

A decision model for the efficient management of a conservation fund over time

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Extended abstract

A decision model for the efficient management of a conservation fund over time.— An important task of conservation biology is to assist policy makers in the design of ecologically effective conservation strategies and instruments. Various decision rules and guidelines originate, e.g., from the Theory of Island Biogeography (MacArthur & Wilson, 1967) and metapopulation theory (Hanski, 1999). Designing effective strategies and instruments, however, is only part of the solution to problems of biodiversity conservation. In the real world, financial resources are scarce, and it is not only important that policies are ecologically effective but also that they are economically efficient, i.e. lead to maximum ecological benefit for a given resource input. Efficiency has been analysed, e.g. in the context of the spatial allocation of conservation funds (Wu & Bogess, 1999) and of the spatial design of compensation payments for biodiversity enhancing land–use measures (Wätzold & Drechsler, 2002).

Decision analysis is a helpful tool for integrating knowledge from different disciplines and identifying optimal strategies and policies (e.g., Drechsler & Burgman, 2003). Methods of decision analysis, such as optimisation procedures, are often a core component of ecological–economic models that bring together ecological and economic knowledge via formal models (e.g., Ando et al., 1998, Drechsler & Wätzold, 2001, Johst et al., 2002). Such models do not only allow a static integration of economic and ecological aspects but also to describe the dynamics of ecological and economic systems in an integrated manner (Perrings, 2002). Examples of such dynamic modelling approaches are Richards et al. (1999), Costello & Polasky (2003) and Shogren et al. (2003).

In the present paper we investigate a dynamic conservation management problem different from those of the above mentioned authors and tackle the problem of long–term conservation when future financial budgets are uncertain. The background for this problem is that many species can only survive if certain types of biodiversity–enhancing land–use measures are carried out on a regular basis, such as regularly mowing meadows to create habitat for butterflies (Settele & Henle, 2002). This means that funds have to be regularly available over time, because a temporal gap in the availability of funds may irrevocably drive a species to extinction.

While over the last two decades or so a growing commitment of society and governments to conserve biodiversity could be observed, that in many cases also included the increasing provision of funds for this purpose, there are signs that this commitment is currently weakening. An example of such signs are opinion polls in some countries (e.g. Germany) showing that environmental and resource protection issues are given a lower priority by the general public than ten years ago. This implies that there is an increasing risk that conservation funds will be lower in the future than today either through a decrease in political support for such funds or through a decline in donations for private organisations that finance conservation funds.

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This risk forces governments and conservation organisations concerned by the long-term prevention of species loss to explore options which ensure that their policy aims will be achieved even if future funds are lower than today's. Obviously, one important option is to save part of the current financial resources to counterbalance possible future budget cuts. In this context, the problem arises which proportion of the available budget should be spent now and which proportion later.

In summary, there is the problem of efficiently allocating a conservation budget over time to maximise the survival probability of an endangered species, where the current budget is reasonably high and future conservation budgets are expected to decline in the medium term (although the size of these budgets is not known with any certainty). The aim of this paper is to address this problem on a conceptual level.

To have a mechanism that is able to transfer current money to the future regardless of subsequent governments' preferences and policies, we make the assumption that a conservation fund is being established that is independent of any future government's decisions and administered by an independent agency with the time-consistent objective function to allocate financial resources over time such that the survival probability of an endangered species is maximised.

The probability η_t of a population surviving $T + 1$ periods, each of length Δt can be written as the product of the probabilities of surviving each individual period (the complete description of the model including a more in-depth discussion of the results than presented here can be found in Drechsler & Wätzold, 2003):

$$\eta_T = \prod_{t=0}^T \exp\left(-\frac{a}{K_t^a} \Delta t\right) = \exp\left\{-\Delta t \sum_{t=0}^T \frac{a}{\left(K^{(0)} + \kappa_t\right)^a}\right\} \quad (1)$$

where a is some species specific parameter and $K^{(0)}$ is the habitat capacity when no conservation measures are carried out (Lande, 1993; Grimm & Wissel, 2004). Conservation measures increase $K^{(0)}$ by κ_t which costs an amount of money $p_t = b\kappa_t$ with b constant. Parameter a depends on the species and is inversely proportional to the coefficient of variation of the population growth rate (Lande 1993; Grimm & Wissel, 2004).

Each year an amount of money $g_t = h_t + \varepsilon_t$ is granted to the conservation manager where h_t is the deterministic component and $\varepsilon_t \in [-\sigma, +\sigma]$ is random and uniformly distributed to describe uncertainty in the future budgets. Money that is not spent can be moved into a fund F_t from which money can be drawn in later periods. The fund thus develops like

$$F_t = F_{t-1} + g_{t-1} - p_{t-1} \quad (2)$$

Borrowing is excluded, such that in each period only up to an amount $F_t + g_t$ can be spent

$$0 \leq p_t \leq \bar{p}_t = F_t + g_t \quad t = 0, \dots, T \quad (3)$$

In each period the conservation manager has to decide how much money (p_t) to spend for conservation in the present period and how much to allocate into the fund F and save for future periods. This inter-temporal optimisation problem is solved via stochastic dynamic programming (e.g., Clark, 1990). Due to the constraint (3) the solution is not straightforward. In each period, two possible solutions may formally occur: a corner solution where all available money is spent ($p_t = F_t + g_t$) and an interior solution where less than that is spent and some money is transferred to the next period. It turns out that the optimal payment in a certain period t depends on the number l of consecutive periods following the present period that have an interior solution:

$$p_t^*(l) = \frac{1}{l+1} \left(F_t + g_t + \sum_{n=1}^l h_{t+n} \right) - \frac{\sigma^2}{\frac{1}{l+1} \left(F_t + g_t + \sum_{n=1}^l h_{t+n} \right) + \frac{K^{(0)}}{b}} \cdot \frac{(a+2)}{6} \cdot \frac{\sum_{n=1}^l 1/n}{l+1} \quad (4)$$

One can see that the optimal payment increases with increasing fund F_t but decreases with increasing uncertainty σ in the grants. The latter has been shown by Leland (1968) in a 2-period model without constraint (3), denoted as "precautionary" saving and explained from the particular shape of the objective function. From eq. (4) one can also see that more money is saved when a is large, i.e., when the aim is to conserve species with weakly fluctuating population growth. One can further show that it is optimal to allocate the payments as even over time as far as the constraint (3) allows. If, e.g., we have constantly decreasing grants it is optimal to save in the beginning and spend the saved money in the final periods.

The problem now is that the number l depends on the future grants and if these are not known l is not known and can only be approximated by a probability distribution $P(l)$. For the case where a negative trend δ is expected in the grants, such that $g_t = h_0 - \delta t + \varepsilon_t$ we have determined $P(l)$ and the expected optimal payment

$$\langle p_t^* \rangle = \sum_{l=0}^T P(l) p_t^*(l) \quad (5)$$

It turned out that if the uncertainty in the grants σ is large or small compared to their deterministic trend δ one obtains a solution that is structurally similar to eq. (4), i.e. we have a situation of precautionary saving. In contrast, if the uncertainty was about of the order of magnitude of the trend we found cases where uncertainty increased the optimal payments. The reason is that the uncertainty σ has two contrary effects. The one is the standard "precautionary saving" effect caused by the shape of the benefit function. The other, opposing effect is that uncertainty may reduce the (expected) number l and thus increase the optimal payment. Sometimes the latter effect is stronger. However, we found strong evidence that the magnitude of such "precautionary spending" is negligibly small and for practical purposes we conclude that uncertainty generally reduces the optimal payment and more money should be saved.

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