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Analysis

Cost-Effectiveness Analysis of Ecosystem Management With Ecosystem Services: From Theory to Practice

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ABSTRACT

Integrated ecosystem management is challenging due to many, often conflicting, targets and limited resources to allocate. A valuable and straightforward approach is to integrate an ecosystem services assessment in a cost-effectiveness analysis as method to evaluate and compare the cost-effectiveness of several management scenarios to reach one or more objectives and take into account the potential effects on other ecosystem functions and services. Nevertheless, this method is not commonly used in ecosystem management evaluation but can provide an alternative for the frequently used but often contested cost-benefit analysis (which requires the step of assigning a monetary value to each benefit). The aim of this study is to apply the cost-effectiveness analysis in combination with an ecosystem services assessment on a real case-study (comparing alternative management strategies for estuaries) to derive lessons learned to go from theory to practice. The application of this method for the case-study reveals many remaining challenges such as data availability and knowledge to assess ecosystem effects of management measures. Nevertheless, the analysis demonstrates that this method can be used for making a more integrated evaluation and supporting better-informed management decisions.

1. Introduction

Optimal and cost-effective management of an ecosystem involves many stakeholders such as management agencies, cities, local residents, economic sectors, acting at different levels from local to global, with often contrasting interests and objectives (Turner et al., 2003; Sanon et al., 2012; Labiosa et al., 2013). This results in different environmental problems to be addressed simultaneously, with potential conflicts and trade-offs between economic, ecological, environmental and social interests (Halpern et al., 2011; Zhang et al., 2014). Indeed, managing an ecosystem to improve a single function can also have an impact on other ecosystem functions with positive (co-benefits) or negative (trade-offs) implications for the ecosystem functioning and society (Seppelt et al., 2013; Smith et al., 2013). Furthermore, policy and legislation is often disconnected in separate departments such as air, water and soil (Smith et al., 2013). The ecosystem services (ES) concept proved to be a useful framework to assess different ecosystem functions and links ecological and socio-economic interests (Boerema et al., 2017). Case-studies aim at optimising ecosystem management for several ES, e.g. for agricultural management (Crossman and Bryan, 2009), forest management (Macmillan et al., 1998), integrated coastal and river management (Pouwels et al., 1995; Breen and Hynes, 2014). A common method for project evaluation is a cost-benefit analysis. If combined with an ecosystem services analysis, a variety of economic, social and ecological benefits and costs of a project can be balanced (Boerema et al., 2016). However, this requires that all costs and benefits are expressed in monetary values which is strongly discussed and contested (Gómez-Baggethun and Ruiz-Pérez, 2011). An alternative economic approach that can be used for environmental management evaluation is a cost-effectiveness analysis. This method compares the investment cost with management effects and this could be expressed in any unit (Balana et al., 2011). Hence data requirements are lower and the step towards the monetary valuation of benefits can be avoided. As a disadvantage, the analysis treats each ES separately and integrating over different ES is not straightforward because they are expressed in different units. Nevertheless, management of ecosystems is oriented towards different targets and therefore it is important to make an integrated assessment of the impact of management alternatives for the different targets. This research paper tests the practical application of the cost-effectiveness analysis to evaluate and compare ecosystem management measures for multiple management targets and additional side-effects.

When managing environmental problems, the effectiveness of planned actions to solve the problem is an important criterion. In

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combination with general budget restrictions, this raises the questions to find the most cost-effective strategy to solve environmental problems at the least possible cost (Interwies et al., 2004). A cost-effectiveness analysis (CEA) is applied in very diverse cases to find an optimal and cost-effective solution, e.g. regarding site selection (e.g. Adame et al., 2014), or forest management options (e.g. Tóth et al., 2013). Another application is to solve specific problems such as water quality improvement, pollution and eutrophication reduction (Comello et al., 2014), biodiversity conservation (Drechsler et al., 2007; Helm and Hepburn, 2012), greenhouse gas emission reduction (MacLeod et al., 2010), water provision improvement (Yang, 2011), and flood prevention (Dawson et al., 2011). Limited examples study the optimal strategy for integrated ecosystem management when taking into account several stakeholders and objectives (e.g. Pouwels et al., 1995). Most CEA studies related to environmental policy evaluation are theoretical and conceptual (Prato, 2007; Wainger et al., 2010). Practical examples use mostly scores to estimate benefits of management options, either given by experts and/or stakeholders (e.g. Macmillan et al., 1998; Bryan, 2010) or translated from biophysical data and models (e.g. Pouwels et al., 1995; Crossman and Bryan, 2009). In these studies, a weighting factor, given by experts and/or stakeholders or randomly chosen (e.g. all with equal weight), is applied to make an integrated evaluation over several benefits.

Assessing the effectiveness of management measures is an important but challenging step in the CEA study. The impact on the targeted objective and also additional positive and negative effects should be investigated to take into account the impact on all the functions and services of the ecosystem (Balana et al., 2011). A common indicator should be found for each service to be able to compare the impact of different management measures (Convertino et al., 2013). This is challenging for services consisting of various components such as water quality regulation (e.g. different nutrients, oxygen, acidity etc.) (Smith et al., 2013). It is important to fully understand and be able to quantify the impact of management measures to the entire coupled ecologic and socio-economic system. Selecting the most effective management strategy for several objectives adds another degree of complexity since the impact on the different objectives could not be added up because the benefits are expressed in different units. The objective of this paper is to test and examine the approach to evaluate and select the most cost-effective ecosystem management strategy for optimising one or more specific ES objectives. First, the basic steps of the cost-effectiveness analysis are shortly described in Section 2. Second, the method is applied on a test case (management of the Scheldt estuary for two different management targets) in Section 3. Lastly, Section 4 discusses the challenges and lessons learned from the application of the CEA method on a real ecosystem management case.

2. Method

For a cost-effectiveness analysis, four steps are followed: (1) collecting data on the cost of the management measures; (2) quantifying the effect of each management measure on the different ES (targets, co-benefits, negative side effects); (3) calculating the average cost of each management measure for each ES (= cost / effect on ES); (4) selecting the most cost-effective management strategy.

2.1. Step 1: Cost of Management Measures

A good estimation of the investment cost is the first crucial step to calculate the average cost of management measures. Accounting for all costs, including social costs and indirect costs, is important (Interwies et al., 2004; Duke et al., 2013). Furthermore, also accounting for maintenance costs after construction is important to take into account. This requires to set a time period for the analysis.

2.2. Step 2: Effect of Management Measures on ES

Evaluating the effect of management measures on different ecosystem services enables the comparison of the effectiveness of the different management measures regarding a specific target but also the additional contribution to delivering ecosystem services and generating societal benefits. This requires a common indicator for each ecosystem service to be able to quantify and compare the effect of each management measure. A review on methods used to quantify ecosystem services revealed the diversity of indicators demonstrating the challenge of finding one common indicator (Boerema et al., 2017).

2.3. Step 3: Average Cost to Invest in ES

After collecting cost data and estimating the effect of each management measure on each ES, the average cost is calculated by dividing the cost by the ES impact (e.g. €/m^3, €/cm, €/kgN, €/tonC).

2.4. Step 4: Cost-Effectiveness Analysis

After calculating the average cost of management measures to invest in several ES, the next step is to select an optimal set of management measures to reach one or a variety of objectives in the most cost-efficient way. In an integrated cost-effectiveness analysis (for different ES), all ES are treated separately since each ES is assessed in different units. Options for integration over several ES effects are via ranking, visual integration or numerical integration. Visual integration based on the average (ACER) and incremental cost effectiveness ratio (ICER) method is applied in this study and both methods are shortly explained below (explained in detail in Compernolle et al., 2012). ACER and ICER are the two most commonly used methods for a cost-effectiveness analysis and give complementary results. The ACER approach results in an investment cost curve with details about all measures in each investment strategy (scenario) per ES, while the ICER approach compares the total outcome of each investment strategy (scenario) against each other per ES.

i. Average cost effectiveness ratio (ACER)

The ACER approach uses the average cost as selection criteria, i.e. ratio of the cost of a scenario relative to the benefit (cost-benefit ratio, €/unit-benefit). Measures with a low average cost are preferred over measures with a high average cost. After calculating the average cost of each management measure, an investment curve is compiled by ranking the measures according to the average cost (Fig. 1 left panel). The X-axis gives the benefit of the measures for a specific ES (e.g. kg nitrogen removed) and the Y-axis gives the average cost (e.g. €/kg nitrogen removal). The surface under the investment curve equals the total cost of the measures (e.g. €/kg nitrogen × kg nitrogen removed with the measure). The curve can be used to select a set of most cost-effective measures given one of more criteria such as achieving a certain benefit (y-axis) or within a certain budget (total surface).

ii. Incremental cost effectiveness ratio (ICER)

For the ICER approach, measures are compared relative to one reference measure (0-point) in a cost-effectiveness plane for both the cost (y-axis) and the effect on the ES (x-axis). This results in four options (Fig. 1 right panel): measure can have higher costs and higher effect on ES compared to the reference measure (quadrant I), lower cost and higher effect on ES (quadrant II), lower cost and lower effect on ES (quadrant III), or higher cost and lower effect on ES (quadrant IV). This leads to following conclusions: measures that are preferred over the reference measure (quadrant II, e.g. ICER2), measures that are not preferred over the reference (quadrant IV), or measures for which it is not clear whether they are preferable over the reference (quadrant I and