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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 normalized 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} year^{-1}; $2500 - 1100$, $p = 0.03$, 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

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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.

Keywords Nutrient retention · River corridor · Wetlands · Flood control · Biodiversity · Economic valuation

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 (Bernhardt et al., 2005; Benayas et al., 2007; Jähnig et al., 2011). Purpose and success of restoration often have been reported with limited rigour (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 the 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 (Hering et al., 2015; Jähnig et al., 2011; Morandi et al., 2014). 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 a comparative analysis across eight European rivers using the ecosystem services approach as an integrating framework (cf Acuña 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 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; Acuña 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 are quantified in their final form (in biophysical units; Wallace, 2007; Bateman et al., 2010), a form which is measurably beneficial to society and is not intermediate leading to

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yet another ecosystem process or service. An example of a final regulating service is nutrient retention in kg of phosphorus retained ha^{-1} $year^{-1}$. 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 (Bernhardt 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. (2015) 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 are carried out at the reach scale (a length of several river widths up to 20 km; Bernhardt et al., 2005; Brierley & Fryirs, 2005). This was also the case for the study sites in our project (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 arrangement of reaches at the wider landscape and catchment scale, the regional scale, are both important in determining the potential for of service provision.

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 (Bernhardt 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. The main questions of this study 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 river 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

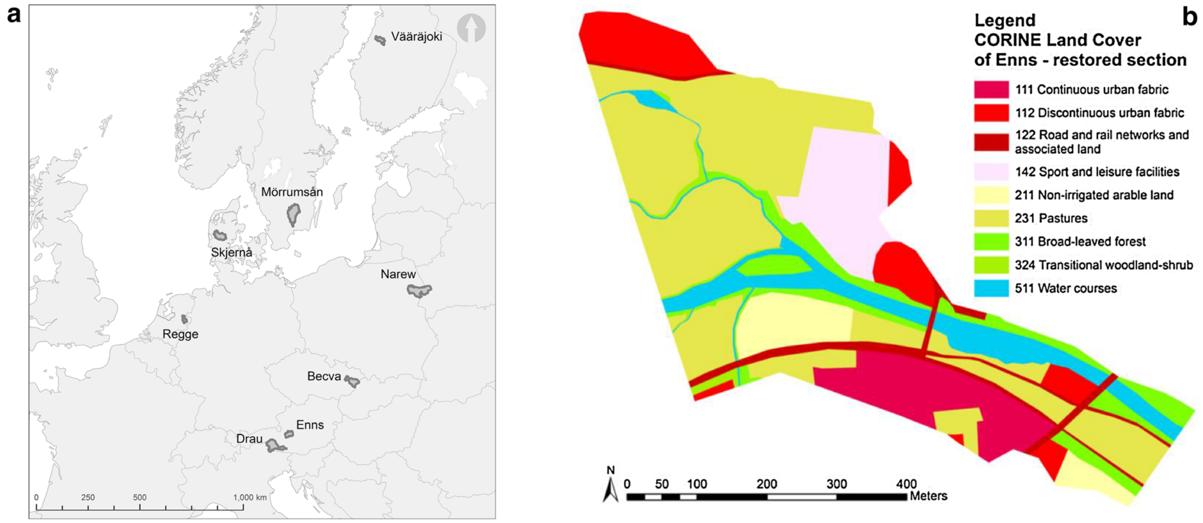

Fig. 1 **a** Location of the study sites across Europe. Indicated are the catchments above the lowest point of the restored or control reach, whichever was further downstream. **b** CORINE habitat map of one of the studied reaches, here the restored reach of the Enns in Austria (from Haverkamp, 2014).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

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 quantitatively accumulates the different services provided by each habitat unit in a reach (Table 2). 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 & 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 (Tables 1, 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 did not distinguish other value domains for service appreciation beyond our monetary assessment for two reasons: First, we are convinced that a limitation to final provisioning, regulating or cultural 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.

Table 1 Characterization of the studied restoration sites along 9 European rivers

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 the floodplain	Re-meandered, re-connected old arms, reduced depth in main channel, re-landscaped and lowered the floodplain	Enhanced minimal flow with hydraulic measures, added gravel beds, facilitated upstream fish migration	Returned large boulders into the river bed, reconstructed gravel beds for spawning salmonids	Floodplain re-wetting with a downstream weir, reconnect side arms,	Allow natural channel development and migration after unprecedented flood event in summer 1997	Stream bed widened and side arm re-opened,	Stream bed widened and side arm re-opened,
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%

Table 1 continued

River	Regge (The Netherlands)	Skjernå (Denmark)	Mörrumsån (Sweden)	Vääräjoki (Finland)	Narew (Poland)	Becva (Czech Republic)	Enns (Austria)	Drau (Austria)
Estimated resident population represented by the interviewed sample	8400[a]	–	31,000	6010	130,000	74,000	3351	5446
Choice experiment design, attributes and associated range of additional annual water tax payment per household[b]	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), Pedersen et al. (2007)	Coersen (2015)	Plug (2014)	Gradzinski et al. (2003), Gielczewski (2003), Banaszuk et al. (2005), Banaszuk & Kamocki, (2008), Tylec (2013)	Kohut (2014)	Haverkamp (2014)	Haverkamp (2014)

Underlined references are our own local case studies a.o. containing the wtp-surveys. The Regge is locally known as Beneden Regge

[a] 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 14,000, which is not so high that we considered it necessary to include an extra value due to non-visiting residents

[b] 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

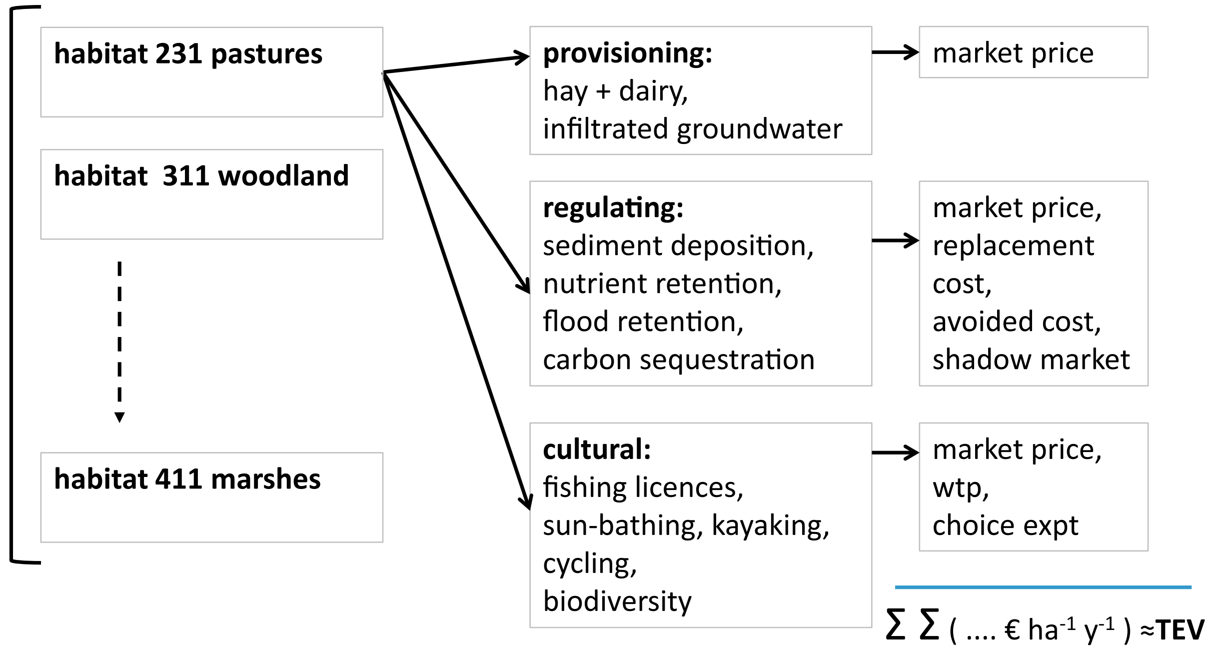

Fig. 2 Flow scheme of the valuation procedure followed for habitats within reaches. Habitat coding is according to CORINE, but only three habitats are displayed for illustrative purpose. Different services and economic methodology are illustrative, not exhaustive. *TEV* total economic value, *wtp* willingness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

Second, a monetary quantification may not grasp the fullness and diversity of societal appreciation (Westmann, 1977), but it does provide a harmonized 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

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 year^{-1})	Local market price (following Dubgaard et al., 2005 and Brander et al., 2006)
	Dairy, meat (production year^{-1})	Local market price
	Arable crops, vegetables, fruit (crops year^{-1})	Local market price
	Wood harvested for construction, paper or fuel (production year^{-1}, artisanal firewood collection not included)	Local market price
	Reed crop for thatching (crops year^{-1}, only Skjernå)	Local market price
	Drinking water production after bank infiltration or deep infiltration to aquifer (m^3 year^{-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} year^{-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} year^{-1} for wetlands and woodlands, respectively, Nabuurs & 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)

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

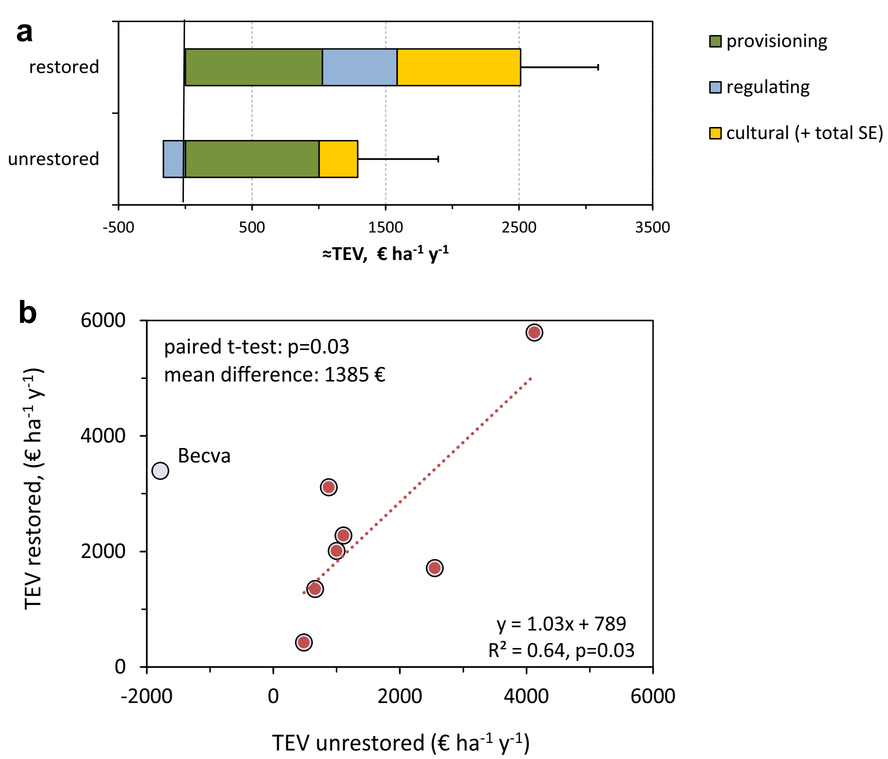

Fig. 3 Overall difference in estimated service delivery between restored and unrestored reaches. **a** Overall stacked means plus 1 standard error of total services (similar *bar charts* for individual rivers are in the supplementary material S1 **b** Scatter plot of restored versus unrestored total 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, $p < 0.01$)

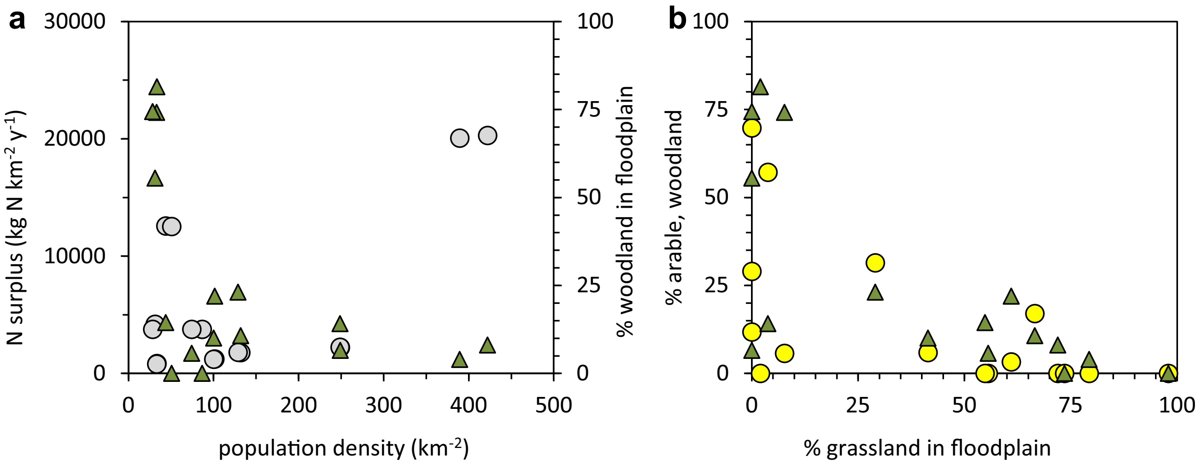

Fig. 4 **a** Variability in catchment human population density versus catchment Nitrogen surplus of agriculture (*circles*) and percentage woodland in the floodplain (*triangles*); **b** percentage woodland (*triangles*) and arable land (*circles*) versus grassland in the studied floodplains

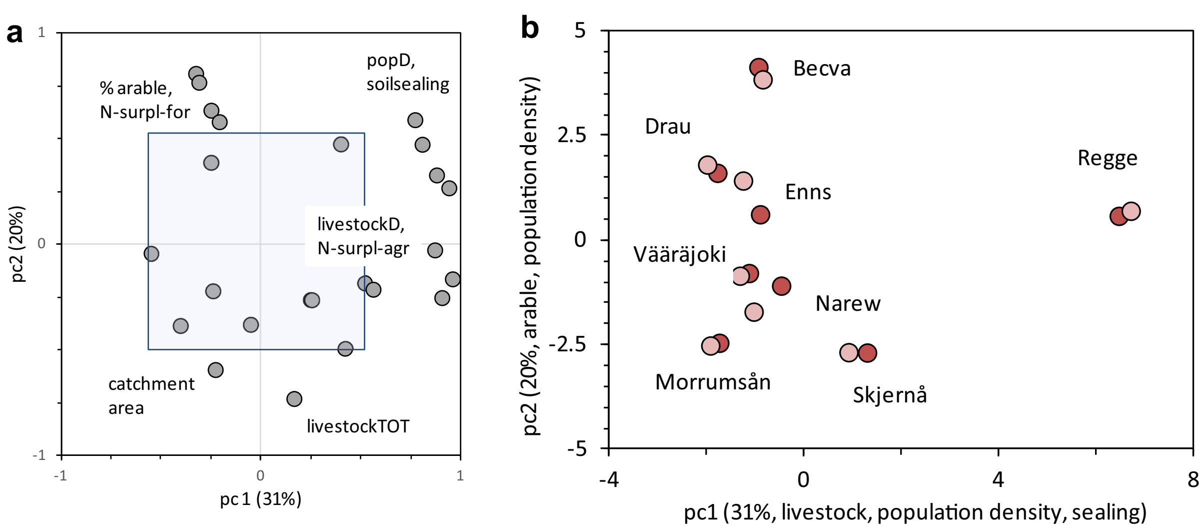

Fig. 5 Principal components analysis of 23 catchment and river corridor variables. **a** Correlations of the original variables versus the first two principal components are plotted. Four principal components explained more than 10% of the variance, together 82%. The transparent *blue square* depicts 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 Fig. 4), *darker symbol* unrestored, *lighter symbol* restored

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 %

Table 3 Relation between ecosystem service value estimates and catchment and river corridor characteristics

Factor	Provisioning	Regulating	Cultural	Total
pc1	0.157	0.219	**0.000**	**0.002**
pc2	0.685	0.761	0.479	0.727
pc3	0.720	0.923	0.989	0.833
pc4	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

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

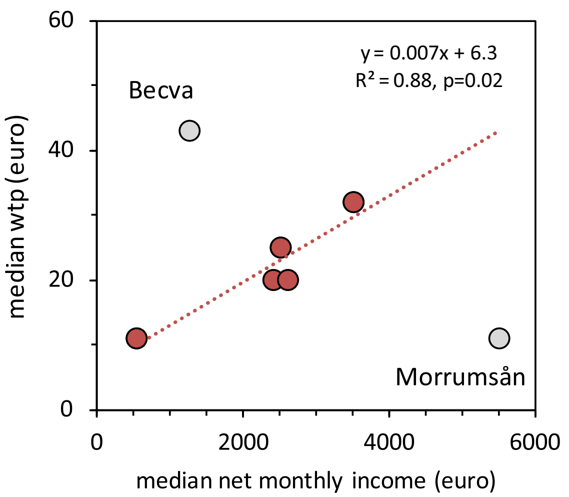

Fig. 6 Median willingness-to-pay per household for river restoration from the seven field surveys versus median reported net monthly income. Displayed regression fit without the data from Becva and Morrumsån

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 biassed 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 Bernhardt 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

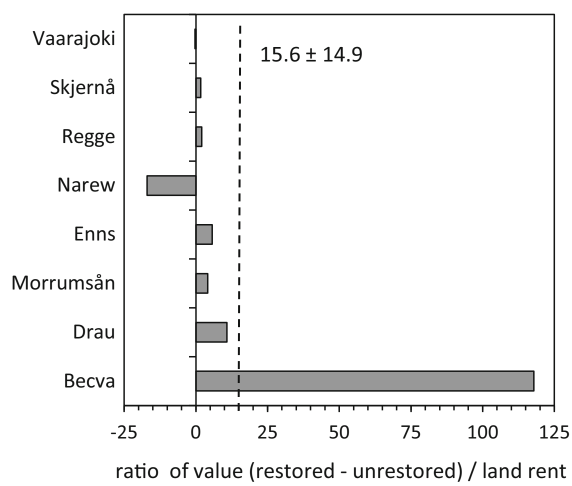

Fig. 7 Ratio of the difference in total economic value between restored and unrestored reaches and their floodplain versus local land rent (*broken line* indicates mean ± standard error, median ratio = 3, from Strelecek et al., 2011)

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 the literature or local agricultural land prices. Our estimates of total ecosystem service delivery (median 1500, range 1800–5800 € ha^{-1} $year^{-1}$) are comparable to those of Murray et al. (2009, for restored Mississippi floodplain habitats (1000 € ha^{-1} $year^{-1}$), Brander et al. (2013, only regulating services of wetlands in agricultural land ~600 € ha^{-1} $year^{-1}$ 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} $year^{-1}$). 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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