A comparative cost-effectiveness analysis of biodiversity indicators in grassland farming systems

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Introduction

One major challenge facing land-managers and policy-makers is the possibility to assess the effects of different agricultural practices and policies on the production of environmental services. Nowadays, relevant attention is given to the implementation of sound agro-environmental schemes with respect to the effects of different agricultural practices on biodiversity (OECD, 2010). This is mainly related to the acknowledgement of biodiversity conservation among the main environmental services demanded by society (TEEB, 2010) and the growing concerns on agriculture activities as one of the main responsible of species extinction in the past 50 years (Polasky *et al.*, 2005).

Despite a large body of scientific literature on environmental indicators, the assessment of policy impacts in order to account for the environmental benefits they produce remains largely unexamined (Finn *et al.*, 2009). In this context, efficiency and efficacy of European agro-environmental schemes in generating environmental services is currently under discussion (Kleijn *et al.*, 2001 and 2006). This is mainly related to the scarcity of effective, feasible and widely-applicable indicators for regular monitoring activities at farm scale. The identification of the effects that a policy has generated is of high importance e.g. in the implementation of policy instruments in which payments to farmers are a function of the amount of environmental services produced (Cooper *et al.*, 2010). The application of indicators able to fulfil such tasks is however dependent on their cost, particularly if a day to day use in regular policy evaluation is to be envisaged. In this context, the availability of reliable cost data concerning biodiversity indicators is of significant importance both for the implementation of sound agro-environmental schemes and for the optimisation of funds for biodiversity monitoring and conservation (Ferraro and Pattanayak, 2010).Therefore, in light of budgetary constraints, a cost-effectiveness analysis should be developed in order to identify high performance indicators given a specific policy evaluation issue.

European semi-natural grasslands are complex agro-ecosystems based on long-established farming activities and related agricultural practices which are a unique example of interaction between humans and natural resources (MacDonald *et al.*, 2000). As a matter of fact, the maintenance of agricultural farming systems based on species-rich semi-natural grasslands in Europe are of particular importance for biodiversity conservation (EEA, 2004). This study is based on the cost analysis results from the measurement of a set of biodiversity indicators in grassland based farm systems. Cost data relates to the fieldwork activities of the Bulgarian and Hungarian research units involved in the BioBio research project (EU-FP7, BioBio - “Indicators for biodiversity in organic and low-input farming systems”) which is endeavouring to develop sound and useful biodiversity indicators at farm-scale in and out of Europe.

Our objective is the comparison of different indicators and their protocol of sampling and to identify the most efficient methods of biodiversity measurement by means of cost-

effectiveness analysis. Our work begins with a background description of cost-effectiveness analysis applied to biodiversity measurement in section 2. Section 3 focuses on the methodology followed for the assessment of the costs of the biodiversity indicators and the estimation of the cost-effectiveness of their measurement. Section 4 provides results and discuss the different cost-effectiveness of the indicators in the studied cases employing the method proposed in section 3. Section 5 addresses conclusions and final remarks.

Background

Indicators were originally proposed to solve the problem of the feasibility of the direct monitoring of biodiversity which would require huge efforts even for small areas (Albrecht *et al.*, 2007). Nevertheless, few examples exist in the literature directly concerning cost-effectiveness procedures and analysis relating to biodiversity indicators. Moreover, this field of research is generally dominated by naturalists and biologists who focus more on the ecological validation of indicators than on economic aspects. Beside this, papers discussing the topic are mainly based on: a) indirect assessment of costs, e.g. based on *ex post* analysis of project costs; b) proxy estimation, such as labour effort; or c) expert judgement. To our knowledge, no cost data based on direct recording of efforts are available for studies covering large areas.

Biodiversity indicators employ economic inputs (quantified by the cost for measurement) to produce an output represented by ecological information (assessment of biodiversity). The cost of the measurement is the sum of monetary costs of resources consumed to undertake the measurement of the indicator and processing of data (Chambers, 1988). This cost can be estimated through direct information collection regarding resource use and unitary costs and employed for the cost-effectiveness analysis. Cost-effectiveness of biodiversity indicators is significant in the context of implementation costs of agri-environmental policies. The cost of the measurement of biodiversity can be related to transaction costs (e.g. costs of monitoring and designing policies) and welfare losses (e.g. costs of policies derived from asymmetric information). The availability of cost-effective biodiversity indicators at farm level minimises the sum of transaction costs and welfare losses and, therefore, it is part of an efficient organisational process of agri-environmental schemes (Beckmann *et al.*, 2009). Theoretically, the relation between the implementation of different cost-effective indicators and the potential benefits of derived policies can be summarized as in Figure 1.

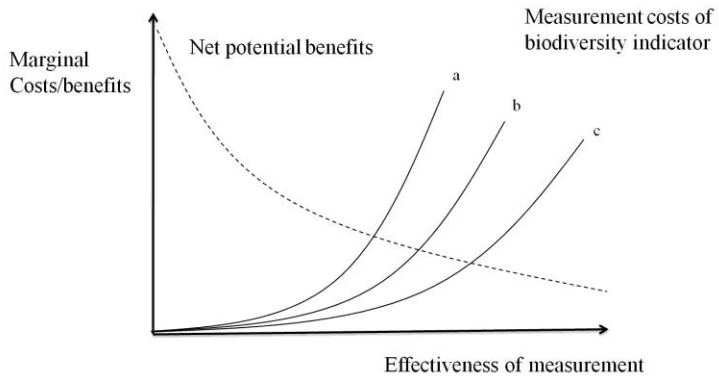

Figure 1 – Relation between effectiveness of the measurement of biodiversity and marginal cost/benefit of derived policies.

Given biodiversity indicators with different cost-effectiveness of the measurement, the net potential benefit curve meets the indicator cost curves at different levels of marginal

cost/benefit of the derived policies. This is related to the efficiency of the indicators or, in other words, to their capacity to assess biodiversity at lower costs. This involves also that there is an optimal level of accuracy of measuring biodiversity indicators, which could be determined as a function of marginal costs and benefits. Such optimal level of accuracy, too, will depend on the differing costs of different biodiversity indicators.

Carlson and Schmiegelow (2002) proposed a cost-effectiveness analysis design for the large-scale monitoring of birds in the province of Alberta (Canada). The effectiveness of sampling was assessed through a simulated sampling design and costs were estimated through a simplified model accounting for transport, labour and equipment costs. The work aimed at designing low cost and high informative monitoring programs. The authors highlighted how the power of detection and the costs of the surveys were not linearly related and that great differences of cost-effectiveness existed depending on the bird species targeted.

Bisevac and Majer (2002) measured the costs and effectiveness of different indicators of biodiversity. Costs were expressed as time required to perform the phases of the measurement per plot. The effectiveness was assessed through a multivariate analysis of the different indicators and their capacity to reflect indicator variability. The authors demonstrated how invertebrate data could be cost-effective compared, for example, to vegetation data thanks to their high information content.

Juutinen and Mönkkönen (2004) tested several biodiversity indicators in boreal forests taking into account the capacity of indicators to reflect the overall biodiversity. Then proposed cost-efficient networks of conservation stands given a budget constraint. Costs included inventory costs of species group which ranged between €2.691 and €34.479 for the inventory of 32 forest stands. These costs were based on actual costs but were not calculated separately for each stand. The authors concluded that the vascular plants and birds indicators were the most cost-efficient indicators and highlighted the importance of accounting for opportunity and inventory costs for cost-effective conservation. Finally, they emphasized the need of local knowledge and data to generalize these results to other regions.

Franco *et al.* (2007) proposed a sub-sampling method able to compare the effort-effectiveness of two different techniques for the assessment of a bird species population. The authors proposed a reliable method for comparing the effort involved in sampling (cost) and the ecological effectiveness of indicators.

Qi *et al*. (2008) undertook a study of cost-efficacy in measuring farmland diversity based on operational data from a vast scale study concerning genetically modified crops in the United Kingdom. The authors analysed operational data to determine the financial and time related costs of the study's protocols for 113 experimental sites. In their cost analysis, the authors focused on the direct costs of the ecological measurement protocols used in the research excluding the government and industry costs involved in establishing the project. The costs assessed were between £217 and £4548 per site depending on the protocol adopted. The paper concluded with a hypothesis concerning the possibility of optimising the measurement protocols with the aim to enhancing the efficiency of the indicators.

Gardner *et al*. (2008) compared the costs and benefits of different indicators of biodiversity in the Amazonian Forest with the aim of identifying high performance indicators. These were meant to be species or groups of species that maximised "the

amount of information returned for any given investment". The authors considered standardised costs and split the analysis between field and laboratory work. Surprisingly, the results indicated that, from an ecological point of view, the inexpensive indicators were often the most effective. The authors concluded that biodiversity conservation and decision-making could gain significant benefits from a locally-designed cost-effectiveness analysis of measurement protocols.

Cantarello and Newton (2008) sought to identify cost-effective indicators and evaluate their suitability for evaluating the conservation status of forested habitats that are part of the Natura 2000 framework. The authors concluded that the indicators should be adapted to the different characteristics of individual sites.

Methodology

The cost assessment was performed through the quantification of the cost of efforts and resources spent in the measurement of a selected set of indicators from the BioBio project: wild, domestic and bumblebees (B), earthworms (EW) and spiders (S). The measurement was performed in semi-natural low-input grasslands in Bulgaria (Rhodope Mountains) and Hungary (Homokhatsag) following a specified protocol which involved two main phases:

- habitat stratification for identification of plots;
- measurement of biodiversity indicators in the defined plots.

Habitat stratification was based on the habitat mapping technique (Bunce *et al.*, 2007) which involves both photo-interpretations and field surveys with the aim to identify and classify habitat categories at farm level. Biodiversity measurement was then performed in the identified habitat categories by means of the three indicators.

Wild, domestic and bumblebees sampling was carried out catching insects along a 100 m transect with an entomological net. Captured species were pinned and frozen in laboratory until taxonomic identification.

Earthworm sampling was carried out following two successive methods: 1) pouring a specific solution (allyl-isothiocyanate plus ethanol diluted with water) into metal frames which were placed on the ground and collecting the earthworms that came upward; 2) extracting the soil core delimited by the frame (20 cm depth) and hand-sorting the earthworms on a plastic sheet. Samples were then placed in cool boxes containing formalin and transferred to refrigerators in the laboratory for taxonomic identification.

Spider sampling was carried out with the aid of a modified vacuum/blower shredder (Stihl SH 86-D), 5 suction samples were taken on each plot. The samples were sorted (*i.e.* the spiders were separated from other material such soil or organic matter), placed in vials and transferred to refrigerators for taxonomic identification (for further details on indicator protocols see Dennis *et al.*, 2010).

Cost data were gathered during 2010 on a weekly basis by the research field units and organised into a relational data-base. The records gathered through the cost data collection were related to staff time, distance and duration of travel, consumables and equipment, food and accommodation (other costs), vehicle costs and costs related to the habitat stratification.

Each record included the following information: date, identification of farm site, resource type and amount, and was linked to the typology tables indicating the salary band of staff, the distance of the farm site from the research centre, transport time, equipment and consumable costs.

Equipment and consumables included all of the materials used for the measurement of BioBio indicators of biodiversity. The unitary cost of the utilisation of equipment was calculated as the cost of the equipment purchase divided by its lifetime in the same measurement unit. Labour costs were expressed in euro per hour and included health insurance and taxes. Labour included time devoted to measurement activities net of labour time for transportation which included travel time by the field staff to get and to come back from the farm plots. Taxonomy identification costs are not included. Vehicle cost was expressed as € per km in the Hungarian case study and included fuel, car insurance and vehicle depreciation. Cost of vehicle was expressed in € per rent day in the Bulgarian case study. Other costs included food and night accommodations for field workers. Habitat mapping included the costs of resources spent for the habitat stratification and was considered as a fixed cost divided by each biodiversity indicator in equal parts. Costs related to reporting, general organisation (e.g. time spent for consumables or equipment purchasing, staff training, etc.) and other costs, such as crop damages due to indicator measurements are not included in the present analysis.

Consumables and equipment, labour and habitat stratification were included among the costs directly involved in the measurement of biodiversity. Transportation, vehicle and other costs were not considered in the analysis of cost-effectiveness in order to avoid cost distortions e.g. different travel distances from the research centre to the field plots in the two case studies.

The changes from Hungarian Forint to Euro were: €1 = 1.818,25 HUF. All costs were related to 2010.

The cost-effectiveness analysis was assessed as the ratio between cost (C) and effectiveness (E) where the calculation of effectiveness of the biodiversity indicators was performed through equation 1:

Eq. 1

$$E_i = \frac{1}{\sqrt{\frac{\sum(xi - R)^2}{ni}}}$$

where *Ei* = effectiveness of the indicator *i*, *xi* = biodiversity value for the *x* sample, *R* = value of biodiversity of reference (see eq. 2), *ni* = number of samples gathered for the indicator *i*.

R is the average value of biodiversity assessed through the set of studied indicators and is calculated following the equation 2:

Eq. 2

$$R = \frac{R_B + R_{EW} + R_S}{3}$$

where R_B, R_{EW} and R_S are respectively the mean values of biodiversity assessed through B, EW and S. Values of biodiversity are expressed in the same unit of measure e.g. Shannon and Wiener index (Margalef, 1958) or others and measured in the same plots.

Given the fact that this methodology is not aimed to the assessment of the accuracy of biodiversity measurement, equation 2 gives the same weight to the biodiversity indicators regardless of their accuracy and the number of samples gathered. Therefore, a meaningful estimation of effectiveness implies the comparison of ecologically sound and validated biodiversity indicators (this is the case of the BioBio indicators). Otherwise, a low-cost

biodiversity indicator could result as the most cost-effective even though not accurate and, therefore, not appropriate.

The sum of squared deviation from R ($\sum(x_i - R)^2$) can be derived from equation 1. This could be used to compare the overall efficiency necessary of the three indicators to reach equivalent values of cost-effectiveness. Employing this methodology and the actual costs assessed, we propose an analysis of the cost-effectiveness performances of B, EW and S in the two case studies given different scenarios of effectiveness.

Results and discussion

The biodiversity surveys were carried out in 16 mountain grassland farms in Bulgaria and 18 grassland farms in Hungary. Measurement plots were 158 in Bulgaria and 167 in Hungary. The case studies (CSs) denoted evident differences concerning the sampling area (239 ha sampled in Bulgaria vs. 3071 in Hungary) and morphological features (hardly accessible plots which could involve 1-1,5 hours by foot or the need of off-road vehicles in the Bulgarian case study). This involved different organisations of field survey in the two case studies: the Bulgarian team reduced the time spent in travels by making use of several night accommodations near the sampling plots (e.g. hostels, free-camping) whereas Hungarian team employed larger teams for field measurement and only some night accommodation (field team composed by 3-7 persons and 30 travels to complete the measurement in Hungary vs. field team composed by 1-3 persons and 8 travels to complete the measurement in Bulgaria). Despite the evident differences in sampling area between the two CSs, the number of plots was similar (only 11 plots of difference).

Table 1 - General data of the biodiversity surveys in semi-natural grasslands in the case studies.

Country	Farms	Plots	Hectares
Bulgaria	16	158	239
Hungary	18	167	3071

Evident differences were highlighted between Bulgaria and Hungary considering the total costs of the measurement of biodiversity (€5592 vs. €16874 in Bulgaria and Hungary respectively, ratio 1:3, see Table 2). All categories of costs were lower in Bulgaria than Hungary. The main differences concerned consumables and equipment, labour, transportation and other costs. Vehicle and habitat mapping costs in Hungary, even if higher, were more similar to Bulgarian costs in comparison to the other cost categories. The average cost per farm amounted to €350 in Bulgaria and €937 in Hungary (ratio 1:2,7). The main portion of measurement costs is attributed to labour and transportation in both CSs. These costs on aggregate accounted for 52% of total cost in Bulgaria and 58% in Hungary. High share of costs resulted also for the habitat mapping in Bulgaria (30%), whereas it was less than 17% of costs in Hungary.

Table 2 - Cost per category for the measurement of biodiversity indicators.

Country	Consumables + equipment (€)	Labour (€)	Transportation (€)	Vehicle (€)	Other costs (€)	Habitat mapping (€)	Total (€)
Bulgaria	258	2461	485	429	291	1668	5592
Hungary	1665	8524	1290	861	1688	2847	16874

The cost differences between the two CSs for the measurement of the three biodiversity indicators were confirmed considering the cost of resources directly involved in the

measurement per indicator (Table 3). The difference of cost of EW was particularly evident between Bulgaria and Hungary (ratio1:3,5), whereas the cost of B was more similar in the two studied case studies (ratio 1:2,4). The rank of costs of the indicators was the same in Bulgaria and Hungary: wild, domestic and bumblebees was the less expensive biodiversity indicator in both countries, whereas EW costs were the highest. The cost differences between the biodiversity indicators were more evident in Hungary in comparison with Bulgaria (€210 vs. €929 were the differences between B and EW in Bulgaria and Hungary respectively).

Table 3 - Cost of resources directly involved in the measurement of biodiversity per indicator in the two case studies (only costs directly spent for the measurement are considered).

Country	B	EW	S
Bulgaria	1386	1596	1405
Hungary	3303	5500	4232

The cost differences between the Bulgarian and the Hungarian case studies can be partly explained by the divergence of unitary costs of resources between the two countries: e.g. salary band for labour = €6 per hour in Bulgaria vs. salary bands from €5,8 to €8,47 in Hungary[1]. Nevertheless, the cost differences are mainly linked with the labour effort spent for the completion of the measurement of biodiversity. Even though the number of farms and sampling plots was similar in the CSs, the amount of labour hours directly spent in the biodiversity measurement was clearly higher in the Hungarian CS (more than 1226 labour hours were necessary in Hungary, whereas only 401 in Bulgaria; see Table 4). This can be related to the large sampling area covered and probably to the organisation of larger sampling teams in Hungary.

The Hungary CS recorded a lower number of samples per farm necessary to complete the biodiversity measurement in comparison to Bulgaria (28 samples for B and EW and 139 for S per farm in Hungary vs. 30 samples for B and EW and 148 for S per farm in Bulgaria). The Hungarian CS recorded higher costs per sample for the three biodiversity indicators, whereas the cost per ha was clearly higher in Bulgaria. Considering the costs directly involved in the measurement of B, the difference between CSs was less evident in comparison to EW and S (cost ratio 1:2,1; 1:3,1; and 1:2,7 for B, EW and S respectively). Thanks to the higher number of samples, S recorded a low cost per sample in both CSs. The difference of cost per sample was particular evident in Hungary.

Table 4 – Labour effort, number of samples gathered, cost per sample, per hectare and per farm in the case studies to perform the measurement of the biodiversity indicators (only efforts and costs directly spent for the measurement are considered).

Country		B	EW	S
Bulgaria	labour (hours)	121	159	121
	samples (number)	474	474	2370
	cost per sample (€)	3	3	0,6
	cost per ha (€)	6	7	6
	cost per farm (€)	87	100	88

[1] Hungarian team employed also free workers (student) for the field activities which contributed, to some extent, to hold down the costs

	labour (hours)	327	578	321
	samples (number)	501	501	2505
Hungary	cost per sample (€)	7	11	2
	cost per ha (€)	1	2	1
	cost per farm (€)	184	306	235

In a fixed effectiveness scenario for the three biodiversity indicators, the differences concerning cost-effectiveness in Bulgaria are not evident (Figure 2a). Earthworms indicator shows slightly higher costs per effectiveness, whereas S and B show very similar values of cost-effectiveness (given E=1 the values of cost-effectiveness for B, EW and S are 1386, 1596 and 1405 respectively). The differences of cost-effectiveness between the biodiversity indicators are more evident in the Hungarian CS (Figure2b). In this case, wild, domestic and bumblebees indicator shows the best performance in a fixed effectiveness scenario, whereas EW highlights the highest values of cost-effectiveness (given E=1 the values of cost-effectiveness for B, EW and S are 3303, 5500 and 4232 respectively). The rank of the biodiversity indicators is the same in the two CSs in a fixed effectiveness scenario, but the indicators highlight evident differences of cost-effectiveness values in the two case studies (e.g. cost-effectiveness ratio of B in Bulgaria vs. Hungary would be 1: 2,4 for E=1). From these results, the effectiveness of EW should be 1,7 times higher than B and 1,3 times higher than S to reach the same value of cost-effectiveness in Hungary. In the Bulgarian case the comparable costs stresses the importance of effectiveness estimation for the selection of the best indicator from a cost-effective point of view.

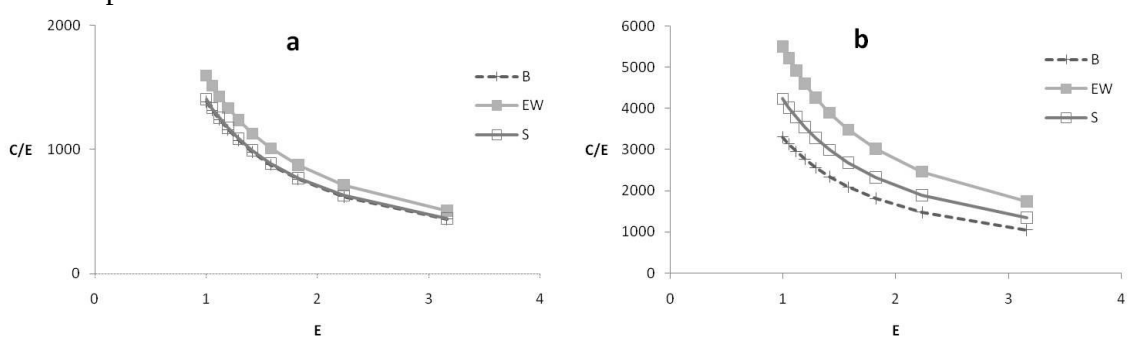

Figure 2 Graphic analysis of cost-effectiveness vs. fixed values of effectiveness for B, EW and S in the Bulgarian (a) and Hungarian (b) case study.

Given the different amount of samples gathered for the three biodiversity indicators, the sum of squared deviation from R ($\sum(x_i - R)^2$) points to significant differences in both case studies (Table 5). In an equivalent cost-effectiveness scenario, B and EW should reach a higher overall efficiency of the measurement. Given C/E=1000, the sum of squared deviation from R of B should be 4,9 and 2,9 times lower than S in the Bulgarian and Hungarian CSs respectively. in the same C/E scenario, the sum of squared deviation from R of EW should be 6,4 and 8 times lower than S in the Bulgarian and Hungarian CSs respectively.

Table 5 - Values of the sum of squared deviation from R ($\sum(x_i - R)^2$) derived from equation 1 in an equivalent cost-effectiveness scenario (C/E= 1000) for B, EW and S. The measurement costs assessed in the present work are included in the calculation.

		$\sum(x_i - R)^2$
Bulgaria	B	247
	EW	186
	S	1200
Hungary	B	46
	EW	17
	S	132

Conclusions

One of the aims of this work was to highlight the importance of a reliable methodology for the assessment of the costs generated by the measurement of biodiversity. Our method was based on the direct recording of actual effort data and combining expertises from both the fields of ecology and economics. This approach is largely absent in existing literature (Münier *et al.*, 2004; Wätzold and Schwerdtner, 2005; Laycock *et al.*, 2009). This is one of the reasons that has lead to penury of data and methodologies integrating ecological and economic approaches. An increased availability of reliable cost data concerning the measurement of biodiversity will be of primary importance for the development of cost-effectiveness analyses and in the enhancement of biodiversity assessments and conservation programmes.

The costs assessed for the biodiversity surveys were clearly related to the cost of workers' salaries. This evidence leads to a much higher cost of biodiversity measurement in countries with higher salary bands (see Targetti *et al.*, 2011). The total costs should be also higher when considering other activities such as organisation, reporting and taxonomy identification which should be included among the indicator costs.

Even though the surveys were performed in similar farming systems, the cost of the measurement of biodiversity was clearly different in the CSs. The cost-effectiveness analysis highlighted best performance for B in Hungary. Even though the analysis pointed to a lower efficiency for EW in both CSs, it was not able to differentiate clearly between the three biodiversity indicators in Bulgaria where the costs of the measurement of the indicators were not too dissimilar.

The employment of the vacuum/blower tool allowed the gathering of a high number of samples for the spiders indicator. This permitted to record the lowest cost per sample for S. This evidence could be significant for the organisation of field sampling activities. As highlighted in Table 5, spiders indicator could compensate a lower accuracy of single samples with their lower cost in comparison to B and EW samples. Given a similar overall accuracy of the measurement (assessed as sum of squared deviation from R), S resulted the most cost-effective indicator in both case study.

As stated in the methodology section, the proposed analysis of cost-effectiveness was not intended for the assessment of accuracy of indicators. Our objective was to compare a validated set of biodiversity indicators employing reliable cost data weighed against its effectiveness. By that way, this method allowed the comparison of a given set of indicators by way of their efficiency.

This analysis points to a considerable importance of the costs of the measurement when comparing the three biodiversity indicators in Hungary, whereas the performance of the indicators could be based essentially on their effectiveness in Bulgaria. This is of particular importance concerning the application of a common set of biodiversity indicators at European scale because the most cost-effective set of biodiversity indicators

could not be the same in all countries. This evidence confirms the conclusions of Juutinen and Mönkkönen (2004) concerning the need of local based studies to perform a reliable cost-efficiency analysis.
The application of this methodology will be further improved and tested employing real effectiveness and cost data from the different BioBio project case studies.

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