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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Abstract

The importance of ecosystem functions for humankind are well known. But only few attempts have been undertaken to estimate the economic value of these ecosystem services. Particularly 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 by 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 €/a) equal 12% of the total costs of the corresponding conservation scheme.

Keywords: Biodiversity conservation programs, cost-benefit-analysis, replacement cost method, ecosystem services, nutrient retention

JEL Code: D 61, D 62, Q 2, Q 25

1 Introduction:

Nature conservation has to cope with two problems which are coming to a head. On the one hand there is an increasing pressure on the remaining natural habitats by 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 important. Efficiency, as tested by cost-benefit-analysis, is to make sure that money is spend according to public preferences and no money is wasted (ZANDER 2000, BROUWER & SLAGEN 1998, 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

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conservation programs which have been neglected so far. The feedback to economic studies underlines this assumption (e.g. PIMENTEL et al. 1997, COSTANZA et al. 1997). So 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 program in the middle west of Germany. One of the assumed benefits of the program is the enhanced nitrogen retention in rivers, which have been altered by beaver activity. To monetarize 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. Especially in the field of nature conservation, where the focus has been set on species and landscapes 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 been already 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 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. This can't be taken for granted. The political input of many Contingent Valuation Studies suffers from low acceptance. Main reason is the welfare-economic concept of the method, 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 bound 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 become increased considerably during the last 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 costs of drinking water purification (GRÜNEBAUM 1993). Thus it is not astonishing that, in studies which deal with ecosystem services the self purification potential is evaluated often (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 (s.

VOUGHT et al. 1994). One important factor is the stream velocity. The higher the residence time of the water in the river system is 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). So flooding causes an increase in denitrification by enhancing the microbiological activity in the soils.

2 Investigated conservation program and study site

The investigated area is the Spessart Mountains in Hesse, Germany, where a beaver reintroduction program has been launched in 1987/88. In the context of this scheme 18 beavers have been released in the local rivers and buffer strips have been purchased. The population numbers are around 200 individuals now and dam building occurs in 16 homeranges (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 ditto reported in the Spessart (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 program. 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 (*Estimation of the ecosystem function*)
2. Definition of the Reference Scenario (*Substitute and its marginal costs*)
3. Economic Valuation (*Estimation 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 riversides and to a decrease of flow velocity in the river. Both effects have to be estimated separately (s. Fig. 1). Direct measurements of nitrogen retention are very complicated to conduct (s. 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 (s. Fig. 1).

Like for all economic evaluations only gradual changes are relevant and suitable for valuation. In this particular case only changes caused by the conservation program 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).

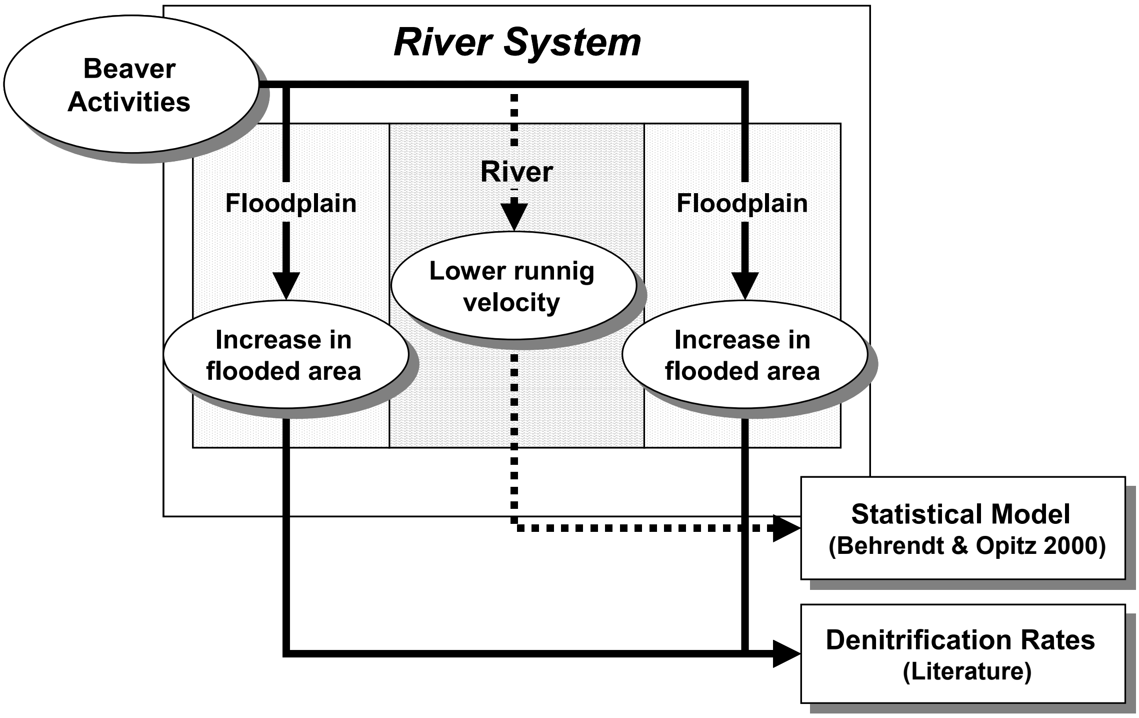

Fig. 1: The hydrological Model: Influence of the beaver reintroduction scheme on the river system and the different quantification procedures of the nitrogen retention. (Effects are caused by impounding by beavers and additional buffer strips)

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).

$$R_N = E_N - \frac{E_N}{1+R_L} \qquad (1)$$

A regression analysis of 100 river basins in Europe shows that the load weighted retention potential (R_L) depend 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 (s. Eq. 2)

$R_L = a * x^b$ The specific coefficients are a = 3.3; b = -0.65. (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 (s. Tab. 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 (s. GREN et al. 1995, KRONVANG et al. 1999) or average nitrification rates (GREN et al. 1995).

Tab. 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 for one river only, the River Jossa. This restriction to the river Jossa is due to the availability of site-specific data. But the river is very suitable as a 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 are 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 in 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 (s. Tab. 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.

Tab. 2: Morphological changes in the investigated river system.

		Jossa (original)	Jossa (Beaver)	Changes abs.	Changes 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 program only the additional flooded area is of interest.

These changes in river structure result in significant changes in self purification (s. Tab. 3). The increased hydraulic load leads to an additional nitrogen retention of 700 kgN/a in the river according to the model from BEHRENDT & 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 amount to 160 – 780 KgN/a. The mean is 470 KgN/a. The total additional retention in the Jossa and the surrounding floodplains sums up to 1,200 kgN/ year.

Tab. 3: N-Retention in the river and the floodplain of the river Jossa and the whole investigated area. Presented are the 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 assumption s. Tab. 1.

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

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

4.2 Definition of the substitute and its marginal costs

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

The substitute used most common to value self purification potential of rivers are 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.

But, main source of nitrogen input in aquatic ecosystems are emissions from agriculture (VOUGHT et al. 1994). This non-point loads can only be eliminated by drinking water purification or political programs 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 s. BRÄUER 2002:214 and HENNIES 1996 unpubl.).

Depending on the production system and the intended reduction level the replacement costs vary between 1-23 €/kg N (HENNIES 1996 unpubl.). 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. So 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 are 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 € (s. Tab. 4). The replacement value of the ecosystem service in the whole investigated area accounts for 12,000 € in 2000 (s. Tab. 4). According to the different assumptions in the estimation of the chemical processes (s. Tab. 1 and Tab. 3), the deviation from the mean value is plus minus 43%.

For a better judgement of the results it is necessary to compare the calculated benefits with the costs of the conservation program. 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 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 Mio.€ (BRÄUER 2002).

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

Tab. 4: Economic value of the 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) The population development is considered.
[2] Deviation according to the results of V_{Min} und V_{Max} in Tab. 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 correspond to 250,300 € (+-106.600 €). The economic benefits of the ecosystem service nitrogen retention make up 12% of the total investment costs.[2]

5 Discussion

Results show that one ecosystem function alone makes up a significant part of the total costs of the investigated conservation program. 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 program. But the results underline how important a systematic consideration of all consequences of nature conservation programs is. So far this is an exception. If at all, economic evaluations of species conservation programs 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 the on hand, there are problems by 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 if 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

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

characteristics which are relevant for the denitrification are not taken into account. To narrow the results down, conservative assumptions have been made to hedge 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 this 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 immissions are not included. This results in an underestimation of the “true value”. Once again the chosen valuation procedure guarantees the prevention of an overestimation. Thus, the estimations are the lower bond 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.

But if this 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 program has been efficient or not, or if enough money is spent for a special task (BROUWER & SLAGEN 1998, ZANDER 2000). The knowledge also helps to design new programs, and they offer 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 programs. The estimated benefits as a by product of a species conservation program make up an important part of the total costs of that program and should not be neglected. This observation underscores the importance of an evaluation of all relevant consequences of conservation programs. 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 program 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. Nonetheless 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 (on the level of the chemical processes as well as on 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 a 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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