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Getting into the water with the Ecosystem Services Approach: The DESSIN ESS evaluation framework

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ABSTRACT

Driven by Europe's pressing need to overcome its water quality and water scarcity challenges, the speed of innovation in the water sector is outpacing that of science. The methodologies available to assess the impact of innovative solutions to water-related challenges remain limited and highly theoretical, which sets boundaries on their application and usefulness to water practitioners. This hampers the uptake of new technologies and innovative management practices, thus foregoing potential gains in resource efficiency and nature protection, as well as wider benefits to society and the economy. To address this gap, the DESSIN project developed a framework to evaluate the changes in ecosystem services (ESS) associated with technical or management solutions implemented at the water body, sub-catchment or catchment level. The framework was developed with a specific focus on freshwater ecosystems to allow for a more detailed exploration of practical implementation issues. Its development, testing and validation was carried out by conducting ESS evaluations in three different urban case study settings. The framework builds upon existing classification systems for ESS (CICES and FEGS-CS) and incorporates the DPSIR adaptive management scheme as its main structural element. This enables compatibility with other international initiatives on ESS assessments and establishes a direct link to the EU Water Framework Directive, respectively. This work furthers research on practical implementation of the Ecosystem Services Approach, while pushing the discussion on how to promote more informed decision-making and support innovation uptake to address Europe's current water-related challenges.

1. Introduction

Europe currently faces great challenges regarding water quality and water scarcity, which coincide with growing economic uncertainty in the region (e.g., political changes, financial fluxes, labour market shifts, among other factors). These challenges can become especially adverse in urban areas, where they can be compounded by increasing population levels and overburdened water and wastewater infrastructures (Koop and van Leeuwen, 2017). Consequently, the EU has opted to direct part of its research, development and innovation efforts in the water sector towards increasing the knowledge base on aquatic ecosystems and water management (often with special focus on urban areas, e.g. EEA,

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2016; Dige et al., 2017) and promoting the uptake and commercialisation of innovative solutions for water supply and treatment (Aho et al., 2014; Schmidt et al., 2016). Examples of such innovative solutions may include new techniques to replenish groundwater resources or treat combined sewage in a decentralised way.

Oftentimes, as new technologies and management approaches emerge, the limitations of the available impact assessment methodologies become evident. Enhancements in such assessment approaches are thus necessary to ensure that the full range of possible impacts on natural systems is accounted for. These enhancements may refer, for instance, to new ways of measuring the benefits that humans perceive from their interaction with nature. In this context, European policy has placed increased interest in the concept of Ecosystem Services (ESS) and the Ecosystem Services Approach (ESA) (Bouwma et al., 2018). In particular, these are perceived to have great potential for enabling more holistic evaluations of the impacts resulting from new interventions. These evaluations should, in particular, integrate economic, environmental and societal dimensions.

To date, much research has been conducted on the concept of ESS and the multiple aspects concerning its potential as a support tool for policy- and decision-making, e.g. the Millennium Assessment (MA, 2003; 2005), The Economics of Ecosystems and Biodiversity (TEEB, 2008; 2010), initiatives in this field through the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2014; Díaz et al., 2015) and the EU-Working Group MAES (Maes et al., 2013, 2016), as well as research projects such as GLOBAQUA (Navarro-Ortega et al., 2015), AQUACROSS (Gómez et al., 2016), MARS (Hering et al., 2015), OpenNESS (Potschin et al., 2014), OPERAS (Kettunen and Brink 2015) and POLICYMIX (Barton et al., 2014). However, and despite the progress achieved so far, the practical application of the ESA continues to be hindered by its highly theoretical nature and by the fact that those involved in such applications are required to transgress disciplinary boundaries if they want to exploit the approach to its fullest extent. This can result in difficulties - the causes for which range from inconsistencies in the use of terminology to contradictory handling of fundamental ESS concepts. In addition, the most advanced efforts are those that focus on national ESS assessments, where downscaling issues have been pointed out by critics as a strong limitation (Potschin and Haines-Young, 2013; Paetzold et al., 2010; Costanza et al., 2014).

In response to these issues, the FP7 project DESSIN (Demonstrate Ecosystem Services Enabling Innovation in the Water Sector), funded by the European Commission, set out to demonstrate innovative solutions to water-related challenges and to develop an evaluation framework to measure their impacts on ESS. In this sense, DESSIN endeavours to contribute to the discussion by bringing forward an evaluation framework that is a) focused on changes resulting from concrete measures implemented at the local level and b) applicable to produce output that can be extrapolated from the bottom-up. The project's exclusive focus on freshwater ecosystems and their services allows for a more concentrated discussion and development work that in turn enables a more detailed exploration of practical implementation issues.

This paper aims to introduce the DESSIN ESS Evaluation Framework to the wider scientific community and to promote its use and further development as a tool for conducting local-level applications of the ESA. The following sections provide an overview of the justification and objective of the framework (Section 2), the rationale for its development based on practical case studies (Section 3), and its conceptual approach (Section 4) and design (Section 5). Sections 6 and 7 then present a discussion of the aforementioned aspects and general conclusions, respectively.

2. Justification and objective

Decision-making in water management relies on information describing ecological, economic, and social aspects collated in a transparent way. Handling, integrating and interpreting such information requires a balanced combination of administrative capacity and specialized expertise. This means water managers and similar authorities in charge of freshwater ecosystems have to collaborate with natural scientists, social scientists, engineers, economists and others in order to reach sound decisions. Tools that support this collaboration, especially through facilitating communication across disciplines, are thus required. A literature review revealed multiple existing ESS assessment frameworks that lay out methodologies linking ESS to human well-being, and that could be useful for authorities and organisations involved in water management (MA, 2003, 2005; TEEB, 2008, 2010; Harrison, 2010; Paetzold et al., 2010; Keeler et al., 2012; Peh et al., 2013; Seppelt et al., 2012). However, some of these frameworks cannot identify how changes in ecosystems impact the provision of ESS, while others are overly time and/or data intensive, focus solely or mainly on a single water issue (e.g., water quality or water scarcity), are limited in their coverage of ESS types (e.g. focus on provisioning services), or exclude sustainability considerations. Furthermore, no direct link between such ESS assessment frameworks and the Water Framework Directive (WFD) seems evident, at a time when integration between WFD objectives and ESS principles is being pursued (Vlachopoulou et al., 2014).

The DESSIN framework aims to enable the practical application of the ESA at the level of an environmental system of interest (e.g. a surface or groundwater body, sub-catchment or catchment) to assist decision-making that considers the specific and current strains put on the ecosystem in focus and the direct effects of a technical or management solution upon it. As opposed to other established assessments that produce aggregate accounts of the services provided by a region's or nation's ecosystems (INBO, 2014; Marta-Pedroso et al., 2014; The Finnish Environment, 2015), the DESSIN framework allows its users to evaluate changes in ESS related to the measures implemented in a given freshwater ecosystem. In other words, the framework focuses on local-level assessments to allow its user to associate small-scale interventions to potential impacts on environmental, economic and social domains. Where quantification of ESS is not possible due to a lack of information, the framework allows for the formulation of qualitative arguments that can also be helpful for consultation and decision-making. The framework facilitates scenario analysis and the comparison amongst different solutions. Furthermore, it includes the option to take broader-term aspects of sustainability of the specific measure into account (detailed descriptions follow in Section 5.2).

The framework builds upon an existing classification system for ESS and a well-established methodological scheme that are generally known and accepted in European ESS research circles. These are the Common International Classification of Ecosystem Services (CICES) developed by Haines-Young and Potschin (2011) and the Driver, Pressure, State, Impact, Response (DPSIR) adaptive management scheme created by the European Environment Agency (1999). In addition, the framework incorporates some of the notions and elements behind the Final Ecosystem Goods and Services-Classification System (FEGS-CS) elaborated by Landers and Nahlik (2013), and the sustainability assessment tool developed in the TRUST project (Alegre et al., 2012).

Adopting the CICES typology ensures that evaluations conducted using the DESSIN framework are compatible and comparable with other assessments undertaken by European institutions. Using the DPSIR scheme as the main structural element of the framework endowed it with an easy-to-follow, sequential evaluation approach and established an important link to the WFD. Finally, building upon the beneficiaries concept and typology used in the FEGS-CS approach provided key functionality to the framework in terms of differentiating between final and intermediate[3] ESS, as this provided the basis for identifying which are actually used by humans in the study area. Because the CICES typology lacked a sufficient level of specificity for practical application at the local level, the DESSIN framework filled this gap by adopting final ESS with importance to beneficiaries, as classified in the FEGS-CS, which narrowed down the evaluation scope to better tailor to local needs and challenges.

3. Development based on practical case-studies

What sets the DESSIN framework apart from other similar methodologies is its practical orientation and focus on smaller-scale ESS evaluations. This approach facilitates involvement of local stakeholders, outlining causal relationships within the boundaries of an ecosystem, and association of specific measures to expected or observed impacts. These characteristics and functionalities were achieved through a process of co-creation, iteration and reflection based on practical case-studies. This aspect was key to shaping the framework and allowed the research group to respond to new questions that emerged as the development work progressed.

3.1. Testing the draft framework elements in data-rich mature case study sites

The first designated users of the DESSIN framework were project members responsible for running retrospective ESS evaluations in sites where innovative management solutions had already been implemented, referred to as *mature case studies*. This user group included specialists from the fields of freshwater ecology, economics, information and communication technologies, and engineering. The mature case study sites were located at the Aarhus River, Denmark, the Emscher River, Germany (Gerner et al., submitted) and the Llobregat River, Spain (Termes-Rifé et al., 2016).

In the Aarhus mature case study, the effects of a real-time control system of the full urban water cycle were examined, including wastewater treatment facilities and recipient waters combined with the opening of the Aarhus River in the city centre. The real-time control system aimed to adapt Aarhus's water system to climate change-related challenges and to raise the recreational potential in the city via river restoration and improved water quality. The evaluation focused on the intermediate ESS "Degradation of pollution by microorganisms, algae, plants, animals, and other ecosystem components" and the final ESS "Experiential use of plants, animals and land-/seascapes in different environmental settings". The first was assessed by estimating changes in degradation of *E. coli* and Enterococci bacteria using the water quality modelling software MIKE 11/ECOLAB. The latter was estimated through changes in the value of houses and apartments located near the re-opened river section.

In the Emscher mature case study, a large-scale river restoration was implemented with special emphasis on water quality and recreational values (Gerner et al., submitted). The improved water quality, hydrology and morphology of the river were to enhance biodiversity, regulating ESS and recreation. The main focus was on the evaluation of the intermediate ESS "Self-purification: nitrogen, phosphate, and carbon retention" and "Biodiversity". Final ESS assessed and monetised were "Opportunity for placement of infrastructure and reduced risk of flooding", "Opportunity for placement of infrastructure in environment", "Opportunity for biking & recreational boating", "Opportunities to understand, communicate, and educate", and "Knowledge that a restored river area exists, with suitable water quality (i.e. Good ecological potential (GEP))". These were assessed for individual sections of the Emscher river network and subsequently transferred to the catchment scale. For visualisation, the resulting monetary value was compared to the investment costs of the restoration. Several other ESS for which no sufficient data was available were described qualitatively.

The Llobregat study focused on the economic valuation of changes in ESS resulting from the implementation of infiltration ponds. These ponds were created to replenish the groundwater reserves and provide drinking and non-drinking water to the Barcelona area. Here, four ESS linked to the infiltration ponds were identified and subsequently assessed: "Water for drinking purposes", "Water for non-drinking purposes", "Education (Research opportunities)", and "Experiential use of landscapes in different environmental settings".

These mature case studies had good data availability and documentation on the implemented measures, guaranteeing that early versions of the DESSIN framework could be tested and fine-tuned. The results of these first applications of the framework were presented in stakeholder workshops to establish discussions with local actors and to gather feedback. Running the development process in an iterative manner, with users and stakeholders directly involved in the conceptual development, testing and fine-tuning of the framework, allowed for identification and consideration of actual needs.

3.2. Further application in demonstration sites

After completion of the development phase, the framework will be applied on five *demonstration sites* facing water scarcity (the City of Athens, Greece, the Llobregat River delta, Spain and the Greenport Westland, The Netherlands) and water quality issues (the Emscher River, Germany and the Hoffselva River, Norway). These demo sites differ from the mature case study sites in the fact that they are places where solutions have only recently (i.e. during the lifetime of the DESSIN project) been implemented for testing purposes, and thus, the necessary data for the ESS evaluations is collected during the project. The Emscher mature case study site and the Emscher demonstration site entail different measures implemented in different timeframes, as is the case for the Llobregat mature and demonstration sites. The solutions tested at the demonstration sites are diverse. Aquifer storage and recovery are demonstrated in Spain and The Netherlands to counteract groundwater depletion, while in Greece, sewage mining and on-site-treatment is implemented to address water scarcity. In Hoffselva, filtration and treatment in combined sewage overflow facilities aim to improve the quality of recipient waters. Similarly, at the Emscher demonstration site, real-time-control of the sewer system and treatment in combined sewage overflow facilities is tested for the same purpose. Given that these water challenges prevail throughout Europe, demonstrating the framework's operability at the different study sites also represents a high potential of transferability to other locations.

4. Conceptual approach

The main structural element of an evaluation conducted with the DESSIN framework is the DPSIR scheme. This was slightly modified and interlinked with other theoretical developments from ESS

[3] Final ESS are defined in the context of a DESSIN evaluation as those ESS that are not only provided by the ecosystem but also directly utilized or otherwise appreciated by humans/beneficiaries. Alternatively, intermediate ESS are defined as those ESS that are only provided by the ecosystem but not necessarily utilized or otherwise appreciated by humans/beneficiaries.

research in order to serve the purpose of DESSIN, i.e. to demonstrate the impact of innovative technologies, to account for changes in ESS and to allow for a detailed evaluation in practice. More specifically, this meant integrating the "ecosystem service cascade" of Haines-Young and Potschin (2010) into the DPSIR concept as done by Müller and Burkhard (2012) and van Oudenhoven et al. (2012). This allowed the positioning of aspects of ecosystem state, ESS, and human well-being in an established conceptual framework from which the causal links between these elements could be explored.

In DESSIN's DPSIR model, responses are at the centre of the framework (see Fig. 1). When a decision-maker is confronted with multiple options for measures to address a known environmental challenge, a need to appraise the impacts of each possible choice emerges. Any technology, management approach, policy measure, or combination of these from which the decision-maker could choose is considered a response. Given their nature, it is assumed that these responses can influence the drivers, pressures or state of the ecosystem under study, or a combination of the three. For example, a policy measure implemented to ban intensive agriculture in the study area is a representation of a response addressing a driver. A real-time-control system preventing combined sewer overflow events is an example of a response addressing a pressure. An infiltration pond used to recharge the groundwater level in an aquifer exemplifies a response addressing the state of an ecosystem. In the DESSIN mature case studies, the implemented measures either alleviated pressures or improved the state directly.

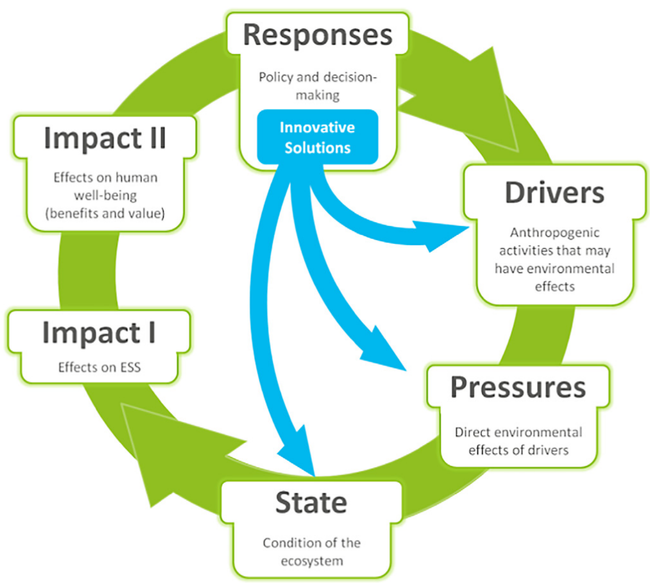

Fig. 1. The structure of the DESSIN ESS Evaluation Framework (based on Müller and Burkhard, 2012; van Oudenhoven et al., 2012; Haines-Young and Potschin, 2010, 2011).

Moving down along the causal chain, changes in state produced by a response can ultimately result in two types of impacts: first, an impact on the provision of ESS, i.e. the range and scale of ESS that are available; second, a change in the actual use of ESS and the resulting human well-being, i.e. the perceived benefits and value resulting from the actual utilisation of the available ESS. In other words, impact I refers to changes in the availability of ESS associated to changes in ecosystem state, while impact II refers to changes on human well-being resulting from changes in ESS (based on Müller and Burkhard, 2012). For example, a restoration measure can increase the water retention capacity of a river's floodplains (impact I), which may result in reduced or avoided damages and costs once a flood event actually takes place (impact II).

In evaluations conducted with the DESSIN framework, the concept of beneficiaries is used to ease the distinction between intermediate and final ESS. This distinction is important as only final ESS can be expressed in monetary terms (Fisher et al., 2009; Boyd and Banzhaf, 2007). The split of impact elements described above (impact I and II) is analogue to this notion of intermediate and final ESS and is further depicted in Fig. 2.

Fig. 2 provides a detailed view of the procedural steps taken in the evaluation to associate responses to their impacts. The user starts off with the full list of ESS contained in the CICES catalogue and attempts to answer the question: *What can the response change in the study area?* Response changes may range from changes in conditions external to the ecosystem (e.g. a change in agricultural policy can reduce the nutrient emmissions reaching a nearby river), to specific water quality parameters (e.g. a new on-site

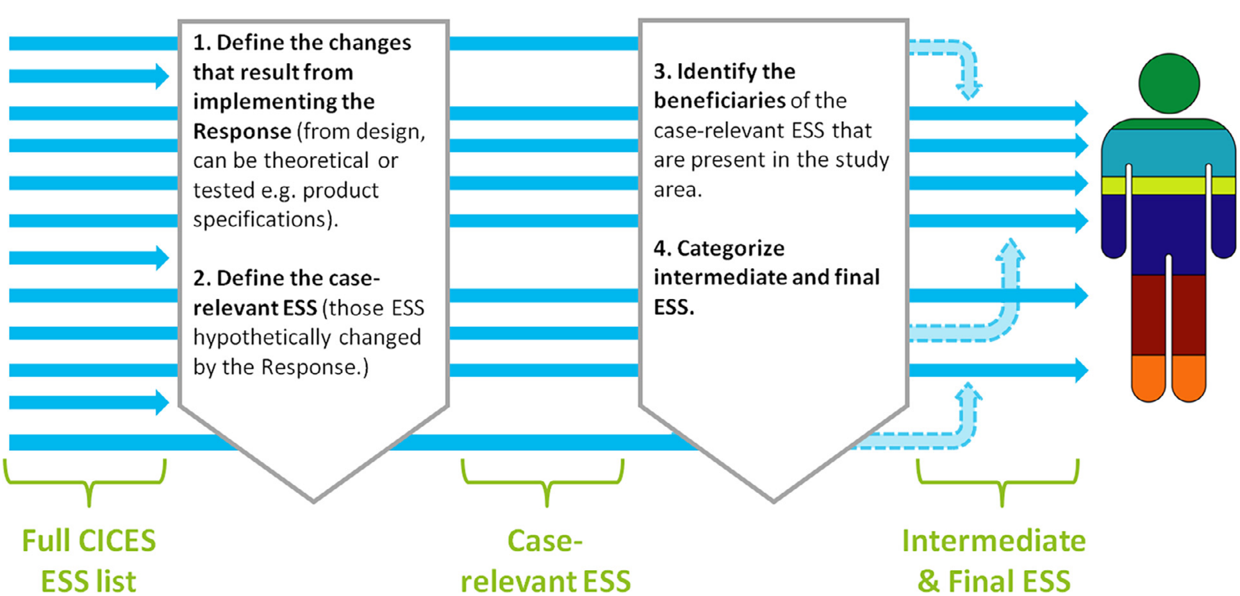

Fig. 2. Procedural steps to associate the implementation of measures (Responses) to changes in intermediate and final ESS (Impact I and Impact II).

filtration treatment can reduce the level of turbidity in a river stretch). Once defined, these changes resulting from the response can then be associated to specific ESS classes from the CICES list (e.g. the reduction in turbidity caused by the new filtration treatment could enhance the "aesthetic" of the river, a cultural ESS). As a result, the *case-relevant ESS,* i.e. the services that are hypothetically affected by the response, can be established as a subset of the full CICES list (further details follow in Section 5). Next, the case-relevant ESS are categorised into final and intermediate ESS by analysing their association to beneficiaries present in the study area. This part of the evaluation uses the beneficiary typology proposed by Landers and Nahlik (2013) to identify associations of individual beneficiary types with the case-relevant ESS. In DESSIN, beneficiaries are defined as any persons, organisations, households or firms whose interests are positively or negatively affected by either the direct use or presence of the ESS that are changed by the response (adapted from Landers and Nahlik, 2013). If—for a certain case-relevant ESS—there is a beneficiary present in the study area, it can be considered a final service. Arguably, the total economic value of these final services for the individual would be the sum of the benefits derived from each of his/her interests in/uses of them (Landers and Nahlik, 2013). This distinction helps to understand and fundamentally, it allows to capture, different concepts of economic value (e.g. use and non-use values) in the ESS assessment. Otherwise, if a beneficiary is not present, the case-relevant ESS is considered an intermediate service which may support the provision of another service. Careful stakeholder analysis has of course to precede any association of beneficiaries to case-relevant ESS. This also allows to unravel possible conflicts and trade-offs among water resource uses (e.g. Castro et al., 2016). For regulating and maintaining services, such as self-purification or nutrient retention, often no immediate beneficiaries can be identified, qualifying these ESS as intermediate services.

As the ESS evaluation is not exhaustive in its coverage of the aspects relevant for a decision-maker to decide for or against a response or between two or more responses, further criteria are inquired in the optional sustainability assessment of the DESSIN framework. Here, the response is evaluated with regard to possible implications on five dimensions of sustainability, i.e. social, environmental, financial, governance or asset performance (e.g. effects on job creation, energy use, investment and operational expenditure, stakeholder involvement, or reliability, respectively).

5. Framework design

5.1. Overview

The DESSIN framework consists of a suite of structured reference materials that provides the instructions necessary to run an evaluation: the DESSIN cookbook (Anzaldua et al., 2016a), a companion report (Anzaldua et al., 2016b), a supplementary material catalogue, an evaluation template, and a webinar. In addition, a software module was developed and integrated into an existing Decision Support System (MIKE Workbench) to ease usability, promote the uptake of the framework and to enable the use of computational models in evaluations.

The DESSIN cookbook is the main interface of the DESSIN framework. It guides the user through the five parts of the evaluation, detailing the procedural steps to follow (see Fig. 3 and the following sub-section). Examples from DESSIN's mature case studies are used throughout the cookbook to illustrate this procedure. The cookbook is written as a practical guidance document and is meant to be read as a step-by-step instruction manual to fill in the evaluation template. The latter gives the user a structured outline to present evaluation outcomes.

The companion report presents the theoretical background considered in the development of the DESSIN framework and explains its conceptual basis. It contains a glossary of terminology which was discussed and agreed by the interdisciplinary team in charge of developing and applying the framework in the case studies. The report includes extensive treatment of the concepts underpinning the five parts of the evaluation.

The supplementary material catalogue provides lists of drivers, pressures, state parameters, beneficiary types, impact indicators and economic valuation studies that the user can refer to when conducting an evaluation. The catalogue functions as a quick reference directory that illustrates possible associations between ESS classes, beneficiary types and the different elements of the DPSIR scheme. The catalogue was created based on literature

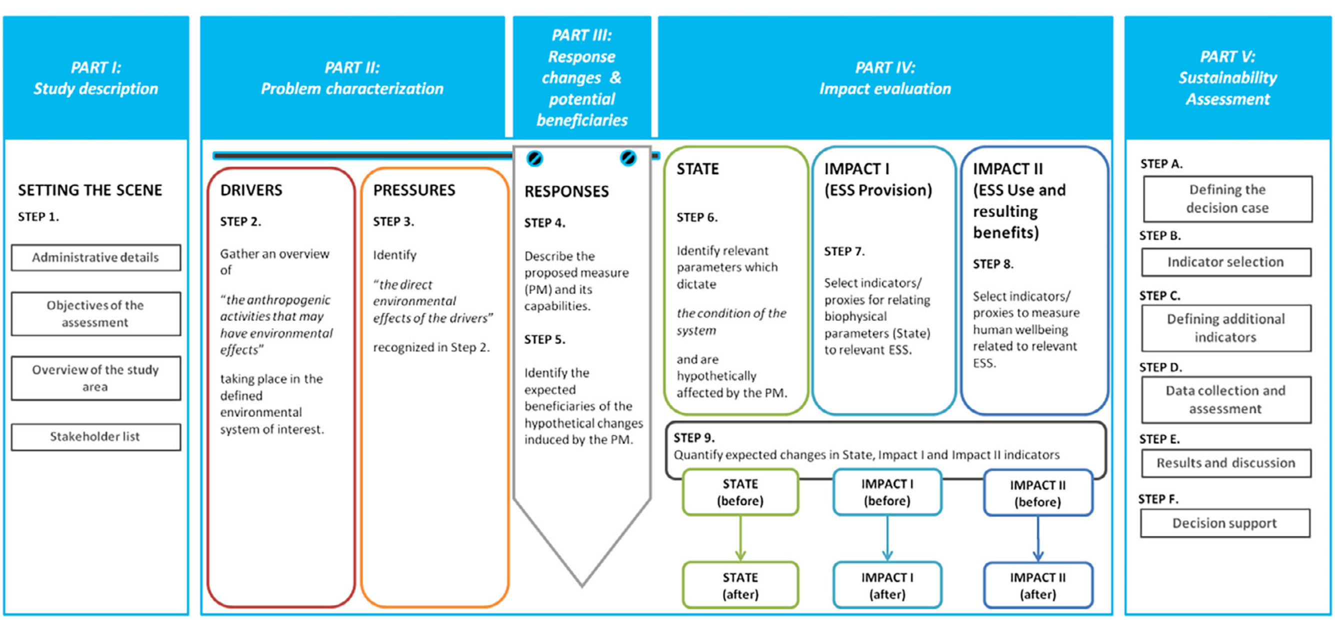

Fig. 3. Procedural steps for the application of the DESSIN ESS Evaluation Framework. *Note: The position of Steps 4 and 5 depend on whether the response affects the drivers, pressures or state of the system as described in Section 4.*

(Haines-Young and Potschin, 2011; Landers and Nahlik, 2013; MARS, 2014; Weber and Ringold, 2015) and the results of the DESSIN mature case studies, which comprised expert knowledge from the direct users of the framework supplemented by stakeholder feedback gathered in workshops. A database of economic valuation studies was compiled and included as a way of showing the user how different valuation methodologies are applied in practice.

Splitting the framework into a cookbook and a companion report is an attempt to overcome the complexity of applying the ESA by balancing the weight given to the theoretical aspects and the procedural steps of an evaluation. This separation between theoretical background and practical guidance increases the user friendliness of the framework without compromising its potential for yielding reliable results.

5.2. Detailed description of the 5 parts of an evaluation

As introduced in the previous sub-section, users can run an evaluation using the DESSIN framework by completing a series of steps that are organised into 5 main evaluation parts. Each part has a specific objective and clear instructions for the user (see Anzaldua et al., 2016a).

Part I: *Study description* helps the user to set the scene for the evaluation. In step 1, the user is asked to declare the objectives of the evaluation and to define the study area, including its physical boundaries. These boundaries serve to delineate the ecosystem of interest for the evaluation, e.g. a surface or ground water body, a sub-catchment or catchment. Furthermore, the user is asked to prepare an exhaustive list of the stakeholders[4] located within the study area. This list is used in Part III of the evaluation to see if the local stakeholder groups can be associated with the case-relevant ESS, in which case they are declared as beneficiares.

Part II: *Problem characterisation* aims to identify and describe drivers and pressures (steps 2 and 3, respectively). Drivers are considered anthropogenic activities that may have an environmental effect, such as agriculture, industry or urban development (based on MARS, 2014). Pressures are considered direct environmental effects that result from human activities (e.g. input of pollutants). In this part, the user is asked to select from a list of predefined drivers those that apply to the study area and then to find the pressures associated to these drivers, again using a predefined list in the supplementary material catalogue.

Part III: *Response changes and potential beneficiaries* aims to identify the responses that can be implemented to address problems in the study area (step 4) and determine case-relevant ESS and beneficiaries (step 5). As stated in Section 4, responses are any technology, management approach, policy measure, or combination of these that aim to moderate the drivers, reduce pressures and/or improve the state of the ecosystem under study. Here, the user is asked to reflect and describe the ways in which the response is expected to change the ecosystem and relate these changes to specific ESS. This yields the list of case-relevant ESS. For this, the supplementary material catalogue offers a list of environmental parameters related to freshwater ecosystems. These parameters are grouped according to the state categories used by the WFD (biological, hydromorphological and physicochemical) and the work by Weber and Ringold (2015) on human apreciation of river characteristics. In the catalogue, these parameters have been associated to specific provisioning, regulation and maintenance, and cultural ESS.

[4] In the context of an evaluation, stakeholders are defined as persons, groups or organisations that may be affected by or may have an influence on the outcome of an intervention taking place in the study area (adapted from Ridder et al., 2005). Notice that the framework distinguishes between stakeholders and beneficiaries on the basis of actual ESS use. In this sense, beneficiaries are a subset of stakeholders.

To help the user identify the beneficiaries of the case-relevant ESS found in step 4, the supplementary material catalogue offers the beneficiary typology used in FEGS-CS (Landers and Nahlik, 2013). The typology provides detailed descriptions of beneficiary types and associates them with specific uses of ESS (e.g. irrigators use water from rivers and streams to grow and maintain crops; industrial dischargers use rivers and streams as a medium for receiving industrial discharge). The DESSIN team has assigned these ESS uses in the FEGS-CS typology to specific ESS classes in CICES. This allows the user of the framework to query the catalogue in search for the case-relevant ESS and retrieve the beneficiary types commonly associated with their use. By finding the matches between the retrieved beneficiary types and the stakeholder groups from the list elaborated in Part I, the user can pinpoint the beneficiaries actually present in the study area. Subsequently, this enables the distinction between final and intermediate case-relevant ESS.

Part IV: *Impact evaluation* aims to measure the impact of the response by quantifying the state of the ecosystem, impact I (ESS provision) and impact II (ESS use by beneficiaries). This part of the evaluation is the most data intensive. Here, the user is asked to select the suitable indicators for state (step 6) and impact (step 7 and 8) from the lists of indicators available in the supplementary material catalogue. The user then calculates the selected indicators (step 9) for two scenarios, before and after the implementation of the measure, to reveal the impact of the response.

Part V: *Sustainability assessment* is an optional set of steps that aims to put the evaluated changes in ESS into perspective by considering further aspects of sustainability (i.e. the wider social, environmental, financial, governmental, and asset performance aspects of the examined case). After selecting indicators, the user can run a multi-criteria assessment that enables the comparison of potential disadvantages of the response (e.g. high implementation costs or additional greenhouse gas emissions) against its potential advantages (i.e. expected benefits).

6. Discussion

One of the key objectives of the DESSIN project was to develop an analytical framework to evaluate and account for integrated impacts resulting from the implemention of innovative solutions in the water sector. The main challenge in meeting this objective was to adequately link the relevant biophysical and socioeconomic elements of the systems under study. The perceived potential of the ESA to facilitate such integrated impact evaluations thus became the basis for developing an analytical framework that held the ESS concept at the forefront. This, however, presented the subsequent challenge of bringing a highly theoretical and complex concept into practice and providing a transparent and applicable, yet solid framework.

As mentioned, the DESSIN framework was developed following an incremental, iterative process largely based on its practical application in case studies. Commissioning the development of the framework to an interdisciplinary team of ecologists, economists and engineers served to recreate the common adversities associated with applying the ESA in practice: contradicting viewpoints of stakeholders (founded largely on disciplinary backgrounds), discrepancies in the use and understanding of terminology, and unaligned group or individual interests, among others. While these issues at times seemed to stall progress, the collaborative experiment of developing the DESSIN framework ultimately evidenced that successful application of the ESS concept in practice requires an openness and willingness of the participants to embark on mutual learning and to move beyond traditional disciplinary boundaries. Spending the extra effort on breaking the gridlock that sets in when the tough questions emerge is crucial to achieve tangible progress in this field of work.

Applying the DESSIN framework on the mature case studies also provided its developers with key insights necessary to shape it into a practice-oriented tool. It allowed close observation of its utilisation by end-users, which helped prioritise development actions by delineating initial gaps and inconsistencies. Addressing such initial issues (e.g. via the development of a supplementary material catalogue and the preparation of a common glossary of evaluation terms) endowed the framework with a more flexible and user-centric character relative to previous efforts in the field. Further iteration of this process in the demonstration sites will reveal new constraints, prompt concentrated action and ultimately bring the framework a step forward before the end of the DESSIN project.

The design of the DESSIN framework is deliberately closely related to the implementation of WFD river basin management (RBM), which is legally binding for all EU Member States. The framework's foundation upon the DPSIR adaptive management scheme fits well into standard RBM approaches (Borja et al., 2006). Placing ESS within the impact category allows for aligning the ESA with an approved management concept, including familiar terminology and accustomed practices (Hering et al., 2015). This conceptual consistency, along with the concrete, stepwise guidance provided by the framework, facilitates the integration of ESS into existing RBM procedures. As highlighted by Grizzetti et al. (2016) such an integration is beneficial in the proper implementation of the economic elements of the WFD, i.e. evaluating cost-effectiveness and -benefit of the mitigation measures and water recovery costs, respectively, as well as co-benefits of nature-based solutions and green infrastructure (e.g. Liquete et al., 2016). The practical integration of ESS evaluation into operational RBM schemes may also support in defining alternative management objectives beyond 2027, especially when exemptions from reaching the WFD targets are increasingly claimed for due to, for instance, disproportionate costs (Klauer et al., 2016).

Large-scale application of the ESA is associated with large investments in terms of effort, time and financial resources. By focusing on local-scale evaluations of case-relevant ESS, the DESSIN framework has attempted to make ESS assessments more accessible, leaner, and yielding results that are more directly relatable and actionable for stakeholders and decision-makers. This has great potential to complement the large ESS assessments being undertaken at the EU and national levels.

The framework's limitations reside principally on the need to incorporate value judgements in the selection of water-related ESS, indicators, choice of biophysical and economic models, means of measurement and choice of valuation methods, which could potentially result in uncertainty and inconsistency if the assumptions made are not adequately documented. This is, however, a common issue of ESS assessment frameworks given their deliberative and multi-stakeholder nature. Further limitations reside in the uncertainty inherent to the methodologies and indicators bundled within the framework and the aggregation along the evaluation. Depending on available data for a given case study, this uncertainty can be reduced through the employment of more elaborate, direct indicators and keeping the use of proxies and assumptions to a minimum. Experience has shown though that data availability is a recurrent constraint in ESS assessments, especially in ex-ante evaluations of measures. This can only be addressed through further fieldwork (measuring and monitoring), environmental modelling and the enhancement of water and environmental data repositories at all levels (EU, national, regional and local).

The authors see the use of the beneficiaries concept inspired by Landers and Nahlik (2013) as one of the key features of the DESSIN framework that enables more locally-relevant ESS assessments as described above. However, it has also been noted that the practical operationalisation of the definition of beneficiaries can be tough, especially in the case of immaterial benefits or cultural and regulating ESS. Further, some criticism has emerged on the use of the term *beneficiary* itself. In the definition, individuals and groups who are both positively and negatively affected by changes in ESS are considered; however, the term does not make this evident since it subsumes all parties under a title that connotates a positive relation. Some suggest that a more neutral term would increase transparency.

Lastly, while the framework establishes that responses can influence drivers, pressures, state, and a combination of the three, detailed instruction on how to deal with combined effects of the response on the other DPSIR elements is generally lacking in the framework, as this specific situation did not emerge during its application on the mature case study sites. Further examples from practice will be useful to illustrate the issue.

7. Conclusions

Through the DESSIN ESS Evaluation Framework, the DESSIN project has brought progress in applied ESS science by attempting to balance the theoretical and practical elements of ESA implementation, by focusing on the evaluation of changes in ESS, and by using the concept of beneficiaries to unlock the often elusive distinction between final and intermediate ESS. While the framework shares some common limitations with earlier approaches, the authors believe that its further use in practical case studies will enhance its capabilities, inter alia by expanding and enhancing the indicator catalogue and validating the associations between responses and subsequent elements of the DPSIR chain. Nevertheless, the DESSIN framework is fit for purpose to support decision-making and promote the uptake of innovative solutions to water quality and water scarcity challenges in urban areas. The exploration of its potential to facilitate the integration of the ESS concept into future WFD implementation is encouraged.

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