sustainable management of ecosystems (Guerry et al., 2015).

In 2010 the parties of the Convention of Biological Diversity adopted a revised Strategic Plan for Biodiversity including the Aichi Biodiversity Targets (CBD, 2010), a reinforced action to halt the loss of biodiversity and ensure ecosystems are resilient and continue to provide essential services. In line with this international framework, in 2011 the European Union (EU) presented the European Biodiversity Strategy to 2020 (European Commission, 2011) that put emphasis on the protection and value of ecosystem services, setting a specific target on maintaining and restoring ecosystems and their services (Target 2).

Aquatic ecosystems (rivers, lakes, groundwater coastal waters, seas) support the delivery of crucial ecosystem services, such as fish production, water provisioning and recreation. Key ecosystem services are also connected to the hydrological cycle in the river basin, for example water purification, water retention and climate regulation. Most of these water related ecosystem services can be directly appreciated by people and quantified, but some, especially regulating and maintenance services, are less evident. Though, all ecosystem services have to be considered for the sustainable use and management of water resources.

In Europe, the development of River Basin Management Plans (RBMP) under the EU Water Framework Directive (WFD, Directive 2000/60/EC) is an actual situation where territorial planning for water management is needed, and where the concept of ecosystem services could be adopted to recognise the multi-functionality of the water systems and account for the benefits people receive from nature, justifying the costs of protection and restoration. The Blueprint to safeguard Europe's water resources (European Commission, 2012) indicated that natural water retention measures can greatly contribute to reduce the effects of floods and droughts ensuring the provisioning of ecosystem services, and

* Corresponding author.
E-mail address: bruna.grizzetti@jrc.ec.europa.eu (B. Grizzetti).

http://dx.doi.org/10.1016/j.envsci.2016.04.008
1462-9011/© 2016 Published by Elsevier Ltd.

these measures should be included in the RBMPs and in the Flood Risk Management Plans. In line with the Blueprint, some recent studies have been reflecting on the potential of the ecosystem service approach in the implementation of the WFD, emphasising the opportunity of holistic system thinking to understand the co-benefits of measures and to integrate different sectoral policies (Vlachopoulou et al., 2014; COWI, 2014; ESAWADI, 2010).

However, the lack of agreed definitions of ecosystem services and approaches for their quantification and valuation has limited the uptake by practitioners and policy makers (Polasky et al., 2015). The MAES Working Group (Mapping and Assessment of Ecosystems and their Services), established to support the implementation of the EU Biodiversity Strategy, has suggested an analytical framework for the implementation of the ecosystem service approach in the EU, and tested it in a pilot study on freshwater and marine ecosystems (Maes et al., 2016). Two FP7 projects, OpenNESS (2015) and OPERA (2015), are currently working on the general definition of concepts and methodologies for assessing and valuing ecosystem services, and on the operationalization of the concepts through real case studies. More specifically on water policy, the FP7 projects MARS (2015) and Globaqua (2015) aim to understand and quantify the impacts of pressures on the ecological status of EU waters and the consequent effects on the delivery of ecosystem services.

Understanding the relationship between multiple pressures, conditions and services of aquatic ecosystems would help design measures to achieve the target of good ecological status of water systems, foreseen by the WFD, by considering the benefits of investing in nature conservation and restoration. But the lack of clear definitions and practical methods to assess the water related ecosystem services could hamper the adoption of the approach (Kull et al., 2015; Crossman et al., 2013). Also, while mapping of ecosystem services directly linked to land occupation is quite straightforward, for fresh water ecosystems the assessment is more complex, as the hydrological cycle and the land-water interactions have to be taken into consideration.

The objective of this study was to develop a practical methodology for assessing and valuing ecosystem services relevant for water resource management, considering the links between pressures, ecological status and ecosystem services. The work is based on literature review and scientific partners' consultation. It started from the experience of the MAES freshwater pilot and was developed within the EU FP7 project MARS.

The paper is structured as follows. The first part describes the methodological approach adopted in the study. The second part presents the results of our analysis in the form of a practical approach for assessing and valuing ecosystem services relevant for water resource management. The third part discusses the challenges in valuing ecosystem services and integrating biophysical and economic assessments.

2. Method

We analysed definitions and methods for assessing and valuing ecosystem services to synthesize the current knowledge and propose a practical and flexible approach relevant for water resource management. The use context of the approach is the study of the relationship between multiple pressures, ecological status and delivery of ecosystem services in water systems, with the overall goal to support the EU water policy (WFD).[1] The analysis was based on literature review and consultation of the scientific partners of the project MARS, from 24 research institutes across Europe.

The focus of the analysis is on inland waters and the spatial scale of interest ranges from the water body to the catchment/river basin and the European scale. While for water bodies the main focus is on specific ecosystem functions that support ecosystem services, and their alteration under different stressors, the catchment is the appropriate scale to observe and quantify processes related to the water cycle, and to implement monitoring and management plans to reduce multiple-pressures. The assessment and valuation of ecosystem services at the European scale allows us to address regional trends, identify hot spots in the delivery or degradation of services, test the effectiveness of regional policies (such as EU Directives) and conduct scenario analysis at the large scale. In the development of the methodology we considered these different spatial scales.

The approach that we developed is organised in four building steps: 1) definitions and scoping (Section 3.1); 2) framework (relations between pressures, ecological status and delivery of ecosystem services) (Section 3.2); 3) biophysical assessment of ecosystem services (Section 3.3); 4) economic valuation of ecosystem services (Section 3.4). In the following part of the paper we describe the results of our study proposing guidelines on how to develop these components.

3. Results: approach for assessing and valuing water ecosystem services

3.1. (Step 1) Scoping – Water related ecosystem services

A large variety of ecosystem services have been addressed by assessments such as Millennium Ecosystem Assessment (MEA, 2005a), the Economics of Ecosystems and Biodiversity (TEEB, 2010), MAES (Maes et al., 2016), and national assessments (e.g. Pereira et al., 2006; UK NEA, 2011). In this study we are interested in ecosystem services related to water and aquatic ecosystems. MAES analysed the ecosystem services per typology of ecosystem, considering the services delivered by rivers, lakes, groundwater and wetlands in the freshwater pilot study, and those provided by transitional waters, coastal waters, shelf waters and open oceanic water in the marine pilot study. With a slightly different approach, Brauman et al. (2007) discussed the 'hydrologic ecosystem services', defined as the ecosystem services that "encompass the benefits to people produced by terrestrial ecosystem effects on freshwater", each hydrological service being characterised by the hydrological attributes of quantity, quality, location and timing. Keeler et al. (2012) described in detail water-quality related ecosystem services. Recently, Guswa et al. (2014) have addressed more generally the 'water related ecosystem services', discussing the link between hydrological modelling and the ecosystem services relevant for river basin management. From these studies we can observe two approaches in the organisation of the analysis, one per ecosystem typology (Maes et al., 2016) and the other per hydrological relevant services (Brauman et al., 2007). Both approaches consider the integration of all the services, the first by accounting for all the ecosystems in the analysis, the second by integrating the processes in the river basin. The ecosystem services of relevance for the water management (and the WFD) are those related to the aquatic ecosystems and to the interaction of water and land in different ecosystems, such as forests, agricultural lands, riparian areas, wetlands, and water bodies. In this study we indicate all these services as 'water ecosystem services'.

For the assessment, the identification of the relevant ecosystem services is the first step. We propose a simplified classification of ecosystem services based on the Common International

[1] In the FP7 project MARS this analysis will be conducted at the European scale and in 16 catchments, representing a great variability of pressures and ecosystem services across Europe.

Classification of Ecosystem Services Version 4.3 (CICES, 2015), which is the framework adopted by the common implementation of the ecosystem assessment approach in the EU (Supplementary material S1, we also linked the classification of the TEEB, 2010). The idea is to offer a coherent terminology relevant for scientists, sufficiently simple for stakeholders, and meaningful for river basin managers. The services (S1) can be related to the following ecosystems: lakes, rivers, transitional waters, coastal waters, groundwater, freshwater wetlands, coastal wetlands, riparian areas, floodplains. Providing a list of ecosystem services can support the practical implementation of the methodology, but of course the list is not to be considered exhaustive and more services can be included, especially hydrological services relevant for river basin planning and decision making.

3.2. (Step 2) Framework – Linking pressures, ecological status and ecosystem services for water management

Understanding the relationship between anthropogenic pressures and ecological status is the basis of the RBMP, in order to devise cost-effective measures to achieve a good ecological status for all water bodies. In particular, for planning sound restoration actions, it is necessary to consider the complex links between pressures combinations and the ecological response of aquatic systems (Teichert et al., 2016; Brown et al., 2013; Halpern et al., 2008), as multiple pressures may have additive, synergetic or antagonistic effects (Nõges et al., 2015). The research project MARS studies the complex relationships between multiple stressors, status of aquatic ecosystems and the delivery of ecosystem services (see Hering et al., 2015 for the MARS conceptual model).

In the EU, water pollution, over-abstractions and hydromorphological alterations have been indicated as the major significant pressures for the European water bodies (European Commission, 2015). At the same time, concern over the increase of alien species exists (Butchart et al., 2010; Regulation EU No 1143/2014). Overall, the main pressures affecting the aquatic ecosystems can be summarised as alterations of water quantity and quality, and changes in the physical habitat and the biological components, as shown in Table 1.

Table 1
Stressors and pressures on water systems.

Alteration of:
Water quantity
Flow modifications (hydrological alterations):
• Quantity and frequency (dams, water abstractions, irrigation, transfers)
• Groundwater abstractions
• Changes in precipitation and temperature
• Changes in runoff
Water quality
Diffuse and point pollution:
• Nutrients
• Chemicals (pesticides, endocrine disrupting compounds, nanoparticles, etc.)
• Metals
• Pathogens
• Litter
• Groundwater salinization
• Sediments, increased turbidity and brownification
Habitat
Hydromorphological alterations (physical alteration of channels, bed disruption, dams)
Biota and biological communities
Alien species, other changes in biological communities

Human activities are the major drivers for generating multiple pressures (Fig. 1). Pressures affect the biodiversity and the status of the aquatic ecosystem, which can result in a change in the ecosystem services and their economic value. The excessive exploitation of ecosystem services can turn into a pressure for an ecosystem. For this reason is important to consider the resilience of the system and to introduce the notion of sustainability when assessing the delivery of ecosystem services (Fig. 1). The interest of RBMP is to quantify the changes in the components of this system under remediation measures and scenarios of pressures.

To support the analysis of these linkages, we developed a conceptual framework for the integrated assessment of water related services (presented in Fig. 2). In the framework, we identify the main pressures affecting aquatic ecosystems (according to Table 1) and the possible links to the alteration of four ecosystem/hydrologic attributes: 1) water quantity (including seasonality); 2) water quality; 3) biological quality elements; 4) hydromorphological & physical structure. The attributes are different from those proposed by Brauman et al. (2007), to include in the analysis the biological and hydromorphological aspects and to make the link to the WFD elements explicit (so that the relationship to ecological status should be in principle more easy). For each attribute we selected a number of representative indicators (as examples) and identified some possible relationships with the ecosystem services suggested in this study (S1).

The purpose of this framework (Fig. 2) is to support the users in describing the relationships between pressures and ecosystem services and design a conceptual scheme of the assessment and scenario analysis. The arrows are examples. Each user can select the relationships under analysis and complete and adapt the framework to the specific case under study. The idea is to think about the links between the selected services and specific stressors. Fig. 3, which presents expected qualitative effects of stressors/pressures on different ecosystem services, could inspire this reflection.

3.3. (Step 3) Biophysical assessment

3.3.1. Tools

Several approaches to assess and map ecosystem services are available in the literature, from land cover maps combined with scoring factors (Burkhard et al., 2009) to specific ecosystem service models based on ecological production functions (Sharp et al., 2015), and decision support tools (Bagstad et al., 2013 reviewed 17 tools for assessing and valuing ecosystem services). These tools

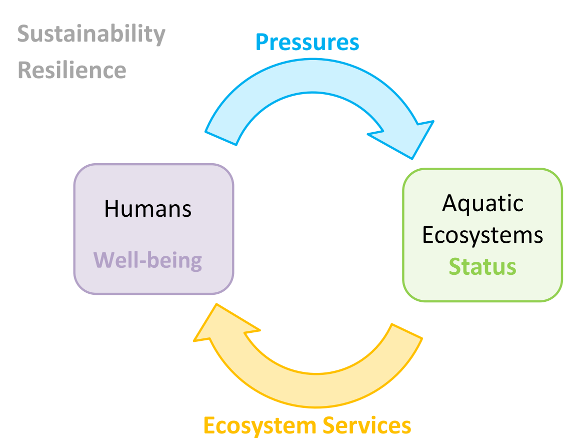

Fig. 1. Schematic representation of the system under analysis. Relationships between humans and aquatic ecosystems under present and future scenarios (explanation in the text).

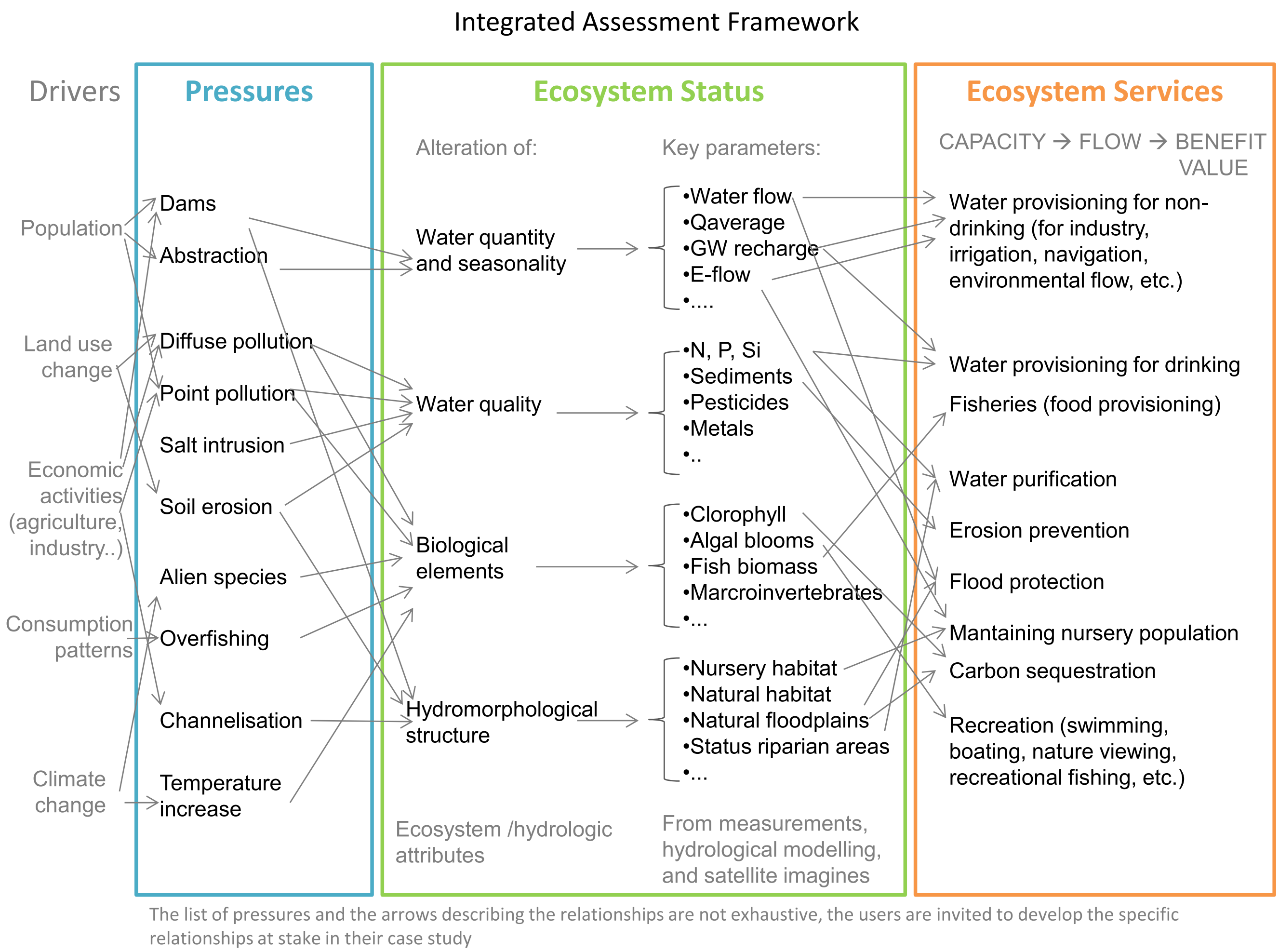

Fig. 2. Integrated assessment framework for analysing the links between pressures, ecosystem status and ecosystem services. The list of pressures and the arrows describing the relationships are not exhaustive; the users are invited to develop the specific relationships at stake in their case study.

usually combine ecology and economics, considering the spatial dimension. The EU FP7 project OpenNESS is studying methodologies for mapping and modelling the biophysical control of ecosystem services and approaches for the valuation of ecosystem services, for application in 27 real case studies. The biophysical methods include spreadsheet/GIS approaches (Burkhard et al., 2012; Vihervaara et al., 2012); Quickscan (2015); Bayesian Belief Networks (Smith et al., 2014); State and Transition Models (Bestelmeyer et al., 2011); ESTIMAP (Zulian et al., 2013); InVEST (2015). These methods apply to all ecosystem services, not specifically to water ecosystem services. Most of them rely on the spatial mapping of the ecosystems and land use.

The water quantity and quality, and the water related ecosystem services, are affected by the complex interactions of climate, topography and geology, land cover and management, and other anthropogenic modification of the landscape. Incorporating water related ecosystem services in the decision making process requires the capacity to predict the effects of land use and climate changes on the water resources, which can be offered by the hydrological models (Guswa et al., 2014). Hydrological and biogeochemical catchment models are appropriate tools for dealing with water related ecosystem services (Guswa et al., 2014; Vigerstol and Aukema, 2011; Brauman et al., 2007). They can represent the dynamic of the river basin (resilience) and the temporal (lag time) and spatial distance between beneficiaries and impacts, and they can be used in scenario analysis of multiple stressors. They also allow describing physical relationships between stressors, status and services as presented in the integrated assessment framework (Fig. 2).

3.3.2. Indicators

Following this line and considering the wealth of knowledge in hydrological modelling, we propose to base the biophysical assessment of ecosystem services on 'indicators' rather than 'tools'. Similar to Maes et al. (2014) and Layke et al. (2012), we suggest the selection of some suitable indicators or proxies of ecosystem services that are directly related to water bodies or to water-land interaction in the watershed, as a flexible and handy approach to measure ecosystem services.

To support the correct understanding and appropriate use of the indicators for ecosystem services, and more generally to structure the assessment, we have to analyse which dimension of the ecosystem service is captured by the indicators. To this purpose we propose a simplified conceptual framework for structuring the analysis and the classification of indicators of water ecosystem services. The framework, presented in Fig. 4, includes the *capacity* of the ecosystem to deliver the service, the actual *flow* of the service, and the *benefits*. Capacity refers to the potential of the ecosystem to provide ecosystem services, while flow is the actual use of the ecosystem services. The capacity relies on biophysical

	Ecosystem services	Flow modifications	Diffuse and point pollution	Groundwater salinization	Erosion/ Brownification	Hydromorphological alterations	Alien species	Overfishing
Provisioning	Fisheries and aquaculture	high	high	low	high	medium	high	high
	Water for drinking	high	high	high	high	medium	low	low
	Raw (biotic) materials	medium	high	low	medium	high	high	medium
	Water for non-drinking purposes	high	high	high	high	medium	low	low
	Raw materials for energy	high	high	low	low	high	medium	low
Regulation & Maintenance	Water purification	high	high	medium	high	high	medium	low
	Air quality regulation	high	high	low	low	medium	low	low
	Erosion prevention	high	low	low	low	high	medium	low
	Flood protection	high	low	low	low	high	medium	low
	Maintaining populations and habitats	high	high	low	medium	high	high	high
	Pest and disease control	high	high	low	medium	high	high	high
	Soil formation and composition	high	medium	low	high	high	low	low
	Carbon sequestration	medium	low	low	medium	high	medium	low
	Local climate regulation	high	low	low	low	high	low	low
Cultural	Recreation	high	high	low	high	high	medium	high
	Intellectual and aesthetic appreciation	high	high	high	high	high	high	high
	Spiritual and symbolic appreciation	high	high	high	high	high	high	high

Legend: Expected impact of each pressure over the ecosystem service: ● high, ● medium, ○ low.

Fig. 3. Expected qualitative effect of stressors/pressures on different ecosystem services.

data, while flow requires the acquisition of socio-economic data. Benefits are associated with human well-being and the value system (for studies discussing the concepts of capacity and flow and cascade model of ecosystem services see Haines-Young and Potschin, 2010; Layke et al., 2012; Villamagna et al., 2013; Maes et al., 2014; Schröter et al., 2014). Services are often associated with high exploitation of the ecosystem; the risk is an unsustainable use of nature. For this reason we are interested in looking at the sustainable flow of services. This is considered in the conceptual framework by including indicators informing about the *sustainability*, i.e. indicators combining capacity and flow (an example could be the Water Exploitation Index). In many cases, the information on capacity and flow is lacking, or the full capacity of the ecosystem is unknown or unaccountable. In these cases we can try to collect indicators about the efficiency of the processes (for example the removal rate of a pollutant per unit of input).

In this study we compiled a list of potential proxies/indicators for water ecosystem services based on the literature review (the indicators are provided in Supplementary Material S2). We classified them according to the categories of the conceptual framework: capacity, flow and benefit (the category of 'sustainability' and 'efficiency' were not explicitly used in the classification). Our compilation includes a total of 206 proxies and is based on Maes et al. (2014),Egoh et al. (2012), Layke et al. (2012), Russi et al. (2013) and Liquete et al. (2013) (minor modifications from the original authors like re-phrasing or re-allocation were required to avoid duplications and to respect our conceptual framework). Table 11 of Maes et al. (2014) comprises all the indicators proposed in the deliberative process of implementation of the EU Biodiversity Strategy around the freshwater pilot. Appendix A of Egoh et al. (2012) summarises an extensive literature review. The Ecosystem Service Indicators Database of the World Resources Institute (www.esindicators.org accessed in December 2015, Layke et al., 2012) compiles metrics and indicators from numerous sources that have been identified and applied by individuals from varied organizations. Russi et al. (2013) highlights the relevance of water and wetlands and links it to decision-making, providing a few examples of indicators for freshwater ecosystem services. We reviewed also Liquete et al. (2013), which includes a systematic compilation of 476 marine and coastal ecosystem services' indicators, in order to cover additional aspects specifically related to transitional and coastal waters. In the literature review, other studies were also considered (although some of them do not provide directly indicators for ecosystem services): the specific studies of the Millennium Ecosystem Assessment dealing with freshwater systems (MEA, 2005b,c); UNEP (2009), UNEP-WCM (2011), Feld et al. (2009, 2010), TEEB (2010), Vigerstol and Aukema (2011) and Clerici et al. (2014)

In Fig. 4 we provide some examples of indicators of ecosystem services for water provisioning and water purification, with references to studies that have used these indicators at the European scale. Other examples of application of the proposed conceptual framework for indicators can be found in Karabulut et al. (2016) for water provisioning, Rankinen et al. (submitted) for

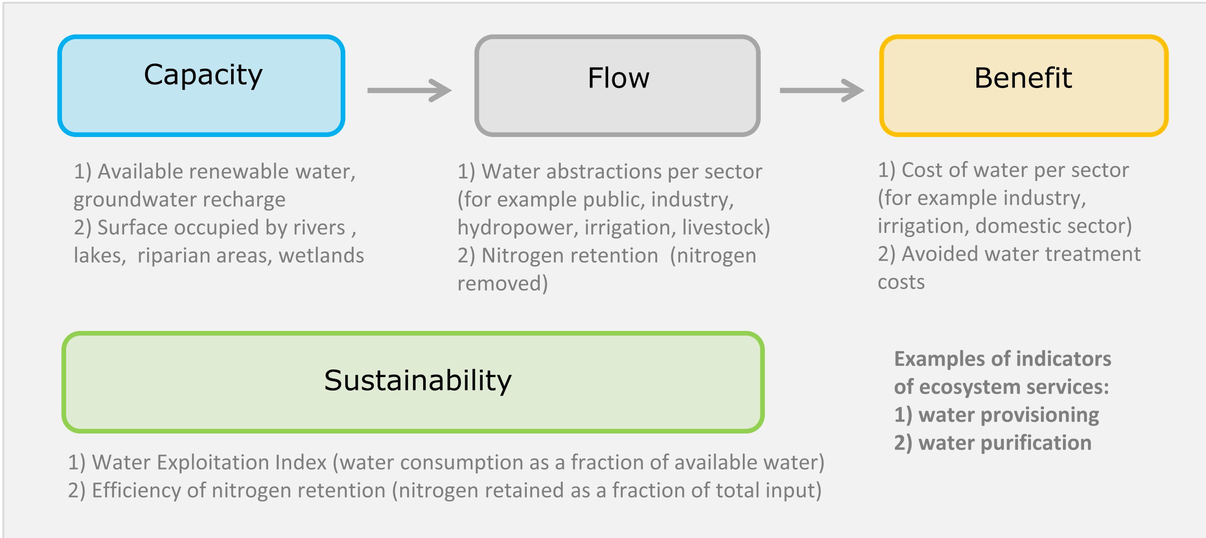

Fig. 4. Conceptual framework to classify indicators of water ecosystem services. Some examples of indicators for the ecosystem services of 1) water provisioning and 2) water purification are reported. For studies using these indicators at the European scale see 1) De Roo et al., 2012 for water provisioning, and 2) Clerici et al., 2013 (*capacity*), Grizzetti et al., 2012 (*flow*), La Notte et al., 2015 (*benefit*), Liquete et al., 2015 (*sustainability*) for water retention (nitrogen purification).

water purification, Vigiak et al. (submitted) for erosion prevention, and Liquete et al. (submitted) for several ecosystem services.

3.4. (Step 4) Economic valuation

Several methods are available in the literature to estimate economic values of freshwater ecosystem services (see for instance Koundouri et al., 2015). Overall, there are three categories of approaches: cost-based, revealed preferences and stated preferences approaches. Cost-based approaches consider the costs that arise in relation to the provision of services. Revealed preferences approaches refer to techniques that use actual data regarding individual's preferences for a marketable good which includes environmental attributes. Stated preferences approaches refer to methods based on structured surveys to elicit individuals' preferences for non-market environmental goods. Another practical way to value ecosystem services under non-availability of site-specific data or funding constraints is the benefit transfer approach. This approach consists of using economic estimates from previous studies to value services provided by the ecosystem of interest (Navrud and Ready, 2007). The methods for economic valuation available in the literature are summarised in Supplementary Material S3.

For the economic assessment, the first step consists of identifying the benefits provided by the ecosystem service to be valued. Fisher et al. (2009), Fisher and Turner (2008) argued that it is the easiest way to perform a valuation exercise avoiding any double counting. Following this approach, only the services that have a direct impact on welfare are valued. The spatial scale of the assessment is also relevant for the selection of the method.

Table 2
Freshwater ecosystem services, type of value and applied valuation methods. The classification of ecosystem services has been developed for fresh and transitional water (Reynaud and Lanzanova, 2015).

Ecosystem services	Category[a]	Value type	Valuation method[b]	Examples of economic good provided
1-Fisheries and aquaculture	Provisioning	Direct	MP, RC	fish catch
2-Water for drinking	Provisioning	Direct	MP, CV	water for domestic uses
3-Raw (biotic) materials	Provisioning	Direct	MP, RC	algae as fertilizers
4-Water for non-drinking purposes	Provisioning	Direct	MP,PF	water for industrial or agricultural uses
5-Raw materials for energy	Provisioning	Direct	RC	wood from riparian zones
6-Water purification	Regulation	Indirect	RC, CV	excess nitrogen removal by microorganisms
7-Air quality regulation	Regulation	Indirect	RC	deposition of NOx on vegetal leaves
8-Erosion prevention	Regulation	Indirect	RC	vegetation controlling soil erosion
9-Flood protection	Regulation	Indirect	RC, CV	vegetation acting as barrier for the water flow
10-Maintaining populations and habitats	Regulation	Indirect	RC	habitats use as a nursery
11-Pest and disease control	Regulation	Indirect	RC, CV	natural predation of diseases and parasites
12-Soil formation and composition	Regulation	Indirect	RC	rich soil formation in flood plains
13-Carbon sequestration	Regulation	Indirect	RC, MP	carbon accumulation in sediments
14-Local climate regulation	Regulation	Indirect	RC, MP	maintenance of humidity patterns
15-Recreation	Cultural	Direct	CV, TC, DC, HP	swimming, recreational fishing, sightseeing
16-Intellectual and aesthetic appreciation	Cultural	Non-use	CV, DC	matter for research, artistic representations
17- Spiritual and symbolic appreciation	Cultural	Non-use	CV, TC, DC	existence of emblematic species
18-Raw abiotic materials	Extra abiotic	Direct	PF, MP	extraction of sand gravel
19-Abiotic energy sources	Extra abiotic	Direct	PF, MP	hydropower generation

[a] Provisioning, Regulation and maintenance, Cultural, Extra abiotic services.
[b] Contingent valuation (CV), Hedonic price (HP), Market price (MP), production function (PF), Replacement cost (RC), travel costs (TC).

3.4.1. Economic valuation at the water body/catchment scale

The choice of the primary valuation method depends on the ecosystem service to be valued and on the beneficiary population. Table 2 reports valuation methods per ecosystem service based on the literature review.

One of the main difficulties in the economic valuation is to decide on the size of the benefiting population (beneficiaries). Aggregate benefits depend on estimates of both individual benefits and of the number of beneficiaries (Hanley et al., 2003). As a general rule, the beneficiaries should be the households/persons aggregated at the relevant geographic scale, and should include both users and non-users impacted by the ecosystem service considered (except for services of only local importance). In addition, for some services (for example recreational services), when spatially aggregating individual benefits, it is usually considered that the willingness to pay (WTP) decreases with the distance from water body providing ecosystem services, as the opportunities of the ecosystem service provision are expected to decrease with the distance, and concurrently the existence of possible substitutes is assumed to increase (Bateman and Langford, 1997; Georgiou et al., 2000; Jørgensen et al., 2013). Generally a distance decay function is adopted to take into account the decrease of the willingness to pay with the distance from the water body providing the ecosystem services (Bateman et al., 2006). This distance determines the boundaries of the geographical area, or so-called economic jurisdiction, over which the individual WTP-values can be aggregated over the population of beneficiaries to calculate the total economic value of a proposed scenario of environmental change (Schaafsma et al., 2012). However, the specification of the distance decay relations has been highly debated among economists. A number of studies have examined in particular how the distance decay relation differs between users and non-users of the ecosystem service (Hanley et al., 2003; Bateman et al., 2006).

3.4.2. Economic valuation at the large/continental scale

At the large/continental scale, such as the European scale, methodologies upscaling values of primary studies (value transfer) and accounting for the spatial heterogeneity of biophysical and socio-economic characteristics are more appropriate. This approach consists of a *meta*-analysis using the results of available past studies on ecosystem services valuation in water bodies to estimate a function that represents the relationship between the features of water ecosystems and the value of the services they provided (see Brander et al., 2006, 2007 for examples of *meta*-analysis for the valuation of ecosystem services).

The first step of a *meta*-analysis consists of searching and selecting studies valuing services provided by ecosystems similar to the one of interest (the policy site), most often through systematic searches. All relevant data from primary studies are collected and organised in a *meta*-database, including information on methods applied, ecosystem services valued, biophysical characteristics of the ecosystem, and the characteristics of the beneficiaries of the ecosystem services. To enable a comparison across studies, the economic values reported using different metrics (i.e. WTP, marginal values, capitalized value) are standardized. However, this is a difficult and controversial task (Ghermandi et al., 2010). Purchasing power parity indexes are applied to the original values to account for differences in purchasing power among countries, and appropriate price deflators are used to deal with the difference in the years of observation (Ghermandi and Nunes, 2013). In addition, values issued by different methods are normalized. For example values are expressed in monetary units per area and time (Ghermandi et al., 2010; Brander et al., 2012); or per visit and time (Brander et al., 2007) or per household/respondent and time (Brouwer et al., 1999; Johnston et al., 2005). The following step of the *meta*-analysis is the estimation of the *meta*-values transfer function. A regression technique allows accounting for the biophysical or socio-economical differences between the primary study sites and the policy site. There are two popular panel-data models which can be used for estimating the *meta*-regression model, e.g. the fixed-effect model and the random-effect model. The random-effects model allows the true effect size to differ from study to study and this is the approach usually recommended. The values of ecosystem services that are estimated by the regression analysis are then transferred and aggregated at the larger geographic areas through a scaling-up procedure. The most appropriate transfer function among the different *meta*-regression specifications has to be selected based on the explanatory power of the model, sign and significance of the coefficients estimated. In addition, the appropriate geographic scale for transferring values has to be defined (Ghermandi and Nunes, 2013).

4. Discussion

Considering the current and impellent challenge of the implementation, i.e. being able to translate the concepts of ecosystem services into practice (European Commission, 2011, 2012; Guerry et al., 2015), the need to be operational constituted one of the leading criteria in the development of the present review and proposed approach. We considered this research as a learning process. The application of the approach is on-going in the project MARS at the catchment and the European scale. This will provide the necessary feedback to improve and refine the approach.

Here we discuss some aspects that we consider important when assessing and valuing ecosystem service to support the WFD and RBMP, and how the proposed approach could address them.

4.1. The valuation of ecosystem services

The WFD refers to economic valuation in decision-making to support the RBMP in the identification and selection of cost-effective Programmes of Measures (PoM, WFD Article 11). Quantifying the benefits (ecosystem services) that nature provides to people would help justify the investments in conservation and restoration of aquatic ecosystems. In addition, the development of the PoM can be improved integrating all relevant ecosystem services, by considering the co-benefits of different measures and nature-based solutions on different ecosystem services (Liquete et al., submitted). The benefits of ecosystem services could also be included in the cost-benefit analysis to implement the cost-recovery principle in the water supply system (WFD Article 9) (Vlachopoulou et al., 2014; COWI, 2014).

Yet the valuation of ecosystem services also involves some important risks, i.e. creating economic markets for provisioning, regulating and cultural services. We have to reflect on the notion of ‘valuation’. Any decision involving trade-offs of ecosystem service implies valuation (Costanza et al., 2014). There are different values in the relationship of human and non-human nature, including inherent, fundamental, eudaimonistic and instrumental values (Jax et al., 2013). The values that are captured by the ecosystem service concept depend on how the concept is operationalised and implemented (approaches and methodologies used). Different stakeholders have different value systems and perspectives. Therefore involving all the stakeholders in the valuation process is necessary to consider the plurality of values, while neglecting some values would exclude the people who embrace these values (Jax et al., 2013).

The notion of value should not be restricted to the mere monetary value but embrace a larger range of values. If restricting the value of ecosystem services to economic value, we risk false accounting of all value dimensions and environmental components (trade-offs) of policy decision (Keeler et al., 2012). 'Value pluralism' refers to the idea that there are multiple values, including economic (monetary), sociocultural and ecological values. An integrated valuation should endorse the value pluralism (Gómez-Baggethun et al., 2014). The valuation techniques vary with the typology of values to be elicited and the scope of the valuation exercise, the geographical scale, spatial resolution, and reliability and accuracy required. The purpose of the valuation can range from awareness raising, to accounting, priority setting, instrument design and litigation (Gómez-Baggethun and Barton, 2013).

In the proposed approach, we think it is important to interpret the economic valuation in monetary terms sensu Costanza et al. (2014), i.e. for awareness raising about relative changes over a period in time. This excludes the intent of treating all ecosystem services as substitutable. We are interested mainly in the change of value as the result of the effects of multiple stressors changes or the implementation of measures.

4.2. Strengthen the connection human-nature

RBMPs are based on the principles of Integrated Water Resource Management (IWRM), "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP, 2000). Before the ecosystem service approach, IWRM already stressed the need for connecting environment and human well-being and proposed the integration of multi-disciplinary knowledge from different sectors and stakeholders in the water management. The ecosystem services approach has significant similarities with IWRM. Cook and Spray (2012) argue that the two concepts are 'nearly identical'. Both aim at a management of natural resources that optimises the economic and social welfare and contemporary insures the ecological sustainability, integrating the knowledge of stakeholders and multiple disciplinary perspectives. Ecosystem services and IWRM both share the goal of negotiating the trade-offs between different human and ecosystem needs, while supporting sustainability, and require the involvement of stakeholders for making explicit the whole range of values (not only economic values). The ecosystem service approach offers a framework for analysing the trade-offs among different services and the links to beneficiaries (Brauman et al., 2007). Learning from the criticisms to IWRM would help improve the adoption of the ecosystem service approach. These criticisms are related to the lack of consistent definitions, the difficulty of developing a holistic approach, the risk of opposite interpretations of the concepts, and the failure to incorporate the principles in the governance (Cook and Spray, 2012). The 'implementation gap' is an important challenge for the ecosystem service approach and this study aims to contribute to this endeavour.

To address current sustainability challenges the recognition of the dependency of human well-being on natural capital is necessary (Guerry et al., 2015). Integrative frameworks such as the ecosystem service approach allow incorporation of natural components in the system analysis (Liu et al., 2015). The concept of a human-ecological system advocated by the ecosystem service approach is powerful in linking biophysical processes and human benefits, and allows ecosystem services to be valued and integrated in the river basin decision making process. However, economic models to value ecosystem services related to water quality are often poorly integrated with the biophysical models describing the underpinning natural processes (Keeler et al., 2012).

In this study we considered both dimensions of biophysical assessment and economic valuation and we suggest to perform them in collaboration. This is a crucial but evasive step of ecosystem service analyses, and remains one of the main challenges in this field research (Polasky et al., 2015). The integration also depends on the method used for the assessment. In the case of freshwater systems, many biophysical results (coming from models or measures) can be used as an input for economic valuations. Some examples are the improvements of juvenile fish to estimate the economic enhancement of commercial fish by seagrass (Blandon and zu Ermgassen, 2014), the nitrogen retention efficiency used to estimate the replacement cost of water purification (La Notte et al., 2015), the forecasted trend of fish biomass used to estimate future employment in the fishing sector, the erosion rate or level of degradation linked to loss in property values, or the climate records and forecasts linked to economic damages caused by floods.

5. Conclusions

The method proposed in this paper to assess and value water ecosystem services provides some knowledge basis for the enrichment of water management; in particular it proposes a more holistic view to the implementation of the EU WFD linking multiple pressures, ecological status and delivery of ecosystem services. Under this perspective, the analysis of cost-effective and remediation measures can be improved including all hidden benefits and beneficiaries from water ecosystem services.

The first part of the analysis should at least identify the ecosystem services of interest and frame the major effects of multiple drivers and pressures on the ecological status of water bodies. Then, the approach suggests a biophysical quantification of the natural capacity, actual flow and social benefit of water ecosystem services. We propose to use selected proxies/indicators based mainly on hydrological models or data for this part of the assessment. One important and novel point in this approach is to assess also some sustainability (or efficiency) index that estimates the flow of service that can be sustained with a certain capacity. This could avoid the overexploitation of certain services. The proposed method includes also the economic valuation of aquatic ecosystem, providing a list of techniques for each service and spatial scale of application. There is a large variety of valuation methods that have to be carefully selected. Valuing water ecosystem services could highlight hidden benefits for society and could raise awareness among users and stakeholders. Even if monetary values are probably the most appealing arguments for water management, we also advocate and describe the advantages of using a plurality of values. Overall, the proposed approach can be used for assessing the benefits of conservation and restoration of aquatic ecosystems in the implementation of the EU water policy.

There are opportunities by adopting the ecosystem services approach to capture and integrate all the effects (economic, environmental and social) associated with new water plans and investments. Performing biophysical assessment and economic valuation collaboratively could boost awareness and inclusion of the interdependence of nature and people for a sustainable management of water resources. The integration of biophysical and economic approaches and data remains one of the main challenges and key aspects of this approach.

Acknowledgements

This study has been funded by the EU FP7 project MARS (Managing Aquatic ecosystems and water Resources under multiples Stress; project number 603378). The authors would like to thank all the MARS partners for their feedback to the methodology.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2016.04.008.

References

Bagstad, K.J., Semmens, D.J., Waage, S., Winthrop, R., 2013. A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Ecosyst. Serv. 5, e27–e39.
Bateman, I.J., Langford, I.H., 1997. Non-users' willingness to pay for a National Park: an application and critique of the contingent valuation method. Reg. Stud. 31, 571–582.
Bateman, I.J., Day, B.H., Georgiou, S., Lake, I., 2006. The aggregation of environmental benefit values: welfare measures, distance decay and total WTP. Ecol. Econ. 60, 450–460.
Bestelmeyer, B.T., Goolsby, D.P., Archer, S.R., 2011. Spatial perspectives in state-and-transition models: a missing link to land management? J. Appl. Ecol. 48, 746–757.
Blandon, A., zu Ermgassen, P.S., 2014. Quantitative estimate of commercial fish enhancement by seagrass habitat in southern Australia. Estuarine Coastal Shelf Sci. 141, 1–8.
Brander, L.M., Florax, R.J.G.M., Vermaat, J.E., 2006. The empirics of wetland valuation: a comprehensive summary and a meta-analysis of the literature. Environ. Resour. Econ. 33, 223–250.
Brander, L.M., Van Beukering, P., Cesar, H.S.J., 2007. The recreational value of coral reefs: a meta-analysis. Ecol. Econ. 63, 209–218.
Brander, L.M., Wagtendonk, A.J., Hussain, S.S., McVittie, A., Verburg, P.H., de Groot, R. S., van der Ploeg, S., 2012. Ecosystem service values for mangroves in Southeast Asia: a meta-analysis and value transfer application. Ecosyst. Serv. 1, 62–69.
Brauman, K.A., Daily, G.C., Duarte, T.K., Mooney, H.A., 2007. The nature and value of ecosystem services: an overview highlighting hydrologic services. Annu. Rev. Environ. Resour. 67–98.
Brouwer, R., Langford, I.H., Bateman, I.J., Turner, R.K., 1999. A meta-Analysis of wetland contingent valuation studies. Reg. Environ. Change 1, 47–57.
Brown, C.J., Saunders, M.I., Possingham, H.P., Richardson, A.J., 2013. Managing for interactions between local and global stressors of ecosystems. PLoS One 8, e65765.
Burkhard, B., Kroll, F., Müller, F., Windhorst, W., 2009. Landscapes' capacities to provide ecosystem services – a concept for land-cover based assessments. Landsc. Online 15, 1–22.
Burkhard, B., Kroll, F., Nedkov, S., Müller, F., 2012. Mapping ecosystem service supply, demand and budgets. Ecol. Indic. 21, 17–29.
Butchart, S.H.M., Walpole, M., Collen, B., Van Strien, A., Scharlemann, J.P.W., et al., 2010. Global biodiversity: indicators of recent declines. Science 328, 1164–1168.
CBD, 2010. Convention on Biological Diversity. COP Decision X/2.
CICES, 2015. http://cices.eu/ (accessed December, 2015).
COWI, 2014. Support Policy Development for Integration of an Ecosystem Services Approach with WFD and FD Implementation. Resource document.
Clerici, N., Weissteiner, C.J., Paracchini, M.L., Boschetti, L., Baraldi, A., Strobl, P., 2013. Pan-European distribution modelling of stream riparian zones based on multi-source Earth Observation data. Ecol. Indic. 24, 211–223.
Clerici, N., Paracchini, M.L., Maes, J., 2014. Land-cover change dynamics and insights into ecosystem services in European stream riparian zones. Ecohydrol. Hydrobiol. 14, 107–120.
Cook, B.R., Spray, C.J., 2012. Ecosystem services and integrated water resource management: different paths to the same end? J. Environ. Manage. 109, 93–100.
Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. Glob. Environ. Change 26, 152–158.
Crossman, N.D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., Drakou, E. G., Martín-Lopez, B., McPhearson, T., Boyanova, K., Alkemade, R., Egoh, B., Dunbar, M.B., Maes, J., 2013. A blueprint for mapping and modelling ecosystem services. Ecosyst. Serv. 4, 4–14.
De Roo, A., Burek, P., Gentile, A., Udias, A., Bouraoui, F., Aloe, A., Bianchi, A., La Notte, A., Kuik, O., Tenreiro, J.E., Vandecasteele, I., Mubareka, S., Baranzelli, C., Der Perk, M.V., Lavelle, C., Bidoglio, G., 2012. A multi-criteria optimisation of scenarios for the protection of water resources in Europe. JRC Scientific and Policy Report. JRC75919, ISSN 1831-9424, EC-JRC-IES, Italy.
Directive 2000/60/EC, 2000. Establishing a Framework for Community Action in the Field of Water Policy. (OJ (2000) L327/1). (Water Framework Directive).
ESAWADI, 2010. http://www.iwrm-net.eu/node/7 (accessed December, 2015).
Egoh, B., Drakou, E.G., Dunbar, M.B., Maes, J., Willemen, L., 2012. Indicators for Mapping Ecosystem Services: a Review. Publications Office of the European Union, Luxembourg.
European Commission, 2011. COM(2011) 244 final. Our life insurance, our natural capital: an EU biodiversity strategy to 2020.
European Commission, 2012. COM(2012) 673 final. A Blueprint to Safeguard Europe's Water Resources.
European Commission, 2015. COM(2015) 120 final. The Water Framework Directive and the Floods Directive: Actions towards the 'good status' of EU water and to reduce flood risks.
Feld, C.K., Da Silva, P.M., Sousa, J.P., De Bello, F., Bugter, R., Grandin, U., Hering, D., Lavorel, S., Mountford, O., Pardo, I., Pärtel, M., Römbke, J., Sandin, L., Bruce Jones, K., Harrison, P., 2009. Indicators of biodiversity and ecosystem services: a synthesis across ecosystems and spatial scales. Oikos 118, 1862–1871.
Feld, C.K., Sousa, J.P., da Silva, P.M., Dawson, T.P., 2010. Indicators for biodiversity and ecosystem services: towards an improved framework for ecosystems assessment. Biodiver. Conserv. 19, 2895–2919.
Fisher, B., Turner, K.R., 2008. Ecosystem services: classification for valuation. Biol. Conserv. 141, 1167–1169.
Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecol. Econ. 68, 643–653.
Gómez-Baggethun, E., Barton, D.N., 2013. Classifying and valuing ecosystem services for urban planning. Ecol. Econ. 86, 235–245.
Gómez-Baggethun, E., Martin-Lopez, B., Barton, D.N., Braat, L., Kelemen, E., Llorente, M.G., Saarikoski, H., van den Bergh, J., 2014. State of the art report on integrated valuation of ecosystem services. Deliverable D4.1/WP4 OpenNESS project.
GWP, 2000. Integrated water resource management. Technical Advisory Committee Background Paper Number 4. Global Water Partnership, Stockholm.
Georgiou, S., Bateman, I., Cole, M., Hadley, D., 2000. Contingent ranking and valuation of water quality improvements. CSERGE Discussion Paper 2000–18. University of East Anglia.
Ghermandi, A., Nunes, P.A.L.D., 2013. A global map of coastal recreation values: results from a spatially explicit meta-analysis. Ecol. Econ. 86, 1–15.
Ghermandi, A., Van Den Bergh, J.C.J.M., Brander, L.M., De Groot, H.L.F., Nunes, P.A.L. D., 2010. Values of natural and human-made wetlands: a meta-analysis. Water Resour. Res. 46.
Globaqua, 2015. http://www.globaqua-project.eu/en/home/ (accessed December, 2015).
Grizzetti, B., Bouraoui, F., Aloe, A., 2012. Changes of nitrogen and phosphorus loads to European seas. Glob. Change Biol. 18, 769–782.
Guerry, A.D., Polasky, S., Lubchenco, J., Chaplin-Kramer, R., Daily, G.C., Griffin, R., Ruckelshaus, M., et al., 2015. Natural capital and ecosystem services informing decisions: from promise to practice. Proc. Natl. Acad. Sci. 112, 7348–7355.
Guswa, A.J., Brauman, K.A., Brown, C., Hamel, P., Keeler, B.L., Sayre, S.S., 2014. Ecosystem services: challenges and opportunities for hydrologic modeling to support decision making. Water Resour. Res. 50, 4535–4544.
Haines-Young, R., Potschin, M., 2010. The links between biodiversity, ecosystem services and human well-being. In: Raffaelli, D.G., Frid, C.L.J. (Eds.), Ecosystem Ecology: A New Synthesis. Cambridge University Press, Cambridge, pp. 110–139.
Halpern, B.S., McLeod, K.L., Rosenberg, A.A., Crowder, L.B., 2008. Managing for cumulative impacts in ecosystem-based management through ocean zoning. Ocean Coastal Manage. 51, 203–211.
Hanley, N.D., Schläpfer, F., Spurgeon, J., 2003. Aggregating the benefits of environmental improvements: distance-decay functions for use and non-use values. J. Environ. Manage. 68, 297–304.
Hering, D., Carvalho, L., Argillier, C., Beklioglu, M., Borja, A., Cardoso, A.C., Duel, H., Ferreira, T., Globevnik, L., Hanganu, J., Hellsten, S., Jeppesen, E., Kodeš, V., Solheim, A.L., Nõges, T., Ormerod, S., Panagopoulos, Y., Schmutz, S., Venohr, M., Birk, S., 2015. Managing aquatic ecosystems and water resources under multiple stress – an introduction to the MARS project. Sci. Total Environ. 503–504, 10–21.
InVEST, 2015. http://www.naturalcapitalproject.org/invest/ (accessed December, 2015).
Jørgensen, S.L., Olsen, S.B., Ladenburg, J., Martinsen, L., Svenningsen, S.R., Hasler, B., 2013. Spatially induced disparities in users' and non-users' WTP for water quality improvements-Testing the effect of multiple substitutes and distance decay. Ecol. Econ. 92, 58–66.
Jax, K., Barton, D.N., Chan, K.M.A., de Groot, R., Doyle, U., Eser, U., et al., 2013. Ecosystem services and ethics. Ecol. Econ. 93, 260–268.
Johnston, R.J., Besedin, E.Y., Iovanna, R., Miller, C.J., Wardwell, R.F., Ranson, M.H., 2005. Systematic variation in willingness to pay for aquatic resource improvements and implications for benefit transfer: a meta-analysis. Can. J. Agric. Econ. 53, 221–248.
Karabulut, A., Egoh, B.N., Lanzanova, D., Grizzetti, B., Bidoglio, G., Pagliero, L., Bouraoui, F., Aloe, A., Reynaud, A., Maes, J., Vandecasteele, I., Mubareka, S., 2016. Mapping water provisioning services to support the ecosystem-water-food-energy nexus in the Danube river basin. Ecosyst. Serv. 17, 278–292.
Keeler, B.L., Polasky, S., Brauman, K.A., Johnson, K.A., Finlay, J.C., O'Neille, A., Kovacs, K., Dalzell, B., 2012. Linking water quality and well-being for improved assessment and valuation of ecosystem services. Proc. Natl. Acad. Sci. U. S. A. 109, 18619–18624.
Koundouri, P., Ker Rault, P., Pergamalis, V., Skianis, V., Souliotis, I., 2015. Development of an integrated methodology for the sustainable environmental and socio-economic management of river ecosystems. Sci. Total Environ. 540, 90–100.
Kull, C.A., Arnauld de Sartre, X., Castro-Larrañaga, M., 2015. The political ecology of ecosystem services. Geoforum 61, 122–134.
La Notte, A., Liquete, C., Grizzetti, B., Maes, J., Egoh, B.N., Paracchini, M.L., 2015. An ecological-economic approach to the valuation of ecosystemservices to support biodiversity policy. A case study for nitrogenretention by Mediterranean rivers and lakes. Ecol. Indic. 48, 292–302.
Layke, C., Mapendembe, A., Brown, C., Walpole, M., Winn, J., 2012. Indicators from the global and sub-global millennium ecosystem assessments: an analysis and next steps. Ecol. Indic. 17, 77–87.

Liquete, C., Piroddi, C., Drakou, E.G., Gurney, L., Katsanevakis, S., Charef, A., Egoh, B., 2013. Current status and future prospects for the assessment of marine and coastal ecosystem services: a systematic review. PLoS One 8.
Liquete, C., Kleeschulte, S., Dige, G., Maes, J., Grizzetti, B., Olah, B., Zulian, G., 2015. Mapping green infrastructure based on ecosystem services and ecological networks: a Pan-European case study. Environ. Sci. Policy 54, 268–280.
Liquete, C., Udias, A., Conte, G., Grizzetti, B., Masi, F., 2016. Integrated valuation of a nature-based solution for water pollution control. Highlighting Hidden Benefits. (submitted).
Liu, J., Mooney, H.A., Hull, V., Davis, S.J., Gaskell, J., Hertel, T., Lubchenco, J., Seto, K.C., Gleick, P., Kremen, C., Li, S., 2015. Systems integration for global sustainability. Science 347, 1258832.
MARS, 2015. http://www.mars-project.eu/ (accessed December, 2015).
MEA, 2005a. Millennium ecosystem assessment. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC.
MEA, 2005b. Millennium ecosystem assessment. Current State & Trends Assessment. Freshwater Ecosystem Services (Chapter 7).
MEA, 2005c. Millennium ecosystem assessment. Ecosystems and Human Well-being: Wetlands and Water. Synthesis. World Resources Institute, Washington, DC.
Maes, J., Teller, A., Erhard, M., Murphy, P., Paracchini, M.L., Barredo, J.I., Grizzetti, B., Cardoso, A.C., et al., 2014. Mapping and Assessment of Ecosystems and their Services. Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. 2nd Report –Final, February 2014. Technical Report – 2014-080.
Maes, J., Liquete, C., Teller, A., Erhard, M., Paracchini, M.L., Barredo, J.I., Grizzetti, B., Cardoso, A., et al., 2016. An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020. Ecosyst. Serv. 17, 14–23.
Nõges, P., Argillier, C., Borja, A., Garmendia, J.M., Hanganu, J., Kodeš, V., Pletterbauer, F., Sagouis, A., Birk, S., 2015. Quantified biotic and abiotic responses to multiple stress in freshwater, marine and ground waters. Sci. Total Environ. 540, 43–52.
Navrud, S., Ready, R.C., 2007. Environmental Value Transfer: Issues and Methods. Springer, Dordrecht.
OPERAs, 2015. http://operas-project.eu/ (accessed December, 2015).
OpenNESS, 2015. http://www.openness-project.eu/ (accessed December, 2015).
Pereira, H.M., Domingos, T., Vicente, L., 2006. Assessing ecosystem services at different scales in the Portugal Millennium Ecosystem Assessment. In: Reid, W., Berks, F., Wilbanks, T., Capistrano, D. (Eds.), Bridging Scales and Knowledge Systems. Island Press, Washington DC, pp. 59–80.
Polasky, S., Tallis, H., Reyers, B., 2015. Setting the bar: standards for ecosystem services. Proc. Natl. Acad. Sci. 112, 7356–7361.
Quickscan, 2015. http://quickscan.pro/ (accessed December, 2015).
Rankinen, K., Butterfield, D., Faneca Sànchez, M., Grizzetti, B., Whitehead, P., Pitkänen, T., Uusi-Kämppä, J., Leckie, H., 2016. The INCA-pathogens model: an application to the Loimijoki River basin in Finland. Sci. Total Environ. submitted.
Regulation (EU), 2014. No 1143/2014 on the prevention and management of the introduction and spread of invasive alien species.
Reynaud, A., Lanzanova, D., 2015. A global meta-Analysis of ecosystem services values provided by lakes. Presented at the 2nd Annual Conference of the French Association of Environmental and Resource Economists, 10–11 September in Toulouse.
Russi, D., ten Brink, P., Farmer, A., Badura, T., Coates, D., Förster, J., Kumar, R., Davidson, N., 2013. The Economics of Ecosystems and Biodiversity for Water and Wetlands. IEEP, London and Brussels; Ramsar Secretariat Gland.
Schaafsma, M., Brouwer, R., Rose, J., 2012. Directional heterogeneity in WTP models for environmental valuation. Ecol. Econ. 79, 21–31.
Schröter, M., Barton, D.N., Remme, R.P., Hein, L., 2014. Accounting for capacity and flow of ecosystem services: a conceptual model and a case study for Telemark, Norway. Ecol. Indic. 36, 539–551.
Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., et al., 2015. InVEST +VERSION+ User's Guide. The Natural Capital Project. Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.
Smith, R., Madsen, A.L., Haines-Young, R., Barton, D., 2014. WP3 Methodological Guidelines for Bayesian Belief Networks. . (accessed December, 2015) http://openness.hugin.com/huginprog/documentation/WP3_Method_Guidelines_BBNs_050314.pdf.
TEEB, 2010. The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundation. Earthscan, London and Washington.
Teichert, N., Borja, A., Chust, G., Uriarte, A., Lepage, M., 2016. Restoring fish ecological quality in estuaries: implication of interactive and cumulative effects among anthropogenic stressors. Sci. Total Environ. 542, 383–393.
UK NEA, 2011. The UK National Ecosystem Assessment Technical Report. UNEP/WCMC, Cambridge.
UNEP, 2009. Water security and ecosystem services: the critical connection. Nairobi, Kenya.
UNEP-WCM, 2011. Developing Ecosystem Service Indicators: Experiences and Lessons Learned from Sub-global Assessments and Other Initiatives. Secretariat of the Convention on Biological Diversity, Montréal, Canada.
Vigerstol, K.L., Aukema, J.E., 2011. A comparison of tools for modeling freshwater ecosystem services. J. Environ. Manage. 92, 2403–2409.
Vigiak, O., Malagó, A., Bouraoui, F., Grizzetti, B., Weissteiner, C.J., Pastori, M., 2016. Impact of current riparian land on sediment retention in the Danube River Basin. J. Sustainability Water Qual. Ecol. submitted.
Vihervaara, P., Kumpula, T., Ruokolainen, A., Tanskanen, A., Burkhard, B., 2012. The use of detailed biotope data for linking biodiversity with ecosystem services in Finland. Int. J. Biodivers. Sci. Ecosyst. Serv. Manage. 8, 169–185.
Villamagna, A.M., Angermeier, P.L., Bennett, E.M., 2013. Capacity, pressure, demand, and flow: a conceptual framework for analyzing ecosystem service provision and delivery. Ecol. Complexity 15, 114–121.
Vlachopoulou, M., Coughlin, D., Forrow, D., Kirk, S., Logan, P., Voulvoulis, N., 2014. The potential of using the ecosystem approach in the implementation of the EU water framework directive. Sci. Total Environ. 470–471, 684–694.
Zulian, G., Paracchini, M.L., Maes, J., Liquete, C., 2013. ESTIMAP: Ecosystem Services Mapping at European Scale. JRC Report EUR 26474 EN.