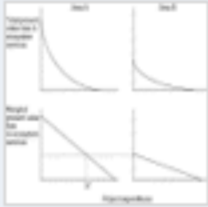
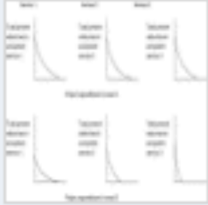
Abstract
Keywords
1. Introduction
2. Common assumptions and optimization cases
3. Efficient selection with certainty
3.1. Weak sustainability



3.2. Strong sustainability



4. Efficient selection with risk
Table 1
5. Efficient selection with uncertainty
Table 2
6. Determining relative losses
7. Project evaluation
8. Discussion
References

Abstract

Climate and land use changes are reducing ecosystem services. Ecosystem managers can alleviate such adverse impacts by being more efficient in allocating limited budgets to projects designed to conserve ecosystem services, and ensuring that implemented projects are effective in stemming losses in ecosystem services. A conceptual framework is developed that managers can use for this purpose. The framework consists of two elements: (1) an *a priori* optimization model for selecting projects that minimize present value loss in ecosystem services subject to a budget constraint; and (2) an *a posteriori* model for determining the extent to which implemented projects have decreased ecosystem losses. An optimization model is formulated for three cases, which assume the ecosystem manager: (1) knows for sure how project expenditures influence losses in ecosystem services (certainty case); (2) does not know for sure how project expenditures influence losses in ecosystem services, but is able to specify the probabilities of service losses for different projects (risk case); and (3) is uncertain how project expenditures influence losses in ecosystem services (uncertainty case). Efficient selection of projects is evaluated for two areas of an ecosystem in mathematical and graphical terms using a continuous negative exponential relationship between present value losses and project expenditures for the certainty case, and for five expenditure classes in the risk and uncertainty cases. Two versions of the certainty case are evaluated, weak sustainability and strong sustainability. Weak sustainability allows gains in one ecosystem service to compensate for losses in another ecosystem service; strong sustainability does not. The risk case requires the manager to specify the conditional probabilities for present value losses given project expenditures, and utilizes expected costs and expected budget amounts in the budget constraint. It is solved by allocating the budget among projects so as to equalize the expected marginal present value losses in ecosystem services across projects. The uncertainty case requires the manager to specify ecosystem sustainability states and the present value losses in ecosystem services for combinations of states and projects. It is solved by selecting projects that minimize the maximum present value loss in ecosystem services subject to the budget constraint. The *a posteriori* evaluation method uses Bayesian statistical inference to test hypotheses about the extent to which implemented projects reduce losses in ecosystem services. It requires specifying ecosystem states that describe conditions for ecosystem services, and decides which hypothesis is true based on posterior probabilities of ecosystem states.

Keywords

Efficient projects; Selection; Evaluation; Ecosystem services