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Short communication

Setting conservation targets under budgetary constraints

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ABSTRACT

Target-based spatial prioritization is the default approach in conservation resource allocation. Here, we clarify a poorly known feature of target-based spatial prioritization that may lead to an unbalanced allocation of resources between species or other biodiversity features. Highest per-species resources will be allocated to species occurring in costly and otherwise species-poor locations, whereas smallest per-species resources will be allocated to species that occur in species-rich locations at low-cost areas. Uncertainty in information about processes determining distributions of biodiversity features may lead to uncertainty in target setting. This can be a problem if unnecessarily high targets emerge to consume excessive resources thus detracting from other conservation action. Difficulties might be encountered in particular when there are many features, targets are given simultaneously to multiple different types of biodiversity features, or components of features, or when there are interactions or correlations between features. Consequently, we recommend that the costs of targets for individual features could be evaluated to screen for such targets that consume a disproportionate fraction of available resources. Costs of targets can be evaluated by a variant of the replacement cost technique. We also find that commonly used reserve selection methods, minimum set coverage, maximum coverage, and utility maximization differ significantly in how they treat targets and their costs.

1. Conservation targets and spatial conservation prioritization

Systematic conservation planning is an operational model that can be used for informed allocation of conservation effort and the implementation of conservation action (Margules and Pressey, 2000; Margules and Sarkar, 2007). This framework is influential in that it provides a practitioner with a well defined list of steps that need to be taken when doing conservation planning (Margules and Pressey, 2000; Knight et al., 2006). The framework is also popular because it provides transparency, allowing stakeholders to clearly identify what the prioritization process is trying to achieve. A fundamental step in the systematic conservation planning process is target setting, in which quantitative requirements are specified for representation levels that are required for different biodiversity features. Targets can be given either for a conservation area network (Pressey et al., 2003; Carwardine et al., 2009), or for the entire landscape if working with retention (Pressey et al., 2004).

Conceptually target setting is guided by the requirement of adequacy; targets should be adequate for guaranteeing the persistence of species or any other biodiversity features (Carwardine et al., 2009). Because persistence itself is an outcome of many components of spatial population dynamics, and because there may be other conservation objectives, targets have commonly been given for several different component-quantities. These include the number of populations or occurrences that are required for a species (Williams et al., 1996; Lombard et al., 1999, 2003), proportion of distribution of species (Richardson and Funk, 1999; Carwardine et al., 2008), the area of habitat type (Lombard et al., 2003; Pressey et al., 2003; Smith et al., 2006; Carwardine et al., 2008), total "habitat value" for a species (Carroll et al., 2003), various proxies for persistence of species (Cowling et al., 1999, 2003; Williams and Araùjo, 2000; Burgman et al., 2001; Noss et al., 2002; Cabeza, 2003; Pressey et al., 2003), for species' future ranges based on climate change projections (Hannah et al., 2007), spatial requirements for the maintenance of evolutionary processes (Cowling et al., 1999, 2003; Cowling and Pressey, 2001; Pressey et al., 2003), various ecosystem processes (Cowling et al., 1999, 2003; Noss et al., 2002; Pressey et al., 2003), ecosystem services (Chan et al., 2006), and so on. Target-based spatial prioritization has been implemented as the primary method in conservation planning software such as Marxan (Ball and Possingham, 2000; Possingham et al., 2000), ConsNet (Ciarleglio et al., 2009) and C-Plan (Pressey et al., 2008), testifying to the strength of the target-based systematic conservation planning paradigm. More comprehensive reviews are available by Carwardine et al. (2009) and Rondinini and Chiozza (2010).

Carwardine et al. (2009) reviews many benefits and problems with the use of targets. Rather than repeating those issues here,

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we concentrate on one poorly documented deficiency in target-based spatial prioritization, which may inadvertently lead to solutions that could be considered unbalanced. The problem arises from the fact that the cost of achieving a target is not known at the time when the target is set. In an ideal world this would not be a problem, but in a complicated and uncertain world some biodiversity features can end up with targets that are very expensive to satisfy thus reducing resources available for other, possibly more worthy conservation causes. We document this possibility, discuss when it is likely to occur and show how it can be detected and addressed.

2. The cost of a target

Assume first that there are many conservation features. Targets need to be set for them all, which may take a lot of effort in itself, unless it is done very simplistically, for example by specifying a fixed number of occurrences that are required per species. Then, assuming the commonly used minimum set coverage planning paradigm is applied, a solution is sought that achieves targets with low or minimal cost (step 4, Margules and Pressey, 2000). Herein lies an issue which may or may not be interpreted as a problem depending on how one looks at it: some targets will be met easily with zero-to-low cost, while others may only be met with great difficulty or cost. The most feasible targets to achieve are those achieved incidentally as by-products of securing other targets where cost of action is low. The most expensive targets require expensive action that benefits few or no other features. Between these two extreme cases the cost of achieving a target varies according to both cost of action and degree of overlap among features – a target for a feature that requires expensive action but functions as a surrogate and benefits many other species simultaneously may have the same cost as a target for a feature that occurs alone but requires cheaper action. Effectively, we are concerned about the per-species additional cost required to satisfy the target for the species.

Fig. 1 schematically illustrates the costs of targets. To calculate the cost of a target, one can use a variant of replacement cost analysis (Cabeza and Moilanen, 2006; Moilanen et al., 2009), in which the difference between the performance of a less constrained solution and a solution with additional extra constraints is measured. These additional constraints could, for example, be constraints to land availability. In the case of targets here, the base solution is taken as the ordinary minimum set solution that satisfies all targets with minimum cost. Then the solution is recomputed once per species, each time relaxing the full constraint (target) set by dropping one species-specific target. In other words, species-specific targets are all in turn treated as extra constraints, to obtain an estimate of the additional cost required to meet them. In Fig. 1, the costs of targets vary widely, with species (*A*) being very expensive and species (*C*) and (*E*) having no cost at all, because they have distributions completely nested inside the distributions of other features.

The replacement cost technique described above can be implemented with any reserve selection optimization method/software to calculate the cost of a target (or group of targets), as a difference between the cost of the minimum set solution for the full problem and the cost of the minimum set solution for a reduced problem from which one (or many) targets have been dropped.

3. Minimum set, maximum coverage and maximum utility-based planning

The cost of targets calculation (previous section) applies to the minimum set planning mode of systematic conservation planning, in which all targets must by definition be achieved. But, what about the next most common planning mode, maximum coverage?

In maximum coverage it is *a priori* recognized that resources are unlikely to suffice for achieving all targets (ReVelle et al., 2002), and the objective of planning is to use all available resources so that as many as possible targets are covered. Which targets become covered then? We suggest that, logically, maximum coverage will satisfy targets in increasing order of marginal cost (Fig. 1). With very small resources, it is a mathematical necessity that one can only cover targets that have very small per-species cost. When the resource is increased, more targets become satisfied, but, always, the next target that can be achieved is the one that results in smallest per-species additional (marginal) cost. The last target to become satisfied, when the resource is gradually increased, is the one single target that has highest "cost of target", as defined in the previous section. Note that the process of targets becoming covered in maximum coverage is not quite this simple, as when the resource is increased slightly, it may in fact become optimal to switch to covering a completely different set of species. Nevertheless, it is by mathematical necessity true, that the greatest number of targets can become covered when the per-target cost is smallest. Thus, if the resource available is gradually increased, maximum coverage covers groups of targets in increasing order of per-species cost. Curiously, maximum coverage will effectively act as if the costs of targets had been evaluated, and the most expensive targets had been removed from the conservation objective.

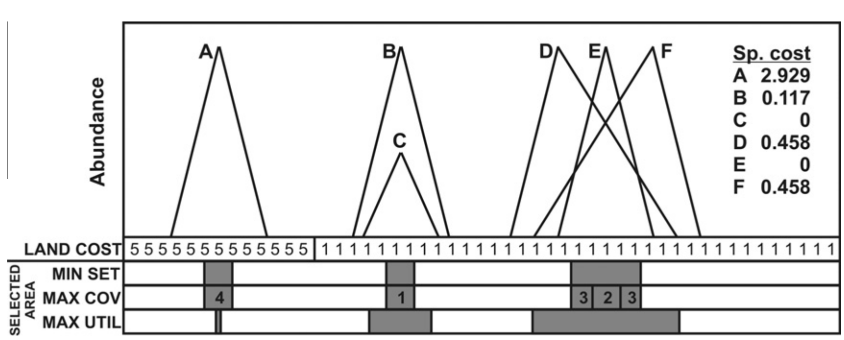

Fig. 1. A schematic illustration of different planning modes and costs of targets. The triangles represent abundances of species A–F in a one-dimensional landscape, and grey blocks represent land area that becomes selected. Minimum set and maximum coverage approaches have proportional coverage targets of 50% of abundance for each species. The numbers in the maximum coverage solution indicate a priority sequence as the budget constraint is gradually increased. The maximum utility solution (benefit computed from power function with $z = 0.25$) has the same budget as the minimum set, and shows a clear trade-off between cheap and costly targets. The costs of individual species in the minimum set context have been measured as the decrease in solution cost when the respective target is set to zero. In this example the landscape was analyzed as a high resolution grid, with land area thus becoming an effectively continuous variable.