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Large-scale river restoration pays off: A case study of ecosystem service valuation for the Emscher restoration generation project

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ABSTRACT

Though the Ecosystem Service (ESS) approach is considered promising for integrated ecosystem management, its operationalisation is hampered by the lack of agreed evaluation instruments. To demonstrate the suitability of a structured ESS evaluation, we conducted a case study estimating the impact of the restoration of the Emscher River and its tributaries on the provision, use and benefit of ESS. The Emscher restoration is a large-scale project with immense temporal and financial efforts. To assess the values generated by this restoration, we applied an ESS evaluation framework and quantified the regulation and maintenance ESS 'self-purification capacity', 'maintaining nursery populations and habitats' and 'flood protection' as well as cultural ESS such as aesthetic, recreational, educational and existence values. Final ESS were monetized using economic methods, e.g. 'damage costs avoided', 'contingent valuation' and 'benefit transfer'. We estimated a *market value/direct economic impact* of 21,441,572 € per year as a result of the restoration. Furthermore, a *non-market value* for people who care about the local environment of 109,121,217 € per year was determined, representing the benefit with 'non-use value' from the Emscher restoration. Our case study demonstrated the successful application of the structured evaluation framework in practice. Its implications and limitations are discussed.

1. Introduction

One of the most extensive river restoration efforts is currently taking place in one of the most populated areas in Europe. The Emscher restoration is a large-scale restoration project in the "Ruhr Metropolitan Area" in the federal state of Northrhine-Westphalia, Western Germany. This area is one of the densest urban agglomerations in Europe. In a 30-year project that started in 1990, the Emscher River and its tributaries are re-converted from highly modified open wastewater channels with concrete beds into near natural stream systems. For this, an underground sewer network of 423 km length is constructed to separate waste and river water. Subsequently, the concrete shells are removed, the channelization reversed, stream profiles widened, and secondary floodplains created. This intergenerational project is worldwide unique in its spatial and temporal scale and associated with the immense costs of approx. 5.3 billion Euro.

Justifying such expenses requires achieving ecological goals as set by the European Water Framework Directive (WFD; European Commission, 2000). Besides the improvement of ecological criteria, also human benefits result from such restorations. Thus, it is important to communicate the value of restored streams and surrounding areas beyond purely ecological criteria. Required to this end are methodologies to quantify how humans benefit from this project. The Ecosystem Service (ESS) approach represents a viable concept to assess material and immaterial values for human well-being provided by ecosystems. The first large-scale assessment of ESS, the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005), illustrated how the ESS approach can visualize the value of nature and the costs of its overuse and

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degradation. The ESS concept is now widely recognised as an integrative approach that can capture different policy objectives in a single assessment and therefore, its application for a sustainable management of ecosystems is increasingly desired by policy makers (Anzaldua et al., 2018). Aims set by the European Union via the European Biodiversity Strategy 2020 (European Commission, 2011) enforce this, as they require the EU member states to evaluate ecosystems and their services via an approach that is being elaborated by the MAES initiative (MAES, 2016, MAES, 2018).

However, a lack of agreed evaluation approaches, ESS classifications and consistent definitions has, so far, hampered the uptake by practitioners and policy makers (Daily et al., 2009). To guide a structured evaluation of ESS, concrete practical guidance via operational frameworks is required but currently lacking. Furthermore, case studies that serve as best-practice examples are needed. Particularly, case studies on freshwater ESS are necessary to advance the ESS approach also in the context of water management. The present study represents such a case study and offers an integrated evaluation of a large-scale river restoration using a structured ESS assessment method (Anzaldua et al., 2016).

This freshwater case study was elaborated within the European research project DESSIN (Demonstrate Ecosystem Services Enabling Innovation in the Water Sector, 2014–2017). DESSIN has developed an evaluation framework (Fig. 1) as a guided approach for evaluating changes in ESS resulting from the implementation of management measures, e.g. mitigation and restoration measures. Essentially, the DESSIN ESS Evaluation Framework compares the situation before and after the implementation (Anzaldua et al., 2016). It consists of a biophysical, an economic and an add-on sustainability assessment and is framed by the Driver-Pressure-State-Impact-Response (DPSIR) adaptive management cycle of the European Environmental Agency (Smeets and Weterings, 1999), merged with the ESS-cascade concept (Haines-Young and Potschin, 2010) as presented by Müller and Burkhard (2012).

Understanding the relationships between the five DPSIR elements is central for investigating the effects that responses have on alleviating man-made pressures on the ecosystem or improving its state. The state of an ecosystem again affects ESS provision and the human well-being resulting from it (Fig. 1; definitions according to Anzaldua et al., 2018). Feedback flows between the single DPSIR elements exist as it is a continuous circular progress. Especially in urban ecosystems, complex interactions between stressors and impacts need to be understood by assessing the interactions among nature, technology and human society with its synergies and trade-offs (see Fig. 2).

The DESSIN ESS Evaluation Framework differs from existing frameworks as discussed by Anzaldua and colleagues (2018). For instance, the IPBES Conceptual Framework as presented by Díaz et al. (2015) gives a structure for analysing the interference between society, nature and ecosystems and nature's benefit to people, focussing on supranational to global geographical scales. In contrast, the DESSIN framework provides guidance for analysing the difference in values of a system before and after a human intervention (like a restoration measure) and is meant to analyse this intervention and its effect on ecosystems at regional scales.

It offers a structured guidance but also gives its user a high degree of freedom in combining diverse sets of ESS, indicators, assessment methodologies and analytical tools. The latter range from basic scientific and sociological data to complex effect modelling. Integrating these and complementing them with DESSIN's sustainability assessment results in a broad holistic perspective. This way, further aspects not addressed by the ESS evaluation but important for decision-makers are covered by the sustainability assessment.

The framework can be applied to ESS as classified in the Common International Classification of ESS (CICES; Haines-Young and Potschin 2013) and the Final Ecosystem Goods and Services classification system (FEGS; Landers and Nahlik, 2013). The latter classification system separates intermediate (IESS) from final ecosystem services (FESS), depending on the presence or absence of direct service beneficiaries. Those ESS that are only provided by the ecosystem but *not* directly used or otherwise appreciated by humans are IESS (e.g. water purification), while those ESS being provided by the ecosystem and directly used or otherwise appreciated by humans are FESS (e.g. the actual use of pure water for drinking). This distinction was also suggested earlier in the UK National Ecosystem Assessment (2011) and by Boyd and Banzhaf (2007). The distinction is used in the DESSIN framework by defining the beneficiaries of the ESS as "*any persons, organizations, 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 proposed*

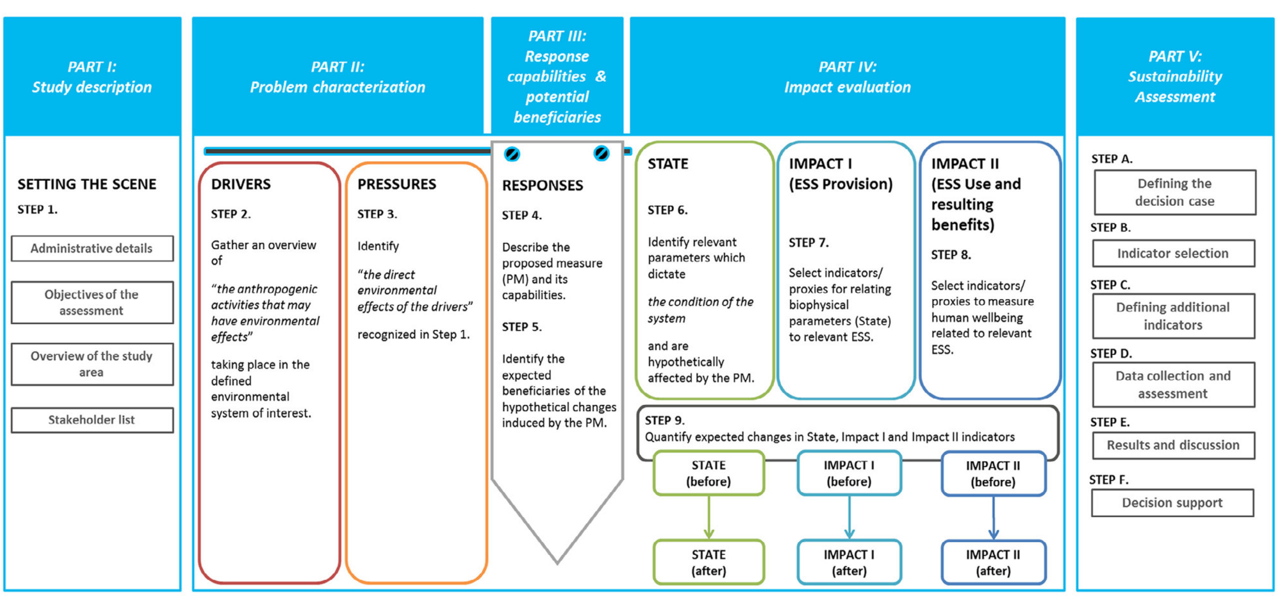

Fig. 1. Procedural steps for the application of the DESSIN ESS Evaluation Framework (from Anzaldua et al., 2018). ESS = Ecosystem services, PM = proposed measure. *Note: The position of Steps 4 and 5 depends on whether the proposed Response affects the Drivers, Pressures or State of the system.*

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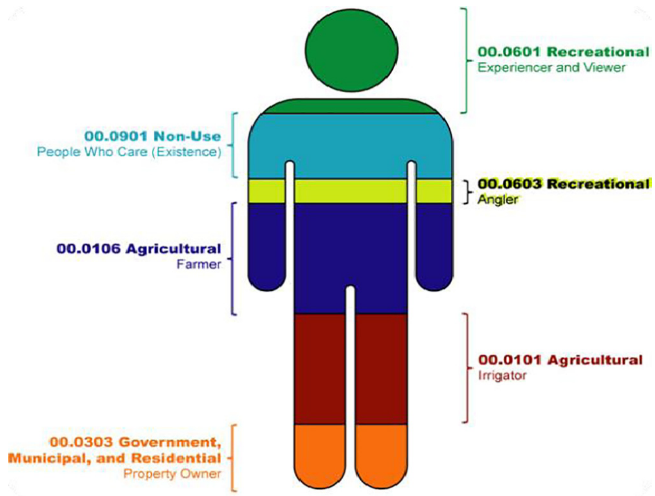

Fig. 2. Illustration exemplifying the different interests of a beneficiary in certain ESS (Source: Landers and Nahlik, 2013). The different beneficiary sub-categories used in this study can be found in Table 1.

measure" (Landers and Nahlik, 2013). A single individual may represent multiple beneficiaries because he/she may have more than one interest and thus makes more than one use of what an ecosystem offers.

The procedural steps for applying the DESSIN ESS Evaluation Framework are illustrated in Fig. 1, consisting of five different parts that cover nine individual steps. In this paper, we present the application of *Parts I to IV* of the framework to the Emscher River restoration case study. *Part V*, the Sustainability Assessment, offers an additional perspective on technologies or management actions affecting the ecosystem, which is not addressed in this paper (but see Gerner et al., 2016). As the restoration of the Emscher system is already partly implemented, we mainly referred to empirical instead of modelled data to evaluate the impact. This is also the reason why the proposed DPSIR order has been slightly adapted to account for the understanding of the impacts of responses that are already implemented.

The DPSIR analysis starts with the Response in an *ex-post* evaluation as the interest is (exclusively) on understanding the effects resulting from the implemented response(s). Furthermore, it has to be noted that the Response can initially affect the Drivers, Pressures or State of the system, followed subsequently by feedback flows within the single elements of the DPSIR. According to the evaluation framework, in the Emscher case study we first provide the study description and problem characterisation, followed by the description of the response and its capabilities to influence any of the identified Drivers and Pressures or the State of the ecosystem. Finally, the potential beneficiaries of the response are identified. Our special focus is on the selection of relevant parameters and indicators for impact evaluation. Out of more than ten ESS identified for the Emscher catchment, two IESS and five FESS were selected for assessment, covering regulation and maintenance as well as cultural ESS. The resulting benefits are compared to the investment costs for the implementation of the Emscher restoration. Finally, we discuss applicability, limitations and implications of this ESS assessment.

2. Material and methods

2.1. Part I: Study description (Step 1 in Fig. 1)

This case study investigates the changes in ESS provision and use in the Emscher River and its tributaries, a river catchment in Germany which is currently undergoing a 30-year and catchment-wide restoration. The first step in the restoration process is the construction of a network of underground wastewater channels and the accompanying grey infrastructures, followed by the ecological restoration of the streams. Vallentin and Scheck (2013) have analysed this restoration project with focus on governance, innovation, integrated planning, blue infrastructure, and quality of life. The authors highlight the socio-cultural and economic upgrading of the region, referring also to ESS. They do, however, not quantify or monetize these values. Experiences to the ecological value generated through the Emscher restoration have been reported, for instance, by Semrau et al. (2011) and Winking et al. (2016).

The Emscher River and its tributaries are located in the Ruhr Metropolitan Area and are discharging into the River Rhine (Fig. 3). The Emscher catchment has an area of 865 km^2 with a population of 2.2 million inhabitants resulting in 2775 inhabitants per square kilometre. With approximately 50%, the artificial land cover in the catchment is higher than in other German catchments. The cover of agricultural land is about 18%, forested area 14% and green leisure area and garden plots 8% (Emschergenossenschaft, 2009).

First, we selected eight sections in seven focus streams, i.e. sections of tributaries of the Emscher River as well as a section in the Emscher headwaters, for which case-relevant ESS were evaluated. The sections differ in their potential for ecological development and in the year in which the restoration was completed (Table S1). In the end, results were transferred and scaled up to the entire Emscher catchment.

In a next step, we identified relevant stakeholders with a wide range of interests in the Emscher restoration. This step checked if local stakeholders can be associated with case-relevant ESS, and if so, to declare them as beneficiaries (Anzaldua et al., 2018). Firstly, residents in the Emscher catchment are key stakeholders in this dense urban area. Many of them enjoy nature for recreation, e.g. for walking, biking or boating. As the Emscher restoration is implemented at an unusual scale, it also attracts researchers and environmental educators. Related to the historical and actual economic activities, industry, mining companies and chambers of commerce represent further stakeholder groups. Non-governmental organisations interested in, for instance, near-natural restoration (e.g. NABU: Nature and Biodiversity Conservation Union, BUND: Friends of the Earth Germany) or the conservation of cultural and industrial heritage (e.g. Heimatverein Hörde), are also present in the Ruhr Metropolitan Area. A key stakeholder in the Emscher catchment is the so-called 'Emschergenossen schaft'. This water board is in charge of sewage discharge and treatment, flood protection, storm- and groundwater management, as well as maintenance of the water bodies in the Emscher catchment in compliance with legal regulations such as the WFD. It is a non-profit public body financed by the cities, municipalities, mining and other large industrial companies in the catchment.

2.2. Part II: Problem characterization (Steps 2 and 3 in Fig. 1)

Starting with the first two elements of the DPSIR cycle, we identified relevant drivers and pressures in the Emscher catchment (Emschergenossenschaft, 2009). Due to the intensive industrial and mining history in the Ruhr Metropolitan Area, industry, transport and urban development represent the main drivers in the catchment. Resulting from the need to protect industrial and urban areas from flooding and diseases, flood protection was of high importance in the past – and still is in the present – leading to channelizing the Emscher River and its tributaries in the late 19th century. Nowadays, tourism and recreation are of increasing significance to the inhabitants of the area. Diffuse and point sources of pollution resulting from industry, urbanization and

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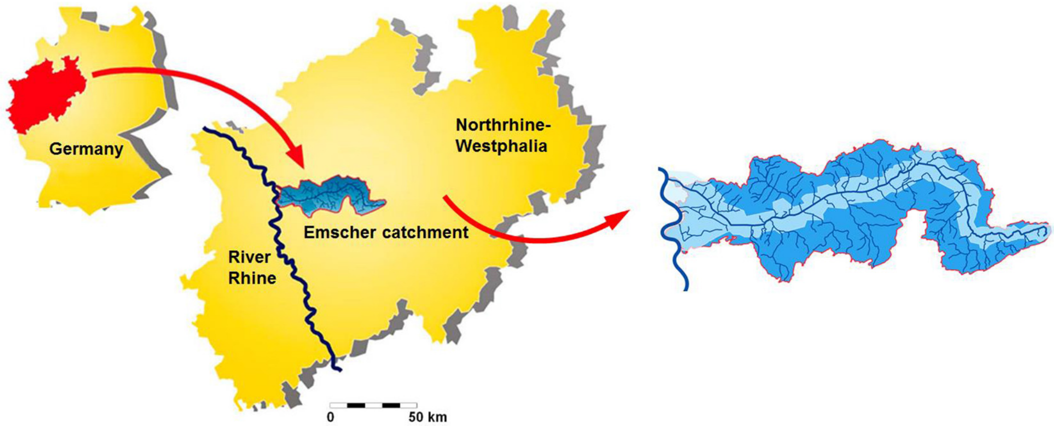

Fig. 3. Location of the case study area: the Emscher catchment in Northrhine-Westphalia, north-western Germany with the New Emscher Valley (light blue, Ruhr, 2005). (For interpretation of the references to colour in this figure legend, the reader is referred to the online version of this article.)

transport represent the main pressures in the Emscher catchment. Industry, transport and urban development also severely altered the morphology of the land- and riverscape, exacerbated by the substantive flood protection measures. Additionally, the open waste water channels had a negative impact on the quality of life in nearby housing areas, e.g. odour in the summertime.

2.3. Part III: Response capabilities and potential beneficiaries (Steps 4 and 5 in Fig. 1)

The Emscher restoration has been implemented as the response to the drivers urbanisation, industrialisation and mining as well as to the pressures related to these drivers. The restoration itself, however, is not capable of affecting the drivers but it can reduce the pressures and improve the state with subsequent positive effects on ESS provision and use. These effects of the response are being evaluated in our study (Emschergenossenschaft, 2009, 2013). It comprises two steps, which were initiated in 1990 and are to be completed in 2020. First, surface water and wastewater are separated by constructing an underground combined sewer network with a total of 423 km of sewers along the Emscher tributaries and the Emscher River itself. This sewer network is the backbone of the implementation. Its lifetime is expected to be about 80 years. Subsequently, morphology and connectivity of the Emscher and its tributaries are restored aboveground (Fig. 4), covering a total length of 341 km. These measures are capable to improve the water quality and morphological structure of the watercourses (*Step 4*), leading to a reduction of point and diffuse pressures and mitigating morphological alterations.

The preliminary list of potential stakeholders collated in *Step 1* was used to identify the beneficiaries actually present in our study area (*Step 5*). These beneficiaries are residential property owners, inhabitants with an intrinsic interest for the environment (i.e. so-called 'people who care'), boaters, experiencers and viewers, researchers, educators and students.

2.4. Part IV: Impact evaluation (Steps 6 to 9 in Fig. 1)

Pressure reduction resulting from the restoration leads to improving the overall ecosystem state (*Step 6;* Emschergenossenschaft, 2013). This improvement results from the ecological restoration of the streams, which follows the construction of an underground sewer network. Though implemented subsequently, these two measures can hardly be separated when analysing the effects on ESS, as the sewer network conditions the restoration. Therefore, when we refer to restoration, it also includes the sewer network. Through the restoration, the physico-chemical conditions of recipient water bodies are enhanced by reducing the point and diffuse pressures. Mitigating morphological alteration improves the hydromorphology of the streams. All response capabilities also positively affect the aquatic communities of benthic invertebrates and fish (Emschergenossenschaft, 2013), and ultimately, parameters relevant for providing cultural services like the appearance of the riparian environment are enhanced.

Fig. 4. Comparison between an unrestored (left) and a restored section (right) (Dortmund Aplerbeck) (Source: Emschergenossenschaft).

In *Step 7* we identified all ESS linked to state parameters potentially affected by the Emscher restoration (see *Step 6*). Based on this assignment, we specified the ESS affected by using the CICES classification (Haines-Young and Potschin, 2013) resulting in the case-specific ESS presented in Tables 1 and 2. Depending on whether a direct beneficiary could be identified (see *Step 5*), the ESS was subsequently classified either as intermediate ESS or final ESS (Table 1; Landers and Nahlik, 2013).

In the Emscher catchment, the self-purification processes as well as the maintaining of nursery populations and habitats do not have a direct beneficiary, as there are no stakeholders in the Emscher catchment directly using these services (Anzaldua et al., 2018). These intermediate services, however, are important for providing a number of cultural services in the catchment, particularly FESS #2 to #5 (Table 1). Cleaner water provided through self-purification improves the aquatic landscape aesthetics while biodiversity makes the ecosystems more attractive and interesting to people.

The impact assessment in the DESSIN framework relies on four types of indicators: indicators of state parameters (*Step 6*), indicators of ESS provision (*Step 7*), and indicators of ESS use and the resulting benefit (*Step 8*; Fig. 1). Only state and provision indicators are relevant for IESS because beneficiaries cannot be identified for these services.

The indicators selected for each ESS are shown in Tables 3 and 4. Below we outline background, data source and computation method of each ESS indicators used in this study.

2.5. IESS #1: Self-purification

Nitrogen retention was estimated via denitrification capacity in-stream (at the water-sediment interface) and in the floodplain (at the land-water interface) (Table 2). The denitrification rates mainly depend on the wetted surface, initial nitrogen concentrations (in-stream) as well as soil type (floodplain). The in-stream water-sediment area was determined based on channel cross-section profiles, comparing the open wastewater channels (i.e. situation before) and the restored streams (i.e. situation after). The land-water interface in the floodplain was delineated by the area statistically flooded at least once every 50 years (i.e. HQ50 or HQ100). For this area, land use was identified as a proxy for soil type, each with specific retention rates (Table 2). For the state after restoration, we derived a partitioning of 45% grassland and 55% woodland from land use data (ATKIS®). For the same areas before restoration, we assumed a land use of 75% grassland, 20% woodland, and 5% concrete bed within the HQ50 areas (Semrau, personal communication). Due to the removal of the channelized

Table 1
Relevant intermediate ESS (IESS) and relevant final ESS (FESS) of the FEGS classification system with their respective CICES classification and beneficiaries.

Intermediate ESS	CICES section	CICES class	FESS supported
#1: Self-purification: N retention, P retention, C retention	Regulation & Maintenance service	Filtration/sequestration/storage/accumulation by ecosystems; Dilution by atmosphere, freshwater and marine ecosystems; Hydrological cycle and water flow maintenance; Decomposition and fixing processes	FESS #2, 3, 4 and 5
#2: Maintaining nursery populations and habitats	Regulation & Maintenance service	Maintaining nursery populations and habitats	FESS #2, 3, 4 and 5
Final ESS	**CICES section**	**CICES class**	**Beneficiary**
#1: Opportunity for placement of infrastructure and reduced risk of flooding	Regulation & Maintenance service	Flood protection	Residential property owners: People living in the floodplain; Industry
#2: Opportunity for placement of infrastructure in environment	Cultural service	Experiential use of plants, animals and landscapes in different environmental settings	Resources-dependent businesses (e.g. operators of cafés and restaurants along the restored riverfront) & Residential property owners
#3: Opportunity for biking & recreational boating	Cultural service	Physical use of landscapes in different environmental settings	Bikers (leisure time bikers, everyday & workday bikers) & Boaters
#4: Opportunities to understand, communicate, and educate	Cultural service	Educational	Educators and students
#5: Appreciation that restored stream sections exist	Cultural service	Existence	'People who care' & Residential property owners

Table 2
Retention rates for N, P, and C for different land use types adopted to determine retention for each focus section.

	N-retention (kg/ha/a)	P-retention (kg/ha/a)	C-stock (t/ha)
Floodplain			
Grassland	5.00	0.75	212
Woodland	5.00	5.00	357
Artificial land cover	0	0.75	0
Literature reference	Scholz et al. (2012)	Scholz et al. (2012)	Cierjacks et al. (2010)
	N-retention (kg/ha/a)	**P-retention (kg/ha/a)**	**C-retention (t/ha/a)**
In-stream	10.95	53.00	4.38
Literature reference	Niemann (2001)	Schulz et al. (2003)	Niemann (2001)

Table 3
Indicators of state and ESS provision for each of the intermediate ESS (IESS) and quantified changes in ESS provision. The results are scaled up to the entire Emscher catchment. Proxy indicators marked with squared brackets (see Discussion).

Intermediate ESS	State indicators	Impact I ESS Provision indicator	Impact I		Unit
			Before	After	
#1: Self-purification: Nitrogen retention	Stream bed and floodplain conditions relevant for denitrification	Total potential denitrification rate in-stream and in the floodplain	2.99	4.12	t y^{-1}
Phosphorus retention	Stream bed and floodplain conditions relevant for P retention	Total potential phosphorus retention rate in-stream and in the floodplain	1.54	5.64	t y^{-1}
Carbon retention	Stream bed conditions relevant for C retention	Potential carbon retention in-stream	416.40	736.06	t y^{-1}
	Floodplain conditions retaining C	Potential carbon stock in the floodplain	95.53	133.16	t
#2: Maintaining nursery populations and habitats	Taxa richness	[Taxa richness]	1	20.48	Average number of taxa per sampling site
	Red list species	[Red list species]	0	4	Number of species
	Saprobic index	[Saprobic index]	2.66	2.02	–
	Good ecological status/potential	[Good ecological status/potential]	0 of 246.73	94.29 of 246.73	Stream km

streams' concrete beds down to the ground rock, soil formation has to take place at first. Thus, the soil type with the lowest denitrification rate (i.e. brown earth, regosols, rendzinas) was allocated to the grass- and woodland area (Scholz, personal communication). Initial nitrogen concentrations were acquired from water quality monitoring data.

Phosphorus retention is a result of the retention of particle-bound phosphorus by macrophytes on the stream bed and by vegetation in the floodplain. Our calculations of in-stream retention referred to the projected channel surface and initial total phosphorus concentration. For the floodplain retention, land use was applied as a proxy for vegetation types within the wetted area (HQ50 or HQ100). Is has to be noted that accumulation in and potential resuspension from the sediment is occurring. This is considered in the low P-retention rates in floodplains. The in-stream P-retention represents a temporary storage which is seasonally followed by remobilisation. The retention rate refers to the rivershore (Schulz et al., 2003).

We interpreted in-stream organic carbon retention as a process provided by the benthic microbial biofilms (via respiration and increase in biomass), while floodplain retention is provided by the underground carbon stock (in the soil, by deposition of organic carbon-rich sediments during flooding) and its correlating aboveground (in vegetation, by CO_2-sequestration for biomass) carbon stock. Both were used as a proxy for C-retention in the floodplain. The latter results from an enhanced net primary production due to nutrient deposition during flooding (Schulz et al., 2003). Relevant for in-stream carbon retention were the wetted surface and the initial carbon concentration in the water. In the floodplain, we referred to the potentially wetted surface area (HQ50 or HQ100), the soil type and the land use as proxies for vegetation types. Initial carbon concentrations, specifically mean total organic carbon (TOC), were acquired from water quality monitoring data and transferred to chemical oxygen demand (COD) by multiplication by 2.67 (ratio of oxygen to carbon, representing chemical oxidation) to account for the oxidable organic carbon share.

2.6. IESS #2: Maintaining nursery populations and habitats

We evaluated this IESS referring to selected indicators of the aquatic macroinvertebrate communities: benthic invertebrate species richness, number of red list species, Saprobic Index (Rolauffs et al., 2003) and ecological potential (Döbbelt-Grüne et al., 2015) in accordance with the WFD requirements.

2.7. FESS #1: Opportunity for placement of infrastructure and reduced risk of flooding

Flood protection in the catchment is jointly achieved via natural and technical measures, the first being realized via widening of stream profiles and reconnection of floodplains as part of the restoration efforts. This increases the retention volume inside the stream bed, which attenuates potential flood waves. Additionally, technical flood protection is provided through embankment, pumping stations and the construction of artificial retention basins. We measured the retention volume of vegetated retention basins, determined the flood risk area and identified the current level of flood protection (Hydrotec, 2004). Against this background, Beysiegel (2015) exemplarily modelled stream discharge before and after restoration for two different types of channel cross-sections (trapezoidal and near-natural profile). Several distribution functions were determined and the distribution best fitting the empirical distribution was selected. Assuming that provision and use of flood protection services are equal, the resulting benefit referring to the costs avoided by reduced flood damage was assessed in the flood action plan (Hydrotec, 2004). The flooded areas were identified for different flood scenarios based on flooding statistics, discharge quantities, water levels and a digital elevation model. Damage costs were calculated by applying damage functions based on the database HOWAS, compiled by the Bavarian Environmental Agency (LfW Bayern, n.d.).

2.8. FESS #2: Opportunity for placement of infrastructure in the environment

The restoration measures influence the placement of new infrastructure and the value of existing infrastructure, such as A) commercial places with a view on restored stream sections (beneficiaries: resources-dependent businesses, e.g. cafés and restaurants) and B) flats/houses with a view on restored stream sections (beneficiaries: residential property owners). For monetizing both use types, we applied two approaches: 1) Focussing only on the already restored Lake Phoenix area (Fig. 5, Table S1) and covering both types of beneficiaries, and 2) focussing on residential property owners in the entire New Emscher Valley (Fig. 3), i.e. the residential and industrial area along the Emscher main stem, and thus, directly affected by the Emscher restoration, according to the Masterplan Emscher Future (Ruhr, 2005). Approach 1 takes the area of commercial and housing places (square meter of properties from Gohrbrandt et al., 2005) as an indicator for the demand for working or living space near the water, respectively, by

Table 4
Indicators of state, ESS provision and ESS use for each final ESS (FESS) as well as indicators and quantified changes in resulting benefit. The results are scaled up to the entire Emscher catchment. In this study, values are differentiated according to different types of concepts of economic value: *market values* (with a *direct economic impact* for the economy, reflected in existing market prices and with relevance for the gross domestic product) and *non-market values* (without a known market price, not reflected in gross domestic product but estimable with established economic environmental valuation methods). IESS = intermediate ESS; NR = not relevant.

Final ESS	State indicator	Impact I ESS Provision indicator	Impact II ESS Use indicator	Impact II Resulting benefit indicator	Impact II Resulting benefit		Unit	Type of economic effect
					Before	After		
#1: Opportunity for placement of infrastructure and reduced risk of flooding[1]	Morphometry of stream beds, floodplains and vegetated basins	Potential water retention in total stream length, floodplain and vegetated basin area; Discharge reduction	Avoidance of flooding	Avoided costs of flood damage	0	$1.78 * 10^6$	€ y^{-1}	Non-market value
#2: Opportunity for placement of infrastructure in the environment	State indicators for IESS #1 and #2	IESS #1 and #2	A) Commercial places with view on restored river sections	1) Increased demand for commercial premises at Lake Phoenix	0	$8.4 * 10^6$–$19.8 * 10^6$	€ y^{-1}	Market value
			B) Housing area with view on restored river sections	1) Increased demand for residential property at Lake Phoenix	0	$2.5 * 10^6$	€ y^{-1}	Market value
				2) Increased demand for residential property in the New Emscher Valley	$11.81 * 10^6$	$20.44 * 10^6$	€ y^{-1}	Market value
#3: Opportunity for biking and recreational boating	State indicators for IESS #1 and #2	IESS #1 and #2	A) Recreational use by bikers	Expenses for recreational activities by bikers	0	$1.33 * 10^6$	€ y^{-1}	Market value
			B) Recreational use by boaters	Expenses for recreational activities by boaters	0	53,600	€ y^{-1}	Market value
#4: Opportunities to understand, communicate and educate	State indicators for IESS #1 and #2	IESS #1 and #2	Acceptance: participation in excursions	Costs for excursions	0	27,840	€ y^{-1}	Market value
#5: Appreciation that restored stream sections exist	State indicators for IESS #1 and #2	IESS #1 and #2	NR	Willingness to pay in appreciation that restored river sections exist	0	$107.34 * 10^6$	€ y^{-1}	Non-market value

[1] FESS #1: State: Flooded area at a 100 year flood event *BEFORE*: 126 (ha), *AFTER*: 0 (ha);
Impact I provision: Average discharge in a 100 year event *BEFORE*: 36.41 (m^3/s), *AFTER*: 27.66 (m^3/s);
Impact II use: Same as impact I provision.

Fig. 5. Comparison of before (left) and after (right) construction of Lake Phoenix and restoration of the Emscher (Sources: City of Dortmund, Emschergenossenschaft).

acquiring data on the number of restaurants along the lake shore, the rental cost for commercial area and the yearly turnover per restaurant (rental cost per square meter from Korte and Wollrath, 2014; business data about number of restaurants and turnover at Lake Pheonix from online data base Statista.com, 2016) as well as rental prices for the housing area (Wohnungsboerse.net, 2016). The value increases at Lake Phoenix can only be compared to a 'before' value of zero, as the lake did not exist before the restoration (Fig. 5). After a steel factory was demounted in the centre of Dortmund-Hörde, the lake was constructed here and the Emscher stream was brought up again from an underground channel. The bike paths, houses, flats, offices, restaurants and bars were built subsequently and would not exist without the lake and stream. For this reason, a comparison of the lake area with a comparable area without a lake is not feasible in practice. The application of two different sets of data resulted in two possible outcomes that define the value range, from which we report the higher one (Table 4, Fig. 6). Approach 2 processed the rental prices for flats as a proxy of the increased demand for residential properties near the restored sites (Barabas et al., 2013). We assumed increasing prices, as those observed at Lake Phoenix, for the New Emscher Valley, amounting to 3.46 € m^{-2}, while constant prices were assumed for the remaining Emscher catchment. This estimation of price increase was derived from the difference in rental prices between an average rental price of 5.22 € m^{-2} (mean price in the New Emscher valley and remaining Emscher catchment in 2011) and the rental price at Lake Phoenix of 8.68 € m^{-2}.

2.9. FESS #3: Opportunity for biking and recreational boating

The benefits resulting from biking activities along the Emscher bike route were transferred from Radschlag (2013) who monetised

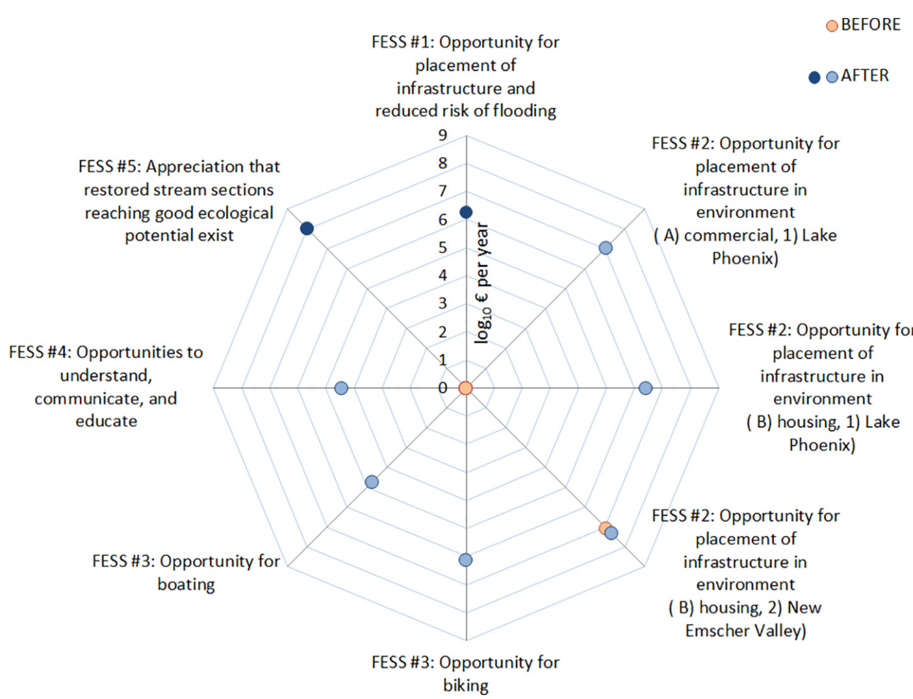

Fig. 6. Spider plot showing the economic effects of all final ESS evaluated in the Emscher case (Axes: $\log_{10}$ € per year). The results are scaled up to the entire Emscher catchment. BEFORE restoration value (highlighted in orange) is zero for all ESS except FESS #2 (B2). AFTER restoration value of FESS with *a non-market value* are highlighted in dark blue, AFTER restoration value of FESS with *market value* causing *direct economic impact* are highlighted in light blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the online version of this article.)

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the economic effects of the Römer-Lippe bike route in the Lippe catchment (adjacent to the Emscher catchment). The total spending per biker on a day trip or a several-day bike-tour was multiplied with the number of bikers per year, representing the willingness to pay (WTP) of the bike paths users. Total expected expenses for the recreation activity 'boating' were assessed for Lake Phoenix via market prices. For this, expenses for boat rental, mooring rental and membership in the local sailing club were obtained (market data from Ruhrnachrichten, 2014).

2.10. FESS #4: Opportunities to understand, communicate and educate

The number of participants in excursions to Lake Phoenix and along streams within the Emscher catchment was obtained from Emschergenossenschaft and multiplied with the price paid by participants of an excursion to Lake Phoenix during the annual meeting of the German Limnological Society in 2015. We, thus, calculated with 834 participants per year in excursions to Lake Phoenix and 1549 participants in excursions along the Emscher streams and costs of 20 € per participant (Table 4, Figs. 4 and 5).

2.11. FESS #5: Appreciation that restored river sections exist

In accordance with the WFD, the good ecological potential is the main management objective for most surface water bodies in the Emscher catchment. Knowing that this objective is met represents a benefit for people who care (non-use existence values) – see list of beneficiary types introduced in Table 1. Based on the gain of stream lengths with good ecological potential through the restoration, we quantified this existence value via benefit transfer from a WTP study for achieving the good ecological status of the Wupper River (Hecht et al., 2015). In that study, contingent valuation was conducted via telephone interviews of 1010 out of the 960,000 inhabitants in the Wupper catchment. The interviewees were asked about their WTP for a good ecological status of the Wupper, which could be achieved by reducing particulate substances, temperature stress and hydromorphological constraints. The average WTP per person (>18 years old) was 3.39 € per month, i.e. 40.68 € per year, which was scaled up to the total number of inhabitants. In our case, the total WTP for restoring the Emscher was derived by transferring the reported WTP of this study to the population in the Emscher catchment.

The IESS were initially quantified for the focus-sections (Table S1) and then scaled up to catchment-level, for which we considered a total stream length of 249.73 km. This reflects the total stream length in the Emscher catchment, excluding the Emscher main stem from Dortmund-Deusen to Dinslaken as well as streams that occasionally fall dry, streams that were not assigned a categorisation of 'Foreland area available for development' (Semrau et al., 2007), municipal stream sections, and pressure pipelines following pumping stations.

Upscaling of the self-purification potential to catchment-level was conducted by grouping all streams in the catchment according to the size of the foreland area that is available for their development. This area was one of the criteria considered to predict the potential for development of streams within the Emscher catchment (Semrau et al., 2007). The length of all streams with the same 'Foreland area available for development' (see Table S1) was summarized, resulting in three groups: streams with a potential area enhancement of <10%, 10–40%, and >40%. In a next step, the self-purification calculated for the focus-sections (see IESS #1: Self-purification) was transferred to the stream group with the same 'Foreland area availability for development' as the focus-section. For this, the self-purification determined for the focus-section was multiplied with the stream length per group.

Upscaling the ecological potential of the focus-sections to the entire catchment was conducted with regard to the 'Potential for ecological development' (Semrau et al., 2007). Good to moderate ecological potential was assigned to streams classified with 'high potential for ecological development', moderate to poor ecological potential to streams with 'medium potential for ecological development', poor ecological potential to streams with 'low potential for ecological development' and poor to bad ecological potential to streams with 'very low potential for ecological development'. 'Very high potential for ecological development' was not applied. The total number of stream kilometres with a certain ecological potential resulted from the summarised length of all streams in the catchment with the same 'Potential for ecological development'.

The FESS were either assessed only for Lake Phoenix (i.e. FESS #2 – rental price increase at Lake Phoenix and FESS #3 – boating), or already calculated on catchment scale (i.e. FESS #1 – flood protection, FESS #2 – rental price increase in New Emscher Valley, FESS #3 – biking, FESS #4 – excursions and FESS #5 – appreciation of restored river) (Table S1). For jointly visualizing the changes in resulting benefits of the FESS quantified in our study, a spider plot was drawn (Fig. 6).

3. Results

Tables 3 and 4 show the quantified intermediate and final ESS before and after the restoration (*Step 9* in Fig. 1), based on the indicators of state, impact I and impact II described above. The results are scaled up to catchment level. The restoration of the streams enhanced their self-purification potential by 38% (nitrogen), 266% (phosphorus), 77% (carbon retention), and 39% (carbon stock). 'Maintaining nursery populations and habitats' also showed a clear improvement through restoration, as demonstrated by all four indicators applied. The level of flood protection after restoration complies with the regulatory thresholds, i.e. the approved protection level, being HQ20 to HQ200 from the Emscher headwaters to its mouth. Therefore, the costs of flood damage within these legal thresholds amount to zero. Thus, all costs of flood damage that could possibly occur within these legal thresholds before the restoration are now avoided, amounting to 1.78 million € per year. This reduction in possible flood damage costs resulted from a very local improvement in flood protection – the rest of the catchment remains at a high flood protection level. Increased demand for commercial premises and new housing developments at Lake Phoenix demonstrated value increases ranging between 2.5 and 19.8 million € per year. The highest monetary value resulting from ESS valuation in our study was 107 million € per year, being the benefit of ESS 'Appreciation that restored stream sections exist' that was derived from WTP figures.

As a means to illustrate changes in the range of economic figures, Fig. 6 shows the monetary benefits of all FESS according to the calculations presented above. The change in benefit ranged from 53,600 € per year (ESS 'Opportunity for boating') to 107,335,717 € per year (ESS 'Appreciation that restored stream sections exist').

The type of economic effect derived from each increased ESS use is classified in Table 4: The evaluation of FESS #1, quantified as avoided costs, represents the *non-market value* for the property owners in the flood zone, because this monetary figure quantifies the (estimated) saved damage costs, which property owners would have to burden in case of no restoration of the Emscher River. The Impact II evaluation of FESS #2, 3, 4 can be interpreted as *market values* (with a *direct economic impact*), derived from the enhanced ESS use: FESS #2 – The increase in house-rent prices for properties in the New Emscher Valley and at Lake Phoenix as well as the ren-

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tal price for commercial premises at Lake Phoenix are direct spending in the regional economy. We excluded the valuation approach of ESS 'Opportunity for placement of infrastructure in the environment' for housing (B) at Lake Phoenix (1) to avoid double counting, as this value is already covered by housing (B) in the New Emscher Valley (2). FESS #3 – The expenses for recreational activities by bikers as well as expenses for recreational activities by boaters are also *direct economic impacts* in regional business sectors. FESS #4 – The costs for excursions can be classified as *direct expenses* as well. All in all, these market values for FESS #2, 3 and 4 can be accounted to 21,441,572 € per year. This reflects the annual *direct economic impact* of increased regional economic activities obtained due to the restoration of the Emscher, attesting its success. Finally, the impact II evaluation of FESS #5 represents a *non-market value* for the people who care about the local environment and benefiting with a 'non-use value' from the restoration of the Emscher. In conclusion, results for FESS #1 and #5 represent increased *non-market values*, being 109,121,217 € per year, while the results for FESS #2, 3 and 4 reflect *market values* with a *direct economic impact*. It is not advisable to aggregate both sums because they represent different value concepts.

4. Discussion

4.1. Large scale river restoration pays off

Restoring the Emscher catchment represents an ambitious endeavour, involving extensive engineering efforts and huge investment costs. The total investment costs spent from the initiation of the Emscher restoration in 1990 until its completion in 2020 will amount to 5.3 billion €. However, ventures like this are precedent and offer unique opportunities for knowledge acquisition. Our study is the first to evaluate the changes in ecosystem service provision and use related to the Emscher restoration.

Our results suggest that annual benefits associated to restoration efforts are substantial. The economic perspective may provide convincing arguments for justifying the restoration efforts. It has to be stressed, however, that we aim to showcase the potential range of benefits, and refrain from a direct comparison of costs and benefits of the Emscher restoration project as a whole.

Two different categories of economic value (Costanza et al., 1997) have resulted from the monetary valuation in this study: The first category is the turnover in a market with relevance for the gross domestic product (GDP). We refer to these values as *market values* with a *direct economic impact*. These comprise values derived via the economic methods of "market pricing", "hedonic pricing" and "travel costs". The second category is the *non-market value*, which is not relevant to the GDP. It comprises the economic method "willingness to pay" but also "avoided costs" in our study. We exemplified the *market* and *non-market values* from the viewpoint of different beneficiaries to demonstrate the range of benefits associated to certain FESS.

The monetization of ESS has been critically discussed in ESS research (e.g. Kelemen et al., 2014). Oftentimes, a monetization might not even be necessary. Nevertheless, the present case highlights the generally appealing character of monetizing benefits in environmental management (see also Boerema et al., 2014, Vermaat et al., 2015): A monetary evaluation allows expressing different ESS values in a common unit of measure, facilitating common value understanding among stakeholders and visualizing the uses and values for different beneficiaries and in comparison to investment expenses. The case study, however, also shows the challenges arising with monetization: It demonstrated that different economic assessment methods lead to different economic value types, like *market* and *non-market values*. The first type of value represents a *direct impact in the economy*, reflected in the GDP, the latter does not. The economic assessments conducted in our study represent a rather simplified monetarization compared to a detailed cost-benefit analysis (CBA). These simplified methods can nevertheless foster comprehension of the evaluation outcomes, emphasizing the substantial economic effects already present a few years after restoration. As these effects are ongoing year by year into the future, they are eventually compensating the investment costs.

If a detailed CBA was to follow the ESS evaluation conducted here, both the costs and benefits would need to be presented comprehensively (European Commission, 2014, Hanley and Barbier, 2009, Pearce et al., 2006). On the cost-side, investment and reinvestment expenses need to be considered along with annual operational costs and discounting of all expenditures. On the benefit-side, the two types of economic effect (as presented in Table 4 and Fig. 6) would need to be integrated into one value. Therefore, the calculated *market values* with their *direct economic impact* (from FESS #2, 3, 4) need to be converted into added economic value, by subtracting production costs of underlying goods and services used. In contrast to a differentiated presentation of the single IESS and FESS, such an integrated value represents a loss of information, as the total benefit simply represents the sum of all monetized final ecosystem services. Such a constraint view, rightly bemoaned in the current ESS debate (e.g. Boeraeve et al., 2015, Silvertown, 2015), neither would integrate the (instrumental and inherent) values of the intermediate ESS that we addressed, nor the values of further relevant services that we could not consider due to data scarcity and quantification problems (e.g. CO_2 sequestration, local climate regulation, research opportunities).

4.2. DESSIN ESS evaluation framework

We performed this study as a test case for the DESSIN ESS Framework, aiming at evaluating changes in ESS as an effect of environmental management measures (Anzaldua et al., 2018). Designed to offer integral evaluation, the framework asks for identifying all services potentially affected by the restoration measures. Despite the cultural services certainly attracting most attention in our study, we looked into provisioning services (not relevant in the Emscher case) and quantified regulation and maintenance services (self-purification, maintaining nursery populations and habitats). The latter are of high relevance *per se* and also for the provision of final cultural services. Thus, their consideration in the evaluation process is indispensable. This holistic perspective constitutes the core of the framework and avoids narrowing the value debate often resulting from unidimensional service valuation (Jax et al., 2013).

The step-by-step guidance of the DESSIN ESS Framework and its stringent commitment to the DPSIR elements render its application quite demanding. Yet, the formalized structure of the framework is decisive to foster the operationalization of the ESS approach. To this end, the DPSIR frame is perfectly suitable for such a holistic evaluation, because it facilitates the revelation of causal linkages in socio-ecological systems (Smeets and Weterings, 1999, Müller and Burkhard, 2012). At the same time, the frame offers a blueprint for conducting and reporting studies in a structured way, enhancing transparency and comparability between studies (Seppelt et al., 2011). The transparency of results in turn is vital for mutual understanding among all actors involved in the evaluation process.

Ultimately, the operationalization of the ESS framework strongly depends on data availability. In water management, the obligate WFD monitoring offers comprehensive data on drivers, pressures and state. For the latter, ecosystem components like species composition and abundance of selected aquatic organism groups are assessed (Birk et al., 2012). A sound evaluation of service provision, however, entails assessing ecosystem functions resulting from both the ecosystem's components and processes

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(De Groot et al., 2002) – at times captured under the term natural capital (Maseyk et al., 2017). Data and indicators on ecosystem state thus only serve as proxies for ESS at best. Such proxies may suffice in evaluating the status-related service of 'maintaining nursery populations and habitats', but are ill-suited for process-related service types. Simple process models (e.g. as applied in our study to quantify the process of nutrient retention) help to acquire functional data (Scholz et al., 2012) but often lack empirical adjustment. Further ecological research is paramount to increase ecosystem process understanding (e.g. Kupilas et al., 2016), paving the way for more informative ESS assessment based on improved data and indicators.

4.3. Conclusion

The practical implementation of the ESS approach is urgently needed for more sustainable decision-making. Its operationalization, however, is currently hampered by a lack of consistent definitions and agreed evaluation methods. In the present study, we have demonstrated the suitability of a structured ESS evaluation as an instrument for estimating the impact of mitigation measures, oriented towards integrated management of socio-ecological systems. The evaluation was conducted by an interdisciplinary team, integrating quantitative, qualitative and simple modelling approaches (depending on data availability) on multiple scales for the most relevant ESS. In the case study, we have estimated the intermediate and final ESS resulting from the restoration of the Emscher River by quantifying the regulation and maintenance ESS 'self-purification capacity', 'maintaining nursery populations and habitats' and 'flood protection' as well as cultural ESS. The final ESS were monetized, with a *market value* and subsequent *direct economic impact* amounting to 21,441,572 € per year. This impact is related to increased regional economic activities due to the restoration of the Emscher. Additionally, we estimated a *non-market value* of 109,121,217 € per year for the people who care about the local environment and benefiting with a 'non-use value' from the restoration of the Emscher. These monetary values, however, do not integrate the intermediate ESS that we addressed and exclude further relevant services that could not be considered yet due to data scarcity and quantification problems (e.g. CO_2 sequestration, local climate regulation, research opportunities). Nevertheless, these values demonstrate that – beyond the regulatory requirements achieved through the restoration measures – an additional benefit is generated. The conceptual framework applied here can, thus, serve for informing decision makers and communicating impacts. As the output integrates water related impacts of concrete measures, it can also inform other sectors (e.g. agriculture, energy sector) by this means, facilitating a holistic inter-sectoral planning.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ecoser.2018.03.020.

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