A method to compare strategies in endangered species conservation. The Amphibian *Bufo bufo* metapopulation in the alpine Rhine valley as a case study.

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INTRODUCTION

AMPHIBIANS are a vertebrate taxonomic group that appears to be particularly sensitive to environmental changes resulting from human activities. Among the several factors that may to be responsible for reducing both amphibian distribution and numbers are increased UV radiation, habitat degradation and obstacles for between-habitat movements. In the case of pond-breeding amphibians in highly fragmented landscapes, habitat management may relay both on increasing water body numbers, quality and persistence, and on landscape complementation (that is the need for connectivity between aquatic breeding sites and suitable terrestrial habitat). In the Bündner Herrschaft district in the upper Rhine valley (Canton of the Grisons, Switzerland) for example, some ponds that serve as breeding sites for amphibians have been rehabilitated for the purpose of conservation and attempts are made to further improve these sites and to add additional sites if justified on conservation grounds. Both these types of intervention require considerable investments that have to be made on the basis of careful evaluation of different strategies. If such habitats fall into intensively managed agricultural, residential land or even industrial sites, decision making in favour of conservation is easier when based on objective quantitative ground. Thereby, regulatory or fiscal measures may be considered together with participatory activities.

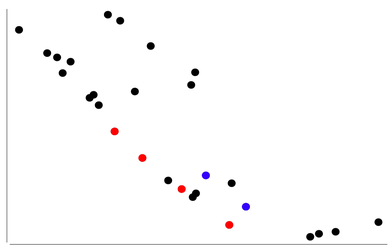
OBJECTIVE

The development of quantitative methods for the comparison of different habitat management strategies.

We propose the use of the *Kullback-Leibler* (KL) divergence ([5]). A metapopulation model, also known as *Incidence Function Model* (IFM) ([3]), allowed the estimation of probabilities for breeding sites occupancy in relation to management options that are evaluated through the KL-divergence. This evaluation requires the definition of a reference measure. The approach is developed for Common European Toad *Bufo bufo* (Linnaeus) populations in the Bündner Herrschaft district that serves as a case study. The strategies for evaluation have been defined by Dr. Josef Hartmann, Cantonal Bureau for Nature and Landscape (Chur, Switzerland). Importantly, these strategies have been defined a priori on the basis of economics of land use rather than considerations regarding the metapopulation dynamics described by the model.

DATA

The Bündner Herrschaft district is located in Southeastern Switzerland and comprises a closed area delimitated by the Rhine river in the West, the Landquart river in the South, high mountains in the Northeast and intensively used land of the Liechtenstein Principality in the North.



Dr. Josef Hartmann, Cantonal Bureau for Nature and Landscape, Chur (Switzerland) proposed two strategies. Strategy SA (RED) was selected because the establishment of four new sites along the Rhine was relatively cost-efficient, but its contribution to Amphibian conservation unknown. Strategy SB (BLUE) was assumed to increase connectivity of habitats.

Figure 1: *Original sites: BLACK. Option SA: RED. Option SB: BLUE.*

For each site i ($i = 1, \ldots, 22$) we know: coordinates of the centroid, area, presence/ absence of the species and the quality of the terrestrial habitat that links site i to every other site. The quality is classified by 3 categories (i.e. bad, good and very good) for the passage of amphibians.

RESULTS

In (1), the distance d_{ij} has been scaled by 1,2 or 5 to take into account the degree of difficulty that amphibians encounter when passing from one site to another. Expert's opinion was used to fix α.

ESTIMATION

Strategy	$(A_0,\ x,\ y)$
S22 (22 siti existing)	(50, 0.412, 508.2)
SA0 (+ 4 empty sites)	(100,0.488,581.8)
SA1 (+ 4 not empty sites)	(32,0.379,213.9)
SB0 (+ 2 empty sites)	(100, 0.446, 449.8)
SB1 (+2 not empty sites)	(35.93, 0.414, 550.6)

COMPARISON

Strategy	KL
S22 (22 existing sites)	37.06
SA0 (+ 4 empty sites)	37.61
SA1 (+ 4 not empty sites)	**48.65**
SB0 (+ 2 empty sites)	37.45
SB1 (+2 not empty sites)	43.43

Noteworthy, the estimate of y is very sensitive to the so selected scalars. This problem has to be further investigated.

As expected, *the increase in the number of sites increases KL. However, the creation of new habitats is of little value if they do not offer suitable conditions for the establishment of a stable local population. In fact, if these sites are not occupied, the value of KL increases only slightly. On the other side, a significant increase in KL results from occupied sites*.

METHODS

INCIDENCE FUNCTION MODEL. At discrete time (years), the occupancy of patch i is described by a **stationary Markov chain** with two states, $\{0,\ 1\}$. Hanski introduces structural assumptions as to how the transition probabilities of patch occupancy depend on the physical attributes of the landscape. In particular, it is supposed that the transitions probabilities are defined as

$$P(1,0) =: E_i = \begin{cases} (A_0/A_i)^x & \text{if } A_i > A_0 \\ 1 & \text{if } A_i \leq A_0 \end{cases}, \quad P(0,1) =: C_i = \left(1 + (y/S_i)^2\right)^{-1}$$

where A_i is the patch area, A_0 is the critical patch area for which the local population has a unit probability of extinction in 1 year; x reflects the severity of environmental stochasticity; y describes the colonization ability of the species. S_i denotes the connectivity of site i and is defined as

$$(1) \qquad S_i = \textstyle\sum_{j \neq i} \delta_i \exp\{-\alpha d_{ij}\} A_j \quad \text{where} \begin{cases} \delta_i & \text{equals to 1 for the occupied patches and 0 for the empty patches} \\ d_{ij} & \text{is the centroid-to-centroid distance between patches } i \text{ and } j \\ \alpha & \text{is a constant setting the survival rate of migrants over a distance } d. \end{cases}$$

Patch area may be corrected for possible spatial variation in habitat quality and d_{ij} may be just the Euclidean distance or some measure that takes into account the quality of the intervening habitat and how it affects the movements of migrant individuals.
The model is fitted with non-linear regression using maximum likelihood estimation.

COMPARISON OF STRATEGIES. We propose the use of the KULLBACK–LEIBLER information of $\mathbf{P_0}$ on $\mathbf{P = \otimes}$ Bernoulli$(\mathbf{J_i})$, where $\mathbf{J_i}$ is the estimated incidence of interest and $\mathbf{P_0}$ is a suitable reference measure, to rank the different strategies (included the one corresponding to the data). Given as reference measure P_0 the product of n independent probability measures degenerate on 0 (i.e. the Dirac on 0), we obtain that the Kullback-Leibler information of P_0 on $P = \otimes\, Bernoulli(J_i)$ is

$$KL(P_0, P) =: KL(P) = -\sum_i \log(1 - J_i)$$

The choice of such a P_0 as reference measure corresponds to the assumption that the worst situation is the extinction of the population.

- If options P_1 and P_2 consider the same sites and $J_{1i} \leq J_{2i}$ for each site i then KL(P_1)$\leq$ KL(P_2) ("**global improvement**")
- we can compare options having a different number of sites by considering as reference measure the product of $n+k$ Dirac measures, where k is the total number of distinct added sites. Indeed formally, when considering an option having $m \leq n+k$ sites, the corresponding log-likelihood equals to $\sum_{i=1}^{m} \delta_i \log(J_i) + (1-\delta_i)\log(1-J_i) + \sum_{i=m+1}^{n+k} \delta_i \log(J_i) + (1-\delta_i)\log(1-J_i)$ if we consider as empty and with incidence equal to 0 the added breeding sites.

DISCUSSION

To our knowledge, two index introduced in literature to assess the extinction risk of a metapopulation could be naturally considered for comparison purposes:
1. the expected extinction time T_{ext} of the metapopulation, ([2]);
2. the metapopulation persistence capacity λ_M, ([6]).

Despite its clear interpretation, and intuitive appeal for comparison, T_{ext} can not be used in practice for computational difficulties when $n > 20$, ([4]). λ_M cames from a *deterministic* model and it has several meaningful interpretations, taking into account the actual spatial configuration of the fragmented landscape. However, it is impossible to derive a general analytical expression for it and even if sometimes it is possible to use some approximations, they do not have general validity. ([6]). Therefore it is clear that there is a need for simple alternative measures permitting a sensible discrimination among several scenarios.
The expected transition time $1/E_i$ from occupancy to extinction can have a wide range among the sites so that any conclusion coming from it seems to be in contrast with the basic assumption of stationarity of the IFM. **Then, we have supposed that a measure which does not depend on future dynamical developments of the system would be more sensible, and we have concentrated on the comparison of the estimated distributions, that is, of the estimated incidences**. The Kullback-Leibler information (or divergence) is well-known and widely used in statistics, however only recently it appeared in the ecological literature, mainly in connection with estimation and model selection problems ([1]). The choice of P_0 as previously described represents only a first attempt, based on some simple ecological considerations. Other meaningful reference measures could be chosen; in any case, the "global improvement" property is a natural requirement to be satisfied by any sensible measure. The fact that the Kullback-Leibler divergence is unbounded could be a drawback: the assessment of the degree of improvement provided from each strategy, with respect to the others, is made difficult. A bounded index could be perhaps more appropriate.

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