Valuation of Ecosystem Services Provided by Biodiversity Conservation: An Integrated Hydrological and Economic Model to Value the Enhanced Nitrogen Retention in Renaturated Streams

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Summary

The importance of ecosystem functions for humankind is well known. But only few attempts have been undertaken to estimate the economic value of these ecosystem services. In particular, indirect methods are rarely used, even though they are most suitable for the task. This discrepancy is because quantitative knowledge of changes in ecosystem functions is scarce. This paper presents a user-friendly procedure to quantify the increased N-retention in a renaturated river using easily available data. In a case study of the renaturated River Jossa (Germany) the benefits of increased nitrogen retention caused by beaver reintroduction are determined by using the replacement cost method. The quantification of chemical processes is discussed in detail, as well as the problems of defining an adequate reference scenario for the substitute costs. Results show that economic benefits from the evaluated ecosystem service (€12,000/annum) equal 12% of the total costs of the corresponding conservation scheme.

Keywords: Biodiversity conservation programmes, Cost-benefit-analysis, Replacement cost method, Ecosystem services, Nutrient retention

JEL Classification: D61, D62, Q2, Q25

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1   Introduction

Nature conservation has to cope with two problems which are coming to a head. On one hand there is an increasing pressure on remaining natural habitats from alternative land use (MITCH & GOSSELINK 2000, TURNER *et al.* 2000). On the other hand, budgets for conservation agencies to cope with the accelerating problems are decreasing (STRATMANN 2002).

In this situation, efficiency and acceptance of conservation policy are crucial. Efficiency, as tested by cost-benefit-analysis, is to make sure that money is spent according to public preferences and that no money is wasted (ZANDER 2000, BROUWER & SLAGEN1998, MARGGRAF & STREB 1997). Acceptance will help to ensure further public spending in the field of nature conservation. One way to promote acceptance is to visualise the benefits of conservation programmes which have been neglected so far. The feedback to economic studies underlines this assumption (e.g. PIMENTEL *et al.* 1997, COSTANZA *et al.* 1997). Thus, acceptance and efficiency can be promoted by cost-benefit-analysis.

To undertake environmentally sensitive cost-benefit-analysis, all relevant benefits of nature conservation have to be taken into account and hence estimated. This study focuses on the evaluation of indirect use values (according to TURNER *et al.* 1993:112). The procedure will be demonstrated in a case study of a beaver reintroduction programme in the centre west of Germany. One of the assumed benefits of the programme is the enhanced nitrogen retention in rivers, which have been altered by beaver activity. To monetise the changes in that ecosystem service, the Replacement Cost Method (RCM) is used.

So far, economic evaluations have concentrated on either direct use values or non-use values. Particularly in the field of nature conservation, where the focus has been set on species and landscape evaluation, the valuation of indirect use values derived from ecosystem services have been of less interest. Often it has been claimed that these values have already been considered by the use of the Contingent Valuation Method (CVM) (GREN 1995, COSTANZA *et al.* 1997). In some studies this might have been the case, depending on the design of the CVM. But, due to the complexity of ecosystems it is questionable if the CVM is the appropriate method for a sound evaluation of particular ecosystem functions.

The Replacement Cost Method allows us to focus on single ecosystem functions. This makes the importance of single ecosystem services more obvious. A further advantage of this

valuation procedure is the use of technical substitutes and their market prices. Together with the easily understandable valuation procedure this will ensure an improved public acceptance of the results, which cannot be taken for granted. The political input of many Contingent Valuation Studies suffers from low acceptance. The main reason for this is the welfare-economic concept of the method and the measurement of consumer's surplus which is difficult to communicate. On the other hand, values estimated by the Replacement Cost Method will always mark the lower boundary of the true value, because the consumer's surplus is not implied.

1.1.1 The value of the ecosystem function "nutrient retention"

Since the nutrient import in aquatic ecosystems has increased considerably during the last few decades, the self purification potential of river systems becomes more and more important to guarantee ecosystem integrity (MITCH & GOSSELINK 2000). Furthermore, the nitrate content in stream or ground water often exceeds critical values of drinking water legislation. Nitrogen removal becomes an increasingly important factor with regard to the cost of drinking water purification (GRÜNEBAUM 1993). Thus, it is not astonishing that in studies which deal with ecosystem services, the self purification potential is often evaluated (BYSTRÖM 2000, 1998, DEHNHARDT 2002, GREN et al. 1995, FOLKE 1991).

Various studies have shown that the self purification potential of a river depends on its structure and its surrounding buffer strips. Restoration of the old stream structures can help to improve the nitrogen removal in these systems. The reasons for this are manifold (VOUGHT et al. 1994). One important factor is the stream velocity. The higher the residence time of the water in the river system, the higher is the denitrification (BEHRENDT & OPITZ 2000).

Another factor is the area of flooded river banks. Flooded soils have a denitrification potential, which is up to 100 times higher than under dry conditions (GÄTH et al. 1999). Thus, flooding causes an increase in denitrification by enhancing the microbiological activity in the soils.

2 Investigated conservation programme and study site

The study area is the Spessart Mountains in Hesse, Germany, where a beaver reintroduction programme was launched in 1987/88. In the context of this scheme, 18 beavers were released

in the local rivers and buffer strips were purchased. The population numbers are now around 200 individuals and dam building occur in 16 home ranges (LOOS pers. com.).

The significant impact on structure and hydrology of highland brooks by beavers is well known (WOO & WADDINGTON 1991, SMITH *et al.* 1991) and similar results were reported in the Spessart study (HARTHUN 2000).

3   Materials and Methods

A higher self purification potential of beaver modified rivers is one of the assumed benefits of the investigated beaver conservation programme. To assess the economic benefits of this improved ecosystem function, the Replacement Cost Method (RCM) is used. This technique looks at the costs of replacing a damaged asset e.g. water quality standard to recover its original state (PEARCE & MORAN 1994).

The RCM requires a three step procedure:

1. Quantification of the retention effects (e*stimation of the ecosystem function*)

2. Definition of the reference scenario (*substitute and its marginal costs*)

3. Economic valuation (e*stimation of the ecosystem service*)

These three steps will be described in detail.

As mentioned above, nitrogen retention occurs in the river as well as in the flooded areas of the floodplains. Beavers affect both areas. Their dam building activities lead to an increase of flooded area along the river sides and to a decrease of flow velocity in the river. Both effects have to be estimated separately (Fig. 1). Direct measurements of nitrogen retention are very complicated to conduct (PETERSON *et al.* 2001). In this study, parameters are measured which are known to influence the denitrification (flooded area, running velocity) instead. In a second step, effects of these changes in the river system on the denitrification are estimated. For the floodplain and the river two different approaches are used (Fig. 1).

As for all economic evaluations, only gradual changes are relevant and suitable for valuation. In this particular case only changes caused by the conservation programme are of interest. Relevant parameters are the additional flooded area in the floodplain and the decreased running velocity in the river. To estimate the latter, changes in the overall area of the river

system are assessed by analysing aerial views of the study side from the year 2000 by means of geographic information system (ARC-VIEW).
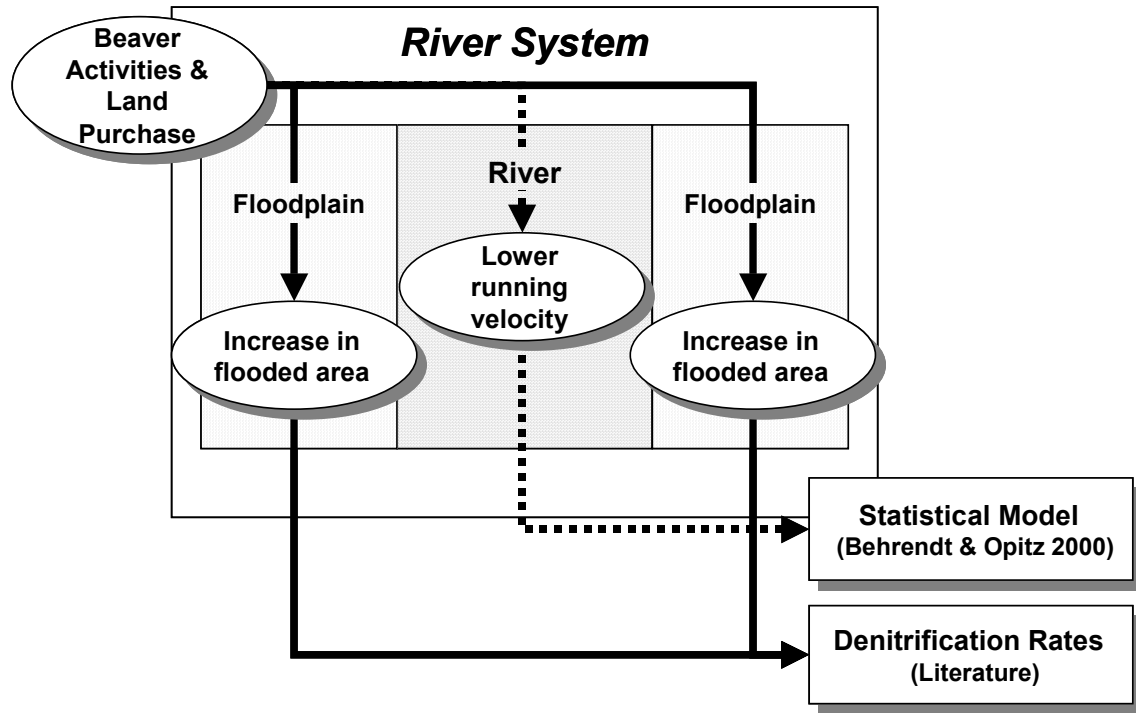

Fig. 1: The hydrological model: Influence of the beaver reintroduction scheme on the river system and the different quantification procedures of nitrogen retention. (Effects are caused by impounding by beavers and additional buffer strips

To quantify the influence of the altered flow velocity on the nitrogen retention within the river, a statistical model from BEHRENDT & OPITZ (2000) is used. For this model the N-retention is derived by comparing the net transport of the river with the theoretically expected loads from the nitrogen emissions inventory. The nitrogen retention (R_N) is linked to the Emissions (E_N) and the load weighted retention potential (R_L) by Equation (1).

$$R_N = E_N - \frac{E_N}{1 + R_L} \tag{1}$$

A regression analysis of 100 river basins in Europe shows that the load weighted retention potential (R_L) depends on the hydraulic load of the river. For river basins with a size of less than 1,000 m^2, BEHRENDT & OPITZ (2000) derived the following equation (Eq. 2)

$$R_L = a * x^b \qquad \text{The specific coefficients are a = 3.3; b = -0.65.} \tag{2}$$

This model explains 44% of the variance in the observed nitrogen retention.

To estimate the denitrification in the flooded areas, denitrification rates from literature are used. The recorded rates vary between 30 and 1200 kgN/(ha*a) (e.g. BYSTRÖM 1998, DÖRGE 1994, GALE *et al.*1993). For the following calculations a mean denitrification rate of 300 kgN/(ha*a) is taken as a basis.

To deal with the high variances of both the statistical model and the nitrification rates for soils, two different variants are calculated (Table 1). In the minimum variant the lower bond of the 90% prediction intervals is used. In the maximal variant the upper bond of the 90% prediction intervals is used. A minimal denitrification rate of 100 kgN/(ha*a) is assumed, for the maximal variant a rate of 500 kgN/(ha*a). Both numbers are common appraisal values for either conservative estimations (GREN *et al.* 1995, KRONVANG *et al.* 1999) or average nitrification rates (GREN *et al.* 1995).

Table 1: Assumptions for the calculation of the minimal and the maximal variant

Area	Procedure	V_{Min}	V_{Max}
river	statistical model	lower bound 90% interval	upper bound 90% interval
floodplain	denitrification rates	100 kgN/ha*a	500 kgN/ha*a

The fieldwork is done at one river only, the River Jossa. This is due to the availability of site-specific data, but the river is a very suitable reference. The four beaver territories along its course differ significantly from each other. They represent the whole spectrum of dam building consequences. For the whole study area the results of the Jossa are projected. For this procedure, the ratio of territories with dam building activities in the Jossa compared to the entire investigated area is taken into account.

To assess the replacement cost value of the estimated nitrogen retention the costs necessary to provide an equivalent service have to be determined. Here, costs reported in the literature come into operation.

4　Results

According to the three step procedure of the Replacement Cost Method, the chapter is divided into three parts: the quantification of the ecosystem function, the definition of the technical substitute and its marginal costs, and finally, the valuation step.

4.1　Quantification of the ecosystem function

The four beaver territories along the river Jossa have significant influence on the morphology of the river. The dam building causes 11 pools and ponds and 2 secondary ponds (Table. 2). These ponds increase the total river surface by 17%. The measure relevant for denitrification, the hydraulic load, diminishes by 15%. In addition, 15,500 m^2 of floodplain are flooded.

Table 2: Morphological changes in the investigated river system

		Jossa (original)	Jossa (Beaver)	Changes abs.	rel.
Runoff	[m³/s]	1,58	1,58	–	–
River area	[m²]	122.268	142.816	20.548	+17 %
Hydraulic load	[m/a]	408	349	59	−15 %
Flooded area	[m²]	–[1]	15.505[1]	15.505	

[1] To estimate the benefits of the reintroduction programme only the additional flooded area is of interest.

These changes in river structure result in significant changes in self purification (Table 3). The increased hydraulic load leads to an additional nitrogen retention of 700 kgN/a in the river according to the model from BEHNDT & OPITZ (2000). Taking the 90% confidence interval into account, values range from 520 – 900 kgN/a. Depending on the assumed denitrification rates, the additional retention in the floodplain amounts to 160 – 780 KgN/a. The mean is 470 KgN/a. The total additional retention in the Jossa and the surrounding floodplains total up to 1,200 kgN/ year.

Table 3: N-Retention in the river and the floodplain of the river Jossa and the whole investigated area. Results of minimum and maximum setting and the mean.

		Mean	V_{Min}[1]	V_{Max}[1]	+/-
River	[kg N/a]	700	520	900	26,8%
Floodplain	[kg N/a]	470	160	780	66,6%
Jossa	[kg N/a]	1,200	670	1,670	42,7%
Spessart	[kg N/a]	4,700	2,690	6,680	43%
Project duration[2]	[kg N]	115,633	66,354	164,991	

[1] Variants according to the assumptions see Table 1.

[2] Population development is considered during the project duration (1987-2012).

To scale these results up for the investigated area, the ratio of territories with dam building activities are taken into account. In the investigated area there are a total of 16 beaver territories with dam building. Assuming that the four investigated territories are representative, the overall effect adds up to ca. 4700 kgN/a in the whole project area (Table 3).

4.2   Definition of the substitute and its marginal costs

The valuation of the assessed ecosystem enables the identification of the potential technical substitute and ascertainment of the costs to provide an equivalent service. The following selection is in accordance with the criteria of BOCKSTAEL *et al.* (1998): (a) the substitute must be able to cope with the main problem and (b) cope in the most cost efficient way. Theoretically, there are three potential substitutes to improve the water quality: drinking water purification, sewage plants and political programmes to avoid nitrogen emissions.

The substitute most commonly used to value self purification potential of rivers is sewage plants (BYSTRÖM 2000, GREN 1995, DEHNHARDT 2002). Here, the functional process and the final effect are very similar: microbiological activity to improve the water quality of the river.

However, the main source of nitrogen input in aquatic ecosystems is emissions from agriculture (VOUGHT et al. 1994). These non-point loads can only be eliminated by drinking water purification or political programmes and not by sewage plants. Drinking water treatment offers a higher quality standard than necessary in rivers, thus it is not cost efficient. The most cost effective alternative to reduce non-point agricultural nutrient loads in the river is their avoidance by political strategies. Most common are agricultural schemes to compensate farmers for special regulations for the application of fertilisers. This compensation refers either to the technique or the amounts of application.

The choice of an adequate substitute does not define the replacement costs automatically. There is a big variety of measures and marginal costs within the agricultural schemes to reduce nitrogen emissions (for a review see BRÄUER 2002:214 and HENNIES 1996 unpublished).

Depending on the production system and the intended reduction level, the replacement costs vary between €1-23 /kgN (HENNIES 1996 unpublished). For the calculations in the presented study, average costs of €2.56 /kgN are assumed to guarantee a conservative calculation.[1] To make this number comparable: for nitrogen removal in sewage plants marginal costs of €5-8 /kgN are reported in Germany (GRÜNEBAUM 1993).

When using replacement costs in a cost-benefit analysis (CBA) it has to be kept in mind that distorted markets exist. Thus, either shadow prices have to be used or - if the CBA includes changes in prices and income only – the economic costs of the respective agricultural schemes are the right figure. In the latter case, the excess-burden of the expenditures have to be added. This would increase the benefits of the ecosystem service. In these calculations excess-burden is not taken into account for two reasons: (i) values in literature vary between 7 and 28% (MUSGRAVE et al. 1993:113) and (ii) to ensure conservative calculations.

4.3   Valuation of the ecosystem service

If marginal costs of €2.56 /kgN are assumed, the economic value of the mean estimated additional nitrogen retention in the Jossa has a value of €3,000 (Table 4). The replacement value of the ecosystem service in the whole investigated area accounts for €12,000 in 2000 (Table 4). According to the different assumptions in the estimation of the chemical processes (Table 1 and Table 3), the deviation from the mean value is plus minus 43%.

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[1] The original value for the calculations was 5 DM.

For a better judgement of the results it is necessary to compare the calculated benefits with the costs of the conservation programme. Therefore, the retention processes of the year 2000 have to be extrapolated for the whole project duration. The project duration is assessed to last 25 years (1987-2012). A definition of a project duration is necessary to account for the standing expenses (e.g. land purchase at the beginning of the project) with the variable costs. The total costs of the reintroduction scheme amount to €1.89 million (BRÄUER 2002).

Table 4: Economic value of measured nitrogen retention

		Econ. Value	Deviation
Jossa	(2000)	€3,000	€1,700 – 4,300
Investigated area (2000)		€12,000	€6,900 – 17,100
Project duration[1]		€250,300	€143,700 – 356,900
Portion of project costs		12 %	8 – 17 %

[1] Values for the whole project duration (1987-2012). Population development is considered.

[2] Deviation according to the results of V_{Min} und V_{Max} in Table 3.

The increased nitrogen retention in rivers is directly correlated to the beaver activities. To extrapolate the results of the year 2000 to the project duration, they have to be adjusted with the size of the beaver population. For this adjustment the population size has been computed using a linear regression. The model describes a highly significant correlation between population size and time after the reintroduction ($y = 12{,}45*x - 24770$; $r^2 = 0{,}97$; $p < 0{,}001$; $F = 297$; $n = 10$). According to this model, the beaver population will expand until ca. 320 individuals in the year 2012. This population size and hence the statistical model is realistic because there are enough habitats in the area.

The corrected retention potential in the investigated area is estimated at 115,600 kgN (+- 49,300 kgN) for the period between 1987-2012. The economic value of this service corresponds to €250,300 (+-€106.600). The economic benefits of the ecosystem service nitrogen retention make up 12% of the total investment costs.[2]

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[2] Sewage plants as reference scenario (see 4.2) would result in a value of €35.980 /annum. This corresponds to 40% of the project costs.

5   Discussion

Results show that one ecosystem function alone makes up a significant part of the total costs of the investigated conservation programme, even though the calculations have been very conservative (choice of the replacement costs, waiving of excess-burden etc.) and consumer surplus has not been considered. The results are surprising because improving the self purification potential has not been the main objective of the beaver conservation programme. However, the results underline the importance of a systematic consideration of all consequences of nature conservation programmes. So far this is an exception. If at all, economic evaluations of species conservation programmes apply the Contingent Valuation Method only where ecosystem functions are not taken into consideration explicitly.

Unfortunately, the results show a high variance. The presented results have to be discussed in two ways. On one hand there are problems with the quantification of chemical processes. Are the methods applied suitable? On the other hand, the valuation step has to be discussed as well. Here it has to be clarified whether the used technical substitute is appropriate.

The hydrological processes have been estimated using a statistical model and general denitrification rates from literature. Both values are only rough estimates because local characteristics which are relevant for the denitrification are not taken into account. To narrow the results down, conservative assumptions have been made to guard against overestimation.

An even more important factor for the final results is the definition of the technical substitute. Theoretically, there are two other plausible technical substitutes next to the chosen substitute "agricultural policies": "drinking water purification" and "sewage plants". The marginal costs per unit abated nitrogen are much higher in these cases than for the chosen substitute. These substitutes would lead to results three to twenty times as high. The applied scenario "agricultural policies" is the most cost-efficient alternative, but it offers less services than the ecosystem, because atmospheric emissions are not included. This results in an underestimation of the "true value". Once again, the chosen valuation procedure guarantees the prevention of overestimation. Thus, the estimates denote the lower bound and can be used in practice as a minimum value.

Conservative calculations are essential to ensure credibility of the valuation procedure, but it opens the door for a massive and dangerous underestimation of ecosystem services. In this context it is essential to point out exactly what the valuation subject was. For example, it

might be tempting to equal the evaluated nitrogen retention with the value of the renaturated river. That's not the case at all. There are several ecosystem services which have been neglected so far, like an increased flood control or higher groundwater recharge. Even the ecosystem service of self purification is only evaluated from one point of view: the nitrogen retention. Yet other aspects of self purification in the river such as phosphate retention, have been neglected.

If these limitations are considered and the results are interpreted with caution, economic valuation can offer big advantages. Results of economic evaluations do not only help to decide whether a given programme has been efficient or not, but also whether enough money has been spent for a special task (BROUWER & SLAGEN 1998, ZANDER 2000). The knowledge also helps to design new programmes and offers the possibility of new approaches in landscape design, respectively. Examples for the latter are studies by BYSTRÖM (2000) or GREN et al. (1997), which have shown that restoration or building of new flood plains are cost-efficient alternatives to wastewater treatment plants to meet the goal "reduction of nitrogen loads to the Baltic Sea".

6 Conclusions

Benefits derived from ecosystem services, in this case the enhanced nitrogen retention potential of a renaturated river, can play an important role in the judgement of conservation programmes. The estimated benefits as a by product of a species conservation programme make up an important part of the total costs of that programme and should not be neglected. This observation underscores the importance of an evaluation of all relevant consequences of conservation programmes. A systematic procedure, which uses an adequate evaluation procedure for each particular category of consequences respectively, is essential for this task. To gather all use and non-use values of a biodiversity conservation programme a combination of Contingent Valuation and Replacement Cost Method seems to be essential.

The RCM is particularly suitable for the evaluation of ecosystem services because it offers a straightforward and easily understandable procedure. Nevertheless, the results are only rough estimates and should be interpreted with caution. To ensure that no overestimation takes place the calculations are based on conservative assumptions (at the level of the chemical processes as well as at the level of the choice of the technical substitute).

The model from BEHRENDT & OPITZ (2000) offers the possibility to calculate denitrification rates in a relatively easy way. This will help to reduce the costs of estimating the benefits of an ecosystem function, a figure very complicated to measure directly. Cost and time savings of the presented procedure will help to establish an economic evaluation of nature capital in the political decision making process.

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(lix) This paper was presented at the ENGIME Workshop on "Mapping Diversity", Leuven, May 16-17, 2002

(lx) This paper was presented at the EuroConference on "Auctions and Market Design: Theory, Evidence and Applications", organised by the Fondazione Eni Enrico Mattei, Milan, September 26-28, 2002

(lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003

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(lxvii) This paper has been presented at the international conference on "Tourism and Sustainable Economic Development – Macro and Micro Economic Issues" jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003

(lxviii) This paper was presented at the ENGIME Workshop on "Governance and Policies in Multicultural Cities", Rome, June 5-6, 2003

(lxix) This paper was presented at the Fourth EEP Plenary Workshop and EEP Conference "The Future of Climate Policy", Cagliari, Italy, 27-28 March 2003