Assessing the societal benefits of river restoration using the ecosystem services approach

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Abstract

The success of river restoration was estimated using the ecosystem services approach. In eight pairs of restored-unrestored reaches and floodplains across Europe, we quantified provisioning (agricultural products, wood, reed for thatching, infiltrated drinking water), regulating (flooding and drainage, nutrient retention, carbon sequestration) and cultural (recreational hunting and fishing, kayaking, biodiversity conservation, appreciation of scenic landscapes) services for separate habitats within each reach, and summed these to annual economic value normalised per reach area. We used locally available data and literature, did surveys among inhabitants and visitors, and used a range of economic methods (market value, shadow price, replacement cost, avoided damage, willingness-to-pay survey, choice experiment) to provide final monetary service estimates. Total ecosystem service value was significantly increased in the restored reaches (difference 1400 ± 600 € ha^{-1} y^{-1} (2500 minus 1100, p=0.03, paired t-test). Removal of one extreme case did not affect this outcome. We analysed the relation between services delivered and with floodplain and catchment characteristics after reducing these 23 variables to four principal components explaining 80% of the variance. Cultural and regulating services correlated positively with human population density, cattle density and agricultural N surplus in the catchment, but not with the fraction of arable land or forest, floodplain slope, mean river discharge, or GDP. Our interpretation is that landscape appreciation and flood risk alleviation are a function of human population density, but not wealth, in areas where dairy farming is the prime form of agriculture.

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Key words: carbon sequestration, retention, sediment, nutrients, Europe, river corridor, wetlands, flood control, biodiversity, economic valuation, choice experiments, willingness-to-pay

Introduction

Over the past decades, rivers have been restored for a range of purposes, such as flood mitigation, habitat and biodiversity enhancement and water quality improvement (Bernard et al., 2005; Benayas et al., 2007; Jähnig et al., 2011). Purpose and success of restoration often have been reported with limited rigor (Bernhardt et al., 2005, Bernhardt & Palmer, 2011; Jähnig et al., 2011), as in other ecosystems (Zedler & Kercher, 2005; Benayas et al., 2007). In addition, indicators of success used vary widely, ranging from geomorphological elements in the floodplain landscape, and water quality parameters to presence of characteristic biota in different species groups as well as aggregate biodiversity indicators. This variation can be due to the purpose of restoration, the scale of the assessment, and the institutional context (Jähnig et al., 2011; Morandi et al., 2014; Hering et al., in revision, J. Appl Ecol). The combination of poor documentation and variable indicators is at odds with standards for study design (Underwood, 1996). It also complicates a comparative analysis across larger numbers of cases at a later stage (Benayas et al., 2007; Morandi et al., 2014), which is an important tool for policy evaluation (Turner et al., 2000).

This study is an attempt to carry out such an analysis across eight European rivers using the ecosystem services approach as an integrating framework (cf Acuna et al., 2013). We will first argue why the ecosystem services approach could be fit for this purpose and address the issue of spatial scale and resolution, then specify our underlying hypothesis on how ecosystem services could be affected by river restoration and conclude with our research questions.

The concept of ecosystem services has been advocated by the by the Millennium Ecosystem Assessment (MEA, 2005) as a means to integrate all possible direct and indirect benefits that accrue from an ecosystem to human society, including those that are not straightforwardly monetized. It has been further developed into a well-specified typological catalogue with three main categories, i.e. provisioning, regulating and cultural services (e.g. Wallace, 2007; Bateman et al., 2010; Watson & Albon, 2011; Weber, 2011; see below, methods section). The ecosystem services approach is applied increasingly (Fisher et al., 2009; report an exponential increase in publications) to include all these potential benefits in comprehensive decision-making and planning efforts (e.g. Carpenter et al., 2009; Nelson et al., 2009; Bateman et al., 2010; De Groot et al., 2010; Acuna et al., 2013). Ecosystem services depend on a variety of intermediate ecosystem processes and states, but their societal value ultimately depends on the use (and non-use) by humans in their final form. A particular habitat can provide several services simultaneously, such as mineable sand, the retention of nutrients, the accumulation of carbon in wood, the excitement of angling, and the enjoyment of the scenic beauty of the riverine landscape. Briefly, our quantification was carried out in three steps. First, services in their final form (Wallace, 2007; Bateman et al., 2010), a form which is measurably beneficial to society and is not intermediate leading to yet another ecosystem process or service, are quantified in biophysical units. An example of a final regulating service is nutrient retention in kg of phosphorus retained ha^{-1} y^{-1}). Then all final services are valued separately using a range of economical methods. Finally, these monetary values are summed for the ecosystem. Since restoration measures can affect a wide range of processes and conditions in river and floodplain, comprehensive evaluation of their success should integrate all aspects considered potential benefits to society. We understand that the summation of ecosystem services is essentially anthropocentric through its focus on societal benefit (Westmann, 1977), but argue that the estimated economic value offers a useful though imperfect common yardstick, which is expressed in tangible units that are understandable to the general public and decision makers.

Ecosystem services quantification is spatially bound by the extent of the providing ecosystem, which is inherently unspecific. River restoration efforts are geographically limited to banks and floodplains, but may still differ widely in spatial extent (Bernard et al., 2005). Overall, restoration is thought to be more successful when longer stretches of river are restored, and the landscape setting is incorporated, particularly for larger and longer-lived organisms, such as fish and macrophytes (e.g. Lorenz & Feld, 2013). In contrast however, Hering et al. (in prep. J Appl Ecol) observed that intensity of habitat modification in the restoration effort had a far more pronounced effect than extent of the restoration (i.e. km of river length restored). This suggests that intensity and extent of restoration are different dimensions, and that the landscape and catchment perspective is important. Most restoration projects (Bernhardt et al., 2005) are carried out at the reach scale (a length of several river widths up to 20 km, Brierley and Fryirs, 2005), and the case study sites in our project conformed to this (Muhar et al., introduction to this special issue). Reaches are viewed as comparatively homogeneous stretches of landscape in the river network draining a catchment (Skøien et al., 2003). Reach-scale floodplain stretches however consist of mosaics of different habitats, such as woodland, grassland, marshes, or gravel beds. Within-reach variability in these habitats can be considerable, and these different habitats can differ markedly in service provision, such as sedimentation and nutrient retention (Olde-Venterink et al. 2006). Therefore, where reaches are the spatial unit of comparison, internal habitat constellation at the local scale, as well as the wider landscape and catchment geography, the regional scale, are important determinants of services potentially provided as well as of societal use.

Gilvear et al. (2013) stress that the ‘degraded, unrestored’ state is the result of previous, anthropogenic ‘improvement’, which also had a distinct, societally recognized purpose, such as drainage, flood protection and navigation. Only the policy perspective has changed with time, and restoration implies that a river has been converted into a state that more closely resembles a historical form and functioning, and is appreciated more highly. Therefore, a ‘no measurable effect’ zero hypothesis is appropriate. The alternative hypothesis can be a compounding of regulating and cultural services, because specific restoration purposes often relate to these two categories (Bernhard et al., 2005; Jähnig et al., 2011). Overall, we expect that regulating as well as cultural services related to habitat structure and dynamics of the river channel and floodplain, including an appreciation of increased scenic beauty of the landscape, are enhanced by river restoration at the reach scale. Our questions are: (1) Do we find significantly higher societal appreciation of restored as compared to unrestored reaches using an ex-post economic quantification of ecosystem services? (2) Is this difference related to regulating and cultural services? (3) Can we identify underlying geographic differences in the patterns of service provision and valuation for these Central and Northwestern European rivers?

Methods

Studied reaches

Seven out of the eight studied pairs of reaches (Fig. 1a, Table 1, see also Muhar et al., introduction to this special issue) were studied in the field by two or more of our co-authors, often assisted by local colleagues. For the Skjernå in Denmark, we could depend on the exhaustive documentation of Dubgaard et al. (2005), which includes the economic assessment of cultural services (Table 1).

The teams collected local information on all possible forms of ecosystem services provided by the river corridor in both the restored and unrestored reach. We assumed that the floodplain corresponded to the spatial extent of each river corridor and determined it with GIS from historical flood maps (see references in Table 1). River corridors of restored and unrestored reaches in a pair varied in length, area, and habitat provenance. We have not normalized habitat provenance to a standard proportion across all reaches (for example all normalized to 50% woodland, 40% grassland and 10% marshland) prior to our analyses, because restoration involves a purposeful alteration of habitats, for example by the re-establishment of marshes and open water.

Quantification of ecosystem services

We applied the methodological framework of Vermaat et al. (2013), which allocates different habitat patches in a reach to uniformly classified units (EUNIS-CORINE, example in Fig 1b; Davies et al., 2004) and accumulates the different services provided by each habitat unit in a reach (Table 2 lists all services quantified in this study). We first expressed all final services in biophysical units in the form they are utilized by society, then monetized these using one of several economic methods available (see below), and finally summed these per reach. Thus, our service accumulation is a simple summation of total ecosystem service delivery across habitats in a reach as annualized monetary value (Fig. 3), which is normalized to reach area.

Environmental economists have developed a range of methods to estimate the economic value of ecosystem services (Bouma & Van Beukering, 2015). They have reviewed applicability and error components (Brouwer et al., 1999, 2008; Turner et al., 2000; Brander et al., 2006; Bateman et al., 2010; Watson and Albon, 2011), and have aggregated estimates derived from different methods (Dubgaard et al., 2005; Acuña et al., 2013, Martin-Lopez et al., 2014). We based our choice of method on a decision tree from DEFRA (2007), and data availability (Table 1 and 2, Fig. 2, Vermaat et al. 2013). Since we aimed to integrate over different services and compare between reaches, we chose to express all services in monetary units. We do not distinguish other value domains for service appreciation beyond our monetary assessment. We have two reasons for this: First, we are convinced that a limitation to final provisioning, regulating or cultural final services should account for all underlying supporting services. This implies that a separate distinction of 'habitat provision' (De Groot et al., 2010) or the 'biophysical domain' (Martin-Lopez et al., 2014) is redundant at the final service level as these are already included as supporting services contributing to final services. Second, a monetary quantification may not grasp the fullness and diversity of societal appreciation (Westmann, 1977), but it does provide a harmonised means to compare, evaluate trade-offs, and inform policy makers. An overview of services evaluated and economic methods applied is given in Table 2. Reference to literature and further details on these methods can be found in Vermaat et al. (2013) and the case study reports (Table 1) available on the project website (www.reformrivers.eu).

Local willingness-to-pay (wtp) surveys followed a general structure but were geared to the local conditions, pre-tested locally, and set in a choice-experiment design (Table 1). Each also included an open-ended wtp-question regarding river restoration. Where the choice experiments allowed breakdown of the willingness to pay for restoration into separate components, we used the value reflecting non-use of biodiversity and/or scenic landscape beauty because we have separate estimates for recreational use. Other final services due to biodiversity, such as pollination or enhanced pest control (Cardinale et al., 2012), have not been quantified. Respondents have been classified as local inhabitants or tourists from elsewhere in- or outside the country. We consider local respondents to represent the human population of the adjacent riparian administrative unit(s), which was municipality or one administrative level higher (Denmark, Poland). The percentage of cooperative respondents was included to correct the number of households and tourist visitors possibly willing to pay for river restoration. Since Dubgaard et al. (2005) used the value of the euro for the year 2000, it was adjusted by 1.45 to correspond to the August 2013 euro values applied for all others in this study. For the sampling periods between April 2013 and September 2014 (Table 1) the value of the euro differed by 4% at most so we did not adjust it.

Statistical analysis

We quantified land use, intensity of agricultural use, human population density and economic indicators of the upstream catchment of a reach from various European spatial databases (supplementary material table S1). Where relevant we included both the mean and standard deviation for each catchment variable. The difference in estimated value between restored and unrestored reaches was analysed with a paired t-test followed by linear regression of restored versus unrestored values, where a significant intercept and slope higher than 1 indicate that restored and unrestored values differ. Robustness of the regression was inspected by the change in parameters after leaving out the most extreme data pair. We analysed the possible relationship between service delivery of a reach as dependent variable and reach land use, as well as catchment geographic data, as explanatory variables using a General Linear Model (GLM). We had no a priori assumptions on geographical hierarchy of the explanatory variables. Covariance among the possibly underlying geographic pattern in catchment (regional) and floodplain (local) variables was first addressed in a Principal Components Analysis (PCA). The significant principal components explaining more than 10% of the variance were used as explanatory covariates in a GLM-ANOVA with restored-unrestored as fixed factor. This assesses whether restoration has a significant impact on service delivery over and above the different covariates grasping geographical variability at local reach and regional catchment scale. PCA and GLM were done with SPSS; exploratory data analysis was done with PAST (Hammer et al., 2001).

Results

Despite considerable variability in the relative importance of provisioning, cultural or regulating services among paired reaches (Fig. 3a, also fig S1), restored reaches and their floodplains provided a significantly higher total value. Also, higher values of unrestored reaches correlated with higher values of restored reaches, with the exception of the Becva (Fig. 3b). This river is an outlier because of the substantial and frequent flood damage (also in recent years; Kohut, 2014) in the unrestored reach, which is largely prevented after restoration. The net sum of regulating services in this unrestored reach was negative, but its exclusion did not lead to a major change in outcome of the paired t-test (difference reduced from 1384 to 840 €, p=0.04).

The studied reaches and their catchments differed considerably in land use and human population density (Fig. 4). Covariance among the 23 catchment and floodplain variables was reduced by retaining only the four principal components together explaining 80% of the total variance (Fig. 5a). Intensity of dairy farming and arable agriculture each correlated highly with a different principal component (respectively pc1 and pc2, Fig 5a). Both co-varied significantly with human population density and soil sealing in the catchment. Nitrogen surplus on agricultural land varied parallel with livestock density (pc1). Nitrogen surplus on forested land appeared to correlate with % arable land, and was negatively correlated with total catchment area and total numbers of livestock in a catchment (pc2). GDP differed greatly among our study rivers, yet pc3 (which was correlated with GDP, data not shown) was not correlated with any ecosystem service. The pairs of restored-unrestored reaches plotted near to each other across the first two principal components (Fig 5b), suggesting that the paired reaches indeed are comparable in floodplain and catchment geography.

Catchment and floodplain land use were related to ecosystem service delivery in a GLM-ANOVA with the four principal components as covariates (Table 3). Consistent with the paired t-test, but now without potential confounding from geographic floodplain and catchment variability, restoration had a significant effect on total service delivery and cultural services. We found a marginally significant effect ($p<0.10$) of restoration on regulating services. However, only cultural services co-varied significantly with pc1. Thus, cultural services are valued higher in areas of higher human population density and more intensive agriculture (pc1), rather than for example in wealthier areas with higher GDP. GDP did not correlate significantly with the first two principal components. This corresponds with the absence of a significant relation between respondents' willingness to pay for river restoration and reported net monthly income (Fig. 6): we had to remove two outliers of the seven cases to find a positive relation as is typically found in valuation studies. The fact that respondents along the Becva are willing to pay considerably more, and those along the Morrumsån much less suggests important site-specific factors. Along the Becva, inhabitants and visitors alike have lively memories of recent catastrophic floods and high expectations of the new floodplain landscape, which is frequently used. In stark contrast, the respondents along the Morrumsån appreciated only a limited tax increase for river restoration, and only 20% of the interviewed people were willing to cooperate.

Discussion

Increased societal benefits due to river restoration

Our analysis of ecosystem services indeed suggests that river restoration enhances societal benefits: averaged across all 8 rivers we found a significantly higher service delivery (Fig. 3, Table 3). This appears to be primarily due to an increase in cultural services, and less distinctly to an increase in regulating services (Table 3), whereas provisioning services were not affected by restoration. Our interpretation is that landscape appreciation and flood risk alleviation are a function of human population density, but not wealth, in areas where dairy farming is the prime form of agriculture. At the same time, variability among rivers was substantial. In one case, the Finnish Vääräjoki, the restoration was limited to the stream bed but this led to a reduction of the already low agri- and silvicultural production (provisioning services), and it slightly enhanced flood risk via an increased frequency of ice dams on restored rapids. In another case, the Czech Becva, agricultural provisioning value was nullified by the high risk of flood damage in the unrestored reach.

When we sought for underlying physical, or social geographic factors in floodplain and surrounding catchment characteristics, we found a distinct correspondence of higher societal restoration benefits with a higher human population density and cattle density. Willingness to pay of the respondents as well as their net income and overall wealth expressed as GDP differed greatly among our study rivers, yet pc3 (which was correlated with GDP) was not correlated with any ecosystem service. We interpret this to imply that rather more people appreciate the enhanced cultural services provided by a restored reach, than that a more wealthy population is individually willing to pay more for restoration, which is in line with findings of Brander et al. (2013). The correspondence of regulating and cultural services with pc1 suggests that restoration to a ‘more natural’ flooding regime of the corridor has led to an increased appreciation by inhabitants and tourists of the scenic beauty of these landscapes. This translated into increased revenues in the recreation sector, notably in the Narew, Regge, Vääräjoki, Skjernå and Morrumsån (Supplementary material S2).

Methodology, uncertainty and implications

Since our aggregation across habitats and potential services uses a wide range of data sources and local as well as literature-based estimates, an estimate of potential systematic and random error is difficult to give. Instead, we will briefly discuss several limitations and aspects of uncertainty related to our estimates. First, we have willingly restrained ourselves and used a single, convergent economic dimension of value for the reasons outline in the introduction. Second, some components of total ecosystem service delivery were not quantified (reduced downstream sedimentation, effects on hydropower delivery, pollination) or may have been overlooked. Others have been estimated conservatively in a systematic way, so we probably have underestimated total ecosystem service delivery, but we see no reason that this may have been biased towards favouring restoration. Third, our selection of restored cases may have been subject to selection bias. Although this is hard to verify in a formal way (see Bernard et al., 2005), we may have unknowingly taken early 'easy success' cases. This calls for a cautious extrapolation of our findings, with due attention to the specific services involved. Fourth, the net benefit accrues to different businesses or individuals in some cases, but to the common case of a nation or global humanity in other cases. For example, regulating services of a floodplain accrue to local farmers (nutrient provision), downstream communities (less flooding), the navigation (water level) or hydropower sector (increased reservoir life span), which is either national or property of larger international consortia, or the global human population (climate mitigation). Where decision-making involves such different sectors and scales, the appropriate level for decision-making may well be national, or supranational (Van Teeffelen et al., 2014). This does not make our conclusion less opportune: river restoration appears economically beneficial to society.

We can ask whether our estimates appear meaningful compared to literature or local agricultural land prices. Our estimates of total ecosystem service delivery (median 1500, range -1800 – 5800 € ha^{-1} y^{-1}) are comparable to those of Murray et al. (2009, for restored Mississippi floodplain habitats (1000 € ha^{-1} y^{-1}), Brander et al. (2013, only regulating services of wetlands in agricultural land ~ 600 € ha^{-1} y^{-1} compare Fig. 3), or Martin-Lopez et al. (2014, for the whole Cota Donana wetland complex, including irrigated rice production and shrimp fisheries, 9000 € ha^{-1} y^{-1}). Our comparison with local land rents suggests that the increase in value due to restoration, observed in six out of the eight cases, was about three times higher than land rent (Fig. 7, using the median ratio). With most provisioning and a limited part of the cultural services grasped in markets, profitability assessment of restoration should still involve a cost-benefit assessment including opportunity costs of the alternatives for the decision maker as well as a conservative rate of interest and return period (Dubgaard et al., 2005). We have not included the cost here. Taken together, this suggests that our economic value estimates of societal benefits of restoration may not be exactly accurate reflections of total economic value, but do appear meaningful and reasonably within range.

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Figures and tables

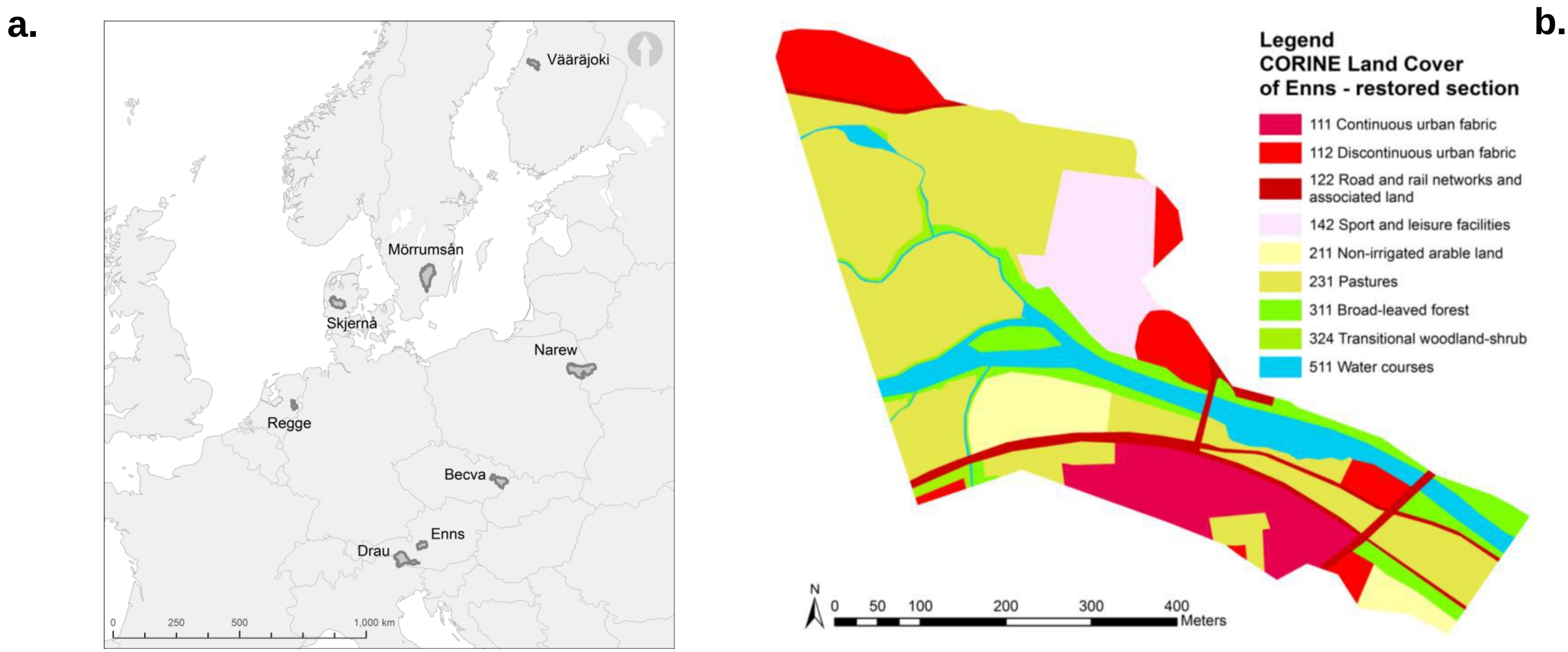


Figure 1. (a) Location of the study sites across Europe. Indicated are the catchments above the lowest point of the restored or control reach, whichever was further downstream. (b) CORINE habitat map of one of the studied reaches, here the restored reach of the Enns in Austria (from Haverkamp, 2014). The legend provides the CORINE three-level classification used (see also Vermaat et al., 2013).

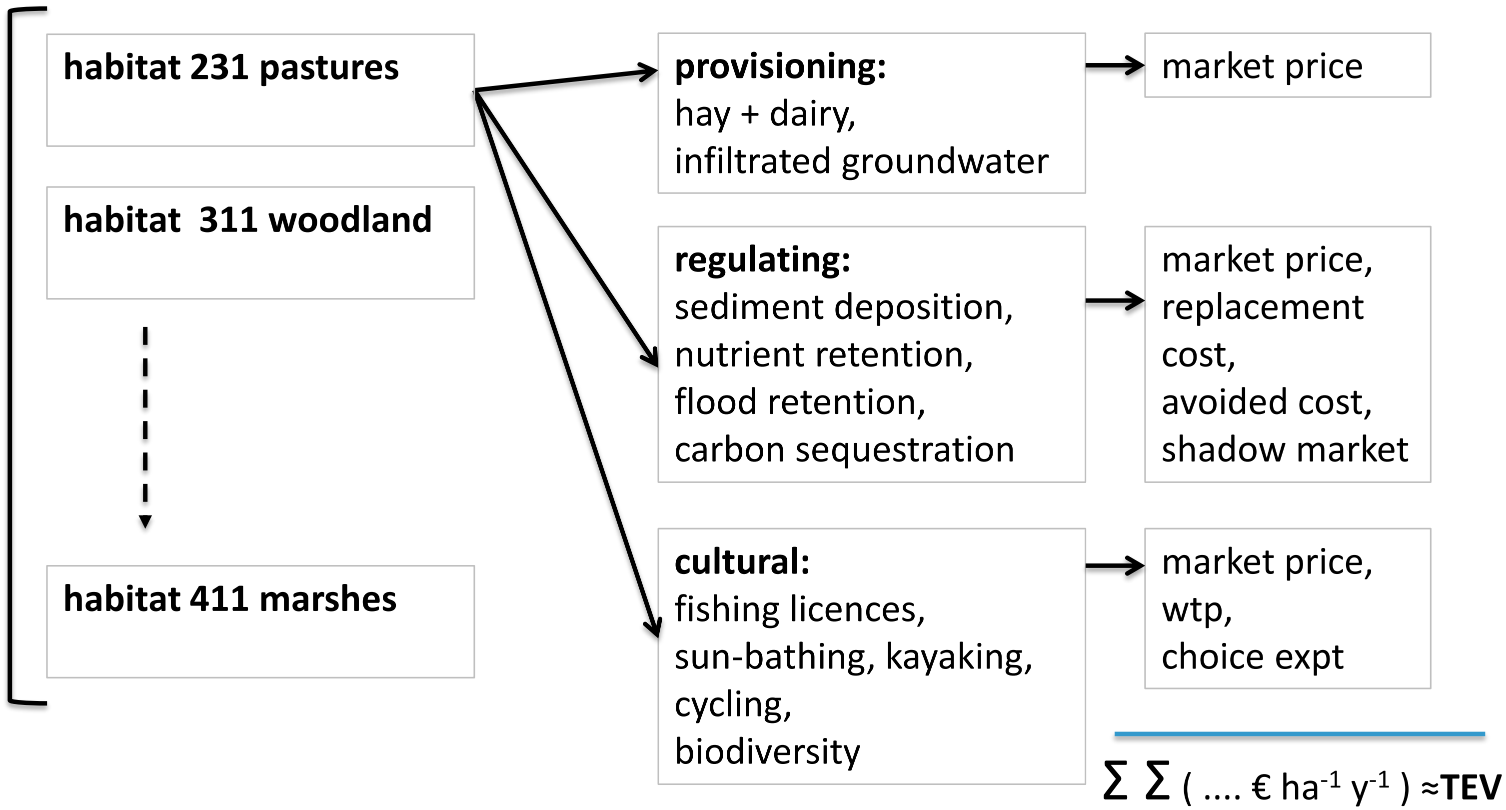


Figure 2. Flow scheme of the valuation procedure followed for habitats within reaches. Habitat coding is according to CORINE, but only three habitats are displayed for illustrative purpose. Different services and economic methodology are illustrative, not exhaustive. TEV is Total Economic Value, wtp = willingness to pay (see text).

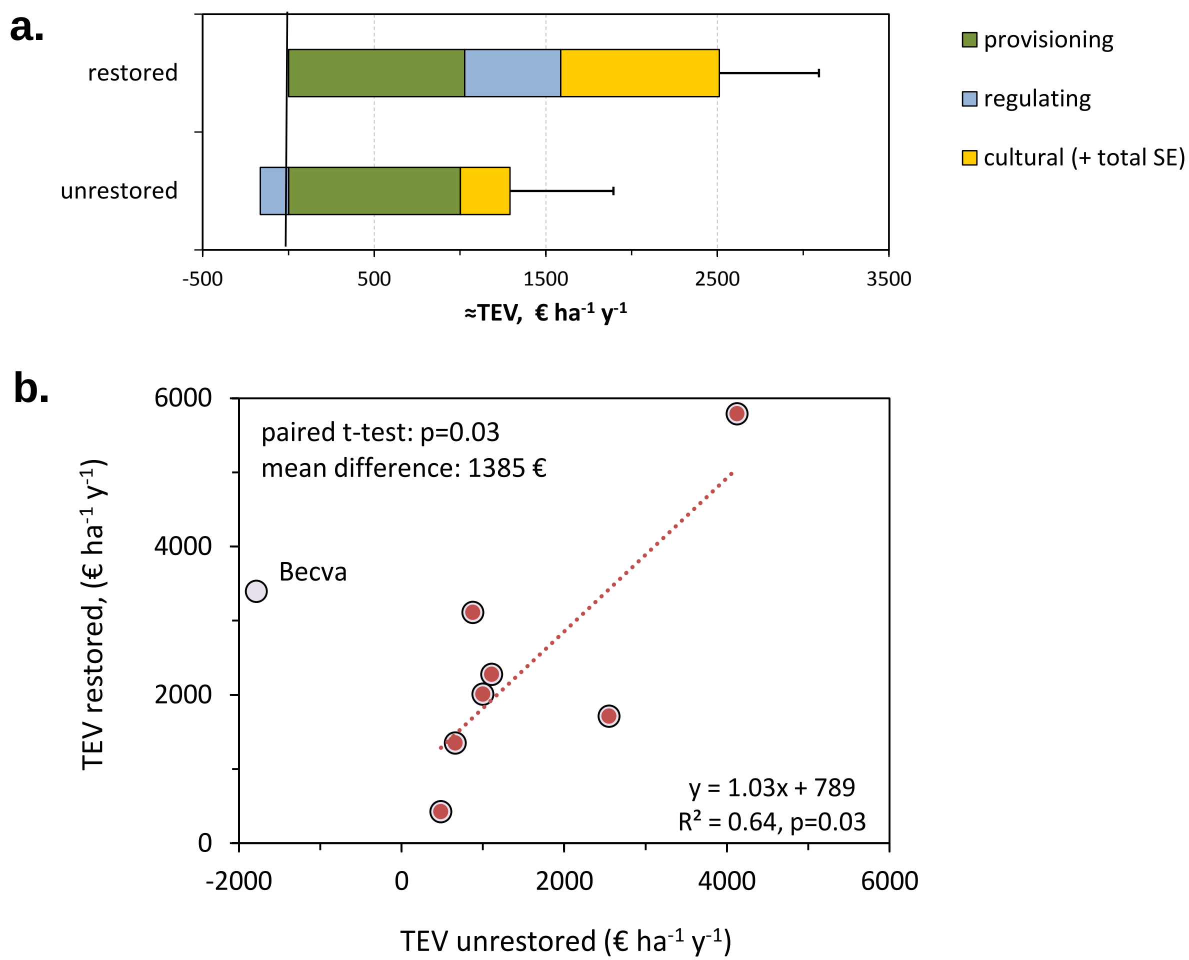


Figure 3. Overall difference in estimated service delivery between restored and unrestored reaches. (a) Overall stacked means plus 1 standard error of total services (similar bar charts for individual rivers are in the supplementary material S1 (b) Scatter plot of restored versus unrestored total services. If the Becva is excluded, the regression is significant. Similar separate regressions for all 8 pairs were made for provisioning services (not significant), regulating services ($p<0.05$, but not significant without the Becva), and cultural services (slope 1.5, $p<0.01$).

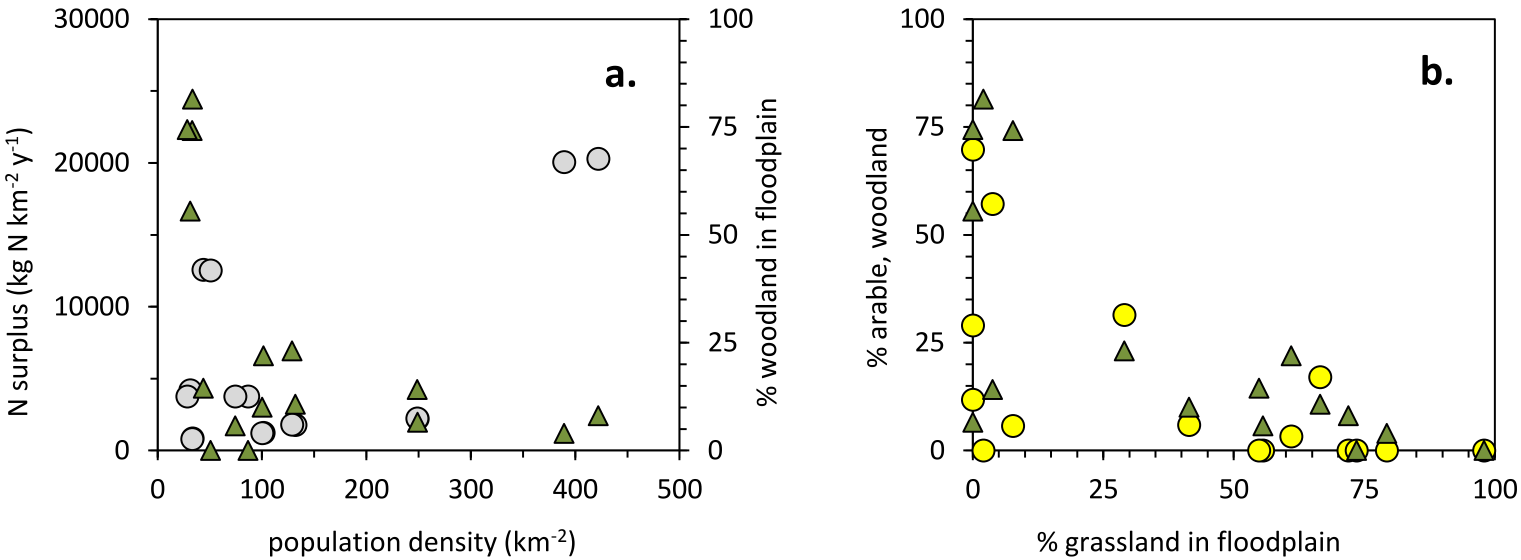


Figure 4. (a) Variability in catchment human population density versus catchment Nitrogen surplus of agriculture (circles) and percentage woodland in the floodplain (triangles); (b) percentage woodland (triangles) and arable land (circles) versus grassland in the studied floodplains.

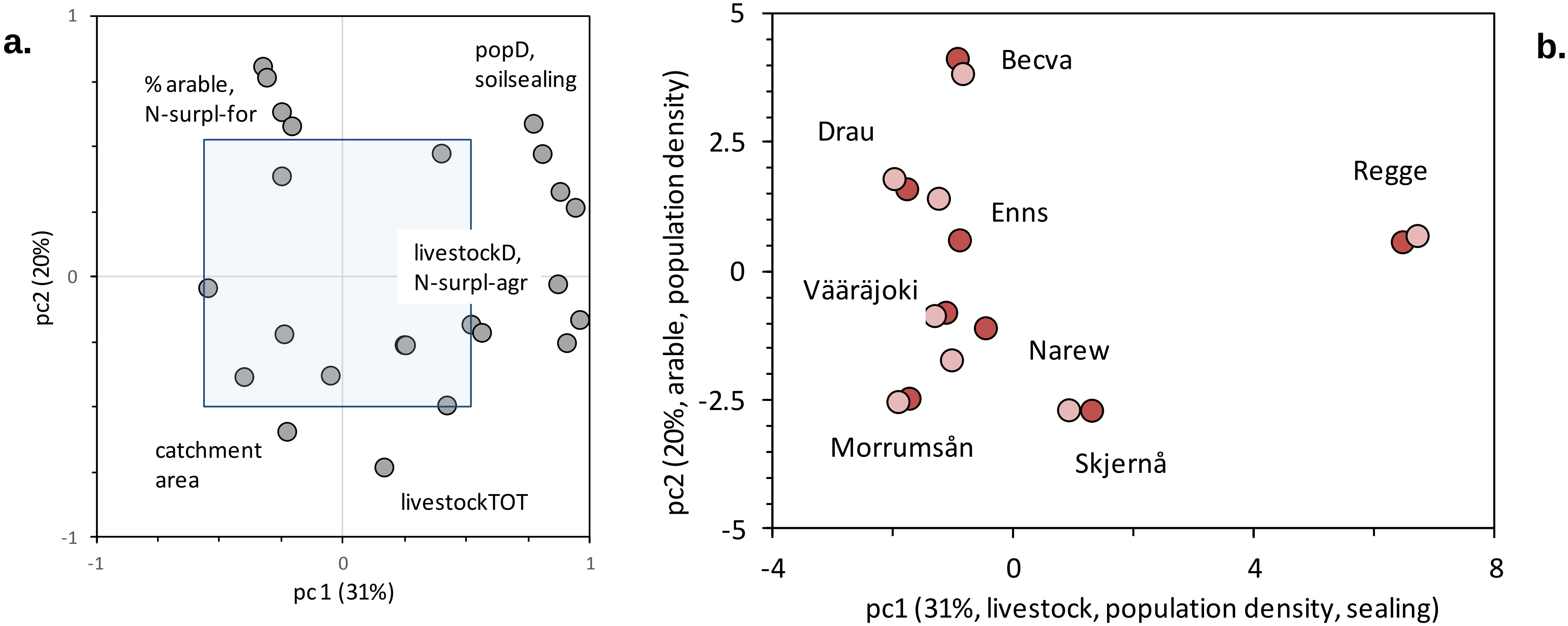


Figure 5. Principal components analysis of 23 catchment and river corridor variables. (a) Correlations of the original variables versus the first two principal components are plotted. Four principal components explained more than 10% of the variance, together 82%. The transparent blue square depicts the area where r<0.5, corresponding to p>0.05 for pairwise linear regressions, within this area we consider the variables to be not correlated with either principal component. Variable labels: % arable = percentage arable land in the floodplain, N-surpl-for = Nitrogen surplus in the forested part of the catchment, popD = human population density in the catchment, soilsealing = the proportion of the catchment area paved, livestockD is cattle density, N-surpl-agr = Nitrogen surplus in the agricultural part of the catchment, livestockTOT = total livestock number in the catchment, catchment area = the area upstream of the reach. Note that we used both mean and standard deviation of a catchment variable, the latter to grasp variability within a catchment. These however were almost always very closely correlated. (b) Plot of the 8 pairs of restored and unrestored reaches versus the first two principal components (see figure 4), darker symbol: unrestored, lighter symbol: restored.

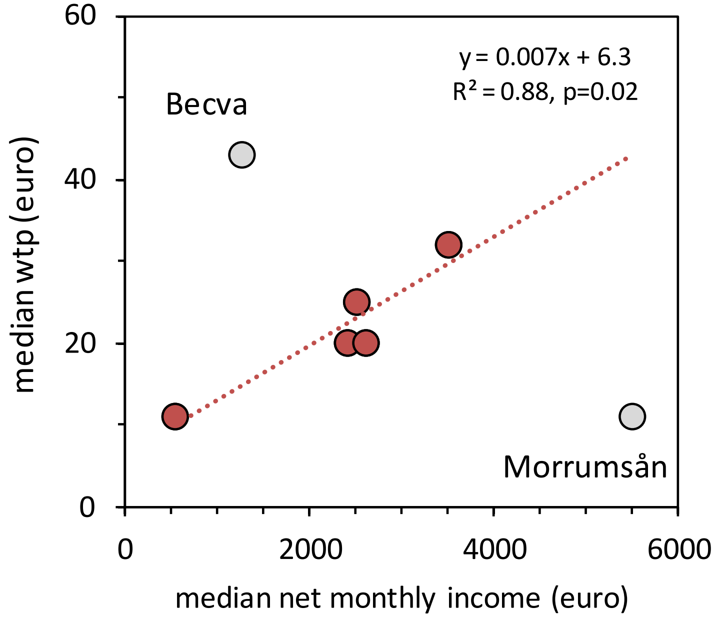


Fig. 6. Median willingness-to-pay per household for river restoration from the seven field surveys versus median reported net monthly income. Displayed regression fit without the data from Becva and Morrumsån.

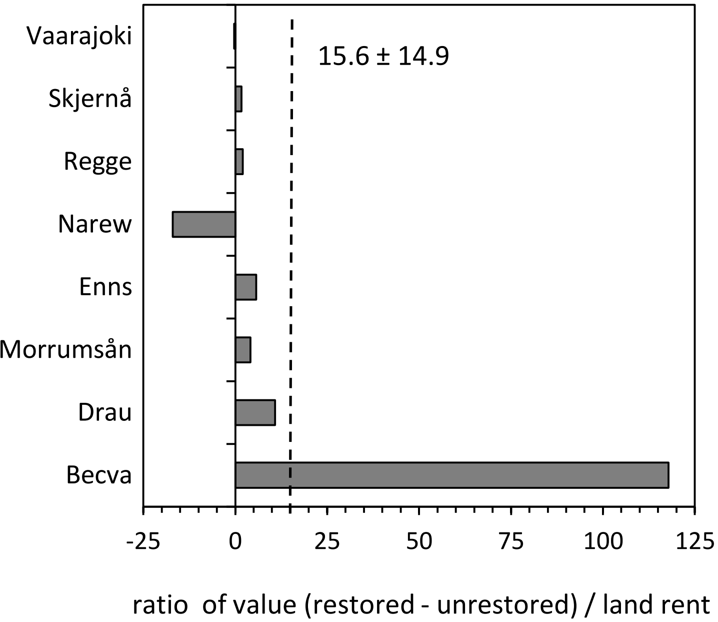


Fig. 7. Ratio of the difference in total economic value between restored and unrestored reaches and their floodplain versus local land rent (broken line indicates mean ± standard error, median ratio = 3, from Streleczek et al., 2011)

Table 1. Characterisation of the studied restoration sites along 9 European rivers. Underlined references are our own local case studies a.o. containing the wtp-surveys. The Regge is locally known as Beneden Regge.

River	Regge (The Netherlands)	Skjernå (Denmark)	Mörrumsån (Sweden)	Vääräjoki (Finland)	Narew (Poland)	Becva (Czech Republic)	Enns (Austria)	Drau (Austria)
Coordinates (°.’ N, E)	52.30, 6.23	55.54, 8.23	56.18, 14.43	63.11, 24.02	53.08, 22.52	49.27, 17.28	47.25, 13.49	46.45, 13.19
Mean annual discharge ($m^3 s^{-1}$)	11	35	25	10	17	18	22	63
Floodplain slope (m km^{-1}, linear, upstream of reach, r^2 indicates goodness of linear fit)	-0.207 (r^2=0.15)	-0.604 (r^2=0.78)	-0.872 (r^2=0.65)	-0.376 (r^2=0.20)	-0.255 (r^2=0.56)	-1.565 (r^2=0.58)	-2.882 (r^2=0.48)	-5.392 (r^2=0.79)
surrounding landscape	Mainly flat, sandy dairyland with glacial moraine ridges	Extensive sandy flat plateaus dissected by broad periglacial tunnel valleys, mainly under agriculture	Forested bedrock hills with interspersed bogs and river valley under agriculture	Forested bedrock hills with interspersed bogs and river valley under agriculture	Gently rolling plateaus under agriculture of variable underlying geology interspersed by marshy, wide periglacial river valleys.	Floodplains and foothills largely agricultural, upslope Carpathian mountains under forest	Comparatively broad alpine valley with agriculture at the bottom and forest and rangelands higher up.	Comparatively broad valley with agriculture at the bottom and forest and rangelands higher up.
Restoration measures	Re-meandered, re-landscaped and lowered	Re-meandered, re-connected old arms, reduced depth in	Enhanced minimal flow with hydraulic measures, added gravel	Returned large boulders into the river bed, reconstructed gravel beds for	Floodplain re-wetting with a downstream weir, reconnect side arms,	Allow natural channel development and migration after unprecedented	Stream bed widened and side arm re-opened,	Stream bed widened and side arm re-opened,

	the floodplain	main channel, re-landscaped and lowered the floodplain	beds, facilitated upstream fish migration	spawning salmonids		flood event in summer 1997		
Length restored – unrestored (km along main stream axis)	1.1 – 0.7	2.6 (in a much larger project) – 1.5	3.1 – 2.4	16 - 30	4 – 5	7 (part of a much larger project) - 7	0.7 – 0.8	2 – 1
Number of interviewed people, % visitors, % willing to respond	100, 30%, not recorded	None (benefit transfer)	47, 23%, 20%	67, 14%, not recorded	100, 14%, 30%	27, 44%, 30%	71, 10%, 50%	112, 20%, 51%
Estimated resident population represented by the interviewed sample	8400*	-	31000	6010	130000	74000	3351	5446
Choice experiment design**, attributes and associated range of additional annual water tax payment per household	Accessibility (3 levels), flood risk (1 in 10, 25, 100 y), water quality (3); 0-25€	-	Accessibility (3), hydropower (3), presence migrant salmonids (3); 0-20€	Landscape aesthetics (3), length restored (3), ecological status (3), 0-70€	Landscape quality (3), biodiversity (3), water quality (3); 0-60 PLN	Landscape aesthetics (3), flood risk (3), biodiversity (3); 0-150 CZK	Accessibility (3), flood risk (3), ecological quality (3), length restored (3); 0-30€	As Enns
Period interviews	April 2013	-	May 2014	May 2013	August 2013	September 2014	April-May 2014	May-June 2014
Main source	Brockhoff (2013)	Dubgaard et al. (2005),	Coerssen (2015)	Plug (2014)	Grazinski et al. (2003), Gielcewski (2003), Banaszuk	Kohut (2014)	Haverkamp (2014)	Haverkamp (2014)

		Pedersen et al. (2007)			et al (2005), Banaszuk and Kamocki (2008), Tylec (2013)			

Notes

* Estimated from the percentage willing to be interviewed, the percentage residents in the sample and the most recent reported population of the riparian municipality. Brockhoff (2013) estimated the existence value of the biodiversity component of cultural service from the wtp and the total visits of 8400 during the tourist season of 7 months; he did not estimate the percentage of non-respondents, and adjacent villages have a population of 14000, which is not so high that we considered it necessary to include an extra value due to non-visiting residents.

** Each choice experiment compared two alternatives with the status quo in 6 or 8 choice cards. Card combination allocation was either optimized or fully random (Vääräjoki, Narew). Water quality and ecological status were chosen to correspond with status levels of the European Water Framework Directive.

Table 2. Approaches to estimate the different specific ecosystem services. Different local market price estimates are in the case study reports (see row 'main source' in table 1 for references)

Service category	Quantification in biophysical units	Monetary valuation
provisioning	Hay, grass, fodder (crops y^{-1})	Local market price (following Dubgaard et al., 2005 and Brander et al., 2006)
	Dairy, meat (production y^{-1})	Local market price
	Arable crops, vegetables, fruit (crops y^{-1})	Local market price
	Wood harvested for construction, paper or fuel (production y^{-1}, artisanal firewood collection not included)	Local market price
	Reed crop for thatching (crops y^{-1}, only Skjernå)	Local market price
	Drinking water production after bank infiltration or deep infiltration to aquifer (m^3 y^{-1})	Local market price
	Hydropower is generated along the Austrian Enns and Drau and in the Swedish Morrumsån. Hydropower provision was not affected by the restoration measures carried out in Austria and the estimated reduction due to restoration in the Morrumsån was hard to verify. A difference in service delivery therefore has not been estimated.	Not valued
	Commercial fish catch: not valued, only recreative fishing occurs in the studied rivers, which is valued as cultural service	Not valued
regulating	Avoided in-reach and downstream flood damage: area flooded times crops lost, reduced forest tree growth, property damage.	Local market value or damage scanner (Bubeck & De Moel, 2010), using conservative median damage per CORINE land use category and discounting for the flood interval available in the local flood statistics.
	Sediment retention may contribute to downstream sediment fill-up, riverbed silting and hydropower impediment. It has not been valued separately since data availability was insufficient.	Not valued

	Nutrient retention. Either phosphorus or nitrogen mass removed during flooding (kg ha^{-1} y^{-1}), to prevent double counting. Retention estimated from concentrations, flow volumes, flood duration, area flooded and habitat specific retention rates (Olde-Venterink et al., 2003, 2006), and a generic in-stream retention estimate from De Klein & Koelmans (2011).	Local fertilizer market price or annualized marginal cost of the least expensive eutrophication abatement measure (Skjernå)
	Carbon sequestration in forest wood and marshland peat: annual accumulation from conservative estimates of aboveground accumulation: (0.1 and 2 ton C ha^{-1} y^{-1} for wetlands and woodlands, respectively, Nabuurs and Schelhaas, 2002; Von Arnold et al., 2005)	Low-end shadow market carbon credit estimate (19 € ton^{-1}, from Derwisch et al. 2009).
	Reduced pumping costs to drain floodplain for agricultural exploitation (Skjernå only)	Directly taken from Dubgaard et al. (2005)
Cultural services	Hunting, fishing	Local numbers of licences issued times licence fee
	Kayaking, rafting	Local rental fees
	Sun-bathing, cycling	Not valued, considered free
	Existence value, increased water quality, scenic beauty and biodiversity	From different local wtp-questionnaires and choice experiments (see table 1 for key references, design summary and response rates)

Table 3. Relation between ecosystem service value estimates and catchment and river corridor characteristics. The latter are represented by the first four principal components to accommodate for considerable covariance among the 23 variables (Fig. 4). Presented are the levels of significance (p) for each of the four principal components as covariates and restoration (yes, no) as fixed factor in four separate GLM-ANOVAs with type III sums of squares. Also given is the explained variance (adjusted r^2) of each of the full models. All $p < 0.1$ are printed bold.

factor	provisioning	regulating	cultural	total
pc 1	0.157	0.219	**0.000**	**0.002**
pc 2	0.685	0.761	0.479	0.727
pc 3	0.720	0.923	0.989	0.833
pc 4	0.123	0.641	0.835	0.131
restoration (yes/no)	0.871	**0.074**	**0.006**	**0.027**
adjusted r^2	0.03	0.05	0.73	0.57

Supplementary material S1. Table 1. GIS variables and the sources these have been extracted from.

variable	Name dataset	Units	Currency	Resolution	Reference system	Data source
Nitrogen surplus	N-surplus for agricultural soils and forests / rough grazing	kgN/km^2/yr	2002	1 km grids	ETRS 1989 LAEA	ftp://mars.jrc.ec.europa.eu/Afoludata/Public/DS237
Livestock density	Livestock density - livestock units per ha by NUTS 2 , 2007	LSU/ha	2007	NUTS2*	n.a.	http://epp.eurostat.ec.europa.eu/statistics_explained/images/3/39/Agriculture_and_environment_2011.xls http://epp.eurostat.ec.europa.eu/tgm/refreshTableAction.do?tab=table&pcode=tgs00045&language=en
Population density	GEOSTAT population density grid 2006 per km2	persons/km2	2006 (LAU data)	1000 meter	ETRS 1989 LAEA	http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/popups/refere
GDP	GDP 2011 Eurostat in PPS on NUTS 3 level (% of EU28 average)	% of EU-28 average, EU-28 = 100	2011	NUTS3	n.a.	http://epp.eurostat.ec.europa.eu/statistics_explained/images/3/3c/Economy_RYB2014.xlsx
Impervious area	EEA Fast Track Service Precursor on Land Monitoring - Degree of soil sealing	% sealing/ha	2006	100 x 100 m grids	EPSG:3035	http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degr
Discharge points	Waterbase - UWWTD: Urban Waste Water	n.a. (discharge points)	2007 - 2011	n.a. (point scale)	Geographic, WGS84	http://www.eea.europa.eu/data-and-maps/data/waterbase-uwwtd-urban-waste-water-treatment-directive-

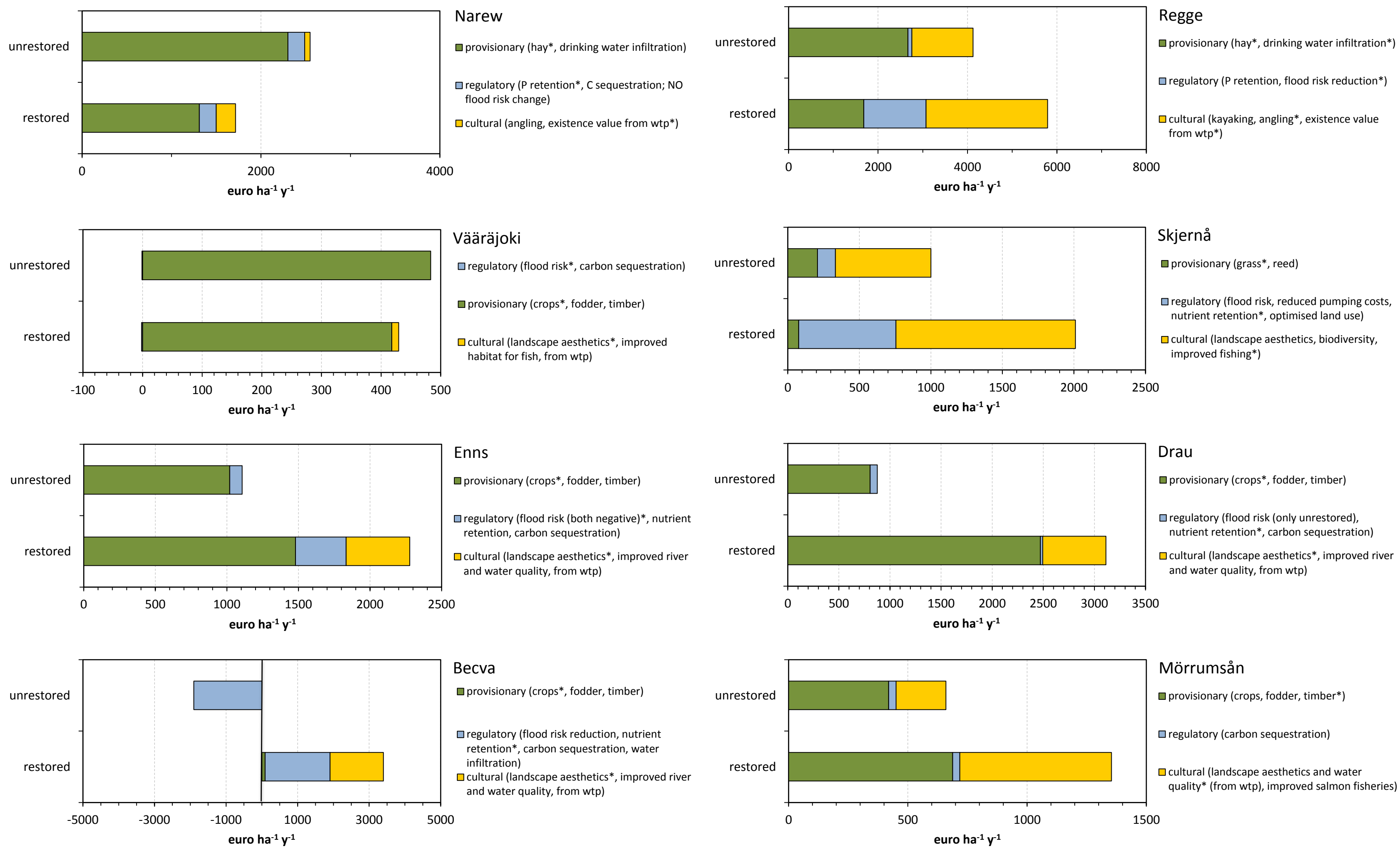
	Treatment Directive					

Supplementary Material S1 table 2. Geographic catchment and reach corridor data used in the multivariate analysis.

label	explanation	Source
catchment		
lengthrestoredkm	length of the restored reach that was used in the assessment of ecosystem services. It is possible that these are only part of a larger restoration project, fx in Skjernå, Becva and Regge	Muhar et al. (in prep)
typeofrestoration	this is a brief text used to turn a qualitative impression of the intensity and extent of the restoration project into a simple number, which follows in the next column	Own assessment
typeofrestorationnumber	code 1, 2,3 in increasing severity	Own assessment
domesticsewageeffluents	the number of waste water discharge points into the river in the catchment upstream	GIS See S1 table 1
PPS2011	a purchasing parity gdp per capita used to estimate the percentage in the next variable	GIS see S1 table 1
gdppercentageeu	percentage gdp per capita of grand overall mean EU28	GIS see S1 table 1
Soilsealing, mn	GIS impervious area, mean	GIS see S1 table 1
Soilsealing, std	similar standard deviation	GIS see S1 table 1
popD, mn	GIS human population density	GIS see S1 table 1
PopD, std	similar standard deviation	GIS see S1 table 1
PopT	GIS total population in a catchment upstream of the study reach	GIS see S1 table 1
area	catchment area used for each study reach	GIS see S1 table 1
Nsurpfor, mn	GIS nitrogen surplus in forested parts of catchment, mean	GIS see S1 table 1
Nsurpfor, 2std	similar standard deviation	GIS see S1 table 1
Nusurpagr, mn	GIS nitrogen surplus in agricultural parts of catchment	GIS see S1 table 1
Nsurpagr, std	similar standard deviation	GIS see S1 table 1
livestock07sumheads	GIS total number of cattle heads	GIS see S1 table 1
livestock07dens	GIS cattle density	GIS see S1 table 1
rivslopemkm	GIS, slope in m/km estimated along the line of the main stream with linear regression, points every 100 m for a varable length of river upstream of the study reach	GIS, own analysis
rivsloper2	GIS, r2 of the linear fit of the regression of height against position for the slope	GIS, own analysis
meanQ	mean annual discharge of each river at or near the studied reach, as reported in the local assessment report	From Muhar et al., in prep, and study site reports
Reach corridor land use		All from GIS analyses, see references in Table 1
Percbuiltup	CORINE 111, 112, 121, 122, 131, 141, 142	
Percarable	CORINE 211	
percgrass	CORINE 231	
Complexagric	CORINE 242 and 243	

percwood	CORINE 312, 313, 324, 333
percmarsh	CORINE 411 and 412
percwater	CORINE 511 and 512

Supplementary material S2. Comparison of the value of ecosystem services of individual pairs of restored-unrestored river reaches. The most important components of each service are mentioned in the legend for each pair, and the primary is indicated with an *. Regulating services exclude flood risk reduction in the Narew because it could not be evaluated. Regulating services are expressed as net values and can be negative where current flood risk is a negative benefit as in the unrestored Drau. In the restored Regge flood risk reduction amounted to 1000 € ha^{-1} y^{-1}; in the Vääräjoki, flood risk reduction was -1 for the unrestored and – 2 € ha^{-1} y^{-1} for the restored reach (an increase in flood risk); In the restore Skjernå, flood risk reduction was 3 € ha^{-1} y^{-1}; in the unrestored Enns flooding was valued at -220 and in the restored Enns this was -150 € ha^{-1} y^{-1}; in the unrestored Drau flooding was valued at -45 € ha^{-1} y^{-1}; in the unrestored Becva flooding costs were estimated at -1900 whereas the restored reach had a benefit of +1800 € ha^{-1} y^{-1}; in the Morrumsån, finally, restoration did not affect flooding.



Assessing the societal benefits of river restoration using the ecosystem services approach

Jan Vermaat et al. HYDR-D-15-00008

RESPONSE TO REVIEWERS

I have broken down the response into two categories, first I will address the main points made, and then I will deal with the detailed page-to-page points either written on the pages of a pdf (REV1) or included as comments in the word file (REV2). I have paraphrased the criticism in my own wording below. I have generally adopted minor editorial suggestions.

REVIEWER 1

Main points of criticism	Response (line numbers of revision)
(a) Introduction and materials and methods are very lengthy and wordy	Upon re-reading, they certainly were. REVIEWER 2 had the same criticism. We hope to have written a far more focused and concise revision. We have completely rewritten large parts of the manuscript.
(b) Introduction needs to be more focused, especially on ecosystem services. It should clarify the concept, give the reasoning behind the work done, and compare with other existing methods. Methods and criteria need to be differentiated in a table.	We have now tried to deal with (our interpretation of) the concept of ecosystem services explicitly. New version L 81. We kept a brief bit on 'how-we-do-it' in the introduction because it explains easier. We have otherwise moved almost everything on methods to the Methods section and included a table specifying services and method used (New table 2) We have not made an extensive comparison with different approaches to estimate ecosystem services because we feel this should be a concise paper and not a textbook chapter. We refer to a recent textbook. We do however argue why we monetize all, rather than retain one or several other, different indicator scales (L 176 and further)
(c) Introduction needs to explain (better) what the research questions are and why	We had our questions spelled out in the last paragraph of the first version, so we think we know what our questions are. We have now hopefully anchored them better in the preceding text, also by weeding away some of the side paths.
(d) Introduction should include scale issues and have them explicitly defined	We now have a paragraph on scale. We distinguish two scales: local (reach plus local floodplain) and regional (catchment). We are aware of the fact that this is qualitative, but see no way to reach a more numerical break down. Vermaat et al (2005; . Ecol.

	Econ. 52: 229-237) have searched for correspondence in scale breaks in spatial/environmental economics in comparison to landscape ecological studies, but found little holdfast on commonalities. Hein et al (2006, Ecol Econ 57) use several more, but then had to stick to administrative scales (municipality, province, country), which then do not correspond to the scales of the ecological and hydro-geological processes. We therefore chose to limit us to these two scales.
(e) Discussion needs order: use subheaders, group the text on uncertainty and compare with other methods	Discussion has been regrouped under subheaders and shortened. We have not spent an elaborate paragraph on methodological comparisons of ecosystem service quantification methods. We feel that this is outside our scope. Our study has a clear design comparing pairs of similar, spatially distinct ecosystems, or pieces of landscape. Very few others did so. See also last part of our answer to comment (b).
Pagewise (line numbers of first version)	
LL63-66 do not see link between standards and documentation	Side path on standards and documentation removed
L 69 what is question and why, move methods to methods	In original version the questions came on L151. We reorganized the methods (see b above)
L 95 insert scale of reach and landscape elements	We do so qualitatively in the text. Quantitatively this is given in table 1. An illustration is figure 1.
L138-155 does this expose really contribute?	We have deleted it
L190 services evaluated: move to methods to explain which parameters were used L165 both groups of success valuation should be described more clearly	We have systematically regrouped the methods on service quantification and added a table
L240 which stats were used to test what?	We think we have written this down already in the first version. Still, we have added some clarifying text to a paragraph with a separate subheader.
L279 removing two outliers is not acceptable. It biases the results	Sure. And that is our main point. We have rephrased the sentences to make this more clear.
L304 discussion should start with ecosystem services and put them in a wider context.	We have considered this. We remain convinced that we should start our discussion with our first question. We have added subheaders to aid reading.
L345 this part of the discussion is very general	We have removed it.

REVIEWER 2

Main points of criticism	**Response (line numbers of revision)**
(a) Paper should be presented more succinctly. Writing is long and winding and contains lots of jargon.	The first author apologises for the lengthiness (I should know better). We have tried to be brief and reduce the jargon. Some economics jargon cannot be evaded since this is a multidisciplinary paper. We were also asked to be more explicit in places so the net effect is that we removed some 40 lines. We now also refer to a recent textbook (Bouma & Van Beukering, 2015) for a readable discussion of the different disciplinary sides of ecosystem services assessment, and their jargon.
(b) Paper could be better organised	We restructured the intro, methods and discussion, mainly following reviewer 1. We think it reads better now.
(c) Strictly use 'habitat' and do not mix with landscape element	Done
Pagewise (line numbers of first version)	
L180 normalizing habitat provenance?	We think we have explained it better now.
L202 why sediment not valued?	We simply could not get enough sensible numbers on this. If we could have estimated a reduced lifespan of a downstream reservoir and corresponding hydropower reduction it would have been feasible, but we could not.
L253 How much of the difference is due to the single outlier	We actually answer(ed) this in the subsequent sentence. Excluding the outlier does not remove the significance
L261 simplify sentences on PCA	Done
L273 ANOVA is on categorical variables	ANOVA, analysis of variance, can also be done on a regression. A classical ANOVA can have both factorial and continuous variables (covariates), and GLM is exactly allowing that, mixing factorial and continuous variables, plus an intercept to enhance power.
L294 these numbers in the discussion repeat the results	Actually they were just a little different, but the reviewer is correct, I should be more orthodox in separating results from discussion.
L306 wtp is actually a different point	We reorganized the section following ref 1. This resolves the issue.

L324 limitation paragraph is too long.	We have pruned the paragraph a bit, but it has not become much shorter. We feel all this has to be said, and it would feel artificial to break up the paragraph.
L334 fifth this is not a limitation	We now stop at fourth
L351 condense paragraph	We have greatly condensed this point and assimilated it into an earlier paragraph (L315 and further)
L370 last paragraph rambles	We have removed most of it because it repeats from a rather short discussion
Figures: standardize the a,b when several figs form a panel. Former fig 2 could be supplementary	Done We kept former fig 2 but moved it to fig 4. It supports the PCA of fig 5 with 'real data'
Table 1 delete the row on floodplain slope	Not done. This is original data obtained by ourselves and entered into the PCA
Table 2 (table 3 in new version) drop interpretation of the low r2 under regulating services. Check your numbers this seems to be wrong.	There is nothing wrong with the outcome of the statistical test. We are more cautious in interpreting this, and keep in mind that variance in particularly this dependent variable, regulating services, was massive due to the Becva. It is not so odd that not much of that variation is explained by the principal components, and the little that is explained is due to restoration.