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Relationship between biodiversity indicators and its economic value – case study

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Abstract

Background and Purpose: *Within the framework of multi-purpose forest management, biodiversity is usually considered as one of forest functions along with production, recreation and other functions of forests, while according to biodiversity definition and its partial components, these functions are integral elements of biodiversity. Forest inventory is an objective method for collecting information about biodiversity and forest functions.*

Materials and Methods: *In the presented study, the data from forest inventory of the University Forest Enterprise Kostelec based on stratification sampling design (1,188 sample plots in 86 strata) were used for the analysis of the relationship between biodiversity indicators and its economic value. The area of the enterprise is characterised by heterogeneous site and landscape conditions. From the inventory data we quantified 171 partial diversity indicators. On the base of ANOVA and multiple linear regression analysis, we selected the most suitable indicators most closely correlated to the sum of the values of individual social and economic forest functions.*

Results and Conclusion: *We found that the relationship between the economic value of biodiversity and selected indicators is significant. Nevertheless, the derived models could explain not more than 25% of the total variability of the analysed relationship. Future research should search for objective indicators of biodiversity, and should aim at improving economic valuation of biodiversity.*

INTRODUCTION

A great number of projects, initiatives, and scientific publications have already dealt with biodiversity, its conservation and protection, as well as its valuation. Although the basic perception of biodiversity usually follows the definition of biodiversity (Convention on biodiversity) and hence, is common in all of the works, the specific quantification approaches vary depending on the assessed scale. While at a large scale biodiversity indicators attempt to summarise the state of biodiversity at the level of a region, country, continent, or even world (e.g. 1), the assessment at a small scale is more specific and more detailed. Nevertheless, from the point of a layman the first question that comes out is why it is necessary to protect and conserve biodiversity and why it is important.

Biodiversity has its own intrinsic value *(2, 3)*. Apart from this, thanks to everything it provides starting from food, drugs, building and construction material up to satisfying the spiritual, cultural and aesthetic needs, it also has multiple importance for mankind *(2)* and for preserving the life on the Earth *(4)*.

Economic literature distinguishes two main categories of biodiversity values: use and non-use values *(5–8)*. Use values result from the specific use of biodiversity and its components *(5),* i.e. when people benefit from biodiversity directly, e.g. during bird-watching *(9)*. Unlike non-use values, use values usually originate from a direct contact of a man with environment *(10)* and their interaction *(11)*. Use values can be divided into direct, indirect and option values (9, 8).

The most evident direct use values are wood production, fishing, plant gathering or hunting animals for food *(12)*. They are called consumptive use values *(8)*. Other authors *(10)* consider also hunting, clean air and drinking water as consumptive use values. Indirect use values of biodiversity result from their importance in creating and maintaining certain ecosystem services *(13, 14),* which directly satisfy human needs or support such economic processes that serve for satisfying needs *(7)*. Hence, indirect use values are related to the benefits arising from ecosystem functions *(5)*. They include e.g. protection against erosion, flooding or insects *(12),* climate regulation and water cycle or other nutrients, or water and air purification *(7)*. Non-use values are completely independent from any current or potential utilisation of biological diversity *(7)*. Sometimes, they are also called intrinsic values *(15)* or passive-use values *(9, 16)*. They result from different motives, e.g. from ethical, moral, intellectual or spiritual desires to conserve nature for future generations or for its own sake *(7)*.

In the presented paper we analyse the relationship between the total economic value of biodiversity consisting of use and non-use values and its non-economic quantification based on species and structural diversity. The analysis focuses on within stand diversity (also called alpha diversity according to *(17)*), because a forest stand is the basic entity of forest management planning procedures. Due to this, the selected indicators are highly specific. The choice of the indicators was performed after a thorough scientific literature review. They are all based on quantitative data as suggested by *(18)* with the aim to measure ecosystem conditions from the biodiversity point of view.

MATERIAL AND METHODS

For the presented study, University Forest Enterprise Kostelec nad Černými lesy, Czech Republic, was chosen as a pilot area (Figure 1). The area of the enterprise is 5,910 ha and its forest cover is 95.4% calculated as a

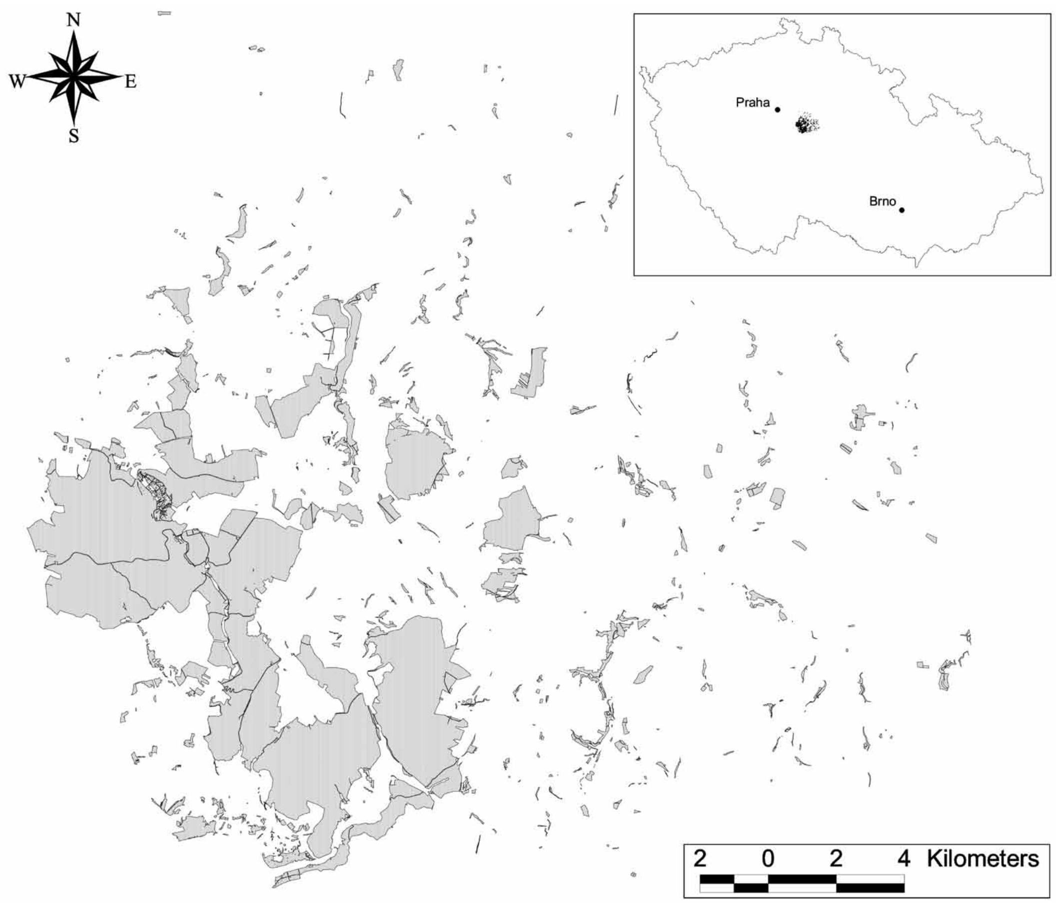

Figure 1. *The forest management unit University Forest Enterprise Kostelec nad Černými lesy.*

proportion of the forest area from the total area of the enterprise including meadows, etc. As can be seen in Fig. 1, the enterprise is fragmented, particularly in its eastern part. The site conditions inside the enterprise are heterogeneous, since it includes five forest altitudinal zones (pine (0.8%), oak (0.5%), oak-beech (18.6%), beech-oak (61.5%) and beech (18.5%). Mean annual temperature varies from 7.0 to 7.5 °C, mean temperature in the growing season ranges between 13.0 and 13.8 °C. Growing season lasts 153 days on average. Mean annual precipitation is from 600 to 650 mm.

In the study, the data from forest inventory (performed in the period from 2009 to 2011) based on stratification sampling design (1,188 sample plots in 86 strata) were used. The area of the enterprise was stratified on the base of three variables: age category, site category and stocking. A simple validation analysis of data obtained from the field inventory in 2009 to 2011 revealed the suitability of the applied design *(19)*.

In total, 171 partial biodiversity indicators were quantified. Selected indicators represent species and structural diversity (N0 – (20), R1 – (21), R2 – (22), BP – (23), E1 – (24, 25), E3 – (26), E5 – (20), D – (27), Si – (28), H – (29), HB – (30), QS – (31), BC – (32), ED – Euclidian distance, BUB – (33), Y – (34), DF –differential index based on the principles of Sørensen coefficient QS, aggregation and mixture according to *(35)* based on field data, volume of fine and coarse woody debris on a plot, number of layers according to *(36))*. The majority of indicators were calculated for pre-defined groups of trees: (i) for a group of young trees with diameter at breast height below 7 cm, (ii) for a group of old trees with diameter at breast height above 7 cm, and (iii) for all trees, i.e. young and old trees together. The indicators were quantified using four parameters: total number of trees, sum of tree heights, average tree height and total growth area. In addition, absolute values of indicators were also relativized to their respective maximum values, which were found during the inventory of the enterprise. Thanks to this transformation, individual indicators were standardised to the same comparative rate and the influence of measuring units on the weight of individual indicators at the value of a complex biodiversity indicator was excluded. The indicators were used as a basis for the derivation of a complex biodiversity indicator (KIB), which was based on an additive principle and which represents a complex non-economic evaluation measure of biodiversity. The most suitable indicators entering the model of KIB were selected using two statistical methods: a univariate analysis of variance (ANOVA) and a multiple regression. Each set of indicators was then used as a basis for the development of models describing the relationship between KIB and economic value of biodiversity. In total, we tested 65,520 variants.

The concept of economic valuation of biodiversity is based on the summary value of socio-economic importance of forest functions *(37)* influenced by biodiversity, which are modified with quotients representing the potential of fulfilling forest functions (KP). The potential of a forest to fulfil a particular function (KP) was assessed at each plot in the field (expert estimate from the interval 0% – no potential to fulfil the particular function, 100% – full potential to fulfil particular function). The functions were valued on per hectare of forests. For the valuation of function (MPTV_ha) we used average annual market price of the standing timber volume per hectare. Value of forest functions for hunting and game breeding per hectare (HG_ha) is estimated 6.63 Eur.ha^{-1}.year^{-1}. In specific regions (game preserves, etc.) its value is increased by multipliers. Value of non-wood production forest functions per hectare (NW_ha) is estimated on the base of forest types. The price of types in which Vaccinium sp. grow is 192.67 Eur.ha^{-1}, while the price of other types is 38.46 Eur.ha^{-1}. Value of hydrological forest functions per hectare (HF_ha) is influenced by three characteristics: maximum and minimum discharge and water quality in water sources. Basic values (35.46; 21.04; 362.43 Eur.ha^{-1}) are modified with the coefficients related to soil cover, soil texture, altitudinal vegetation zone, urgency of compensatory measures, degree of forest damage, concentration of N-NO$_3$ in mg.l^{-1} in water and forest categorisation. Value of soil conservation forest functions per hectare (SC_ha) depends on the threat level of erosion and the level of silting of water reservoirs and water courses. General value of atmosphere protection forest functions (AP_ha) is estimated 38.97 Eur.ha^{-1}, which is modified with the coefficients that vary with forest types. Value of sanitary hygienic forest functions (HS_ha) depends on the level of recreation use of forests (highly exposed areas 293.10 Eur.ha^{-1}; other 100.27 Eur.ha^{-1}). Value of cultural and scientific forest functions per hectare (CS_ha) is related to qualitative characteristics of cultural and scientific use of forests that refer to the position of forests inside/outside specific conservation and protection areas. Basic values (85.07 – 276.50 Eur.ha^{-1} depending on the qualitative characteristics) are modified with the coefficient reflecting the degree of forest naturalness. The formula for the calculation of economic biodiversity value (EBV) per hectare is as follows:

$$\begin{aligned} \mathrm{EBV} = {} & \mathrm{MPTV\_ha} + \mathrm{KP}_{HG} \times \mathrm{HG\_ha} + \\ & + \mathrm{KP}_{NW} \times \mathrm{NW\_ha} + \mathrm{KP}_{HF} \times \mathrm{HF\_ha} + \mathrm{KP}_{SC} \times \mathrm{SC\_ha} + \\ & + \mathrm{KP}_{AP} \times \mathrm{AP\_ha} + \mathrm{KP}_{HS} \times \mathrm{HS\_ha} + \mathrm{KP}_{CS} \times \mathrm{CS\_ha} \end{aligned} \quad (1)$$

Tree volume was calculated according to *(38)*. Wood assortment was performed using assortment tables *(39)*.

The relationship between economic biodiversity value (EBV) and a complex biodiversity indicator (KIB) was examined using a linear and a non-linear quadratic model:

$$\mathrm{EBV} = a + b.\,\mathrm{KIB} \quad (2)$$

$$\mathrm{EBV} = a + b.\,\mathrm{KIB} + c.\,\mathrm{KIB}^2 \quad (3)$$

The relationship was analysed with a correlation coefficient. The coefficient was tested with Student t-test with the null hypothesis that it is equal to zero, i.e. that there is no relationship.

RESULTS

The first variant for selecting indicators was a univariate analysis of variance (ANOVA), which was used to examine the influence of main stratification variables (factors) on calculated diversity indicators. On the base of this analysis we selected the following 12 indicators: range of tree heights (A), Euclidean distance between mean heights of trees with diameter below and above 7cm (B), number of moss and lichen species (C), R2 index calculated from the number of trees with diameter above 7cm (D), E3 index calculated from the number of trees with diameter above 7cm (E), BC index of similarity between mean heights of trees with diameter below and above 7cm (F), H index calculated from tree heights of trees with diameter below 7cm (H), number of layers according to *(36)* (I), ratio of deadwood volume to living volume (J), ratio of fine woody debris volume to living volume (K), ratio of mean heights of trees with diameter below and above 7cm (L), DF index of similarity between mean heights of trees with diameter below and above 7cm (M). From these 12 indicators, 4,095 different combinations were created for the derivation of a complex biodiversity indicator KIB.

The second variant for selecting input variables into KIB model was based on a multiple linear regression analysis. Individual diversity indices were selected using stepwise linear regression. The following indicators were selected: Euclidean distance between the sum of heights of trees with diameter below and above 7cm (N), indicator (B), volume of fine woody debris (O), indicator (C), QS index of similarity between trees with diameter below and above 7cm (P), 1 – QS index (Q), R1 index calculated from the number of trees with diameter above 7cm (R), R2 index calculated from the number of all trees (trees with diameter below and above 7cm together) (S), indicator (D), Si index calculated from the mean height of trees with diameter below 7cm (T), Si index from the sum of heights of trees with diameter below 7cm (U), Si index calculated from mean tree height of all trees (trees with diameter below and above 7cm together) (V).

Correlation of economic biodiversity value (EBV) to a complex biodiversity index (KIB), which was created from the indicators selected using ANOVA, fluctuates from 0.495 to 0.498 (Table 1). The highest correlation was found in case of two quadratic models, in which KIB is calculated as a sum of two or three indicators. Two indicators are the same in both models: range of tree heights (A) and number of moss and lichen species (C). These two indicators are included in all 20 models with the highest correlations. Both indicators increase with the level of stand maturity. The third indicator is R2 index of species richness calculated from the number of trees with diameter above 7cm (D), which enters 8 models from the best 20 models (Table 1). In these models, KIB is composed of 2 to 5 partial indicators. Other indicators that affect the final value of KIB are: index of species evenness (E), Bray-Curtis index calculated from mean heights of trees with diameter below and above 7cm (F) and differential index calculated from mean height (M).

TABLE 1

Correlation between economic biodiversity value (EBV) and a complex biodiversity index (KIB) derived from 1,188 sample plots. Partial indicators of KIB were selected by ANOVA (LM – linear model, QM – non-linear quadratic model).

Economic Biodiversity value	Model	Complex biodiversity index (KIB)	*Correlation* R_{xy} (I_{xy})
EBV	LM	A+C	0,497
	LM	A+C+D	0,497
	LM	A+C+E	0,497
	LM	A+C+D+E	0,496
	LM	A+C+M	0,496
	LM	A+C+D+M	0,495
	LM	A+C+F	0,495
	LM	A+C+E+M	0,495
	LM	A+C+D+F	0,495
	LM	A+C+E+F	0,495
	QM	A+C	0,498
	QM	A+C+D	0,498
	QM	A+C+E	0,497
	QM	A+C+D+E	0,497
	QM	A+C+M	0,496
	QM	A+C+D+M	0,496
	QM	A+C+F	0,496
	QM	A+C+E+M	0,496
	QM	A+C+D+F	0,496
	QM	A+C+D+E+M	0,495

Note: A – range of tree heights, C – number of moss and lichen species, D – R2 index according to *(19)* calculated from the number of trees with diameter above 7cm, E – E3 index according to *(23)* calculated from the number of trees with diameter above 7cm, M – DF index of similarity between mean heights of trees with diameter below and above 7cm, F – BC index of similarity according to *(29)* between mean heights of trees with diameter below and above 7cm

The value of indicator (E) does not significantly change with the maturity level of forest stands, but as the value of the index grows, the economic biodiversity value also increases. Indicator (F) decreases with the increasing differences between the groups of trees. The values of DF index of similarity between mean heights of trees with diameter below and above 7cm (M) increase with the increasing stand volume and EBV.

After the values of biodiversity indicators were relativized to maximum recorded value in the enterprise, the highest correlations (R_{xy} or I_{xy}) between the price and KIB fluctuate from 0.451 to 0.501 (Figure 2). Also in this case the best model was a quadratic model, in which KIB is composed of two indicators: range of tree heights (A) and number of moss and lichen species (C). When using relative values, the number of indicators entering KIB

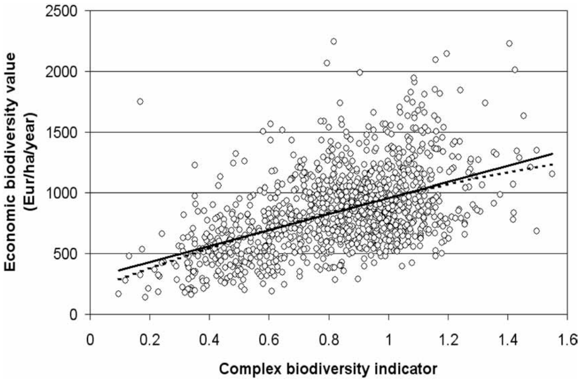

Figure 2. *The closest relationship between economic biodiversity value (EBV) and a complex biodiversity indicator (KIB) derived from 1,188 sample plots (KIB=A+C). Values of biodiversity indicators (A) representing range of tree heights, and (C) standing for the number of moss and lichen species were relativized to maximum recorded value in the enterprise (—— linear model, – – – – non-linear quadratic model).*

model is lower compared to absolute values, and varies from 1 to 4. Other most frequent indicators entering 20 most close relationships were: ratio of fine woody debris volume to living volume (K) and a ratio of deadwood volume to living volume (J), which occurred in 8 and 7 out of 20 models, respectively. Both indicators (J) and (K) decrease with the increasing stand volume.

The selection of indicators using multiple regression analysis showed that the models derived from these indicators are less tight than in the previous case, because correlation coefficients do not exceed the value of 0.393. The number of indicators in KIB linear model varies from 2 to 5, while in the quadratic model it is from 3 to 6. Most frequent indicators were Euclidean distance between mean heights of trees with diameter below and above 7cm (B) and number of moss and lichen species (C), which occurred in all 20 most correlated models. Other significant indicators were R2 index calculated from the number of all trees (S) and R2 index calculated from the number of trees with diameter above 7cm (D), which occurred in 14 and 10 models out of 20 best models, respectively. Both indicators (S) and (D) have a positive relationship to EBV. Relativisation of the indicators in this group to the maximum recorded value resulted in the reduction of the number of indicators in the models and in higher correlation. The number of indicators in best models fluctuated from 1 to 4 and the best correlation coefficient increased to 0.41 (for non-linear quadratic model) or 0.40 (linear model). As in the previous case, the most frequent indicators were again Euclidean distance between mean heights of trees with diameter below and above 7cm (B) and the number of moss and lichen species (C).

DISCUSSION

In spite of a great number of internationally approved conventions and agreements that bind the signed parties to protect and conserve biodiversity, the process of destruction has not stopped, but according to some authors (e.g. 5, 1) its rate is still increasing. One option how to change the attitude of policy makers and public opinion about conservation and sustainable use of biodiversity, is to document, that such an approach has a positive economic value and that this value can even exceed the value of alternative use threating biodiversity *(5)*. This was also confirmed in our work, since we found that the protected sites were characterised not only by greater biodiversity but also by its higher economic value *(19)*. For example, the average value of indicator (A) calculated from the plots inside the nature reserve was by 19% greater than the overall average value for the whole enterprise and by 21% greater than for the plots outside the nature reserve. In case of indicator (C), the average value inside the nature reserve is 4% greater than the overall average value. Economic biodiversity value of the nature reserve is significantly higher than the total EBV for the whole area, since it is by 50% or 61% greater than EBV of the whole area and the area outside the nature reserve, respectively.

As already pointed out in introduction, diversity can be measured at many levels ranging from genes to ecosystems *(40)*. Hence, its assessment needs to reflect the level, at which it is performed. At a large scale, biodiversity indicators usually describe ecosystem status at the national level including not only the components of biological diversity, such as habitats, species or genes, but also ecosystem integrity, its sustainable use, conservation and protection of areas *(41)*. However, when assessing biodiversity at a small scale, some of the large-scale indicators may not be relevant, e.g. the coverage of protected areas, because the subject of interest is a forest stand. Nevertheless, some indicators are included at both levels, species abundance being one of them. For example, in the *(41)* process the experts agreed that the abundance and distribution of selected species is to be one of the biodiversity indicators *(41)*. In our study this indicator is represented by several indices that were included in both variants of KIB model: species richness of moss and lichens (C), R2 (D, S), R1 (R), Si (T, U, V), H (H), and E3 (E). Another important indicator that is included in the majority of schemes for biodiversity assessment regardless of the scale is deadwood, because this indicator is considered as a proxy for the state of many invertebrates *(41)* and biodiversity as a whole *(42, 43, 44, 45)*. While at a national level, usually only the amount of deadwood is accounted for, in our study we found that both coarse and fine woody debris, as well as their ratio to living volume (indicators J, K, O) are important indicators of biodiversity at a stand scale. Indicator (A) covers the effect of vertical differentiation of a forest and also the level of stand maturity that influences timber volume as well as EBV. It represents one component of tree size diversity, which positively affects ecological values of stands by ensuring a wide range of habitats *(40)*. The increase of the number of moss and lichen species (C) with the level of stand maturity is related to enhancing microclimatic conditions in a forest stand, specifically more amount of light. This relationship was documented in a number of studies (e.g. *46–48*).

Although nowadays a great number of works dealing with biodiversity valuation exist, in many cases it is biological sources that are valued *(3, 9)*. This results from the fact that a biological source (i.e. specific gene, species, site or ecosystem) is often much easier to be identified than biological diversity or its components (e.g. species rarity) *(9)*. In addition, the difference between biodiversity and biological sources is not always clear and sometimes the meanings of these terms overlap *(3)*. A useful tool supporting decision process on using biological source is a so-called total economic valuation of their assets *(5, 49)*. Total economic value (TEV) is a sum of all use and non-use values. The problem is how to determine TEV. In case of traded products, market price is used as an equivalent for TEV. Biological diversity as a whole is however not a traded commodity, only its partial components. Non--use values represent the greatest portion on biodiversity value. In the presented paper we also applied the principle of biological sources, since biodiversity valuation was based on valuation of individual forest functions. We found that the relationship between the economic value of biodiversity and selected indicators is significant, since all correlation coefficients in Table 1 highly exceeded minimum value of R_{xy} or I_{xy} 0.056 calculated for the sample consisting of 1,188 plots. Nevertheless, the derived models could explain not more than 25% of the total variability of the analysed relationship.

Hence, future research should search for objective indicators of biodiversity, and should aim at improving economic valuation of biodiversity.

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