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# REFORM

REstoring rivers FOR effective catchment Management

Interviewing Finnish inhabitants; photo's Maarten Plug

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

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Summary

The success of river restoration is often poorly quantified due to poor design, absence of proper monitoring or incomplete documentation. This study is an attempt to overcome this ex-post using the aggregating nature of the ecosystem services approach. In 8 pairs of restored reaches and their adjacent floodplains of middle-sized European rivers, we quantified as many provisioning, regulating and cultural services as possible that were of final value to humans as annual biogeochemical or –physical fluxes, or densities per year, and summed these to annual economic value normalised per area. We separated different forms of land cover using the European harmonised land cover classification CORINE, summing per habitat type and service type. Non-market values were obtained from questionnaire surveys among inhabitants and visitors leading to a.o. willingness-to-pay estimates for restoration, water quality improvement and scenic beauty. We found a significant difference in total ecosystem service value between unrestored and restored reaches of 1400 ± 600 € $ha^{-1}$ $y^{-1}$ (2500 minus 1100, p=0.03, paired t-test and regression). We analysed possible relations with 23 physical and social geographical characteristics of the floodplain and upstream catchment after reducing these to 4 principal components explaining 80% of their variance. Cultural and regulating services correlated with human population density, cattle density and agricultural Nitrogen surplus in the catchment, but not with the fraction of arable land or forest, the slope of the floodplain or mean river discharge, or GDP. We interpret this that landscape appreciation and flood risk alleviation are a simple function of human population density. Our total ecosystem service values are comparable to recent literature values from elsewhere and scale with local annual land rent with a median ratio of 3. We conclude that our approach allows ex-post evaluation of river restoration success, and posit that restoration of middle sized rivers in Europe, by and large enhances overall societal benefit.

Acknowledgements

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We thank our colleagues in the project for the cooperative spirit, and for thinking through the most useful study design we could simply adopt, and Tom Buijse for his energetic project coordination.

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# 1 Introduction

Over the past decades, rivers have been restored for a range of purposes (Bernard et al., 2005; Benayas et al., 2007), and not unlike other ecosystems (Zedler & Kercher, 2005; Benayas et al., 2007), purpose and success of restoration have often been assessed or reported with limited rigor (Bernhardt et al., 2005, Bernhardt & Palmer, 2011; Jähnig et al., 2011). Interestingly, whereas Palmer et al. (2005) proposed standards for river restoration, a team with the same first author (Palmer et al. 2007) concluded firstly that documentation in the notes of restoration project managers was often not traceable, and secondly that citizen involvement generally corresponded to better documentation. In addition, managerial or political perception of restoration success did not correspond measurably with ecological success (Jähnig et al., 2011). Still, despite these two major grounds of uncertainty, considerable sums of public money are spend on river restoration (Bernhardt et al., 2005) suggesting considerable societal value and political confidence.

In the current study, we take this limited documentation of river restoration projects as a given fact and instead carry out an ex-post assessment of the multiple components of societal value, which are possibly enhanced by river restoration. For this assessment, we adopted the ecosystem services framework proposed by the Millennium Ecosystem Assessment (MEA, 2005) and further defined by CICES (Weber, 2011). The ecosystem services approach is increasingly applied (Fisher et al., 2009) to estimate those benefits accruing to society which are not straightforwardly monetised, and to include these in comprehensive decision-making and planning efforts (e.g. Carpenter et al., 2009; Nelson et al., 2009; Bateman et al., 2010). We are aware of one other study that has used ecosystem services to assess the economic benefits of river restoration, in this case the addition of dead wood to 4 first order streams in Northern Spain (Acuna et al., 2013). We used the methodology worked out by Vermaat et al. (2013), which estimates the sum of final provisioning, regulating and cultural services provided by a river reach and its flood plain. We applied the methodology at the reach scale to a range of river restoration projects spread out across Central and Northern Europe. In each case we have been able to identify paired restored and control reaches as part of a larger effort to assess the multiple ecological effects of river restoration (Hering et al., in prep). By comparing within and among pairs with a standardised methodology, we hope to overcome problems of insufficient design rigor (Bernhardt and Palmer, 2011), whereas we allow for an assessment of the importance of catchment- or possibly country-specific variation. We thus presume that the total of societal benefits that accrue from a river reach, can be grasped as final ecosystem services in the sense of Wallace (2007, see also Watson and Albon, 2011) and quantified in (pseudo-)monetary terms. By distributing our study sites across Europe, we expect to be able to offset the benefits attached to restoration against regionally variable preferences, economical importance of floodplain land use, economic market strength of societies and population density.

River restoration projects differ widely in spatial extent and financial investment (Bernard et al., 2005), and economic valuation is not scale-independent (e.g. Brander et al., 2006; Brouwer et al., 2008), whereas it is also often difficult to geographically identify an objective boundary between different ecosystems. The tentative formulation of the MEA (2005) is illustrative: ´a useful ecosystem boundary is the place where a number of relative discontinuities in the distribution of organisms, or the biophysical environment coincide´. Reaches are viewed as comparatively homogeneous stretches of landscape in the river network (Skøien et al. 2003), and most restoration projects (Bernhardt et al. 2005) are carried out at this scale (a length of several river widths up to 20 km, Brierley and Fryirs, 2005). We therefore used reaches as our study units. Reach-scale floodplain stretches however consist of mosaics of different landscape elements, such as woodland, grassland, marshes, or gravel beds. Within-reach variability in these elements can be considerable, whereas these different elements will provide markedly different services. Sedimentation and nutrient retention, for example, vary greatly (Olde-Venterink et al. 2006). Our approach therefore quantifies the extent of different landscape elements within each studied reach using a standardized European habitat classification (EUNIS-CORINE, Davies et al. 2004; for an extensive breakdown of potential services by floodplain habitats see Vermaat et al. 2013) and accumulates all services which can be reasonably estimated, across these landscape elements. Our approach is similar to that of Martin-Lopez et al. (2014), but our explicit use of landscape elements ensures a higher spatial resolution within reaches.

Accumulation of the benefits derived from different ecosystem services involves the summing up of entirely different entities, ranging from flood damage to the appreciation of the knowledge that a particular bird species breeds in an area. Also, these rivers flow through landscapes of highly variable geography, human population density and economic activities, which may modulate the relative importance of different services. Environmental economists resort to a range of methods to estimate the associated economic value of these services and have developed a considerable methodological literature including analyses of their support in economical welfare theory, geographical benefit transferability, and error analyses (Brouwer et al., 1999, 2008; Turner et al., 2000; Brander et al., 2006; Bateman et al., 2010; Watson and Albon, 2011). In this study we have used a range of methods, primarily guided by data availability and following a decision tree as printed in e.g. DEFRA (2007). In their extensive meta-analysis of wetland valuation studies, Brander et al. (2006) noted that from all methods, and contrary to expectations based on theory, only contingent valuation led to significantly higher value estimates. Similarly, for example Dubgaard et al. (2005), Acuna et al. (2013), and Martin-Lopez et al. (2014), used an array of valuation techniques. However, contrary to Martin-Lopez et al. (2014), we do not distinguish other value domains for service appreciation beyond our economic, monetary, assessment. We have two reasons for this: (1) Separate indicators of services in what Martin-Lopez et al. (2014) label as the ‘biophysical domain’ would at least partly be covered as supporting services and therefore included in either provisioning, regulating or cultural final services. (2) A monetary quantification may not grasp the fullness and diversity in total societal appreciation (Westmann, 1977), but it does provide a harmonised means to compare, and hence also evaluate trade-offs.

Table 1. Characterisation of the studied restoration sites along 9 European rivers. Underlined references are our own local 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 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% |
| 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 | apr-13 | - | May 2014 | May 2013 | aug-13 | sep-14 | April-May 2014 | May-June 2014 |
| Main source | Brockhoff (2013) | Dubgaard et al. (2005), Pedersen et al. (2007) | Coerssen (2014) | Plug (2014) | Grazinski et al. (2003), Gielcewski (2003), Banaszuk et al (2005), Banaszuk and Kamocki (2008), Tylec (2013) | Kohut (2014) | Haverkamp (2014) | Haverkamp (2014) |

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 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.

Since river restoration is carried out with a purpose, whatever the quality of the justification and monitoring of project success, this must be guiding the formulation of our research questions and add relevant precision to the generic, expected difference between ‘unrestored’, ‘degraded’ or ‘control’ reaches, and restored reaches. Gilvear et al. (2013) stress that this ‘degraded’ state is the result of previous, anthropogenic ‘improvement’, which also had a distinct, societally recognized purpose, such as drainage, flood protection and navigation. Rivers have been engineered to meet these societal demands of the past and are currently re-engineered. Whilst Bernhardt et al. (2005) found that the most frequent objectives of river restoration across the USA were the enhancement of water quality, the management of the riparian zone, and the improvement of in-stream management (the three most important, in order of declining frequency), Jähnig et al. (2011), concluded, also from a survey among river managers, that for Germany the main objectives were the enhancement of hydromorphological structure and dynamics, the re-establishment of hydrological continuity, and floodplain development. These German managers also stressed the subjective, increased appreciation of the scenic landscape as their gut feeling of success even though it was not a formal restoration objective. The absence of water quality as a major objective in Germany is striking, since the European Water Framework Directive is water-quality directed and its achievement by 2015 drives major river restoration projects across Europe (Hering et al. 2010). Taking this together 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 will be enhance by river restoration at the reach scale. Our questions are: (1) Do we find significantly higher societal appreciation of restored reaches using an ex-post economic quantification of ecosystem services? (2) Is this difference related to regulating and cultural services? and (3) can we identify underlying geographic differences in the patterns of service provision and valuation for these Central and Northwestern European rivers?

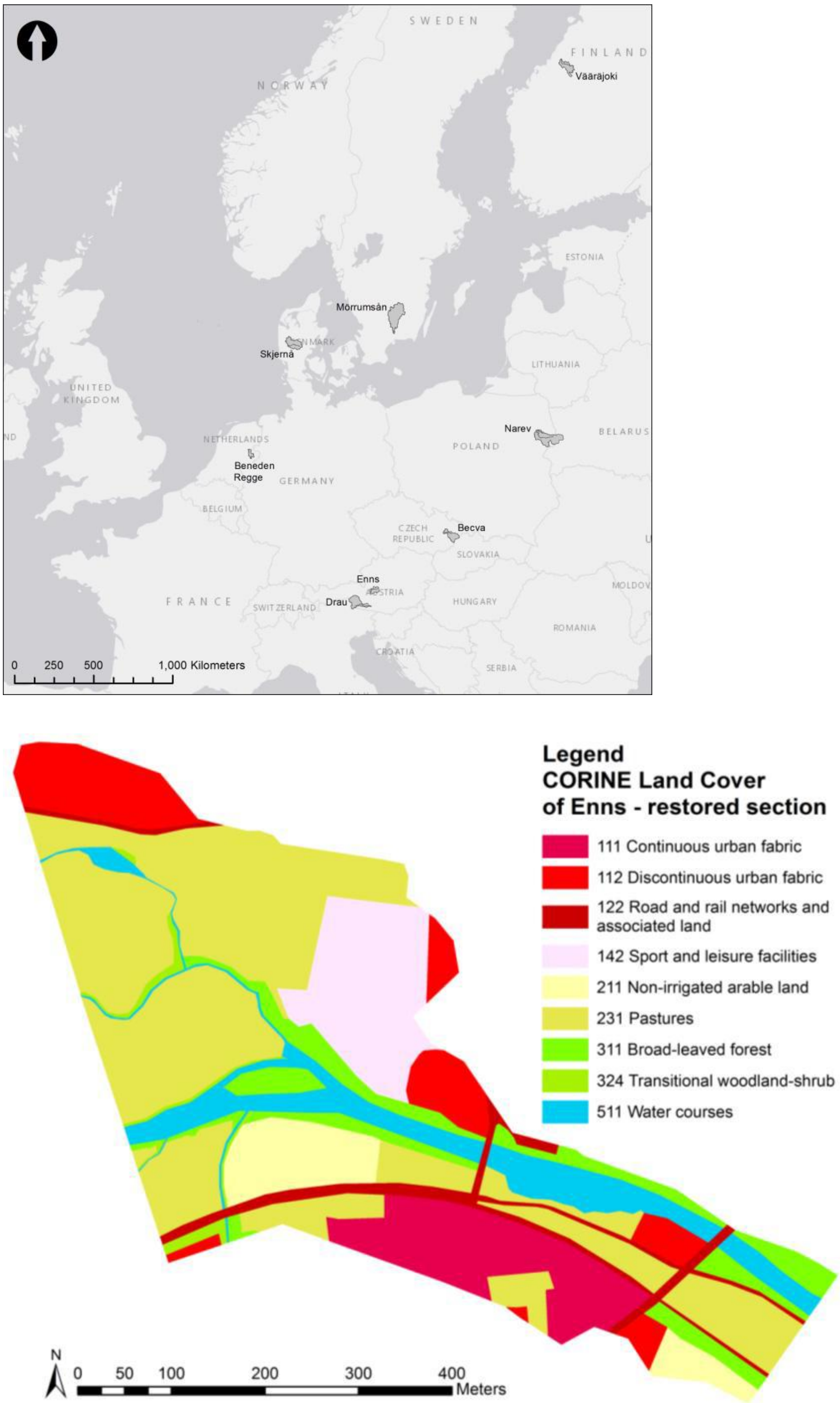


Figure 1. (a) Location of the study sites across Europe. Indicated are the catchments above the lowest point of the restored or control reach, whichever was most downstream. (b) CORINE habitat map of one of the studied reaches, here the restored reach of the Enns in Austria (from Haverkamp, 2014). The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

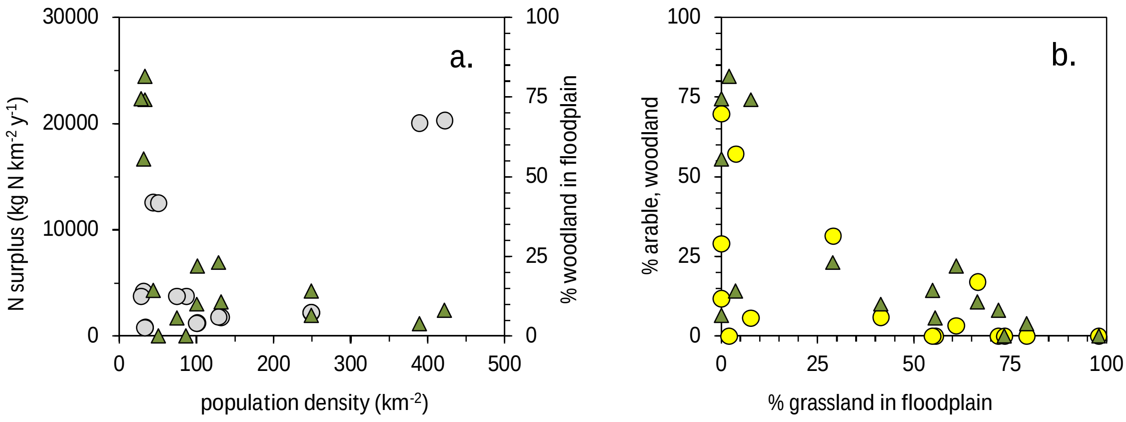


Figure 2. (a) Variability in catchment human population density versus catchment Nitrogen surplus of agriculture (circles) and percentage woodland in the floodplain (triangles); (b) percentage woodland (triangles) and arable land (circles) versus grassland in the studied floodplains.

# 2 Materials and methods

Seven out of the eight case study rivers (Fig. 1a, Table 1, see also Hering et al., in prep) were studied in the field by two or more of our co-authors, often assisted by local colleagues. These reaches and their catchments differed considerably in land use and human population density (Fig. 2). 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 applied the methodological framework of Vermaat et al. (2013), which allocates different landscape patches to uniformly classified habitat units (EUNIS-CORINE, Fig 1b; Davies et al., 2004) and accumulates the different services provided by each habitat unit in a reach. A particular habitat can provide several services simultaneously, such as mineable sand, the retention of sediment, the accumulation of carbon in wood, and enjoyment of the scenic beauty of the viewed riverine landscape. Our service accumulation is a simple summation of total ecosystem service delivery as annualized monetary value (Fig. 3), normalized with reach area. The spatial extent of each river corridor was determined 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 the latter prior to our analyses, since restoration in most reaches involved a purposeful alteration of habitats, for example by the re-establishment of marshes and open water.

For one river, the Skjernå in Denmark, we could depend on an exhaustive and well-published documentation, which includes the economic assessment of cultural services (Dubgaard et al., 2005; Table 1). Since this study used the 2000 euro value, it was adjusted by 1.45 to correspond to the August 2013 euro values applied for all others in this study. The euro value for the sampling periods between April 2013 and September 2014 (Table 1) differed 4% at most and have not been corrected.
Provisioning services quantified here were agricultural crops, fodder, dairy, wood for construction or fuel, and human drinking water used via bank infiltration or aquifer recharge. Monetary value of these services were estimated from local market prices as suggested in Dubgaard et al (2005, see also Brander et al., 2006).

Regulating services included: (a) Foregone flood damage, downstream or in the study reach, using a market value estimate of lost crops (Regge, Vääräjoki), or the damage scanner tool (Bubeck and De Moel, 2010). (b) Sediment and either nitrogen or phosphorus (depending on data availability and preventing double counting) retention as mass removed during flooding from concentrations, flood duration, and specific habitat retention rates (Olde-Venterink et al., 2003, 2006) or a generic retention estimate from De Klein and Koelmans (2011); sediment retention was not monetised, nutrient retention was estimated from fertilizer market prices assuming equivalent cost reduction for local farmers, or for the Skjernå, from the annualised marginal cost value of the least expensive alternative eutrophication abatement measure. (c) Carbon sequestration as annual wood accumulation in woodland and peat accumulation in wetlands using conservative estimates of aboveground carbon 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) and a low-end international carbon credit estimate (19 € ton$^{-1}$, from Derwisch et al. 2009, higher values a.o. in Bonnie et al. 2002). Hydropower was generated along the Austrian Enns and Drau and the Swedish Morrumsån, but it was not affected by the restoration measures carried out and any difference in service delivery could thus not be estimated.

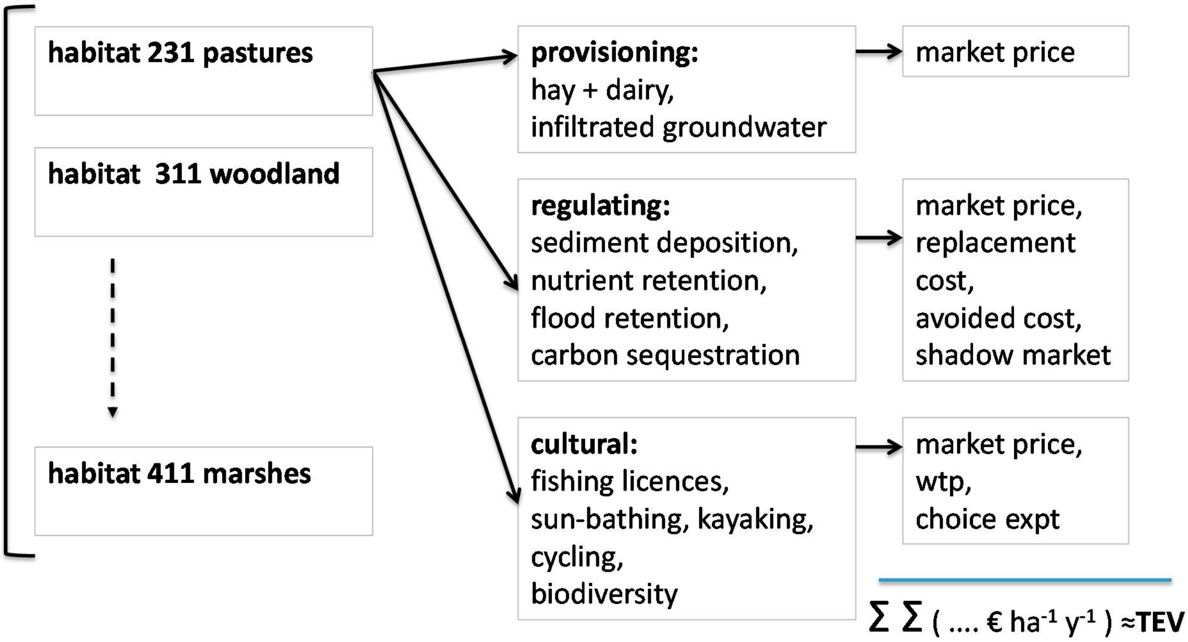


Figure 3. Flow scheme of the valuation procedure followed for habitats within reaches. Different services and economic methodology are illustrative, not exhaustive. TEV is an approximation of Total Economic Value.

Cultural services quantified were recreative fishing, hunting (from license sales data) and canoeing (rent information from local entrepreneurs), appreciation of the scenic landscape and biodiversity existence (from the wtp-surveys). Local willingness-to-pay surveys were carried out in 7 of the 8 study rivers (Table 1). Questionnaires followed a general structure but were geared to the local conditions, pre-tested locally, and set in a choice-experiment design. These questionnaires can be found in the respective local study reports (Table 1). Where the choice experiments allowed separation 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 recreative use. Separate services due to biodiversity, such as pollination or enhanced pest control (Cardinale et al., 2012) have not been quantified. A separate paper on the choice experiments is in preparation (Brouwer et al., in prep). Respondents were classified as local inhabitants or tourists from elsewhere in- or outside the country. Local respondents were considered 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 in this specific area. Our sum of provisioning, regulating and cultural services expressed in € $ha^{-1}$ $y^{-1}$, can be seen as an approximation of total economic value (TEV).

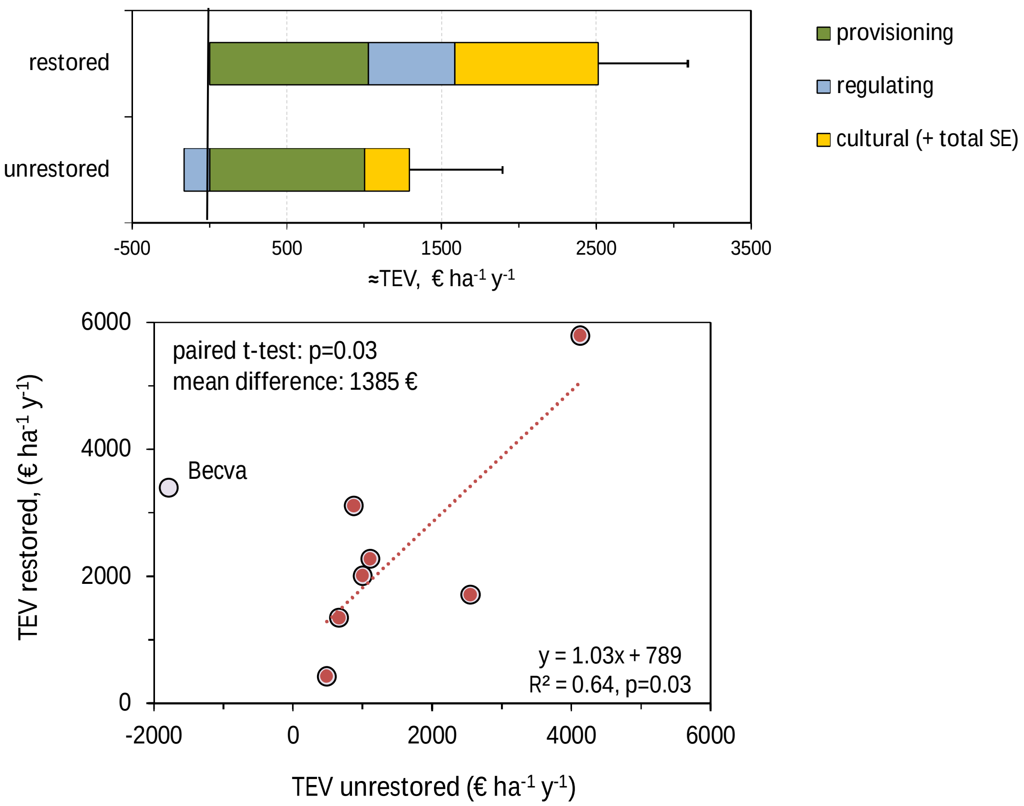


Figure 4. Overall difference in estimated service delivery between restored and unrestored reaches. (upper) Overall stacked means plus 1 standard error of total services (similar bar charts for individual rivers are in the supplementary material S1). (lower) Scatter plot of restored versus unrestored total services. If the Becva is excluded, the regression is significant. Similar separate regressions for all 8 pairs were made for provisionary services (not significant), regulating services ($p<0.05$, but not significant without the Becva), and cultural services (slope 1.5, $p<0.01$)

Land use, intensity of agricultural use, human population density and economic indicators of the upstream catchment of a reach were quantified from various spatial European 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. Robustness of the regression was inspected by the change in parameters after leaving out the most extreme data pair. We analysed the possible relations 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 possible underlying geographic pattern in catchment and floodplain variables was first addressed in a PCA. The significant principal components explaining more than 10% of the variance were then used as covariates in a

GLM-ANOVA with restored-unrestored as fixed factor. PCA and GLM was done with SPSS, exploratory data analysis was done with PAST (Hammer et al., 2001).

# 3 Results

Despite considerable variability in the relative importance of provisioning, cultural or regulating services among paired reaches (Fig. 4, 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. 4, lower panel). 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 exclusion did not lead to a major change in outcome of the paired t-test (difference 840 €, p=0.04).

Covariance among the 23 catchment and floodplain variables was captured in four principal components together explaining 80% of the total variance (Fig. 5, top). Two major forms of agriculture, livestock and arable land, varied perpendicularly along pc1 and pc2 respectively, but at the same time co-varied both with human population density in the catchment. Nitrogen surplus on agricultural land varied parallel with livestock density, and soil sealing in the catchment did so with population density. 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. The pairs of reaches plotted very near to each other across the first two principal components (Fig 5, bottom), with possible exception of the Narew (more marshland in the restored floodplain) and Enns (more built-up in the restored floodplain). Overall, the PC-plot suggests that the paired reaches are very similar in floodplain and catchment geography.

Catchment and floodplain land use were coupled to ecosystem service delivery in an ANOVA with the four principal components as covariates (Table 2). Consistent with the paired t-test, restoration was significant for total service delivery and also for cultural and regulating services (if we accept p=0.07). However, only cultural services co-vary significantly with pc1, and here also the explained variance of the ANOVA is considerably higher than for regulating services. Thus, cultural services are valued higher in areas of higher population density, rather than for example in wealthier areas with higher GDP. This is also reflected in the pattern observed when we relate respondent willingness to pay for river restoration (with enhanced biodiversity and flood regulation as main purposes, but context-specific in each of the 7 cases) to their reported net monthly outcome (Fig. 6): only if we remove two outliers the regression is significant. The fact that respondents along the Becva are willing to pay considerably more, and those along the Morrumsån so much less points to 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 contrast, the respondents along the Swedish river appreciated only a limited tax increase for river restoration, and only 20% of the interviewed people were willing to cooperate.

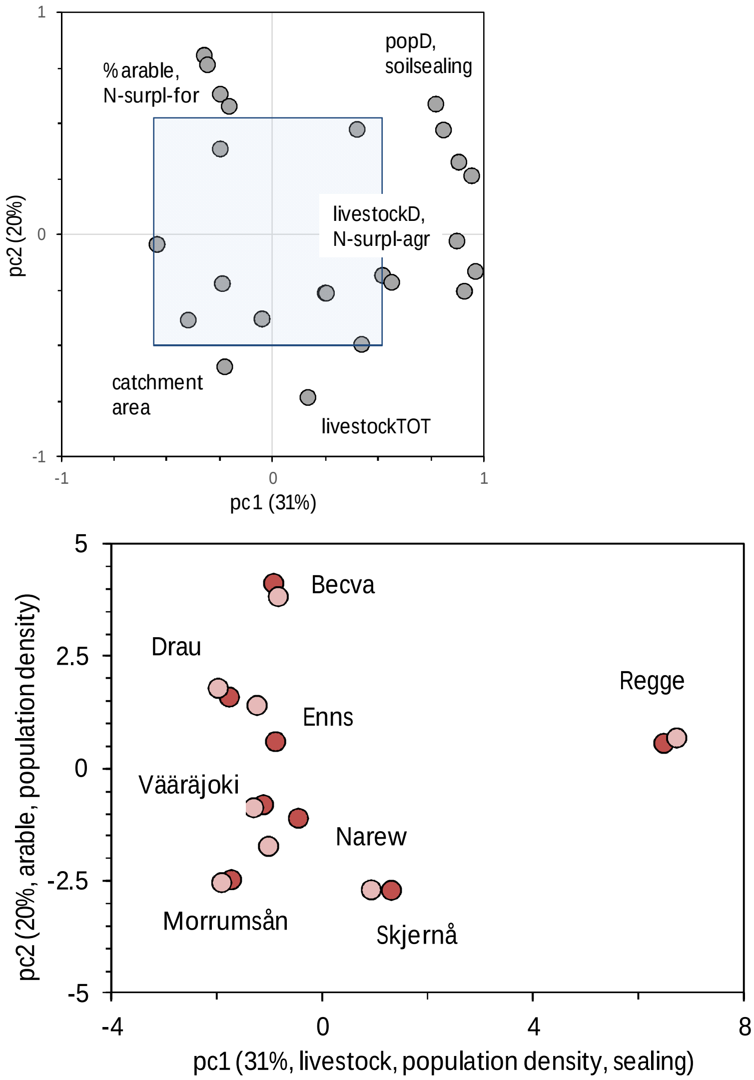


Figure 5. Principal components analysis of 23 catchment and river corridor variables. (top) Correlations of the original variables versus the first two principal components are plotted. Four principal components explained more than 10% of the variance, together 82%. The transparent blue square depicts 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. (bottom) 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. Land use differed substantially between the restored and unrestored reach for the Enns (more built-up in restored) and Narew (more marshes in restored). This explains the larger distance between these two pair members in the plot compared to the others.

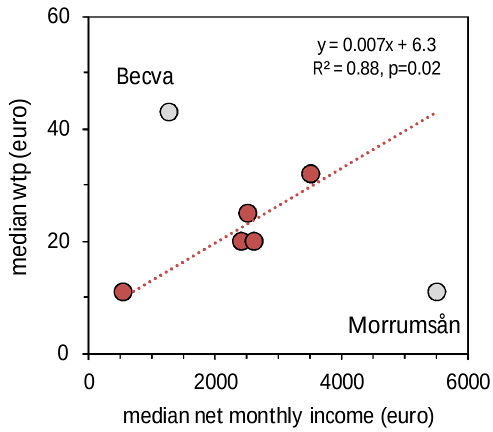


Fig. 6. Scatterplot of median wtp per household from the 7 field surveys versus median reported net monthly income.

Table 2. 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 |

# 4 Discussion

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 (mean difference 1400 € $ha^{-1}$ $y^{-1}$, 2500 minus 1100, standard error 600, Fig. 4). This appears to be primarily due to an increase in cultural services, and also, but less distinctly to an increase in regulating services (Table 2), whereas provisioning services were not affected by restoration. 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 appreciation of restored reaches with a higher human population density in areas where also cattle density was higher. Willingness to pay of the respondents as well as their net income and overall wealth expressed as GDP differed greatly among our study rivers. GDP correlated significantly with pc3 (data not shown), but this pc was not correlated with any ecosystem service. We interpret this to imply that rather more people appreciate the enhanced cultural service provided by a restored reach, than that they individually are willing to pay more for restoration, which is in line with findings of Brander et al. (2013).

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 probably we have underestimated total ecosystem service delivery, but we see no reason that this may have been biased towards favouring restoration. Third, 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 (existence value of biodiversity, C-sequestration). This means that our expression as an approximate total economic value can be compared with e.g. land rent, but should not be seen as a direct income for the authority administrating the land. Instead, our estimates must be used cautiously, and in the cost-benefit sense of Dubgaard et al. (2005), who showed the prevailing importance on the outcome of the cost-benefit analysis of the long-term rate of interest, which is inherently uncertain and subject of debate. Fourth, 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 € $ha^{-1}$ $y^{-1}$), 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 6 out of the 8 cases, was about 3 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 cost-benefit assessment including opportunity costs of the alternatives for the decision maker, and depending on the rate of interest and return period chosen (Dubgaard et al., 2007). 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. The approach we followed here, in our view, also should be meaningfully informative to the decision maker at the landscape scale, hence we see no great challenges preventing its use (De Groot et al. 2010).

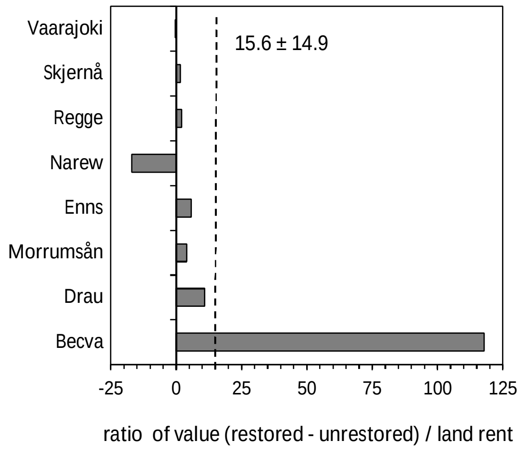


Fig. 7. Ratio of the difference in total economic value between restored and unrestored reaches and their floodplain versus local land rent (broken line indicates mean ± standard error, median ratio = 3, from Streleczek et al., 2011)

The societal benefits we have identified will accrue to different categories of stakeholders. Agricultural productivity provides farmers with a living and their credit agents with rent. Generally, the former are local inhabitants, whereas the latter are corporate, multinational institutions. 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). Cultural services are beneficial to local visitors, foreign tourists, and local entrepreneurs in the tourist sector. These cultural services derive from the improved (landscape) ecological state of the restored river. Where decision-making involves such different sectors and scales, the appropriate level for decision-making may well be national, and supranational (Van Teeffelen et al., 2014). This does not make our conclusion less opportune: river restoration appears economically beneficial to society. Although each river has its specificities and we studied a limited number of cases in Central and Northwestern Europe, our data demonstrate a clear benefit of river restoration, notably through the regulating services connected to a (more) natural flooding regime of the original flood corridor overall and the appreciation of inhabitants and tourists of the scenic beauty of these floodplain landscapes which also translated directly into increased revenues in the recreation sector, notably in the Narew, Regge, Vääräjoki, Skjernå and Morrumsån (Supplementary material S2). We trust that this assessment goes beyond the gut feeling of the water manager (Jähnig et al., 2011). We conclude that our approach allows ex-post evaluation of river restoration success, and posit that restoration of middle sized rivers in Europe, by and large enhances overall societal benefit.

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# 6 Supplementary material

## 6.1 S1. Table 1. GIS variables and the sources these have been extracted from.

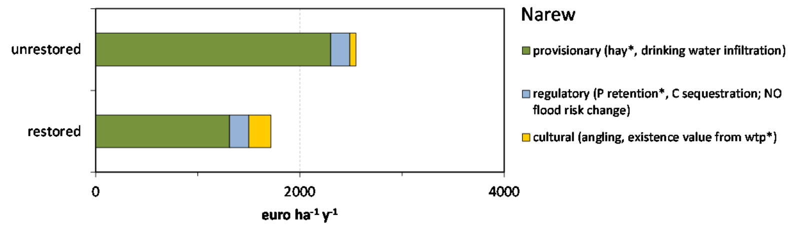
| Variable | Name dataset | Units | Currency | Resolution | Reference system | Data source |
|---|---|---|---|---|---|---|
| Nitrogen surplus | N-surplus for agricultural soils and forests / rough grazing | kgN/km$^2$/yr | 2002 | 1 km grids | ETRS 1989 LAEA | ftp://mars.jrc.ec.europa.eu/Afoludata/Public/DS237 |
| 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 or 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/references/population_distribution_demography |
| 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-degree-of-soil-sealing |
| Discharge points | Waterbase - UWWTD: Urban Waste Water Treatment Directive | 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-3#tab-additional-information |

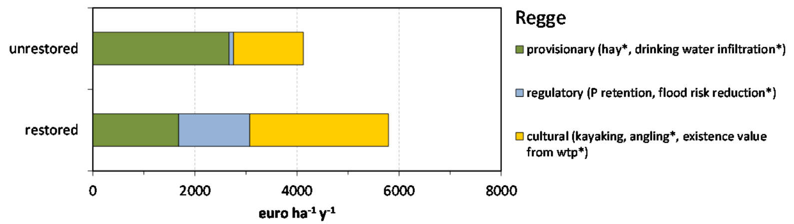
## 6.2 S1 Table 2. Geographic catchment and reach corridor data used in the multivariate analysis.

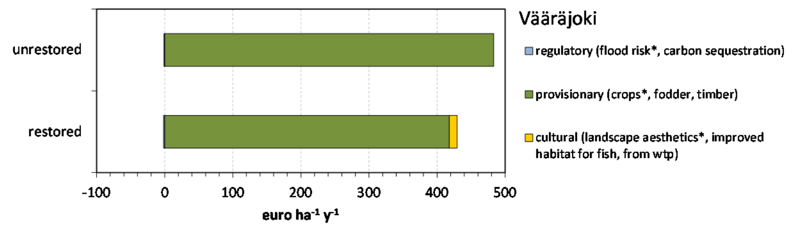
| Label | Explanation | Source |
|---|---|---|
| *catchment* | | |
| lengthrestoredkm | length of the restored reach that was used in the assessment of ecosystem services. It is possible that these are only part of a larger restoration project, fx in Skjernå, Becva and Regge | Hering et al. (in press) |
| 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 gdppc used to estimate the percentage in the nect variable | GIS see S1 table 1 |
| gdppercentageeu | percentage gdppc 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 |

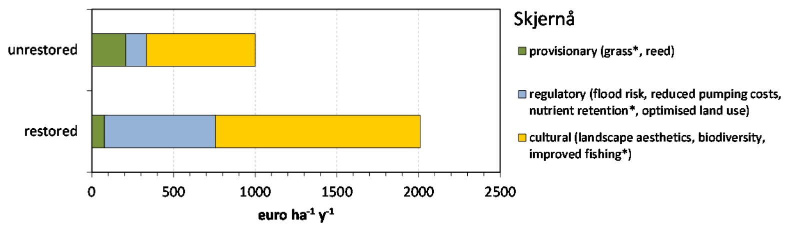
| Label | Explanation | Source |
| --- | --- | --- |
| livestock07sumheads | GIS total number of cattle heads | GIS see S1 table 1 |
| livestock07dens | GIS cattle density | GIS see S1 table 1 |
| rivslopemkm | GIS, slope in m/km estimated along the line of the main stream with linear regression, points 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 Hering et al., in prep, and study site reports (see table 1 main paper) |
| *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 | |

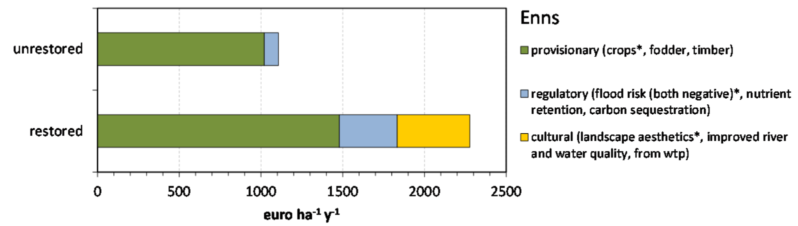
### 6.3 S2. Comparison of the value of ecosystem services of individual pairs of restored-unrestored river reaches. The most important components of each service are mentioned in the legend for each pair.

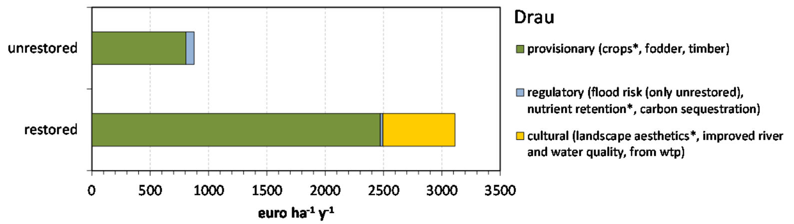


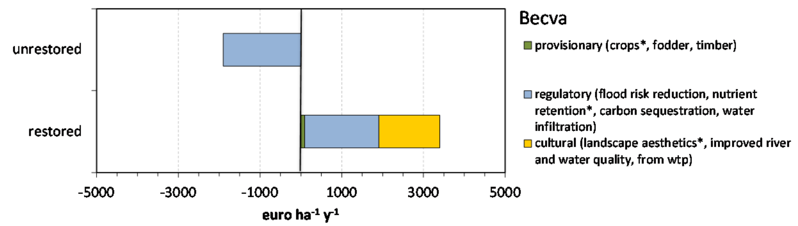



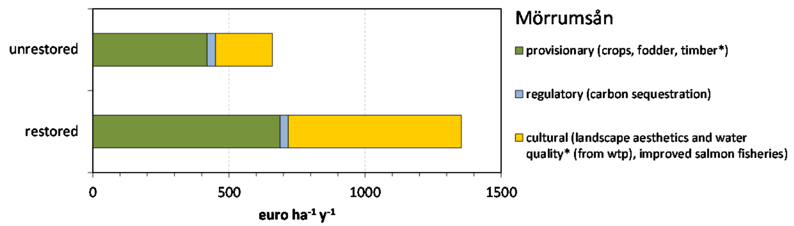



## 6.4 S3. Abstracts of Master and BSc theses supporting this deliverable. Kohut (2013) was not a student report.

*Brockhoff T, 2013.* River restoration along the Regge – a comparative analysis of the effects of river restoration on the valuation of ecosystem services. MSc Thesis Environment and Resource Management VU University, Amsterdam, The Netherlands.

This paper is part of an overarching research project called REFORM. This research project analyzes to what extent river restoration has the potential to improve the overall conditions of the river and its floodplain, but also looks how the ecosystem services that river corridors provide are valuated among people. This particular research gives more insight into the valuation of ecosystem services of restored and not restored river sections, of the Dutch river de Regge. In doing so, this research assesses the possible differences between a control site (a not restored river section – Dalmsholte) and an experimental site (a restored river section – Archemermaten). To perform a comparative analysis between these river parts, this study gives an overview of the ecosystem services that both river sections provide. For this analysis, the provisioning, regulating and cultural services of the river system are taken into account. In order to gather the necessary data and information, this report is based on both primary and secondary sources.

Although Dalmsholte turns out to be more productive in terms of provisioning services, Archemermaten 'scores better' on the regulating and cultural services. The annual TEV of the delivered ecosystem services in Archemermaten amount to €6,904 (per ha), while this value for Dalmsholte is equal to €5,103 (per ha). This implies that the restored river section performs better in terms of the benefits that it provides to society. When asking people the amount they would be willing to pay to restore more river sections along the Regge in the same way as Archemermaten, people indicate an average of almost €25 a year. People are willing to pay most for good accessibility (€24.30), followed by good water quality (€10.90) and a low flood frequency (once in 100 years; €2.00). This shows the general perception that people are positive about river restoration and that they attach great value to the ecosystem services that the Regge provides, even in today's challenging financial times. Generally, the effects of river restoration on the valuation of the ecosystem services that the Regge and its floodplain provide can be considered positive. Managing rivers and floodplains, by restoring them to their original state, could be seen as a sustainable solution for the provisioning of a wide range of services that river systems can provide. Especially the regulating and cultural services can benefit from river restoration. If restored river parts are maintained properly after restoration has taken place, this could be a long-term benefit for society.

*Coersen M, 2014*. Ecosystem services valuation of degraded and non-degraded river segments of the Morrumsån river in Sweden. BSc thesis Earth Sciences and Economics, VU University Amsterdam

Using the REFORM framework of analysis, this study assessed the ecosystem services delivered by two sections of the Morrumsån, a salmon river in Southern Sweden. One section was restored to increase the possibility for salmon to migrate upstream, whereas the non-restored section, 10 km upstream, is strongly regulated for hydropower generation. The framework couples provisioning, regulating and cultural services to CORINE land units and then estimates the sum of societal benefits as an approximation of total economic value. Cultural services were partly estimated from interviews with local residents and visitors of the river. Unfortunately a very low willingness to participate was met with (20% of 47 people addressed). Both restored and unrestored sections provided timber (valued at 700 and 400 € $ha^{-1}$ $y^{-1}$). Regulating services such as flood protection, nutrient retention and carbon sequestration contributed little value, whereas cultural services differed greatly between restored and unrestored sections (600 and 200 € $ha^{-1}$ $y^{-1}$), due to enhanced water quality and improved salmon fisheries. The total, summed ecosystem services were estimated to value 1400 and 700 € $ha^{-1}$ $y^{-1}$, respectively. Thus, it is concluded that the restoration has increased the societal value of the Morrumsån, as estimated using the ecosystem services approach.

*Haverkamp J, 2014*. Assessing river restoration of two Austrian rivers, the Enns and the Drau, a comparative analysis of river restoration by valuing ecosystem services. MSc thesis Transnational ecosystem-based Water Management, Radboud University Nijmegen, The Netherlands and University of Duisburg-Essen, Germany.

The effects of river restoration on the Austrian rivers Enns and Drau and their accompanying floodplains are investigated by using the CORINE land cover and EUNIS habitat classification and by assessing ecosystem services for a restored reach and a non-restored reach of both rivers. The ecosystem services are used as method to compare the ecosystem services and their monetary value. The rivers could be compared with other European river corridors, which used the same method of Vermaat et al. (2013) within the REFORM project.

The assessed services in monetary values were divided in provisioning, regulating and cultural services. Agricultural production and timber is provided for all reaches of the Enns and Drau. Only the restored reach of the Drau provides hydropower. The regulating services nutrient retention and flood damage are dependent on the occurrence of flood events. These services are assessed for a flood probability of once in 30 years and once in 100 years. The restored reach of the Drau is the only reach which would be not affected by these flood probabilities, and therefore no nutrient retention and damage are assessed for this reach. The restored reach of the Enns includes a village, which would be flooded statistically once in 100 years and this causes a lot of residential damage. Carbon sequestration is also assessed as a regulating service. The cultural services are assessed by the willingness to pay for river restoration and count for the restored reaches of the Enns and Drau. All monetary values of the services together results in the total ecosystem services for the restored and non-restored reach of the rivers Enns and Drau.

The restored and non-restored reaches are compared for both rivers to assess the effect of river restoration by the monetary value of the ecosystem services and the effects of river restoration of the Enns and Drau river are compared as well.

*Plug MC, 2014*. Uncovering the pitfalls and quantifying the merits of river restoration: a case study on the Finnish Vääräjoki. MSc Thesis Earth Sciences and Economics, VU University Amsterdam, The Netherlands.

Rivers provide a wide range of utilities for society, which can be expressed in ecosystem services. Especially in Europe, many rivers have been regulated to optimize them for a particular use. Due to unexpected negative side effects of the regulations and a changing mentality towards nature, more and more European rivers are the subject of river restoration programs. Both regulation and restoration have a pronounced effect on the ecosystem services a river provides. Quantifying these effects can be an important in the decision whether or not to restore a river. The REFORM project is an initiative of the European Commission to develop a framework to compare ecosystem services before and after river restoration. Part of this project is a case study on the partially restored Vääräjoki in Finland. In the case study the ecosystem services present in a restored and unrestored part of the river and the surrounding landscape have been compared.

In the Vääräjoki the restorations consisted of replacing previously removed boulders and the construction of gravel beds. The effect the river has on the surrounding landscape has been delineated based on the extent of extreme floods that occur approximately once every 50 years. In the next step a list of potential river ecosystems has been used to determine the ecosystems present and affected by the restorations in the Vääräjoki. Services that are directly influenced are fish catch, the ecology and aesthetics of the river and flood regulation. Timber production, agricultural production and carbon sequestering are indirectly affected a change in flood occurrence.

Several methods have been applied to quantify these services. For flood regulation first the current risk had to be determined, using data gathered by Syke and combining these with values found in literature. After the current costs were calculated, the effects of the restoration efforts have been estimated with Manning’s formula. Manning’s formula also delivered a change in the water table, which has been used to determine a change in carbon sequestering. The derived change in flood probability could be combined with timber and agricultural production. For both these services the total annual yield or growth has been evaluated for the entire river corridor with the use of data on production levels in Northern Ostrobothnia and Finland. The values of a change in aesthetics and ecological quality have been derived with a Choice Experiment included in a survey among residents of the area and visitors. Fish catch could not be quantified, due to a lack of data.

The main benefits of the restoration comprise a change in aesthetics and improved ecological conditions. On average residents are willing to pay 83 cents per kilometer of restored river for a change in aesthetics and 30 cents per kilometer for an improved ecological condition. The main negative effects of the restoration are due to flooding damage, either directly or through the loss of harvest or reduced timber growth. Especially agricultural land is heavily affected by a flood event, because this will in most cases destroy the entire harvest, were a few days of inundation in a forest will mainly arrest growth. A change in fish catch could not be observed, due to a lack of data, although conditions for marketable species have most likely improved. Nutrient deposition after floods and carbon sequestering have a relatively small effect. Summing up the total benefits and negative effects results in a value of 65,500 euro a year for an area of 102 km2. Per kilometer of river restored this value becomes 4,100 euro annually. It should be noted that these results are highly dependent on land use. The restored section contained a higher portion of forest compared to the unrestored section. When differences in land use are compensated for over both sections, the overall effect of restoration becomes negative with a value of 880,619 euro a year which corresponds to a value of 28,246 per restored stretch of kilometer. On the other hand a higher portion of peat lands, would increase the overall benefits of restoration.

*Tylec L, 2013*. An assessment of the societal benefits of the Narew river restoration versus the restoration costs using the ecosystem services approach. MSc thesis Civil and Environmental Engineering, Warsaw University of Life Sciences, Warsaw, Poland.

The main aim of the thesis was an assessment of the societal benefits given by the Narew river ecosystem. It also presented a description of ecosystem services. The Narew river restoration project was described. The methodology of the research and valuation method was described. The data was collected during research and based on this data analyses were performed. These analyses include analysis of characteristics of the respondents, their willingness-to-pay and Choice Experiment analysis. Analyzed areas were also described in terms of the presence of different habitat types.